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1984

Woburn Environmental Studies

PHASE II REPORT

Volume 1

REMEDIAL INVESTIGATION

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DATE: AUGUST 1984

PHASE II REMEDIAL INVESTIGATIONTABLE OF CONTENTS

	<u>PAGE NO.</u>
I. INTRODUCTION	I-1
Legislative/Regulatory Perspective	I-1
Report Organization	I-2
Site Background	I-4
- Site History	I-4
- Phase I Investigation Summary	I-6
Summary of Phase II Investigation	I-12
II. PHASE II PROGRAM	II-1
Scope	II-1
Description of Work vs. Plan	II-2
Strategy/Overview	II-4
- Health/Safety	II-4
- Soil/Waste Deposits	II-5
Reevaluate Phase I Data	II-5
Test Pit Survey	II-5
Soil Borings	II-6
- Identification of Organics in Soil	II-6
- Identification of Heavy Metals	II-7
Off-Site Investigation	II-9
- Groundwater	II-9
Resampling Phase I Monitoring Wells	II-9
New Monitoring Wells	II-10
Aquifer Transmissivity	II-10
Shallow Groundwater Flow	II-11
- Volatile Emissions/Odor	II-11
Screening for Sources	II-11
Identification of Gas Emission Rates and Constituent	II-12
Odor Survey	II-12
Validation of Analytical Methods for Odor Detection	II-13

TABLE OF CONTENTS - continued

	<u>PAGE NO.</u>
III. SUBSURFACE INVESTIGATION	III-1
- Methods of Investigation	III-3
Conductivity Survey	III-3
Soil Boring Program	III-8
Phase I	III-8
Phase II	III-11
Surface Soil Study	III-14
Test Pit Program	III-16
Observation Well Installation	III-18
Rock Wells	III-19
Sand and Gravel Wells	III-21
Ground-Water Sampling	III-23
- Hydrogeology	III-25
- Soil and Waste Investigation	III-39
Conductivity Survey Results	III-39
Soil and Waste Analytical Results	III-43
- Ground-Water Levels and Flow	III-55
- Ground-Water Quality	III-61
Metals	III-61
Organic Compounds	III-64
Additional Investigations	III-65
- Findings and Conclusions	III-70
IV. GAS EMISSIONS	IV-1
Program Objectives	IV-1
Bar Hole Investigation	IV-2
- Bar Hole Program Objectives	IV-2
- Sampling Methods	IV-2
- Bar Hole Sampling Results	IV-2
- Bar Hole Sampling Conclusions	IV-3
Bore Hole Sampling Program	IV-4
- Bore Hole Program Objectives	IV-4
- Bore Hole Sampling Methods	IV-4
- Bore Hole Sampling Results	IV-5
- Bore Hole Sampling Conclusions	IV-10
ADL Odor Survey	IV-11a
Gas Generation: Objectives	IV-11
- Factors Affecting Gas Production	IV-11
- Factors Affecting Gas Release Rates	IV-12
Selection of Gas Production Rate	IV-13
Air Modeling	IV-15
Summary and Conclusions	IV-16

TABLE OF CONTENTS - continued

	<u>PAGE NO.</u>
V. HEALTH AND SAFETY	V-1
Summary	V-1
Responsibilities, Site Security & Decontamination	V-2
Use of Protective Equipment	V-2
- Protective Clothing	V-2
- Respiratory Protection	V-2
Exposure Monitoring	V-3
- Background	V-3
- Test Pit Digging	V-3
Total Particulate	V-3
Chromium, Arsenic and Lead	V-3
- Real Time Monitoring	V-4
Total/Respirable Particulates	V-4
Organic Vapors	V-5
H ₂ S	V-5
- Bore Hole Drilling	V-5
Personnel Monitoring	V-5
- Total Particulate	V-5
- Chromium, Arsenic and Lead	V-5
Real Time Monitoring	V-6
- H ₂ S	V-6
- Organic Vapors	V-6
- Auger Drilling	V-6
- Summary/Conclusions	V-7
VI. ANALYTICAL PROCEDURES	VI-1
Modification to Planned Procedures	VI-1
Determination of Hexavalent Chromium in Soils	VI-2
Determination of Volatile Emission in Bore Holes	VI-4
Quality Assurance	VI-6
- Soil Metals	VI-6
- Bore Hole Air, Groundwater and Soil Organics	VI-7
- Data Quality	VI-8
Soil Sample Analysis	VI-8
- Metals	VI-8
- Organics	VI-8
Groundwater Volatile Organics	VI-9
Bore Hole Air Analysis	VI-9

LIST OF TABLES

	PAGE NO.
III. SUBSURFACE INVESTIGATION	
Well Construction Data	III-19
Water Level Data	III-55
Concentration of Benzene and Toluene in Source Determination (SD) Samples	III-68
IV. GAS EMISSIONS	
IV-1: Bore Hole Gas Generation Rates	IV-6
IV-2: Bore Hole Air Analysis	IV-7
IV-3: Downwind Gaseous Component Concentrations Based Upon Worst Case Conditions	IV-17
IV-4: Summary of Gas Emissions/Odor Program	IV-20

LIST OF FIGURES

4-1: Bar Hole Sampling Locations and Results	IV-2
4-2: Hide Pile Deposit Location Map	IV-2
4-3: Bore Hole Sampling Locations and Results	IV-4
4-4: East Hide Pile - Combustible Gas and H ₂ S Measurements	IV-5
4-5: West Hide Pile - Combustible Gas and H ₂ S Measurements	IV-5
4-6: East-Central Hide Pile Area - Combustible Gas and H ₂ S Measurements	IV-5
4-7: East-Central Hide Pile Area - Bore Hole Combustible Gas Measurements with Minor H ₂ S Concentrations	IV-5

Intro.

Vol 1

WOBURN ENVIRONMENTAL STUDIES
PHASE II INVESTIGATION

Introduction

Legislative Perspective

In December 1980, Congress passed the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), commonly called "Superfund". CERCLA was passed to assure the prompt and cost effective response to inactive hazardous waste disposal sites and releases or threatened release of hazardous substances. The Act required the United States Environmental Protection Agency (EPA) to take the following major actions:

- 1) Prepare an inventory of hazardous waste sites;
- 2) Prepare and publish a national list of at least "400" top priority known or threatened releases of hazardous substances;
- 3) Revise the National Contingency Plan published under the Authority of Section 311 of the Clean Water Act to include procedures and criteria for investigations and developing cost effective remedial actions for hazardous waste releases listed on the National Priority List.

The Act also established a tax on oil and feedstock chemicals. The tax revenues would be used to establish a \$1.6 billion dollar Fund to be used by EPA for investigations, studies and remedial actions.

Regulatory Perspective

EPA assembled an inventory of hazardous waste sites that might require CERCLA attention. In December 1981, from this Inventory, EPA published an Interim List of "115" Top Priority Sites. The Woburn Industri-Plex 128 site was on the list.

In 1982, EPA proposed the revisions to the National Contingency Plan. The revisions specified procedures for setting priorities, investigating, evaluating and selecting remedial actions to cost effectively and expeditiously achieve the objectives of CERCLA, i.e., clean up releases of hazardous substances.

EPA implemented a program to negotiate with potentially responsible parties to pay for and clean up hazardous waste sites. This negotiated settlement approach would reserve the Superfund monies for truly abandoned waste sites, would provide the scarce management and technical expertise needed to clean up the top priority waste sites as expeditiously as possible, and would avoid unnecessary legal costs.

EPA Action

On May 25, 1982, Stauffer Chemical Company, a former site owner and responsible party, voluntarily signed a Consent Order with EPA and the Massachusetts Department of Environmental Quality and Engineering. The Consent Order included an Investigative Plan prepared by Stauffer. The objective of the investigation was to collect the information needed to locate waste deposits, assess the environmental impacts of waste deposits, apportion responsibilities, and evaluate and recommend remedial actions.

The site investigation consisted of two Phases. Phase I detailed specific data collection requirements. It was designed to screen the site to locate waste deposits and gather information on groundwater, surface water and odors needed to assess environmental impacts. The details of the Phase II investigation were not specified. The objective of Phase II was to collect site information in addition to the Phase I data needed to apportion costs and evaluate remedial alternatives.

The Phase II Report is comprised of three volumes. Volume 1: Remedial Investigation describing the work and the findings and conclusions. Volume 2: Feasibility Study is the risk assessment and selection of cost effective remedial actions. Volume 3 contains the appendices of maps, plot plans and figures showing sampling locations, waste deposit locations, surface water and structures, and log book sheets. Each volume has an index to facilitate its use.

Phase II Report Composition

Volume 1: Remedial Investigation consists of the sections listed below:

I. Executive Summary

This section traces the industrial use of the Woburn site from 1853 to the present and summarizes the Phase I and Phase II investigations.

II. Phase II Program

This section describes the area studied in the Phase II investigation, sets forth the sampling and analysis work, discusses the environmental objectives, and compares the work done in the Phase II study to the requirements specified in the Investigative Plan.

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III. Subsurface Investigation

This section describes the sampling and analysis done to locate and define the boundaries of waste deposits and determine the impacts of waste deposits on groundwater quality. This section also discusses the Phase II findings and conclusions.

IV. Gas Emissions

This section discusses the sampling and analysis of volatile and hazardous chemicals in air deep inside the waste deposits. It also relates the findings to odor emissions.

V. Health/Safety

This section describes the Safety and Health Plan prepared to assure protection of workers and the public during field work activities. It includes findings and conclusions from the evaluation of the procedures and the monitoring conducted in Phase II.

VI. Analytical Testing

The method of collection and analytical testing used are described for each type of sample collected. This section also discusses the evaluations of screening methods and provides the reason for selection of the methods chosen. The section also discusses the Quality Assurance procedures and evaluations included in the study.

WOBURN ENVIRONMENTAL STUDIES
PHASE II INVESTIGATION

Site Background/History

The Woburn Industri-Plex 128 site was used for manufacturing various products from 1853 to present. The records of insurance companies, newspapers and journal accounts, and aerial photographs were researched to determine the materials handled at this site and the waste disposal practices.

The following three periods are the most appropriate to describe the activities on the 244 acres investigated in Phase I:

1853-1933 - Woburn Chemical Works, Merrimac Chemical Company, New England Manufacturing, Monsanto Chemical Company

1934-1969 - New England Chemical Company, Consolidated Chemical Company, Stauffer Chemical Company

1969 - present - Mark Phillip Trust and a few other parties.

1853-1933

During this period, the Woburn site was used for manufacturing chemicals for local textile mills, leather and paper industries, arsenic insecticides, acetic acid and dry colors.

A major product manufactured at the site was sulfuric acid. The acid was then used to manufacture hydrochloric acid and tin chlorides. The sulfuric acid process used both sulfur and pyrite ore as feedstock. Pyrites contain a significant number of heavy metals. Also, New England Manufacturing produced organic chemicals including phenol, benzene, picric and toluene.

Based on aerial photographs and maps, most wastes from these operations were disposed onsite by filling in swampy, low lying areas. Also, these maps and photographs show a settling lagoon area in the vicinity of the present arsenic pit.

The major substances used in these processes were lead, arsenic, sulfur, pyrite ore containing heavy metals, and dry colors probably containing lead, mercury, chromium, etc.

1934-1969

In 1934 the property was sold to the New England Chemical Company. New England Chemical constructed an animal glue manufacturing plant on the property which was subsequently purchased by Consolidated Chemical Company, and then by Stauffer Chemical Company.

The glue manufacturing process took raw animal hides and waste chrome tanned hides from the area industries and extracted the glue by cooking these materials and concentrating the extract by evaporation and drying. To speed the extraction process, sodium hydroxide, sulfuric acid and magnesium carbonate were used.

Hide residues from the extraction were buried in pits on the property. Wastewater from the washing and disinfection process steps were sent to a settling lagoon to remove suspended solids and separate the grease for sale. The water was then sent to the municipal sewer system.

The major substances used in these processes were chrome tanned hides, raw animal hides, lime, caustic, sulfuric acid and magnesium carbonate.

1969-Present

In 1969, Stauffer sold the major portion of the property to Mark Phillip Trust and a small fraction to others. Mark Phillip Trust began to develop the site for industrial uses. Excavation activities during this development period created noxious odors by exposing decaying hide material. In addition, these activities relocated and commingled many waste deposits into piles near swampy areas on the property.

In 1979, neighbor complaints about odor and site development activities resulted in EPA obtaining a Court Order to stop further development activities. In 1981, the site was listed on the Superfund Interim List of "115" Top Priority Hazardous Waste Sites.

On May 25, 1982, EPA and DEQE signed a Consent Order with Stauffer Chemical Company requiring Stauffer to undertake a site investigation and recommend remedial action.

Scope/Purpose/Description of Work

The Consent Order agreed to by Stauffer Chemical Company, EPA, and DEQE specified a two phase site investigation for the purpose of assessing environmental conditions at the site, selecting remedial action and apportioning responsibility.

The site boundaries specified for investigation are shown on the map below.

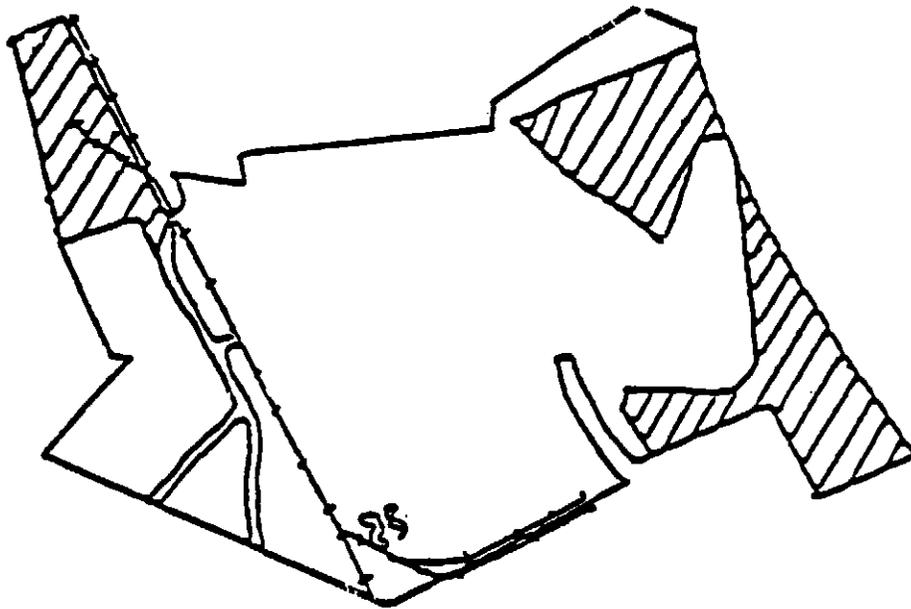


Fig. I 244 Acre Woburn Site
Clear Area Formerly Owned By
Stauffer Chemical Company

This is a 244 acre piece of property in an industrial area of North Woburn called the Industri-Plex 128 property. The site has streams and ponds, operating facilities, abandoned facilities, waste deposits buried and in piles, roads, railroad tracks, and utility rights of way. About 150 acres are fenced.

Purpose

The purpose of the Phase I investigation was to expeditiously and cost effectively locate hazardous waste deposits and assess their impact on surface waters, groundwater and air. The Phase II investigation gathered additional information needed to apportion responsibility and evaluate and recommend remedial actions.

Summary of Phase I

The following summarizes the key findings and conclusions of the Phase I investigation. For more detail, the Phase I report is available from EPA.

Safety and Health

The purpose of the safety and health plan was to assure that worker health and safety would be protected during Phase I. The safety and health plan was prepared by Stauffer's certified Industrial Hygienist and was followed during Phase I activities. Protective clothing and equipment was used during trenching and drilling. Monitoring was conducted. Procedures were followed and were effective in protecting worker health and safety.

Airborne Contaminants: Based upon industrial hygiene worker exposure monitoring of airborne contaminants onsite during the Phase I study, no exposures to arsenic, lead or chromium were found above OSHA safe limits. Total dust measurements averaged well below OSHA's permissible exposure level.

Biological Agents: Based on a site inspection, process review, and sampling and analysis of waste deposits by Dr. Stephen Edberg (Yale School of Medicine), no hazard exists from anthrax or other disease causing microbes.

Analytical Testing

The purpose of the analytical testing in Phase I was to use as much as possible rapid, cost effective screening techniques to analyze soil and assure the adequate quality.

X-Ray Fluorescence (XRF): We evaluated X-ray fluorescence (XRF) as an analytical screening method for determining metals in soil at Woburn. We found XRF to be unsuitable because of variation in the Woburn soil matrix. Therefore, we used the more precise and traditional atomic absorption method to analyze the soil.

Organic Chemical Screening: We evaluated the following analytical screening techniques for soil: loss on drying, loss on ignition, solvent extraction/residue on evaporation to dryness, oil and grease, capillary G.C. analysis of solvent extract and head space gas chromatography. "Head space" gas chromatography was selected as the method suitable for rapidly screening of the soil for volatile organic chemicals. The other methods lacked sensitivity.

Bore Hole Air

The purpose of analyzing air in bore holes installed in the waste deposits was to identify possible odor causing compounds and hazardous air contaminants.

Total Reduced Sulfur: The sampling and analysis of air 6-20 feet deep inside two 6" diameter borings showed high levels of hydrogen sulfide (up to 47,000 parts per million (ppm)) and methyl mercaptan (up to 470 parts per million (ppm)) in the east waste pile. At no time during Phase I did we detect hydrogen sulfide above ground level in the worker breathing zone. We concluded that no health hazard existed during the Phase I investigation from H₂S exposure.

Hydrogen sulfide and methyl mercaptan gases are produced during degradation of natural substances such as hides, animal remains, etc. The odor produced by household septic systems is hydrogen sulfide (H₂S). Hydrogen sulfide and methyl mercaptan odors are recognizable at extremely low concentrations. Since no H₂S or other total reduced sulfur compounds were found in the other 8 bore hole samples, we concluded that one of the probable sources of the Woburn odor is the degradation of east waste pile material to H₂S.

Arsine: No arsine was detected in 23 of 27 air samples collected from the 10 bore holes 6-20 feet below surface. Arsine was detected in 4 bore hole air samples collected from the east and west waste piles at levels from 0.3-0.5 ppb, barely above the detection limit of 0.3 ppb. The OSHA safe limit is 50 ppb. Therefore, based on this data, no potential for health hazard from arsine exists at the Woburn site. In addition, at these very low concentrations, i.e. tenths of a part per billion, the analysis could have represented a microscopic particle of soil contaminated with arsenic, rather than arsine vapors.

Volatile Organics: We had sampling and analysis difficulties due to interference caused by extremely high levels of sulfur compounds and cross contamination and were able to collect and analyze only 6 valid bore hole air samples from 2 of the 10 bore hole locations.

The 2 bore holes where valid samples were collected were located in areas which we thought were the most likely sources of volatile organic chemicals, based upon preliminary Phase I data. No priority pollutant volatile organic chemicals were detected and 95% of the volatile organics found were sulfur or compounds containing sulfur.

Subsurface

The purpose of this investigation was to locate hazardous waste deposits and assess the impact of waste deposits on the groundwater.

Locate Waste Deposits: To locate the waste deposits, a total of 175 test pits (dug by backhoe) and soil borings (drilled by auger rig) were installed and 461 samples of waste and contaminated soil were collected. Based upon the observation of Roux Associates, 199 soil/waste samples were selected for heavy metals analysis and 151 were screened for organic chemicals.

In addition, Roux Associates performed a conductivity survey of the entire site to provide a screen for unnatural deposits. This survey supported and added confidence to our test pit and boring findings.

Of the 244 acres that required investigative test pits, soil borings and conductivity work, we found the following:

- . 32 acres east of Commerce Way contained no waste deposits
- . 120 acres is shallow bedrock and buildings
- . 92 acres have some contamination

Of the 92 acres with some contamination, we found the following:

- Lead and arsenic were the most widespread contaminants and 22 acres had lead and/or arsenic levels above 1000 ppm
- Chromium was found on about 5 acres above 1000 ppm and such findings were generally detected in the area where hide residues were found and near the chromium lagoon
- Barium, copper, and zinc were widespread throughout the site in levels greater than 100 ppm
- Mercury was found in a few samples above 100 ppm.
- Hide residues were found on about 8 acres
- Analytical screening of soil for organic chemicals identified a few areas that might contain volatile organic chemicals. However, the screening technique did not identify or quantify chemicals.

A finding that was helpful in the Phase II investigation was that waste materials and contaminated soil can be distinguished visually from natural soil.

Groundwater: Fifteen (15) groundwater monitoring wells and 8 piezometers wells were installed upgradient, lateral to and down-gradient of the site of the groundwater flow direction. The purpose of these wells was to determine the groundwater flow direction and rate to assess the impact of waste deposits on the groundwater quality.

- The groundwater flows from north to south in both the bedrock and deeper portions of sands immediately above the bedrock.
- No potable supply wells are downgradient of the site in the area north of Mishawum Road (about 1/2 mile from the site).
- Organic priority pollutants were found in higher concentrations in wells upgradient of the site than in downgradient wells.
- Arsenic was found in one downgradient well at 420 ppb which is above the drinking water standard of 50 ppb.
- Arsenic was found at 200 ppb in a well lateral to the site groundwater flow.
- Lead was found in two wells, one lateral to the site groundwater flow at 74 ppb and one onsite at 120 ppb, which are above the drinking water standard of 50 ppb.
- Cadmium was found in one well onsite at 28 ppb which is above the drinking water standard of 10 ppb.

- . Only three organic priority pollutants were detected in downgradient wells and none at levels greater than 100 ppb—the drinking water standard for trihalomethanes.
- . One downgradient well showed 1.8 ppm of benzene acetic acid. This compound is not on the EPA's priority pollutant list.

Surface Water

Stauffer collected and analyzed 9 low and 9 high flow surface water samples, 14 soil sediment samples from the bottom of ponds and streams and 3 leachate samples. The purpose of collecting these samples was to evaluate impacts of waste deposits on surface waters, either through seepage, erosion of wastes and sedimentation and/or direct discharges of water seepage emanating from waste deposits.

We found the following based upon the low flow sampling:

- . No heavy metals were found above drinking water standards in samples of surface water on the site and downstream of the waste deposits.
- . Lead was found 100 ppb (drinking water standard is 50 ppb) upstream of the site.
- . A common plasticizer used in many plastic products, Bis(2-ethylhexyl)phthalate was found in all surface water samples.
- . Surface water samples collected in locations upstream and downstream of the site show no noticeable increase in organic chemical concentration.
- . While sediment samples collected downstream of waste deposits showed elevated levels of arsenic (up to 808 ppm), lead (up to 1374 ppm), copper (up to 3366 ppm) and zinc (up to 1386 ppm), the surface water analyses show that these metals are not dissolving in and migrating with surface water.
- . The waste deposits do not appear to be contributing chromium contamination to sediments.
- . Only one elevated level of an organic priority pollutant in sediments (benzene at 320 ppm) was found. The sample was collected near the west waste pile.
- . Generally, there were few organic chemicals found in sediments and their concentrations were in the low parts per million concentrations. In any event, the surface water analyses showed that organics are not dissolving in and migrating with the water.
- . During dry weather conditions, direct liquid discharges (leachate) from waste deposits are not a significant source of contamination to surface waters because only one small leachate stream was observed.

We made substantial progress toward evaluating the impacts of the waste deposits at the Superfund listed site called "Woburn - Industrialplex 128". However, we needed more information to apportion responsibility and evaluate and select remedial action(s). Therefore, a Phase II investigation was conducted to collect the additional information needed.

Phase II Investigation Summary

Following completion of the Phase I investigation and submission of the report, the Phase II site investigation plan was submitted to and approved by EPA and the Massachusetts DEQE.

Scope

The Phase II investigation collected additional site data on soil and waste deposits, groundwater quality and volatile emissions (particularly odor). The 100 acre portion of the 244 acre site to the west of Commerce Way were subjected to a detailed and extensive soil and waste deposit sampling program, volatile emission and odor survey. The groundwater investigation continued onsite and extended well beyond the southern site boundary and downgradient of the site groundwater flow. Also, an offsite investigation designed to visually locate waste deposits south of the site southern and southwest boundaries to the Boston Edison Right-of-Way was added.

Purpose

The purpose of the Phase II investigation was to collect data, in addition to Phase I data, needed to evaluate remedial alternatives and apportion investigation costs per the Consent Order as follows: define waste deposit boundaries; evaluate groundwater south of the site boundary in greater detail; define the contamination plumes, if any; and determine sources, emission rates and compositions of volatile emissions and odor causing compounds.

Description of Work

The field work and data collected met or exceeded the Phase II plan, except for hexavalent chromium (Cr^{+6}) analyses of soil. The EPA analytical method for Cr^{+6} was not applicable to the Woburn soil matrix. In all, about 2,000 air, water, and soil samples were collected of which 1,700 were analyzed, resulting in over 10,000 analyses.

Specifically, the following work was completed:

Soil/Waste Deposits

Soil and waste deposit studies were aimed at defining more accurately the waste deposit boundaries and locating sources of contamination.

Test Pit/Visual Survey for Heavy Metals/Hides Deposits. Within the Consent Order boundaries, about 350 test pits were excavated to a depth of 8 to 10 feet with a backhoe and visual identification of heavy metal waste deposits and geologic logging was made by site experienced hydrogeologists.

The area offsite to the south of the southern Consent Order boundaries and extending to the Boston Edison Right-of-Way boundary and across to the Halls Brook area was also visually inspected. About 70 test pits in undeveloped areas offsite and 5 soil borings in the developed area offsite were installed and visual identification of waste deposits and geologic logs was made by the consultant hydrogeologist (Roux Associates).

To verify the effectiveness of the visual waste deposit identification program, 50 samples were collected from test pits identified as uncontaminated and 20 of these samples were randomly selected and analyzed for chromium (Cr), arsenic (As), lead (Pb), copper (Cu), mercury (Hg) and zinc (Zn).

Soil Boring for Heavy Metal/Hide Deposits. About 425 soil borings were drilled on a pre-established grid of 5 borings per acre in the accessible areas of 100 contaminated acres of the 244 acre site. About 85 acres were accessible and borings installed. From these borings soil samples were collected at three depths, where feasible, and analyzed for the six heavy metals found most prevalent in Phase I, e.g., As, Pb, Cr, Hg, Cu and Zn.

Soil Borings for Organics. In areas where Phase I "head space" gas chromatography results detected organics greater than 100 counts/gram of soil, 10 soil borings were installed in areas containing the highest counts per gram of soil. Those borings were sampled at three depths and analyzed for the organic priority pollutants plus the 20 other most prominent chemicals.

Groundwater

Groundwater monitoring results from the fifteen Phase I wells left unanswered some questions about organic chemical contamination downgradient to the south of the site boundary and arsenic and lead contamination lateral the site groundwater flow.

In Phase II, five (5) new monitoring wells were installed, and sampled along with 15 existing Phase I wells. These 20 wells samples were analyzed for the priority pollutants plus the 20 most prominent other organic chemicals and cyanide, phenol, pH and conductivity. Upon receipt of the above analytical results showing elevated levels of benzene and toluene in downgradient and onsite wells, the groundwater investigation was expanded to locate the source of benzene and toluene. About 61 temporary wells were drilled, sampled and analyzed for benzene and toluene. In addition, 4 new permanent groundwater monitoring wells were installed further downgradient of the site. These 4 new groundwater monitoring wells were screened in the upper and lower portion of the aquifer to detect contamination that might be stratified.

Aquifer Flow Characteristics. To estimate the groundwater flow rate for developing remedial action conceptual designs, a specific capacity test was conducted on six monitoring wells, in the event, groundwater intercept and pumping would be needed. Also, two (2) 6" diameter monitoring wells were drilled to allow pump testing for final design. Furthermore, 23 soil boring were converted to piezometers and a detailed water table map was prepared of shallow groundwater flow to determine the impact of shallow groundwater on waste deposits.

Gas Emissions/Odors

Since the Phase I program to identify and characterize gas emissions and odor sources was incomplete and only partially successful, the Phase II investigation was intensified and analytical methods modified based on Phase I findings.

The site was screened for potential volatile organic emission and odor sources using an HNu photoionization organic vapor detector. In addition, during test pit and soil boring programs, periodic HNu readings were made to locate possible organic vapor sources. Based upon these results, over 350 bar holes (1/2 inch diameter steel tubes) were inserted to a depth of 30 inches and measurements of H₂S and methane concentrations were made with a portable gas analyzer. Also, the ADL Odor Panel walked the site and identified odorous areas.

With the screening program completed, 19 locations were selected as potential gas emission and/or odor sources. Bore holes were drilled in these locations and gas emission rates were measured by sealing plastic bags of a known volume over the vent and recording the time to fill. Air samples from fifteen (15) bore holes, selected on the basis of the gas emission rates, were collected in Tedlar bags and analyzed for volatile organic chemicals. Concurrently, the ADL Odor Panel evaluated samples of the air and characterized the odor intensity and likely chemical constituents of the odor. When the odor panel identified a chemical not detected by the chemical analysis of the gases, a sampling bag was spiked with a known amount of that chemical and analyzed to determine the detection limit.

Findings/Conclusions

The Phase II investigation produced the information and data necessary to evaluate remedial options, apportion costs and conceptually design the recommended remedial actions. The key findings and conclusions, based on both Phase I and Phase II data, are as follows:

Soil/Waste Deposits

- . The waste deposits are buried generally to a depth of 8-10 feet below grade and piled in some areas 40 feet above grade (hide residues).
- . Waste deposits, contaminated soil and hide residues can be visually distinguished from natural sediments by the site experienced hydrogeologist.

Heavy Metals

- . Zinc is the most widespread metal found on the site.
- . Mercury was found at only 8 locations at greater than 100 ppm.
- . Chromium is generally found along with hide residues. About 25 acres contain chromium at 100 ppm or greater, with 18 of the 25 acres greater than 1000 ppm.
- . Lead is usually found in combination with arsenic and about 57 acres contained arsenic and/or lead above 100 ppm of which 29 had greater than 1000 ppm of one or both metals.
- . Surface soil contamination (e.g. top 2 feet) is well mapped and the following areas were defined in excess of 100 ppm:

 Arsenic Pit - 11 acres

 Chromium Lagoon - 9.5 acres

 Wedge Area West of Railroad Tracks - 6.0 acres

 Northwest Railroad Ditch - 2.0 acres

- . RCRA EP Extract tests performed on waste deposit composite samples shows that wastes do not leach heavy metals in excess of 100 times the drinking standards (see Appendix I, Table 6.4)
- . Groundwater quality data directly below the waste deposits show no evidence of significant leaching of heavy metals.

Hide Residues

- . Hide residues are found on four distinct areas for a total of 13 acres. The areas are identified as follows and shown in Appendix VII, Figure 70.
 - . The East Hide Pile covers 3.2 acres with an estimated volume of 125,000 cubic yards
 - . The West Hide Pile covers 2.6 acres with an estimated volume of 50,000 cubic yards

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- . The East Central Buried Hides covers 5.7 acres with an estimated volume of 106,000 cubic yards
- . The South Central Hide Pile covers 1.4 acres with an estimated volume of 60,000 cubic yards

Organic Chemicals in Soil

- . Particularly along New Boston Street, low ppm levels of organic compounds were found including benzene (typically about 20 ppm) and diethylene glycol (an antifreeze) (typically 500 ppm).
- . One sample showed benzene near the surface at 275 ppm. This was a visibly oily area near a culvert.
- . No waste deposits of benzene, toluene or other organic compounds were found; simply low level residues in soil.
- . Other organics were found sporadically at low ppm levels.

Offsite Areas

- . Buried hides were found along the Boston Edison Right-of-Way south of the property boundary. These deposits were identified and defined visually.

Groundwater

Flow Patterns

- . Shallow groundwater patterns are complex and are influenced by topography and permeability differences.
- . A portion of the shallow groundwater discharges into the Aberjona River and its tributaries.
- . Groundwater flows north to south in the buried valley under the Aberjona River.
- . Groundwater in the bedrock discharges into the buried valley.
- . Precipitation onsite is the source of groundwater recharge while upgradient groundwater flow onto the site is less significant.
- . The groundwater flow rate in the buried valley downgradient of the site is estimated from specific capacity tests and visual observation of soil cores to be .2 to 1 foot per day.
- . Differences in permeabilities of aquifer soils downgradient can lead to stratified flows.

Groundwater Quality

Heavy Metals:

- . Phase II resampling of the Phase I wells which showed 120 ppb Pb, 120 ppb As and 28 ppb Cd resulted in no detectable levels.
- . No hexavalent chromium (Cr⁺⁶) was detected in any groundwater sampling.
- . As, Pb and Zn were found in a few downgradient wells in excess of drinking water standards.
- . Since waste deposits have been onsite for years, sporadic levels of heavy metals above drinking water standards does not indicate significant leaching or a plume of contaminants.

Organics:

- . Benzene and toluene were found in the groundwater onsite up to 32 ppm.
- . Benzene at 747 ppb and toluene at 177 ppb was found immediately downgradient of the southern site boundary.
- . No benzene, toluene or significant levels of priority pollutants or other organics were detected in monitoring wells installed further downgradient.
- . Priority pollutants were found upgradient of the site at levels of 14-195 ppb. Higher levels in onsite and immediately downgradient permanent wells, i.e., 15-3004 ppb priority pollutants were primarily due to benzene, toluene and bis (2-ethylhexyl) phthalate.

Groundwater Use:

- . No potable water supply is downgradient in the vicinity of the site.

Gas Emission/Odor

As a result of the photoionization organic vapor screening, bar hole screening and ADL odor survey walkover, the following four areas were identified as potential sources of volatile emissions and odor:

East Pile
West Pile
South Central Buried Hide
South Hide Pile

Based on the ADL Odor Panel analysis and sampling and the analyses for volatile organics and total reduced sulfur compounds of air extracted from 15 bores installed in the above areas, the following resulted:

- . The East Pile was identified as the predominant source of odor and gas emissions with H₂S levels ranging from 5,600 ppm to 21,000 ppm, mercaptans at 400 ppm, gas emission rates measured up to 1.25 cfm and ADL's highest odor intensity score.
- . The West Pile had a low ADL odor intensity rating, H₂S levels about 250 ppm and measured gas emission rates of .7 cfm.
- . East Central and South Hide Deposits had a moderate ADL odor intensity rating (higher than the west pile) but no gas emission rate could be measured. However, ADL noted localized odors at uncovered areas of the East Central Buried Hides.

Other Gas Emission/Odor Findings

- . ADL determined that H₂S was the predominant odor causing compound.
- . Benzene and toluene inside the bore holes were detected at low ppm level (1-11 ppm).
- . Odors and gas emissions were strongly influenced by sharp drops in barometric pressure.
- . Estimated gas emissions from the entire East and West Pile areas are 1.82 cfm and .64 cfm respectively.

Analytical

- . Analysis of the extensive quality assurance data collected and the rigorous chain of custody program showed that the quality of data is excellent for hazardous waste site investigations.
- . Recoveries of heavy metals from soil ranged from 83% to 94%; reproductibility was good and all spikes were detected.
- . Quality assurance results for organic chemical analyses of soil samples compare favorable to other hazardous waste site studies.
- . Groundwater analytical quality assurance results compared favorably to EPA's round robin sampling and analytical study of waste water effluents.

~~DRAFT~~

- . Bore hole sampling/analysis performed as expected. ADL Odor Survey findings and bore hole analytical results compared favorably. ADL identified a few low boiling compounds that were not detected in bag samples collected from the bore holes. Dichlorobenzene and naphthalene were identified as possibly present by ADL and detection limits for bag sampling method were established at 1 ppm and 10 ppm respectively.
- . Hexavalent chromium recoveries in Woburn soil using EPA methods were low (16% at 50 ppm spiking levels) which is attributable to organic interference from hide materials in the Woburn samples.

Phase II
Program

Vol. 1

II. Phase II Scope and Investigation

The Phase II investigation plan was approved by the Environmental Protection Agency (EPA) Region I and the Massachusetts Department of Environmental Quality and Engineering (DEQE) on May 19, 1983. The plan was also reviewed by the Woburn Citizens' Advisory Committee (CAC).

II.1. Phase II Scope

The Phase II investigation was designed to gather data in addition to the data collected in Phase I, that was needed to evaluate remedial alternatives according to the National Contingency Plan (NCP) and apportion the study costs per the Consent Order.

The Phase II investigation covered the following environmental media:

- . Soil/Waste Deposits
- . Groundwater
- . Volatile Emissions

Since Phase I data adequately addressed surface water, no additional data was needed. In addition, engineering design data, not collected in Phase I, was collected in Phase II as determined by the consultant engineering contractor, Malcolm Pirnie.

The Phase II investigation, except for groundwater, was generally conducted on the 100 acre portion of the 244 acre site west of Commerce Way since in Phase I no waste deposits were found east of Commerce Way or in the upper northwest corner of the site (see Figure 1). However, Phase I data showed waste deposits present at the southern site boundary. Therefore, the Phase II investigation was extended beyond the southern boundary to the southern edge of the Boston Edison Right-of-Way (Figure 1 see area D). The investigation beyond the southern boundary was limited to visual identification of waste deposits by hydrogeologists through test pit digging in undeveloped areas and borings in developed areas. To verify the effectiveness of visual waste identification, soil sampling and analysis was performed on a selected number of samples.

With agreement of the EPA, the investigation south of the site as defined by the Consent Order would not be used in evaluating remedial alternatives or apportioning costs. These data would simply be used to identify waste deposits to assess the need for further study and alert property owners.

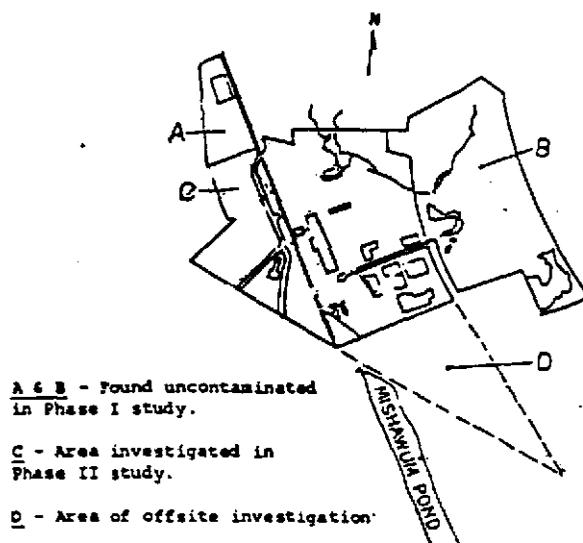


FIG. 1 - 244 Woburn Site

II.2. Description of Phase II Work vs. Plan

The Phase II study collected about 2000 air, water and soil samples. About 1700 samples were analyzed with over 10,000 analytical results reported. The remaining 300 samples were retained for future analysis.

Professionals in industrial hygiene, hydrogeology, safety, hazardous waste management, analytical chemistry, odor evaluation, and engineering participated in the conduct of the study. A field office and site laboratory normally staffed by 15-20 personnel were provided. Three contract laboratories, surveying crews, and several consultants were also involved.

The objective of the Phase II study was to better define contaminated soil/waste deposits in the approximately 100 acres identified as contaminated during the Phase I screening. Heavy metal and organic chemical concentrations in soil and hide waste burials were determined by a combination of visual inspection, laboratory analysis and field measurements. In addition, an offsite area was screened using visual correlations developed from the Phase I and II investigation.

The study investigated the air emissions and odors from the site. Two consultants, the Arthur D. Little Company and Malcolm Pirnie, Inc., assisted in evaluating the odor and gas emissions from the site. The consultants observations, borehole air analyses, and organic chemical analysis of soil samples were used to evaluate site air emissions and odors. A large amount of supporting information on air emissions was gathered by industrial hygiene monitoring of H₂S, organic vapors and total particulates.

Groundwater was sampled, analyzed and evaluated for about a one square mile area on and down gradient of the site. Groundwater data previously collected by others from a much larger area was also reviewed. A hydrogeology consultant, Roux Associates, was used to plan and supervise all field activities associated with the hydrogeologic investigations and to evaluate groundwater findings.

Table A is a summary of the Phase II Plan vs. Work Accomplished. All Phase II goals were met or exceeded. In particular, the groundwater investigation was expanded well beyond the original scope. The original groundwater investigation provided for drilling 5 new monitor wells and collecting 20 groundwater samples. There were 9 new monitor wells installed, 61 temporary screening wells installed, and a total of 92 samples were collected.

TABLE A

Phase II Plan Vs. Work Accomplished

Task	Phase II Plan	Phase II Accomplishments
A) Field		
- Dig and log test pits	350	346+
- Dig and log offsite test pits	not specified	70
- Select visually clean soil for heavy metal analysis	20	20
- Drill/sample 10 borings for soil organic sampling	10/30	10 borings/29 samples
- Drill/log/sample apportionment borings	5 borings/acre	5 borings/acre for total of 426 borings/1331 samples
- Collect 10 soil samples for Cr ⁺³ /Cr ⁺⁶ analysis	*	*
- Drill soil borings to bedrock	15	32
- Examine and log geologic description of 0-5' surface soil samples	<1000	1346
- Collect various soil types for physical testing	15	17
- Drill and log (5) offsite borings	5	5
- Drill/sample new monitor wells	5/5	9/9
- Shallow groundwater wells for benzene/toluene screening	not specified	61
- Resample existing monitor wells	15	15
- Monitor well VOC sampling	not specified	7
- Monitor well specific capacity test	not specified	6
- Piezometer Installation	<100	23
- Drill/sample borehole for air VOC	15/15	19 boreholes/15 samples
- A.D. Little Odor Survey	1	1
- Bar holes for H ₂ S and combustible gas measurements to screen gas emissions	not specified	350+
- Prepare survey map of east/west hide piles	1	1
- Industrial Hygiene Meter readings/samples	daily reading	daily readings/9 samples for total dust, As, Cr, Pb
B) Analysis		
- Soil Heavy Metals As, Cr, Cu, Hg, Pb, Zn	not specified	1065
- Soil organics	30	29
- Soil Cr ⁺³ /Cr ⁺⁶	*	*
- Soil Physical characteristics	15	17
- Monitor well priority pollutant	20	24
- Monitor well VOC	not specified	7
- Monitor well Cr ⁺³ /Cr ⁺⁶	5	24
- Shallow groundwater screening for benzene/toluene	not specified	61
- Industrial Hygiene - Total dust, As, Cr, Pb	not specified	9
- Borehole air samples	15	15

*The Cr⁺³/Cr⁺⁶ analysis on ten selected soil samples was not done after extensive testing found the Woburn soil matrix unsuitable for EPA Cr⁺³/Cr⁺⁶ analytical method.

II.3. Strategy/Overview

The strategy of the Phase II program was to utilize as much as possible the Phase I data for both evaluating remedial alternatives and apportioning costs. The Phase II sampling and analysis to the maximum extent possible, combined the sampling and analysis for remedial alternative evaluation and for apportionment. The approach assured a cost effective program by avoiding duplicative sampling and analysis.

A) Health and Safety

Protection of worker and public health and safety transcended all other Phase II activities. Health and safety professionals and specialists monitored and controlled all site activities to assure health and safety procedures were followed and appropriate protective equipment was worn. These professionals had the authority to stop work if the activities were threatening the health and safety of the workers or the public.

The Phase II health and safety program was based on the successful Phase I program. Health and safety professionals and specialists reviewed the Phase I findings and modified the program to fit the more extensive Phase II investigation. A certified industrial hygienist thoroughly inspected the site, conducted site measurements during start of work, trained site personnel and monitored operations throughout the investigation.

Portable instruments were used for online monitoring and measurement of potential worker exposure during the investigation. A HNu photo-ionization monitor was used to measure organic concentrations. Drager tubes and a continuous H₂S monitor with 5 ppm alarm (Ecolyzer Model 241) were used to measure H₂S concentrations and a RAM 1 particulate monitor was used for dust particulate monitoring.

Field measurements were made with these instruments daily, throughout the Phase II investigation. In addition, 9 industrial hygiene personnel samples of total dust were collected with belt worn devices. The samples were collected during operations and for wind conditions that created dust. The personnel samples were analyzed for total particulates, total dust, arsenic, lead and chromium to establish a guide for worker safety.

Physical examinations were given to all exposed workers.

Site access was limited and no one was allowed on site without safety equipment and training (unless accompanied by trained site personnel). All vehicles used on the site were steam cleaned and inspected prior to leaving the site. All workers exposed to potential hazards were issued clean clothing daily. All site clothing, towels, etc. were laundered daily at the site.

A site Project Engineer/Manager was responsible for assuring health and safety procedures were followed. The Site Project Engineer/Manager was familiar with the site activities in Phase I. A site safety and health specialist was assigned to assist on a daily basis with the implementation of site safety and health programs.

B) Soil/Waste Deposit Study

The purpose of gathering more data on the nature and extent of soil contamination and waste deposits was to enable evaluation of remedial alternatives and apportion costs.

The investigation covered the 100 acre area of the 244 acre area site west of Commerce Way. The area from the south and southwest Consent Order boundary to the southern edge of the Boston Edison Right-of-Way was visually inspected by backhoe excavation for waste deposits.

A detail survey map was made of east hide pile area on a 1" - 40' scale and 2 foot contour to match the 1981 EPA topographical maps. The survey was expanded to include the pond shoreline between and adjacent to the east and hide piles.

1) Re-evaluate Phase I Data/Retained Soil Samples

A substantial amount of information on soil contamination and waste deposits was obtained in Phase I. Also, a substantial number of retained samples suitable for metals analysis were available. All Phase I data was reviewed and incorporated into the Phase II remedial action investigation as appropriate. There were also 34 Phase I soil retain samples selected and analyzed for As, Cr, Cu, Hg, Pb, and Zn.

2) Test Pit Survey

Roux Associates surveyed the 100 acre portion of the site, plus the undeveloped area south and southwest of the Consent Order boundary line to the southern edge of the Boston Edison Right-of-Way using a backhoe and logging the geologic strata. The backhoe pits were dug to a depth of 8-10 feet. The Geologist logged the pits visually and noted the presence of groundwater and waste or unnatural deposits.

The onsite (100 acres) backhoe test pits concentrated on areas outside the contour map areas where Phase I data found concentrations greater than or equal to 100 ppm Cr, As, Pb, Zn, Cu or Hg to better define waste boundaries. However, some backhoe test pits were also located inside the 100 ppm contour lines to expeditiously and cost effectively give a substantial amount of information on the depth of contaminants and the site geology.

The backhoe investigation was conducted over a three week period. About 350 test pits were dug. Each pit was marked and located on the map.

To verify that the visual identification of waste deposits was achievable, 50 samples were collected of soil described by the Geologist as natural. Of the 50 samples, 20 were randomly selected and analyzed for the Cr, Pb, Zn, Cu, As and Hg. Organic chemical contamination cannot be identified visually.

3) Soil Borings

Soil borings were needed to collect samples suitable for gathering additional information to evaluate remedial alternatives and apportion costs. Soil borings were drilled into undisturbed soil or to refusal, as appropriate. These borings provided further definition of extent, thickness and depth of waste deposits. The borings were drilled by hollow stem auger and split spoon core samples were collected. The core samples were inspected, logged and preserved in sealed glass jars. A sample from each boring was collected at 0-2 feet from the surface to assure that data essential for evaluating remedial actions to protect against direct contact, exposure to dust and/or erosion to surface water were collected. For each boring, samples were collected at near surface, mid-point, and bottom of the boring. Each two foot core sample was collected as a single sample. Each of these three samples were analyzed individually. They were not composited with samples from other depths.

To properly consider remedial action, soil borings were extended to bedrock where deemed necessary by the engineering and hydrogeologic consultants.

. Identification of Organic Chemicals

In Phase I, a few areas were identified that might contain significant quantities of organic chemicals. However, the screening technique used to identify possible organic chemical contamination did not characterize or quantify the chemicals present. The screening method simply recorded the counts of volatile organic chemicals present per gram of soil analyzed.

- .. In areas that had greater than 100 counts/gram readings in Phase I, a total of 10 borings were installed. The location of each boring within the 100 counts/gram contour was placed in that portion of the region where the Phase I counts/gram were the highest.
- .. For each soil boring, an average of three representative samples were collected at predetermined depths, e.g. 0-2 feet, 4-6, and 8-10 feet.
- .. Each of the 30 samples was placed in sealed glass jars refrigerated and analyzed for the organic priority pollutants and 20 other organics, per the EPA approved methods.

. Identification of Heavy Metal Concentrations

The soil boring program for developing data needed to evaluate remedial actions and apportion study costs consisted of the following:

- . Five (5) soil borings were installed per acre on the planned 100 acres except for developed areas, roads, rocks, or where Phase I data was sufficient. The 426 soil borings resulted in 1331 samples for analysis of the six metals. It was planned to use EPA method 3060 and 7197 (Determination of Hexavalent Chromium in Soil Waste) to measure the Cr⁺³/Cr⁺⁶ split. However, extensive laboratory method development on Woburn type soil matrix indicated the method was unsuitable. Therefore, with EPA agreement, the analysis of soil samples for trivalent and hexavalent chromium (Cr⁺³/Cr⁺⁶) was not performed.
- . As determined by the consulting hydrogeologic firm, Roux Associates, 32 soil borings were drilled to depths needed to sample the underlying soil and determine depth to bedrock and underlying soil characteristics.
- . Roux Associates collected 1386 surface soil samples (0-5 foot range) throughout the site, logged the geologic description, located on a map and visually classified the soil samples by type. Seventeen (17) typical samples of varying soil types present on the site were tested for permeability, moisture content, density and specific gravity.

The entire site was surveyed and staked out in 50 x 86.6 foot grids. All soil borings were located with an accuracy of ± 5 foot, based on surveyor's stakes and tape measured locations due to obstructions. If possible, all borings were located on the exact grid intersection marked by a surveyor's stake. However, if rocks or an obstruction prevented drilling, the boring would be relocated and the reason noted in the Geologist's field notebook. If a boring could not be located within 20 feet of the correct grid location, then it was omitted and noted.

All borings and test pits on the site or the triangular offsite area to the south were assigned a five digit location number, locating them within a 50' x 86.6' rectangle. The first two digits were the north grid and the next two the east grid at the south west corner of the rectangle. The last number identified the boring/test pit type. If the last number was zero, then the location represented a heavy metal sampling point. If the last number was 1-9, the location represented a bore hole air sample, soil organic sample, test pit, etc. located within the rectangle.

Soil borings were drilled to bedrock or several feet into natural undisturbed soil with truck mounted or crawler drilling rigs. Soil samples were collected from one half of a two foot section of a split spoon sampler. Soil samples were collected from top 2 feet, middle two feet and bottom two feet directly above natural/undisturbed soil. Samples were collected whenever there was at least one foot of soil as follows:

- ... 1-2 feet soil/waste: A sample was collected from 0 to 1-2 foot waste depth.
- ... 3-4 feet of soil waste: Samples were collected from 0-2 feet and 2 to 3-4 feet.
- ... 15 feet of soil/waste: Samples were collected from 0-2 feet, 6-8 feet and 13-15 feet.

Additional samples were collected whenever discolored or unnatural layers were not included in the above samples at about 20 locations. Samples were collected for evaluation in the two feet of natural/undisturbed soil directly under waste deposits.

Each soil sample was documented using a rigorous chain of custody procedure and taken to a site laboratory for preparation for analysis. All soil samples from top, middle and bottom and approximately 100 other soil samples were sent to a contract laboratory for As, Cr, Cu, Pb, Hg and Zn analysis. Each batch of (15) soil samples had (5) Quality Assurance samples submitted to measure analytical accuracy and reproducibility. Duplicate samples of all soil samples and Quality Assurance samples were kept.

A computer program was provided to assemble, file and track the vast amount of data gathered in Phase II. A separate computer program was used to calculate the analytical quality assurance scores. The data handling system for Phase II was as follows:

- 1) Location of boring, test pit, well, etc. -

A location sheet and geologist notebook was used to document location, fill depth and for apportionment borings the Massachusetts plane coordinates. The location sheet data was entered in the computer.

- 2) Samples -

All sample data was recorded in the field sampler's notebook, transferred to the laboratory custody notebook and entered on a sample sheet. The sample sheet data was entered in the computer.

3) Quality Assurance Batches -

A batch of samples and quality assurance samples were prepared, entered in the quality assurance chemist's notebook and a batch sheet. A transfer sheet was prepared to transfer custody to the contract laboratory. The batch sheet data was entered into the computer.

4) Analytical results -

The contract laboratory transferred a computer file of the analytical results, which was entered into the computer.

. Exploration of Developed Areas South to Mishawum Road

Since contamination in Phase I was found at the site boundary line, the investigation in Phase II was to extend to the south beyond the Boston Edison Right-of-Way. Therefore, an estimated 70 test pits were excavated and visually logged in this area. Seven of the test pits were dug and logged offsite along the railroad right-of-way, between the site and the Halls Brook bridge. There were also 26 soil samples collected from 6 off-site test borings, and analyzed for benzene/toluene (Appendix I, Table 1.5).

Any data collected beyond Consent Order boundaries will be used simply to gain a better understanding of waste boundaries and to alert current property owners to any hazards that might be encountered in future property development.

4) Groundwater

The groundwater information developed in Phase I was not sufficient to thoroughly evaluate the remedial alternatives or assess the impact on the groundwater. A better definition of the groundwater quality downgradient of the site, shallow groundwater flow directions and groundwater flow rates in the aquifer of concern was needed to evaluate remedial alternatives. The potential for the contamination to be stratified in groundwater was also evaluated.

Therefore, an important part of the Phase II investigation was the following:

. Resampling the Existing 15 Phase I Monitoring Wells

The 15 monitor wells installed in Phase I were resampled and analyzed for the priority pollutants, plus the 20 most prominent organic chemical peaks that were not priority pollutants. In addition, well water samples were analyzed for Cr^{+6} , and pH, conductivity, cyanide and total phenol.

. New Monitoring Wells

In Phase I, the groundwater flow direction was established as north to south and flowing in a buried channel under the Aberjona River. Arsenic contamination and some organic chemicals not listed as priority pollutants were found in the downgradient well OW-12 at the southern site boundary near the buried channel. Also, arsenic contamination was found in well OW-5 at the southeastern site boundary near Phillip's pond which is lateral to groundwater flow direction under the site. Therefore, five new wells (#15, 16, 17, 18, 18a) were drilled and sampled to evaluate further these Phase I findings. The samples were analyzed for the same parameters as the existing 15 Phase I wells.

When benzene and/or toluene were found in a few wells, an expanded investigation was conducted to determine the source and extent of contamination. Sixty-one (61) shallow temporary groundwater wells were drilled with a truck mounted boring rig. The temporary wells were drilled to below the water table. Grab samples were collected and screened for benzene and toluene. In addition, monitor wells #12, 14, 16 and 17 were reanalyzed for volatile organic compounds. Well #16 was also sampled three more times for volatile organic compounds over a 24 hour period of continuous pumping.

Four additional wells (#19, 19a, 20, 20a), were then installed based on the review of geologic data and screening wells. The wells were installed as two sets of cluster wells, i.e., one well at 80-100 foot depth and an adjacent well at 40-60 foot. Cluster wells allow sampling for possible contamination in layers within the aquifer (stratification). Wells #19 and 19a were installed about 400 yards south of the site on the east side of Mishawum pond. Wells 20 and 20a were installed about 100 yards north of the Mishawum Road bridge on the east side of Mishawum pond. The four wells were developed, sampled and analyzed for priority pollutants plus up to 20 other organics present in the highest concentrations. The wells were also analyzed for pH, conductivity, cyanide and total phenol. In addition, 24 monitor well samples were analyzed for hexavalent chromium.

In all, 9 new monitor and 61 shallow temporary wells were drilled and sampled.

. Estimate Aquifer Transmissivity

Specific capacity tests were conducted on 6 monitor wells (#12, 16, 17, 18, 19, 19a), to estimate aquifer hydraulic conductivity.

The specific capacity test consisted of the following:

- 1) Selecting the appropriate wells;
- 2) Measuring the water level in each selected well;
- 3) Pumping each well at 10-20 gpm for 15 minutes;
- 4) Measuring the drawdown (water levels) in each well each minute;
- 5) Determining the specific capacity for each well by dividing the pumping rate by the drawdown;

- 6) Entering the specific capacity into a standard calculation relating specific transmissivity of the aquifer in the vicinity of each well (Walton, 1970; Groundwater Resource Evaluation); and

The specific capacity test gives sufficient information on aquifer flow rate to estimate roughly the volume of water that might be intercepted and treated. In addition, two (2) of the new wells installed in Phase II are 6" in diameter, and they can be used for pump testing which will be needed for developing more detailed design information.

. Shallow Groundwater Flow

To determine if shallow groundwater is moving through or rising into waste deposits, and what if any remedial actions are needed to minimize this movement, 23 soil borings were selectively converted to piezometers and a much more detailed map of the flow pattern of localized shallow groundwater flow was developed.

. Gas Emission/Odors

The following describes the additional Phase I data collected to identify and evaluate sources of gas emissions and odor. The purpose of this portion of Phase II was to develop and gather sufficient data to evaluate remedial actions for odor control and, if needed, other volatile emissions.

- Screening for VOC Emission Sources

All areas of the site were screened by a walkover with a HNu photoionization organic vapor detector prior to beginning field activities. While digging and sampling test pits and borings, periodic HNu photoionization meter readings also were taken to measure possible sources of organic emissions. Visual observation and odors were also used to screen the site for possible sources of organic emissions. Then, based on this screening, extensive subsurface gas measurements were made with a hand probe to determine below ground H₂S and combustible gas concentrations. Over 350 locations were sampled to locate decaying hides or organic waste that were generating gases.

The subsurface gas samples were collected by forcing a 1/2 inch diameter steel bar into the soil to a depth of 3 to 30 inches. The bar was extracted and a 1/4 inch diameter, hollow core steel pipe was inserted to the bottom of the hole. Gases were drawn from the bottom of the hole through the pipe and attached flexible tubing, and into the intake of the portable gas analyzer. The portable gas analyzers used were a 0-100% combustible gas indicator (MSA Model 60) and a 0.5-250 ppm H₂S analyzer. (Energetics Science 2000 Series).

- Identification of Gas Emission Rates and Composition

The gas emission investigation planned on drilling and installing 15 boreholes in areas with high odor potential and areas identified in Phase I or II screening as having potential volatile organic emission. Nineteen (19) boreholes were drilled during the gas emission investigation and 15 were analyzed for Volatile Organic Priority Pollutants, plus 20 highest peaks, and Total Reduced Sulfur Compounds.

All nineteen (19) boreholes were equipped with 4" vent pipes to measure the gas generation rates. A 6" diameter boring was made to undisturbed soil or below the water table. A ten foot 4" vent pipe with perforations in the bottom 6 feet, was installed 8 feet deep and sealed around the outside at ground level. A large plastic bag with a known volume was then placed over the open end of the 4" vent. The time for the bag to fill was measured and the gas generation rate calculated.

Meteorological data and subsurface gas pressure and temperatures were obtained to determine possible weather and seasonal effects on gas emission.

The 15 boreholes with the highest gas emissions rate/concentrations were selected for air sampling. Air samples were collected with the bag sampling method proven most applicable in Phase I. The bag samples were analyzed for TRS, priority pollutant VOC and if present, up to 20 other VOC's.

- Odor Survey

The Arthur D. Little (ADL) Company was hired as a consultant to characterize site odors. Borehole air sampling and ADL's odor testing/sampling were conducted contemporaneously to provide a correlation between subsurface gas analysis and odor characteristics. A teflon sampling tube was lowered about one foot above the borehole bottom. An air sample was collected and analyzed for VOC's and TRS. ADL immediately used the sampling tube for odor characterization.

ADL used a panel of three trained odor analysts to characterize the borehole odor. The borehole gas was run through equipment to isolate/dilute borehole gas, and was then evaluated in the field by the odor panel. The borehole gas was also absorbed on sampling media for laboratory comparison. The sample media with absorbed borehole gas was taken to Stauffer's site laboratory for further evaluation. The absorbed borehole air samples were solvent eluted and compared with known odors.

- Validate Analytical Methods for Odor Detection

At the same time bore hole air samples were collected, a trained odor detection consultant characterized the odor components of the gases. Results of the gas analyses were correlated with chemical characteristics reported by the odor consultant. Specific characteristic compounds reported by the odor consultant not identified in the gas analyses, were added in standard amounts to sampling bags and analyzed to determine if such compounds could be measured, and the approximate level of detection. The correlation was performed for dichlorobenzene and naphthalene which were detected by ADL but not by the bore hole air analysis.

Engineering Design and Cost Estimating Data

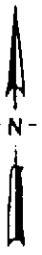
A consultant engineering firm was hired to assist Stauffer in assuring that the data needed to evaluate remedial alternatives and conceptually design the remedial action selected was gathered.

INTRODUCTION

The Phase I and Phase II investigations of the Industriplex-128 Site have been completed. The subsurface investigation, including ground water, soils and buried waste deposits is discussed in this section of the report. The work was carried out during 1982 and 1983 by, or under the supervision of geologists from Roux Associates with chemists, engineers, quality assurance technicians and a safety officer from Stauffer Chemical Company.

The location of the Site and areas of investigation are shown on Figure 1. The portions of the Site that were included in the subsurface investigation are shown in greater detail on Figure 2 (Appendix VIII). Shaded areas of Figure 2 are either developed or very shallow bedrock and were investigated where possible as part of Phase I. The off-site areas that were visually examined as part of Phase II are also shown on Figure 2.

The Phase I subsurface investigation at the Woburn Site, conducted from July through October 1982, consisted of a preliminary definition of the nature and extent of waste deposits and contaminated soil and a preliminary evaluation of ground-water conditions.



WILMINGTON

TOWN OF WOBURN

SITE

READING

DEVELOPED AREA

Route 128

STONEHAM

BURLINGTON

Route 38

Route 93

Route 3

WINCHESTER



TITLE	
SITE LOCATION MAP	
PREPARED FOR	
Stauffer Chemical Company	
SCALE	FIGURE
1:5000	1
ROUX CONSULTING GEOMETRIC WATER CONSTRUCTION	DATE
ROUX ASSOCIATES INC.	3/84

The waste deposits and soil investigation was carried out with electrical conductivity surveying equipment, a backhoe and an auger drilling and core sampling rig. Many soil and waste samples were collected, described and chemically analyzed during this portion of the investigation. The ground-water conditions at and around the Site were evaluated by installing fifteen observation wells, measuring water levels and collecting and analyzing water samples.

The Phase II subsurface investigation was carried out from August to December, 1983. This portion of the investigation included a detailed waste extent and characterization boring program of 425 borings, a visual analyses of subsurface conditions with a backhoe, installation of piezometers for detailed water table mapping in the waste area and installation of nine additional observation wells.

The various methods used in the Phase I and Phase II subsurface investigations at the Woburn Site are described below. The results of these investigations, and the findings and conclusions drawn from the results are given in subsequent sections. Finally, recommended remedial actions for ground-water conditions at the Site are given.

Conductivity Survey - Phase I

A preliminary screening of the Site was undertaken using a geophysical method known as induction conductivity. Induction conductivity makes use of a device called a "non-earth-contracting terrain conductivity meter", which utilizes the principle that the electrical properties of various natural earth minerals and artificial fill (or waste) can be significantly different.

It was expected that the individual types of waste material at the Woburn Site would each have their own recognizable and distinct conductivity range, and that this would permit the delineation of these materials. At the very least, the waste materials were expected to have a substantially different conductivity from natural soils and rock at the Site. Thus, the conductivity survey was intended to provide the initial screening of the Site and help guide the boring and test pit programs to follow.

A second purpose of the conductivity survey was to give a very thorough coverage of the Site to insure that all buried waste deposits were located. This blanket coverage is not practical with pits and borings alone.

The conductivity equipment used in Woburn was manufactured by Geonics, Ltd. of Mississauga, Ontario. Two types of terrain conductivity meters were used: the

one-man EM-31 and the two-man EM-34-3 (hereafter referred to as the EM-34). Both the EM-31 and the EM-34 work in a similar fashion. A time-varying electromagnetic field is produced by a battery-powered transmitter which in turn acts to generate electrical eddy currents in any subsurface conductors present. These eddy currents then serve as the source of a secondary electromagnetic field, generally 90 degrees out of phase with the transmitter-generator (primary) field. Since the secondary field is out of phase with the primary field, it can be detected by the receiver. At the low frequencies used by the EM-31 and EM-34, the strength of the secondary field is directly proportional to terrain conductivity, which allows the equipment to display direct readings of apparent conductivity.

The EM-31 was used for this project because of its continuous-reading capabilities which allowed a rapid identification and delineation of high-conductance areas. The EM-34 was used to verify results from the EM-31 and determine conductivities at greater depths than the EM-31 is capable of.

The depth from which conductivity data can be gathered is related to the geometry of the receiver and transmitter coils. Since the EM-31 has a fixed intercoil spacing,

the conductivity data it collects corresponds to conditions within six to seven meters (20 to 23 feet) of the surface. The EM-34 however, due to the flexible cable attaching the transmitter and receiver coils, allows for changes to be made in its intercoil geometry. The EM-34 can be used with a 10 meter, 20 meter, or 40 meter (30, 60 or 120 feet) intercoil spacing. When both coils are held coplanar and vertical (called the horizontal dipole mode), an effective depth of penetration of 7.5 meters (22 feet) for the ten meter intercoil spacing is obtained. Depths of penetration of fifteen meters (45 feet) are obtained in the 20 meter intercoil spacing, and up to 30 meters (90 feet) penetration is obtained when the coils are 40 meters apart. The coil geometry can also be changed so that both coils are lying horizontal (vertical dipole mode) which effectively doubles the depth of penetration expected for each intercoil spacing.

The EM-31 and EM-34, like any electromagnetic equipment, are subject to interference. Sources of interference can be numerous in developed areas, and may not be easily avoided. Interference may be caused by buildings, buried pipelines, metal fences, railroad tracks, power lines and other large metal objects. Their adverse effect on data quality can only be avoided by keeping the equipment an

appropriate distance away from the source of interference. The appropriate distance must be determined by the operator through past experience, or through on-site interference testing in an area of known terrain conductivity.

A second limitation that must be considered before interpretation of results can be made is imposed by the local geology. For example, since clay is a relatively good electrical conductor, it can mask the evidence of waste buried at a particular location. The degree of understanding of the local geology is, therefore, related to the degree of confidence of interpretation of conductivity data.

The conductivity survey at the Woburn Site was conducted on a 200-foot grid spacing. A tighter grid spacing was used in some areas. The orientation of the grid lines was chosen to coincide with the survey grid used on the two-foot contour-interval Woburn Site base map. The conductivity measuring points were then plotted on this map as the survey was being conducted. Altogether, over 640 conductivity measurements were made at approximately 460 locations. The conductivity measuring point locations are shown on Figure 3 (Appendix VIII).

One of the stations was arbitrarily chosen as a starting point and located in the field with the aid of the map, a compass, and a tape measure. From this point, the other stations were located through the use of a compass, optical tape measure, and the two-foot contour-interval map.

The grid network was designed to cover the entire Site, as well as portions beyond the Site where possible, to allow for a conductivity contrast between clean soil and wastes to be observed. Certain areas could not be included in the grid due to the presence of extensive sources of interference.

The conductivity at each grid site was first measured by the EM-31. These results indicated the need for a closer data spacing in several portions of the Site. A series of continuous-reading traverses were then conducted through these areas. This was done to better define the more complex zones, and to identify any deposits that may have been missed previously.

The EM-34 was used primarily in the western portion of the Site, on land adjacent to the Woburn Landfill (west of the Site) and in the area south of the Site near the chrome lagoons. Due to the high water table and

relatively shallow bedrock throughout much of the Site, the ten-meter intercoil spacing was used for both horizontal and vertical dipole readings with the EM-34. The horizontal dipole data (with a 7.5 meter (22 ft.) depth of penetration) was used to verify data collected with the EM-31. The vertical dipole data (with a 15 meter (45 ft.) depth of penetration) was used to evaluate the possibility of deeper sources of contamination, to aid in the delineation of buried construction materials.

Soil Boring Program-Phase I

The purpose of the Phase I boring program was to screen the Site for extents and types of wastes present and to confirm the conductivity results. To accomplish this, fifty-seven soil borings were drilled on the Woburn Site between July 27, and August 19, 1982 by Parratt-Wolff, Inc. of East Syracuse, New York, under the supervision of geologists from Roux Associates. In addition, eight borings were completed for the Phase I air sampling program (AS1-AS8). Boring logs are included in Appendix II. The locations of the borings are shown on Figure 4 (Appendix VIII).

The sites for the Phase I borings were located by the geologists based on the information obtained from the conductivity survey, historical aerial photographs and an

inspection of the surface. Borings were drilled primarily in areas where digging test pits with a backhoe was not practical, such as in developed areas where the surface could not be significantly disturbed and in areas where it was desirable to sample deeper than eleven feet below the surface (the depth limitation of the backhoe).

A truck-mounted hollow stem auger rig was used to take continuous cores to refusal or until natural deposits were encountered. Where several borings were placed close together, one boring was advanced to refusal and the others were terminated approximately ten feet into natural deposits.

Split-spoon core samplers were used to collect continuous samples. A split-spoon sampler would be driven two feet into undisturbed sediments by a standard 140 lb. weight and then extracted. The geologist would then open the spoon on a plastic sheet, log the core in detail, and then remove the sample from the split-spoon using vinyl gloves and plastic spoons. The sample was placed in a pre-cleaned, wide-mouth quart jar under the supervision of a chemist. Cross-contamination was minimized by thoroughly steam-cleaning each split-spoon sampler before reuse.

After the 0-2 foot interval sample was collected, the hole was advanced to the two foot depth with power driven six-inch diameter hollow stem auger flytes. The 2-4 foot interval was then sampled by split-spoon. Cross-contamination within the hole was prevented as samples were collected ahead of the auger flytes. The auger flytes were steam-cleaned before moving from one area of the site to another to further avoid cross-contamination. To prevent dilution of any contaminants that might be present, water was not used in the drilling process. When the sampling was completed, the open hole was back-filled with the cuttings and the site marked with a metal stake and flagging. The location of each boring was surveyed and plotted on the site map.

Soil Boring Program-Phase II

The purposes of the Phase II soil boring program were to aid in the selection of appropriate remedial measures and to provide data for allocation of the study and remedial costs. This was accomplished by defining in detail the extents and types of wastes and contaminated soil present at the Site.

For the Phase II test boring program, 425 borings were drilled, 1331 samples were collected and 1032 of these were analyzed. The borings were located on a regular grid. The East-West grid lines were set 50 ft. apart and the North-South grid lines were set 86.6 ft. apart.

All borings were drilled between August 23 and October 14, 1983 by Parratt Wolff Inc., of Syracuse, New York using a truck mounted hollow stem auger rig, a tracked auger rig and a portable tripod rig. The tracked rig and tripod rig were used in difficult access areas such as swampy and hummocky terrain. When obstacles such as rock piles, streams and overhead power lines, made it impossible for a boring to be drilled at the predetermined location, a new location was selected within a 20 foot radius of the grid point. The new location was accurately plotted on the Site base map by

using a tape measure and the new coordinates determined.

Phase II borings were drilled through the thickness of the fill and into natural deposits as determined by the on-site geologist. The ability of the geologists to distinguish natural sediments from fill was established during Phase I and was substantiated by sampling and analyses done as part of the Phase II test pit program.

The soil samples from each boring were laid out on plastic sheeting until the depth of fill was determined. Samples were collected from the top, middle and bottom of the fill unit and in the natural deposits immediately below the fill. Other samples were collected as determined to be appropriate. The geologist described all samples in detail and coded them based on color, odor and texture.

The samples were collected in a similar manner to Phase I. All split-spoons were opened on a plastic sheet and disposable plastic gloves and utensils were used to place the sample in pre-cleaned sample jars in the presence of a trained quality assurance technician. A chain of custody was maintained.

In addition to the soil borings drilled for remedial

action/apportionment sampling, ten borings were drilled, sampled and analyzed for organic compounds. These borings (OS-1 through OS-10) were located based on Phase I organic screening results. The borings were drilled in a similar manner to the other borings. Three samples, generally from the top, middle and bottom of the wastes, were collected for analysis from each boring. The sample selection was based on Phase I data, field observations and portable field instruments. All samples collected were immediately prepared by the on-site quality assurance technician and placed on ice.

Air sampling holes, (BH 9-25) were drilled in the same manner as the borings. Split-spoon cores were collected and logged by the geologist but no sediment samples were retained. After completion, each hole was left open and ten feet of 4-inch diameter perforated PVC was installed in the hole allowing for two-foot stick-up. A plastic sheet was tightly attached over the top of each PVC pipe. Shelby tube samples were collected at the surface near each air sampling hole and were delivered for compaction, density, moisture content and permeability analyses to a local laboratory. All air monitoring points are shown on Figure 4 (Appendix VIII).

Five soil borings (TA1 - TA5) were drilled in the

developed area south of Atlantic Ave. and north of the Boston Edison Easement (Figure 5). The borings were located based on aerial photographs and discussions with EPA. No waste deposits were encountered.

At certain boring sites, it was determined that a piezometer would be useful to measure water levels in the shallow sand and gravel deposits. The piezometers consist of a 4.5-foot length of two-inch diameter PVC slotted pipe with blank PVC riser pipe extending above grade. The formation was allowed to collapse around the screen zone and the remaining annular space was back-filled with material initially removed from the hole.

A total of twenty-seven piezometers were installed and subsequently developed with compressed air. The elevation of a designated measuring point at the top of the PVC casing was determined with respect to mean sea level. Water levels were measured with an electric probe and steel tape to +0.01 feet. The locations of the piezometers are shown on Figure 73 (Appendix VIII).

Surface Soil Study

A surface soil study was conducted at the Site to determine the different soil types and where waste deposits were within three inches of the surface. A core

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sampling tube was used to collect samples at grid points between soil boring locations. The geologist then logged each sample for color, texture, odor and sediment type. A map showing the surface sampling points, soil types and waste deposits at the surface was then compiled.

Test Pit Program

A backhoe was used in Phases I and II at the Woburn Site and on the Boston Edison Right-of-Way below the Site to dig 469 test pits. All pits were dug between August 26 - September 9, 1982, August 1-19, 1983, and October 4-7, 1983 by Warren Cummings of Woburn, Massachusetts, under the supervision of geologists from Roux Associates. Test pit locations were selected by examination of analytical results, the conductivity data, surface deposits, discussions with EPA and historical aerial photographs. The locations of the test pits are shown on Figures 4 and 5 (Appendix VIII).

Each test pit was dug to the limit of the backhoe (about 8-11 feet below land surface), to refusal (bedrock) or to a depth where collapse occurred due to intersection with the water table. Test pits allowed the geologist to view the shallow stratigraphy and could be dug at a faster rate than the soil borings. However, this method was limited to a maximum depth of about 11 feet below land surface and to areas where the surface could be disturbed.

Each individual test pit was excavated in steps allowing the geologist to accurately describe the deposits and

obtain representative samples by hand. When the pits were more than five feet deep, samples were collected without the need for the geologist to enter the trench by using a steel trowel attached to the end of a long rod.

The area of the wall of the trench where any samples were to be taken was scraped to remove any sediments that had been in contact with the backhoe. The depth to each sampling location was measured. Each sample collected by the geologist was immediately delivered to the chemist at the Site for labeling and preservation.

Most of the test pits dug during Phase II were used to visually log waste deposits overlying natural deposits. To verify the usefulness of this method, a total of fifty soil samples from visually clean areas on and around the Site were collected. Out of these fifty, twenty were randomly selected for analysis. Nineteen out of twenty showed the six metals analyzed for (lead, arsenic, chromium, zinc, copper and mercury) at levels less than 100 ppm and thus were judged to be uncontaminated. This clearly demonstrated that the geologists could differentiate waste deposits from clean sediments in the field. The backhoe was then used as a tool to visually log the shallow geology and waste deposits at the Site.

After the logging and/or sampling at each test pit was completed, the pit was backfilled with the material that had been removed from it. All sampling implements were either disposed of or cleaned with distilled water. The backhoe itself was steam-cleaned between areas and at the end of each working day. The location of each test pit was plotted on a map and a stake was left at the location in the field.

The backhoe was used as an effective screening tool in delineating the vertical and horizontal extents of waste deposits on the Site and Boston Edison Easement. An additional eleven test pits were dug and visually logged in the Hall's Brook Area at the request of EPA. The geologic logs of all the test pits are included in Appendix II.

Observation Well Installation

The observation wells were installed between August 10 - September 22, 1982, August 16 - 24, 1983 and December 12 - 15, 1983 by D.L. Maher Corporation, Reading, Massachusetts. Well drilling and installation were observed by geologists from Roux Associates. A truck-mounted combination air/mud rotary rig was used at all sites.

Two types of wells were installed, sand/gravel wells and rock wells. The rock wells are simply an open hole cased off from the overburden, whereas the sand/gravel wells are constructed with a PVC screen (slotted pipe) and casing. The PVC casing is protected at the surface by an outer steel casing with a locking cover. The locations of the observation wells are shown on Figure 6. Well construction data are given in Table 1.

In areas where the saturated thickness of the sand and gravel deposits was greater than ten feet, a sand/gravel well was installed. Where rock was close to or at the surface, a bedrock well was drilled. At location OW-1 both a rock well and a sand/gravel well were determined to be necessary. A two-well cluster system was installed at locations OW-18, OW-19, and OW-20 to provide more representative analytical results over greater saturated thickness of the aquifer. The rock and sand/gravel wells were installed in two different manners described in the following sections.

Rock Wells

Six rock wells were installed at the Woburn Site. For these wells, a thirteen-inch roller bit was used to drill through the unconsolidated materials and five feet into

Table 1 - Well Construction Data

<u>Well Number</u>	<u>Date Installed</u>	<u>Well Type</u>	<u>Screen Zone (1)</u>	<u>Elevation of Measuring Point 2)</u>
OW-1	8/13/82	Rock	24-108	80.32
OW-1A	8/14/82	Sand	5-25	79.72
OW-2	8/17/82	Rock	16-100	128.02
OW-3	8/3/82	Rock	25-83	74.76
OW-4	8/5/82	Rock	25-44	71.54
OW-5	8/27/82	Sand	9-49	68.08
OW-6	9/17/82	Sand	6-16	62.67
OW-7	9/16/82	Sand	6-36	57.88
OW-8	8/25/82	Rock	9-100	68.85
OW-9	8/9/82	Rock	28-123	68.88
OW-10	8/18/82	Sand	2.5-32.5	64.63
OW-11	8/12/82	Sand	2-42	71.22
OW-12	8/19/82	Sand	12-52	63.74
OW-13	8/20/82	Sand	8.5-33.5	64.99
OW-14	9/22/82	Sand	5-50	65.54
OW-15	8/17/83	Sand	8-28	64.60
OW-16	8/25/83	Sand	15.7-35.7	67.29
OW-17	8/19/83	Sand	10-30	57.86
OW-18	8/23/83	Sand	15-55	62.76
OW-18A	8/24/83	Sand	5-15	62.08
OW-19	12/15/83	Sand	40-70	55.97
OW-19A	12/16/83	Sand	5-40	55.87
OW-20	12/12/83	Sand	49.5-99.5	57.33
OW-20A	12/13/83	Sand	10-40	57.97

- 1) Feet below land surface, length of open holes in rock wells
- 2) Feet with respect to mean sea level

solid bedrock. Six-inch diameter steel casing was set in the hole allowing for a one-foot stick-up above land surface. The steel casing was used to seal off any ground water in the unconsolidated deposits and to prevent collapse. This assures that representative ground-water samples from the bedrock can be obtained. The annular space around the casing was pressure-grouted with a cement/bentonite slurry to land surface. The inside of the steel casing was then flushed out with clean water to remove any drilling fluids and sediment.

After the steel casing had set in the hole, a six-inch diameter pneumatic hammer was used to drill to the desired depth in the rock. Drilling continued until water-bearing fractures were encountered or to at least eighty feet into rock if no such fractures were found. A geologist logged the rock fragments coming from the hole as the drilling progressed. Well logs are given in Appendix VI.

No casing was set in the hole since the rock is dense enough to allow the hole to stay open indefinitely. After the well was finished, a metal plate with a hasp was welded to the top of the steel casing allowing the well to be locked. All six rock wells were purged immediately after installation by a submersible pump.

Each well was pumped until ten times the volume of water standing in the open hole was removed (OW-3 and OW-4) or until it went dry (OW-1, OW-2, OW-8 and OW-9).

A designated measuring point on top of each well casing was leveled in with respect to mean sea level. Water levels in all wells were measured on three occasions to ± 0.01 feet by an electric probe and measuring tape.

Sand/Gravel Wells

Nine sand/gravel wells were installed in Phase I and nine (including three clusters) in Phase II. These wells are screened in the saturated, unconsolidated deposits. All borings in sand/gravel were drilled by the mud rotary method using Revert and/or bentonite and water from the municipal supply system as drilling fluid additives.

In constructing these wells, an eight-inch roller bit was used to drill through the unconsolidated section and five feet into solid bedrock. After the hole was drilled, the geologist selected the appropriate length of four-inch diameter PVC slotted pipe (screen) to be used. For Phase I, the entire saturated thickness of the sand and gravel aquifer was screened. Portions of the aquifer were selectively screened by the wells installed in Phase II. Threaded, four-inch, blank PVC casing was used in the

unsaturated sections, allowing for a one-foot stickup above land surface.

Two wells, OW-18 and OW-19, consist of six-inch diameter screen and pipe set in a twelve-inch diameter borehole. This was done to facilitate pumping tests, if needed for remedial design considerations.

The screen zone of each well was packed with clean silica sand of a suitable grade for the slot sizes (.010-inch openings). A seal of bentonite pellets was placed immediately above the sand pack and the remaining annular space was pressure-grouted to about three feet below land surface with a cement-bentonite mixture. A cement seal was poured in the remaining few feet to land surface and a protective steel standpipe with a lock was used to protect each well.

Seven test borings were drilled in the buried valley south of the Site to select optimum locations for the two cluster well systems (OW-19 and 19A; OW-20 and 20A). Geologic logs for these borings are given in Appendix VI.

The sand/gravel wells were developed in two steps. The first step consisted of surging and pumping the well with air. This process removes fluids introduced during

drilling and much of the fine sediment from the formation around the screen, thus allowing a free flow of water from the aquifer into the well. The second step of the development process consisted of pumping with a submersible pump to remove at least ten times the volume of water contained in the casing and sand pack. This step insures that all aerated water and/or water introduced during drilling has been removed.

The six-inch well at OW-19 was further developed by using a surge block. This was done to increase the effective yield of the well should a pumping test be required.

Ground-Water Sampling

Ground-water samples were collected from the OW series of wells on September 27-29, 1982, August 30-31, 1983 and January 3-4, 1984. Resampling of selected wells for conformation purposes was done during September through November 1983. Immediately prior to sampling, each well was purged by pumping it dry or by removing from five to ten casing volumes of water. The submersible pump used for purging was thoroughly rinsed and steam-cleaned between wells.

Samples were collected by Roux Associates and Stauffer personnel using stainless steel and teflon bailers.

Prior to sampling each well, the bailer was thoroughly washed with tap water and rinsed three times in distilled water. In addition, the first three bailer volumes removed from the well were discarded. All sampling gloves, bailer cord, etc. were changed between wells.

HYDROGEOLOGY

Geologic deposits in the study area can be divided into groups or units based on sediment character, origin and permeability differences. From oldest (deepest) to youngest (shallowest), they are:

Unit E - Crystalline bedrock

Unit D - Poorly sorted to unsorted mixture of clay,
sand and gravel

Unit C - Fine to medium sands with silty and gravelly
layers

Unit B - Peat and silty peat

Unit A - Miscellaneous artificial fill deposits

Twelve geologic cross sections (locations shown on Figure 7) have been compiled, eleven crossing the Site in an east-west direction and one trending north-south (Appendix VII, Figures 8-19). The oldest deposit in the study area, the bedrock (Unit E) will be discussed first, followed in succession by the younger, unconsolidated deposits of Units D, C, B and A.

Unit E

Woburn is located on the Eastern Avalonian Platform of

the North Appalachian Mountain System. The area has been subject to several mountain building and deformational events that occurred more than 200 million years ago. What is observed today in the bedrock are remnants of these tectonic events.

The area of investigation is located between the North Boundary and Blood Bluff fault zones which divide the greater Boston area into a series of northeast trending blocks. These blocks are in turn dissected by north-south trending faults, one of which has controlled the location of the Aberjona River Valley. The deformation associated with faulting caused a suture and a weakening of the bedrock, paving the way for preferential weathering along this plane of weakness. Therefore, a distinct valley was present prior to glaciation of the area. This valley was subsequently filled and covered with sand and gravel and is referred to as a buried valley.

The bedrock at the Site is the Salem Gabbro-Diorite (Barosh, et al 1977) which has been radiometrically dated as late Middle Ordovician (approximately 450 million years old). At the northern portions of the Site, bedrock is exposed as knobs and ridges throughout (Appendix VII, Figure 8). Towards the south where the Aberjona River Valley

is more pronounced, bedrock occurs as knobs rising rapidly from the valley to the east and west (Appendix VII, Figure 17).

The dominant rock type is a gray gabbro that consists of mafic minerals (pyroxene and/or hornblende) and plagioclase feldspar, with minor biotite and pyrite. This rock is massive in appearance and has a fine to medium grained texture.

In outcrop, the bedrock weathers chalky with a green or gray tinge. The rock is dissected by numerous fractures, many of which are filled with white or pink quartz. Layers of green rock are common and show phyllitic partings. This compositional banding as well as a pronounced foliation, give the rock a gneissic texture.

The green bands or layers are much softer and are highly fractured. They consist of epidote, chlorite, muscovite and plagioclase. The contact between the massive gray rock and the green layers is very irregular and often fractured.

The permeability of bedrock is dependent upon the occurrence of joints and faults and the extent of weathering. The extent of weathering of the bedrock in this area is minimal because the rock is very dense and

tends to resist weathering and because, geologically recent glaciation has abraded the surface and removed the loose rock that may have been present. Permeability, therefore, is dependent upon fractures that have been developed in response to volume changes, or to externally applied forces such as those that produce faulting. In general, these joint and fault openings decrease markedly with depth.

On the Site, the bedrock appears to be massive at topographic highs (OW-2) and fractured/jointed in lower areas (OW-9). The gray massive phase of the bedrock, where dominant, is unfractured. Thin (less than one foot) quartz veins appear to fill any fractures.

At OW-1 and OW-8, the gray rock alternated with zones of softer, green rock. However, no major water bearing fractures were encountered at those locations. At OW-1, a very soft zone (non-water bearing) was encountered between 96 and 106 feet below land surface. This is believed to be a gouge of finely abraded material that occurs along the wall of a fault. Wells OW-1, OW-2 and OW-8 went dry during pumping and recovered at less than 0.1 gpm (gallons per minute).

At OW-9 the rock was very fractured at the top and became

massive with depth. Though fractures were abundant, they were filled with quartz and yielded less than one gpm to the well.

At OW-3, the massive gray rock was present the length of the hole. However, at approximately 83 feet below land surface, a thin fracture, partially filled with rosy quartz, yielded three gpm.

The rock quarrying operation has facilitated the development of fractures in the area where OW-4 is located. Fractures filled with quartz have been reopened by the blasting operations. OW-4 yielded greater than 15 gpm during development.

The bedrock encountered below the buried valley south of the Site appears to be dense and unfractured (OW-18, 19 and 20). However, rock encountered on the sides of the valley (OW-17, TB-3) is fractured near the top.

In summary, the bedrock of Unit E, even though fractured at many locations, generally has a very low permeability. Many fractures are filled with quartz and the open, water-bearing fractures, such as found at OW-3 and OW-4, may be localized and not connected to other fractures in the area. Thus, the bedrock cannot be considered a

significant aquifer for industrial and/or municipal water supply in this area.

Unit D

Unit D was formed during the last glacial period (12,000 years ago) when glaciers in the Aberjona River Valley stopped advancing. Initially, the glacial ice mass had widened the existing bedrock valley by plucking blocks of rock and abrading the valley walls. As the glacier advanced over the land surface, it picked up sediment. However, when the rate of advance equaled the rate of retreat, the sediment it had picked up was deposited in conveyor belt-like fashion. Thus, Unit D consists of unsorted sediments showing a high variability in grain sizes.

Unit D can be designated a till which mantles the irregular surface of the bedrock. Till is exposed at the surface where bedrock is close to the surface. The till was found to be twelve feet thick as a maximum. It is thickest at the sides of the valley (OW-17) and is absent or thin near the center of the valley (OW-12) where it was probably scoured away by currents.

The till can be divided into three distinct types in the

study area. Immediately overlying the bedrock at most of the Site is a gray-colored non-sorted mixture of particles ranging in size from clay to boulders. Examination of the coarser particles indicates that this till was derived locally, because rock fragments of the mafic bedrock are found exclusively. Above this layer is an assemblage of mafic bedrock and quartz cobbles and boulders in a greenish-gray clayey matrix. These rock fragments are exclusively of Unit E and are partially weathered. This layer is generally thin (less than 4 feet in thickness) and may represent a weathered part of the till below it. Overlying these deposits in a few areas removed from the buried valley, is a brown, medium to coarse sand with boulders and cobbles of lithologies exotic to the immediate area (such as granite, schist and gneiss).

Regardless of type, Unit D has a very low permeability due to the variable sizes, poor sorting and tight packing of the individual grains. In the core samples, the till is observed to be moist or dry, even though overlying sands (Unit C) are saturated. In a number of test pits, a small amount (0.1 gpm) of water was observed perched above clayey parts of the till, demonstrating that the till layer inhibits the downward movement of water to the bedrock.

Unit C

Overlying Unit D are younger deposits of glacio-fluvial origin called outwash. These were formed by meltwaters from the retreating glacier which sorted sediments previously carried and deposited by the ice. Therefore, these deposits contain sediments having more uniform grain sizes and are more permeable than till deposits.

The contact between the till and outwash is easy to see because of color and sedimentological differences. Moreover, the outwash deposits below the water table are saturated, while the underlying till appears dry and is much denser.

Unit C is either very thin or absent where bedrock is close to the surface (throughout most of the Site), but reaches a maximum observed thickness of 80 feet near the center of the buried valley (OW-20). This unit consists of a series of three sand beds with different sediment character that vary in thickness from four to twenty feet. Frequently these three beds are graded. From the top to the base, each graded bed consists of:

- Medium to coarse sand with granules and pebbles, 50% quartz, 30% rock fragments (schist, gneiss, granite,

mafic rock, etc.) and 20% feldspar, muscovite and dark minerals.

- Fine to medium sand, well sorted; quartzose, 10 to 20% feldspar, muscovite, dark minerals and rock fragments.
- Silty fine sand, quartzose, finely laminated, 10 to 15% muscovite, disseminated organic material.

The coarser beds are dominant up valley (closer to the Site). The fine to medium sands are prevalent down valley. The silty sands are dominant usually near the middle of the aquifer.

Based on the uniform sizes, high degree of sorting and loose packing of the individual grains, Unit C has a high permeability. The sand/gravel observation wells are screened in this unit and have relatively high yields. The piezometers are screened in thinner deposits of Unit C which occur toward the fringe of the buried valley. Where the sands and gravels of Unit C are thick, as in the buried valley, they can serve as a water supply aquifer.

The buried valley begins at the southern end of the Site near OW-14 and OW-12. Two smaller valleys or troughs are present at the Site that merge with the buried valley. A smaller trough trends from the area of the Woburn City Dump through OW-11 to OW-14 to OW-12. South of OW-12 the

center or deepest part of the buried valley extends through OW-18, OW-19 and OW-20. The valley is relatively narrow immediately below the Site but doubles in width in the area south of the Digital Equipment building (OW-19 and TB-6). The valley also becomes deeper to the south, away from the Site.

Since the buried valley deepens and the topography is gentle, the saturated thickness of the sand deposits becomes greater towards the south. At OW-12, 44 feet of sediment above the bedrock are saturated with water as compared to OW-20, where 82 feet are saturated.

The sediments become finer and more uniform in grain size to the south. Thick beds of coarse sand, pebble gravel, and small cobbles are dominant up-valley whereas these beds are less common and thinner, where present, down-valley and have relatively lower permeabilities.

Below the Site near OW-18, the valley appears to be stratified. A silty sand and silt sequence separates an upper permeable zone of coarse sand and gravel (where OW-18A is screened) from a lower permeable zone of sand (where OW-18 is screened). This stratification becomes less pronounced at OW-19 and TB-6, though a silty sand sequence is present near the middle of the aquifer.

Further south there is no evidence of stratification at OW-20.

The effect of stratification is to hydraulically separate the aquifer into two parts. The upper part at OW-18 consists of coarse sand and gravel which is more permeable than the lower part which consists of sand and silty sand. This hydraulic separation does not continue down-valley, though the upper part of the aquifer appears to be more permeable throughout the valley. The purpose of the cluster wells (OW-18 and OW-18A, OW-19 and OW-19A and OW-20 and 20A) was to monitor ground-water quality in these upper and lower zones of the aquifer.

The coarsest sediments (coarse sands and gravels) are present at the flanks or sides of the valley. Gravel consisting of pebbles and small cobbles dominates the sequence at OW-17. This gravel is moderately sorted and loose which gives it a high permeability. Because of this, ground-water may flow at a higher rate along the sides of the buried valley.

The sediments in the buried valley become siltier (and less permeable) with depth. Above the till/bedrock surface, there is frequently a silty clay present which along with the till will inhibit any movement of ground

water between the rock and buried valley deposits.

Till is thin or absent near the center of the buried valley, presumably due to removal by current action. Till is thickest at the sides of the valley (OW-17). Though it is absent at several locations, the silty clay sequence above it serves as an aquitard.

At OW-6, twelve feet of sandy deposits were found to overlie 36 feet of a gray clayey silt resting on bedrock. During the time melt-waters were active in the valley, transporting and depositing sands of Unit C, a body of standing water existed in the area of OW-6. Finer clay and silt-sized particles settled out of suspension. Coarser sand particles and gravel are found in places embedded in the clayey silt. Due to the fine grain sizes and cohesiveness, this deposit is of very low permeability.

Unit B

Overlying the outwash deposits in part of the Site are peat deposits. Peat consists of partially decomposed organic matter such as mosses, trees and other flora that flourish in marshes and wetlands. Peat deposits are

found in depressions within Units C and D and have been covered by man-made fills on the Site. Marshy areas still exist within the Site suggesting that these conditions have persisted at various locations in the past 10,000 years.

The peat deposits are considered a separate unit even though, in places, the peat can be seen interlayered with sand as the contact between the two deposits is gradational. Peat was encountered in many borings and test pits. At OW-5, 11.5 feet of brown peat is present beneath a thin veneer of fill and above the sands of Unit C. Peat deposits generally have a high porosity but a low permeability because water is tied up by molecular attraction.

Unit A

Unit A consists of a heterogeneous assemblage of artificial fills and is present throughout the Site and industrial complex to the south. The waste deposits on the Site, which are part of this unit, are discussed in later sections of this report.

On the portion of the Site east of Commerce Way, Unit A is a coarse regolith that mantles the natural deposits of

Units B, C and D. This regolith consists of gravel and coarse sand and is essentially reworked and redistributed till. Piles of this material, which was used for road beds in the area, are found throughout this part of the Site.

Within the industrial complex south of the Site, the of sandy fill deposits average between two to ten feet in thickness. Even though it is poorly sorted in places, its loose consistency readily allows percolation of water to Unit C and to the water table.

SOIL AND WASTE INVESTIGATION

An important part of the two-phased investigation was the characterization of waste types on the Site and determination of the volumes and distributions of the various wastes identified. To accomplish this, the following tasks were undertaken: an earth conductivity survey, test pit and test boring programs, a surface soil study and a soil sample analysis program. These tasks are described in detail in the methods of investigation section of this report. The waste types and distributions at the Site, based on the interpretation of the results of these tasks, are described below.

Conductivity Survey Results

The purposes of the conductivity survey were to help locate optimum sites for pits and borings, and to help insure that the entire site had been surveyed and no waste deposits were missed. The conductivity survey has significantly guided both Phase I and Phase II test pit and test boring locations. A description of the conductivity equipment and its operation is included in the methods of investigation section.

To provide the control necessary to make the initial interpretation of the conductivity data, measurements were made in areas where subsurface conditions could be determined from the surface. These control measurements were made on the large hide residue piles, bedrock outcrops, the so-called Arsenic Pit, piles of construction debris, wetland and in the area east of Commerce Way where no waste materials were visible. There were, however, no boring or test pit logs or analytical results from soil samples for the initial conductivity interpretation.

The conductivity survey was based on a 200-foot grid system (Appendix VIII, Figure 3). A reading from at least one and frequently both instruments (EM-31 and EM-34) was made at all of the accessible grid points. In addition, continuous readings were made with the EM-31 along traverse lines through critical areas. Some EM-31 readings between grid points are shown on Figure 3. In many cases, however, the operator simply noted the changes in readings as he walked. In this way, it was determined that no waste deposits were missed by the survey.

For the purposes of defining areas containing waste materials and contaminated soil, the EM-31 and EM-34 (H)

(Horizontal dipole mode) data proved to be the most useful. EM-34 (V) (vertical dipole mode) data reflects deeper conditions and was not used to locate waste deposits.

Based on the control points established, the experience of the operator at other sites, and a comparison of conductivity results between the two instruments, the initial conductivity interpretation was made. This interpretation divided the site into six classifications based on conductivity: 1) bedrock and clean, nonconductive soil, 2) contaminated ground water, 3) solid waste, 4) hide residue, 5) construction debris containing metal objects, and 6) areas where there was interference and conductivity would not work.

This preliminary interpretation was used to help guide the Phase I boring and test pit digging program. Borings and test pits were located in all of the different areas defined by the conductivity survey. Also, an attempt was made to evaluate the accuracy of the conductivity area limits by locating pits and borings on both sides of various boundaries.

After completion of the Phase I soil sampling and analysis program, the conductivity data were

reinterpreted. The reinterpretation indicated that it is not possible to distinguish as many categories of site conditions and waste types as was initially attempted. It was found that the EM-31 and EM-34 (H) data could be combined and divided into three ranges that represented site conditions quite accurately. These categories are, in umho/m:

less than 10	- uncontaminated (background)
between 10 and 50	- contaminated soil or ground water, or thin waste deposit
greater than 50	- waste deposit

The areas defined by these three conductivity ranges are illustrated on Figure 20 (Appendix VIII). The effectiveness of the conductivity equipment in identifying waste deposits is evident when the figures showing soil and waste sample analytical results (next section) are compared to Figure 20.

Figure 20 shows that a large portion (32 acres) of the site (east of Commerce Way) contains natural sediments and rock with no waste materials. The one exception is a small area directly north of the Site trailer which was initially thought to be buried waste, but has subsequently been determined to be shallow contaminated

ground water from the hide residue burial area to the west. This hide residue burial area is quite clearly defined by the conductivity, as are the two hide residue and waste material stockpiles in the northern portion of the Site.

The portion of the Site that has been developed and is not a part of the investigation could not be surveyed with the conductivity equipment because of interference. In addition, portions of the Site that contain metallic construction debris, steel fences, railroad tracks, etc. could not be surveyed with the conductivity equipment. These areas are shown on Figure 20 (Appendix VIII).

The conductivity survey has provided a useful tool in guiding the boring and test pit program and has substantiated the location of waste materials as defined by analyses of soil samples. The conductivity survey has also helped to demonstrate that areas containing wastes have not been overlooked.

Soil and Waste Analytical Results

Both the selection of appropriate remedial measures and the apportionment of their costs as provided for in the consent agreement, require that the extents, volumes and

types of wastes and contaminated soil at the Site be defined. To accomplish this, samples of the waste materials and soil were collected and analyzed.

For the Phase I soil and waste sampling survey, 462 samples from 57 boreholes and 123 test pits were collected. Of these 204 were analyzed for selected metals. The metals analyzed for were antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, mercury, nickel, thallium, silver, selenium, and zinc. Arsenic is grouped with the metals because of its similar environmental properties, but is technically a semi-conductor and not a metal. In addition, the following analyses of soils were obtained, 21 from Janpet, 7 from EPA/DEQE, 7 from earlier Stauffer work and 15 from Boston Edison.

For the Phase II Study, 1331 samples were collected from test borings and some test pits. Of these, 1032 were analyzed for the significant metals (copper, chromium, lead, zinc, arsenic and mercury) as determined in Phase I. The results of all analyses are given in Appendix I of this report.

The Phase II study area (or the contaminated area delineated in Phase I) was divided into seven areas shown

on Figure 21. Thirty-eight cross sections were compiled in these seven areas showing detailed subsurface deposits (Figures 22 through 59, Appendix VII). These cross-sections depict the thicknesses and extent of the fill deposits, their relationship to the water table, and the underlying natural deposits. An isopach map has also been prepared showing the thicknesses of waste deposits at the Site (Figure 60).

The cross-sections show seven geologic units; bedrock, till, sand, peat, clean fill, chemical wastes, and hide residues. The natural geologic units underlying the fill, chemical wastes, and hide residues have been described in detail in the hydrogeology section of this report.

Based on the analyses of fill samples, the unit can now be divided into waste or contaminated fill, hide residues and clean fill. The concentrations of the six metals analyzed for in Phase II have been superimposed on the cross sections. Three ranges of concentrations were used: 0-100 ppm; 100-1000 ppm; and greater than 1,000 ppm.

The cross sections show where the waste deposits are present below the water table. Water-level data

collected January 3-4, 1984, was used since it reflected a higher than usual water table. Figure 61 (Appendix VIII) shows the areas of the Site where wastes are present below the water table.

In addition, the extent of leaching of wastes into the underlying natural deposits can be determined. It is interesting to note that some natural peat deposits below wastes are contaminated. The organic matter in peat has a high cation exchange capacity which causes metals to be absorbed and tied up indefinitely. Sand deposits of Unit C below peat showed significantly lower levels of metals.

In the Phase I test boring program, continuous cores were taken through the fill and into natural deposits. All split-spoon samples were retained. The geologist selected the samples that would be analyzed based on color, odor and texture, since these physical characteristics separated the fill deposits from underlying or adjacent natural geologic deposits. The geologists selected at least one soil sample for analysis from each of the variations in color and texture, so that every fill sample having a different color and texture would be analyzed. In addition, samples collected in natural deposits beneath the fill deposits (peat, sand, till) were retained and some were selected for analysis.

The geologists had greater visibility of subsurface fill deposits in the test pits. Samples were selected to represent all different deposits encountered in a test pit. In addition, samples of natural materials were collected below the fill or where they were exposed at the surface.

The results of the Phase I soil and waste analyses for heavy metals showed that while all of the metals analyzed for except beryllium, are present at 100 ppm in at least one location, six (arsenic, barium, chromium, copper, lead and zinc) are by far the predominant species. Mercury, found at a relatively few locations, is of concern.

Soil and waste sampling in Phase II was done on a predetermined grid pattern over areas determined as contaminated by Phase I analyses. Samples were collected at land surface and at the middle and bottom of the fill deposits. The geologist could retain any other samples in each of these borings for analysis. In addition, test pits were dug between grid points to collect waste samples and delineate waste boundaries.

The distributions of the various metals identified in the soil and wastes close to the surface are shown on Figures

62 through 66 and give the distribution of each metal to the extent that the Phase II data has defined it. The surface soils on the Site are shown on Figure 67 (Appendix VIII).

Arsenic and lead, because of their concentrations and widespread distribution on the Site, have been further defined on Figure 68 (Appendix VIII). This figure illustrates the distribution of arsenic and/or lead in two ranges, 100-1000 ppm and greater than 1000 ppm. The shaded areas representing these ranges were constructed by tightly contouring the points of known concentration and thus represent approximate minimum areas where metals are present at the reported concentrations.

The total area of the Site is approximately 250 acres. Half of this area consists of shallow bedrock and buildings. Of the remaining 125 acres, 32 acres east of Commerce Way do not contain waste materials and required no further soil sampling in Phase II. Combining the arsenic and lead data and eliminating overlapping area, there are 29 acres containing arsenic and/or lead at concentrations greater than 1000 ppm and an additional 28 acres greater than 100 ppm (Figure 68, Appendix VIII).

Figure 69 shows the distribution of chromium at the Site in the same manner that Figure 68 showed lead and

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arsenic. Eighteen acres contain chromium concentrations greater than 1000 ppm and another 17 acres greater than 100 ppm.

The thicknesses of waste materials and soil containing arsenic, lead and chromium have been determined, and they generally range from less than 1 to 8 feet (Figure 60). A comparison of concentrations of chromium, lead and arsenic at various depths in all pits and borings where samples were collected and analyzed at more than one depth, shows that while concentrations decrease with depth in many cases, there are also a significant number where the reverse is true. This second case reflects the areas where clean fill was placed over and between waste materials. In all of the borings and many of the test pits, however, natural sediments were identified under the waste materials. Soil samples were collected and analyzed from these natural sediments and were found to contain background concentrations of metals.

In addition to the metals, hide residues, because of odor problems, are a waste product of concern at the Woburn Site. Hide residues are readily identified in the field because of their color, texture and odor, and chemical analyses are not necessary for defining extent. The Phase I and II investigations have defined areas

containing hide residues which are 13 acres in extent. These are shown on Figure 70. The thicknesses of these deposits range from a few feet to about 20 feet below land surface and, in the waste piles, up to 40 feet above grade.

The southern hide residue area shown on Figure 70 (Appendix VIII) is where the hide residues were originally buried during the glue plant's operation. This area contains primarily hide residues and associated chromium. The northern waste pile area is a stockpile of wastes that was deposited by the Site developers during construction. These waste piles are composed of a comingled variety of materials, including hide residues, zinc, and lead. There are also two areas that were suspected of containing hide residues in Phase I that were investigated during Phase II and are shown on Figure 70 (Appendix VIII). Both of these sites contain stockpiled wastes and did contain a variety of substances in addition to hide residues.

An attempt was made in the Phase I survey to correlate various physical characteristics of samples with their chemical composition. Details of dominant and subordinant sediment, texture, color and odor were recorded for each sample and coded into the computer

printout. The results are shown in Appendix I.

The coding system failed to establish a visual method of distinguishing between the various metals at the Site. However, some generalizations based on color and texture can be made. Initially, a fill deposit with a red color was thought to be indicative of high lead concentrations. This was held true, though arsenic, barium, copper and zinc were almost as abundant in red-colored fill deposits. In addition, trace metals at the Site including antimony, cadmium, nickel, silver and thallium were found at greater than 100 ppm levels in red-colored deposits.

The gray or white colored deposits associated with what has been referred to as the Arsenic Pit, not only reflected high arsenic concentrations, but in most cases contained significantly higher concentrations of lead, zinc, copper and barium.

A black color, when associated with hide residues, was thought to reflect higher chromium concentrations. However, as previously mentioned, the reworked hide residues piles at the northern end of the Site contain other metals as well (arsenic, barium, lead, copper and zinc).

Defining specific wastes based on the dominant and subordinate textures of the sediment grains, was also not a total success. When a fill containing artificial components, such as demolition debris, was analyzed, arsenic, lead, copper, barium and zinc were usually abundant. However, these metals, as well as chromium, were found in abundance in deposits ranging in texture from coarse sand to clay.

A fill deposit of certain colors (red, gray, blue, white and orange) and comprised of artificial components such as construction debris, contained high concentrations of barium, copper, lead and zinc, as opposed to chromium. Chromium deposits generally occur independently of the other metals, though the other dominant metals, arsenic, lead, copper, zinc, have been admixed where chromium deposits were disturbed and redeposited.

The only way to accurately characterize a waste material at the Woburn Site is through chemical analyses of the fill deposits. However, it was determined by the geologists in the field who examined the samples, that waste materials could be distinguished from natural sediments by visual inspection. This proves to be useful since the chemical analyses indicate that most of the waste material contains at least one of the metals of concern.

The samples characterized as having natural physical characteristics invariably contain approximate background concentrations of metals. Ninety percent of samples that have been classified as artificial fill or waste materials contain greater than 100 ppm of several metals. Thus, while the type of waste cannot be determined visually, the physical inspection can distinguish between contaminated and natural deposits.

In addition to analysis for metals, soil samples were screened for organic compounds in Phase I. Figure 71 (Appendix VIII) shows the areas where sediment samples registered organic contents of greater than one hundred and greater than one thousand counts per gram. An area encompassing New Boston Street and the adjacent industrialized sector shows the highest levels of counts per gram.

The areas that showed the highest counts per gram readings were examined more closely in Phase II. Ten soil borings were located in these areas and a total of twenty-nine samples were collected. These samples were analyzed for organic compounds. Low parts per million concentrations of a variety of organics including benzene, toluene and diethylene glycol are present in most of the samples.

The low ppm concentrations of organic compounds are present in the soil in the areas where the Phase I screening showed the highest counts per gram readings. No particular source or sources can be identified.

The concentrations of organic compounds ranged from 0-328 ppm (priority pollutants) and 0-1605 ppm (other compounds). The location with the highest concentration of priority pollutants is OS-7 with 328 ppm (275 ppm benzene, 13 ppm toluene, 10 ppm nitrobenzene, 7 ppm naphthalene, 2 ppm anthracene, etc. . .). The location with the highest concentration of non-priority pollutants was OS-2 which had a total of 1605 ppm (including 1580 ppm diethylene glycol).

Location OS-7 is on the Boston Edison Right-of-Way about 200 feet midway between New Boston and Merrimac streets. The sample showing the highest levels was collected at the 0-2 foot interval where evidence of an oily residue was observed. Location OS-2 is at the south end of the Chrome lagoons. The sample with the highest levels of organics was collected at the 10 - 12 foot interval. The major pollutant detected at OS-2 and in other boring locations, diethylene glycol, is used as a plasticizer, softening agent and antifreeze component.

Ground-Water Levels and Flow

Ground-water levels in wells and piezometers have been measured on numerous occasions during 1982 and 1983. Complete rounds of measurements in all Phase I wells (OW-1 through OW-14) and piezometers were made on September 22, 1982, October 27, 1982, and January 12, 1983. Complete rounds of measurements in all Phase I and Phase II piezometers and wells were conducted on October 12-13, 1983, December 19-20, 1983, and January 3-4, 1984. The elevations of the water table on these six dates are given on Table 2.

The data were used to plot water table elevation contours so that ground water flow directions throughout the summer, fall and winter seasons could be determined. The resulting representative water tables are based on data collected from the OW-series wells on January 3-4, 1984, (Figure 72, Appendix VIII) and from the piezometers on the same date (Figure 73, Appendix VIII). These water-table maps are similar to maps based on data collected at other times. Two maps are included to show both the shallow ground-water flow on the Site and the more generalized flow patterns around the Site, particularly downgradient.

Table 2 - Water-Level Data

Elevation in Feet (MSL)

<u>Well Number</u>	<u>9/22/82</u>	<u>10/27/82</u>	<u>1/12/83</u>	<u>10/12,13/83</u>	<u>12/19,20/83</u>	<u>1/3,4/8</u>
OW-1	72.71	72.68	72.64	72.60		
OW-1A	72.59	72.55	72.68	72.58	73.86	73.24
OW-2	106.67	116.18	116.63	83.34	74.41	73.86
OW-3	66.06	66.56	66.99	64.97	122.92	120.71
OW-4	62.73	62.73	64.80	62.16	68.24	67.52
OW-5	58.84	58.84	59.10	58.89	66.35	65.29
OW-6	53.52	53.52	54.02	53.39	59.56	59.22
OW-7	50.67	50.67	51.18	50.22	54.71	54.15
OW-8	51.87	51.87	51.93	51.51	51.37	50.91
OW-9	57.87	57.87	58.38	57.36	53.18	52.55
OW-10	58.70	58.70	59.03	58.63	60.18	59.62
OW-11	66.76	66.76	67.07	66.87	61.38	60.33
OW-12	55.71	55.71	56.24	55.11	67.36	66.76
OW-13	58.90	58.90	59.20	58.37	57.27	57.02
OW-14	57.30	57.30	57.69	56.69	60.24	59.57
OW-15	---	---	---	59.76	59.26	58.59
OW-16	---	---	---	62.12	60.34	60.18
OW-17	---	---	---	52.45	62.88	63.07
OW-18	---	---	---	53.91	52.44	52.45
OW-18A	---	---	---	53.95	54.60	54.23
OW-19	---	---	---	---	54.52	54.26
OW-19A	---	---	---	---	52.17	51.49
OW-20	---	---	---	---	51.76	51.48
OW-20A	---	---	---	---	51.25	50.70
B-1	63.64	64.20	64.50	63.24	51.51	51.24
B-4	67.13	67.35	67.71	66.39	65.53	64.58
B-6	68.94	69.44	70.12	68.43	68.17	67.67
B-12	69.31	70.00	70.43	69.40	72.51	71.18
B-27	56.01	56.37	56.70	55.53	71.09	70.45
B-41	59.66	60.14	60.18	60.65	57.69	57.09
AS-5	57.01	58.05	58.45	---	62.77	61.77
TP-6	62.27	62.69	62.90	61.76	---	60.49
50/44	---	---	---	69.95	62.36	62.22
47/45	---	---	---	69.64	71.05	70.80
44/56	---	---	---	dry	70.93	70.18
43/53	---	---	---	dry	dry	dry
45/51	---	---	---	70.46	73.86	74.45
51/29	---	---	---	dry	73.82	69.00
35/54	---	---	---	64.05	72.91	71.26
38/52	---	---	---	65.32	65.65	65.63
41/57	---	---	---	67.84	69.25	67.97
40/40	---	---	---	64.46	71.83	67.84
41/41	---	---	---	64.72	67.95	67.27
40/47	---	---	---	67.02	69.36	69.57
44/40	---	---	---	67.10	72.86	71.31
46/30	---	---	---	68.69	69.17	68.48
44/32	---	---	---	66.76	71.03	70.18
TP-400	---	---	---	62.07	68.85	68.25
28/48	---	---	---	57.78	62.62	62.47
29/43	---	---	---	dry	59.93	59.53
					62.40	55.99

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Table 2 - Water-Level Data

Elevation in Feet (MSL)

<u>Well Number</u>	<u>9/22/82</u>	<u>10/27/82</u>	<u>1/12/83</u>	<u>10/12,13/83</u>	<u>12/19,20/83</u>	<u>1/3,4/84</u>
29/35	_____	_____	_____	dry	59.43	58.76
22/42	_____	_____	_____	55.04	57.33	56.52
25/47	_____	_____	_____	55.70	58.20	57.65
23/50	_____	_____	_____	54.41	56.49	55.85
38/48	_____	_____	_____	65.29	69.29	69.04
GZ-1	_____	_____	_____	_____	_____	67.84
GZ-2	_____	_____	_____	_____	_____	67.48
GZ-3	_____	_____	_____	_____	_____	65.58
GZ-4	_____	_____	_____	_____	_____	64.38
GZ-5	_____	_____	_____	_____	_____	58.95
GZ-6	_____	_____	_____	_____	_____	58.57
B-2A	_____	_____	_____	_____	_____	61.24
B-6A	_____	_____	_____	_____	_____	_____
B-9A	_____	_____	_____	_____	_____	65.47
B-14A	_____	_____	_____	_____	_____	66.81
41/29	_____	_____	_____	_____	_____	65.46

Figure 72 shows that ground water enters the Site from the north. Ground water west of the buried valley will flow towards the southeast, whereas ground water east of the valley will flow towards the southwest.

The highest water level elevations (73.2 and 73.9) were measured at OW-1 and OW-1A located at the northern edge of the Site. The lowest elevation (50.9) was measured at OW-7, the most southerly well. These values indicate an overall gradient of 0.005 ft/ft. However, the slope of the water table is steepest under the Site (0.008 ft/ft) and flattens out below the industrial complex (0.002 ft/ft).

Based on the direction of ground-water flow, OW-9, OW-12, OW-13, OW-14, OW-16, OW-17, OW-18A and OW-18 are located immediately downgradient of the Site. Wells OW-19, OW-19A, OW-20, OW-20A and OW-7 are further downgradient of the Site and are located in the buried valley. Ground-water samples collected from these wells will reflect the quality of ground water leaving the Site. OW-1, OW-1A, OW-2 and OW-3, OW-4, and OW-11 are upgradient wells tapping ground water that is entering the Site from the north. OW-5, OW-6, OW-8, OW-10, and OW-15, are located lateral to the Site with respect to ground-water flow.

Examination of the water table map (Figure 72) indicates ground water entering the Site from the northeast (east of Commerce Way) will flow under the eastern portion of the Site and into the buried valley or thickest part of the aquifer north of Mishawum Road. This ground water will not flow under the portion of the Site containing waste materials.

Ground water entering the Site from the north will turn towards the southwest and into the buried valley just to the south of the Site. Ground water entering the Site from the northwest will flow under the western portion of the Site and into the buried valley north of Mishawum Road.

Water levels from both the rock and sand/gravel wells were used to compile the area-wide water table map (Figure 72) because the water table is below the rock surface in much of the northern portion of the Site.

Water levels obtained from the piezometers are generally higher than nearby upgradient observation wells. Since most of the piezometers are screened in the sands of Unit C where the unit forms a thin veneer over till and bedrock, they are essentially measuring shallow ground water which is influenced greatly by local recharge.

Thus, the shallow water table under the Site is treated separately and discussed later in this section.

Water levels measured in OW-2 have been anomalously higher than levels in nearby OW-1 and OW-3. The water level measured on January 3, 1984 is 46.47 feet higher than OW-1. This is probably due to the well intercepting an isolated and confined water-bearing fracture near the bottom of the hole. In this case, water entering the well will be under artesian pressure and will not reflect the regional water table.

Water levels increased in all wells from .2 to 2 feet from late September 1982 to mid-January 1983, with the exception of OW-1 which showed a decrease of 0.07 feet. During 1983, water levels increased nearly one foot from October to December but decreased slightly by January 1984.

Figure 73 depicts the shape of the water table under the portion of the Site containing waste materials. The most predominant feature is the mounding centered around the topographically high area near the center of the Site with a similar but less pronounced mound under the east waste pile at the northern edge of the Site. These mounds are caused by the presence of elevated bedrock

knobs and the permeability difference between these knobs and overlying waste deposits.

The effect of the water-table mounding beneath the waste areas at the Site will be to keep the lower portions of the wastes saturated.

Ground water flows from areas of high water table elevation to areas of lower water-table elevation, approximately perpendicular to the equipotential lines. Figure 73 shows that ground water under the waste area of the Site does not flow from north to south as shown on the general, area wide map (Figure 72) but rather, follows a more complex pattern. In the western half of the Site, ground water converges into the head of the buried valley. Thus, ground water from as far west as the western edge of Figure 73 and as far east as the east waste pile will flow into the buried valley near OW-17.

Ground water originating under the eastern half of the topographically high area (just west of the extension of Commerce Way), however, will flow east and some will discharge into the marshes and ponds east of Commerce Way. Ground water that does not discharge in this area, however, will eventually flow south and then west into the buried valley (under the present Aberjona River) in the vicinity of Wells 19 and 20.

The ground-water flow rate is dependent upon the gradient of the water table and the permeability of the sediments through which it flows. As mentioned previously, the gradients beneath the Woburn Site range from .005 ft/ft on the area wide map (Figure 72) to .012 ft/ft on the more local Site map (Figure 73) where the effects of mounding can be measured.

The permeability of the sediments around the Site has been calculated based on visual inspection of hundreds of core samples and specific capacity tests run on six wells. The results of these tests are given in Appendix III.

Visual inspection of cores and test pit walls indicate that sediments generally range in permeability from 10^{-2} gal/day/ft² (silty and clayey till) to 10^3 gal/day/ft² (clean, well sorted sand). Permeability calculated from specific capacity tests (generally in the more permeable sediment) ranges from 10 gpd/ft² to 250 gpd/ft².

Based on visual observations, ground-water flow on a local scale will vary from less than 1 foot per year to 5 feet per day. Within the sand units beneath and downgradient of the Site, average ground-water flow rates will be between .2 and 1.0 feet per day.

GROUND-WATER QUALITY

Ground-water samples were collected on September 27 and 29, 1982 and August 30 and 31, 1983 with resampling of a few, selected wells in September and October, 1983. The last four wells installed, OW-19, 19A, 20 and 20A were sampled on January 3-4, 1984.

All ground-water samples were analyzed for the EPA listed priority pollutants and 20 highest organic peaks on GC scan. Concentrations of metals in ground water will be discussed first, followed by a discussion of the organic compounds detected. All of the ground-water quality results are given in Appendix I.

Metals

Five of the fifteen monitoring wells installed in 1982 contained metals exceeding drinking water standards. In 1983 there were a total of 24 wells (Figure 6, Appendix VIII) and eight contained metals exceeding drinking water standards. These results may be summarized as follows:

- In 1982 arsenic was found at 200 and 420 ppb in ground-water samples collected at OW-5 and OW-9 respectively. In 1984, arsenic was found above the

drinking water standard only in OW-20A (106 ppb). The drinking water standard (USEPA, July 1976) is set at 50 ppb.

- In 1982 lead was found at 120 and 74 ppb in OW-7 and OW-14. In 1983, lead was found in OW-13 and OW-17 at 120 and 70 ppb. The drinking water standard for lead is 50 ppb.
- In 1982 cadmium was detected at 28 and 11 ppb at OW-10 and OW-12 respectively. In 1983 cadmium was not detected in any wells. The drinking water standard for cadmium is 10 ppb.
- In 1982 zinc did not exceed drinking water standards in any well. Zinc was detected at 5,700, 6,090 and 47,000 ppb in wells OW-10, OW-18 and OW-19 in 1983. The drinking water standard for zinc is 5000 ppb.

Wells OW-9, OW-12, OW-13, OW-14, OW-16, OW-17, OW-18, OW-18A, OW-19, OW-19A, OW-20, OW-20A and OW-7, are the wells located downgradient of the Site. Arsenic, lead and zinc are found in some of these wells above the drinking water standards. Chromium was detected in two of the wells but is not present in the hexavalent state and thus not above drinking water standards.

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A review of data collected from monitoring wells on Janpet property, (Goldberg, Zoino and Associates, Inc.) also indicates the presence of arsenic and lead in the ground water. Ground water from four wells screened in sand and gravel deposits contained arsenic greater than drinking water standards. Two of these wells showed lead in concentrations above potable standards. Chromium was not found above 50 ppb in ground water under Janpet property.

One well lateral to the Site, OW-10, contained cadmium at 28 ppb in 1982. The upgradient wells showed no detectable lead, arsenic or chromium, nor do metals exceed drinking water standards in any of these wells. Of the other wells lateral to the Site, a ground-water sample from OW-5 contained arsenic in 1982 but was not detected in the 1983 sampling. Wells OW-6 and OW-8 did not contain detectable concentrations of arsenic, lead and chromium in either sampling.

Based on the analytical results from the wells downgradient and lateral to the Site, there is no significant source of metals to the ground water. There is no plume of metal contamination in the ground water as would be expected if the waste deposits on the Site were leaching. Rather, the very low and sporadic findings of

metals suggest there may be a variety of sources, both on and off the Site, but that none is particularly significant.

The variation in results between the 1982 and 1983 samplings reflects the fact that contaminants are not present in a plume from an identifiable source and concentrations will depend on when a particular well is sampled. In addition, overall trends in ground-water quality cannot be seen with only two complete samplings.

Organic Compounds

The monitoring wells were also analyzed for EPA's list of priority organics and other organic compounds. All of the wells sampled contained low levels of at least one organic compound. Ground-water analytical results are given in Table I in Appendix I.

In 1982 ground water from OW-9 showed two priority pollutants less than 17 ppb and carbon disulphide at 108 ppb. Ground water from OW-12 contained five organic compounds greater than 100 ppb, but only one organic priority pollutant at 15 ppb. OW-13 showed no priority pollutants.

In the 1982 sampling, ground water from Well OW-11, upgradient of the Site, contained four organic compounds and two priority pollutants, each at a concentration less than 66 ppb. Two organic compounds (carbon disulphide and trichloropropane) were detected each at 90 ppb in the sample collected from OW-6. OW-6 is located in the southeastern portion of the developed area and is lateral to the Site with respect to ground-water flow.

In the 1983 sampling, additional organic compounds were found in several wells. The more significant findings include benzene in wells OW-12 and OW-17 at 491 and 747 ppb; toluene in wells OW-12 (1.1 ppm), OW-14 (114 ppb), OW-16 (950 ppb), and OW-17 (177 ppb); phenol (total) in wells OW-12, OW-16 and OW-17 at 390 ppb, 1900 ppb and 7840 ppb; and acetone and MEK in Well OW-16 at 2110 and 276 ppb.

Additional Ground-Water Investigation

None of these priority pollutant organics had been detected in the 1982 sampling. After they were first detected in 1983, the Phase II investigation was expanded to include both an on-site well installation program and a downgradient well drilling program. The purposes of these programs were to define the sources of the organics

and evaluate the extent of organics in the aquifer south of the Site.

The first step in the expanded organics sampling program was to repurge and resample OW-12, OW-14, OW-16, OW-17 to confirm the original results. On the second round, all of the well showed similar results for organics except OW-16 where toluene rose from 950 to 32,000 ppb. This increase is apparently the result of pumping a nearby slug of toluene into the well during purging.

When the organics concentrations in the wells had been confirmed, four additional wells were installed downgradient of the Site to evaluate the extent of the organics in the ground water. Wells OW-19 and OW-20 were installed at the locations shown on Figure 6 and screened over the lower half of the aquifer. Wells OW-19A and OW-20A were installed adjacent to OW-19 and OW-20 but were screened only over the upper 30 feet of the saturated portion of the aquifer.

The four new wells were sampled on January 3-4, 1984. The analytical results are listed in Appendix I. Three of the wells contained no detectable organic compounds and one, OW-19A, contained no priority organics but did contain 10 extractible compounds at less than 50 ppb

levels. These compounds could not be identified by the laboratory.

Based on the results of the downgradient well program, organic compounds from the Site are presently limited to the area somewhere between OW-17 and OW-19. Continued movement of the organics downgradient can be expected and they may appear in Well OW-19 or OW-19A during the next year or so.

The finding of significant concentrations of toluene and benzene prompted an investigation to determine the possible source(s) of these compounds. Sixty-one temporary wells were installed both upgradient and downgradient of OW-16 and OW-12 and sampled in the same manner. Their locations are shown on Figure 74 (Appendix VII). A boring was advanced by power driven hollow stem augers to between 5 to 30 feet below the water table depending upon the saturated thickness. Two-inch diameter PVC casing and screen (.020 slot) were introduced into the hole through the hollow stem. The auger flytes were then raised five feet out of the boring and the top flyte was removed. This was done to clear the screen zone from the surrounding auger and open the well up to the formation. A water level measurement was taken and the total volume of water in the casing was calculated. Three volumes

were removed from the well prior to sampling by using a stainless steel or teflon bailer.

All wells were purged and sampled immediately after installation. After the sampling was completed, the well casing was removed from the ground and the hole was backfilled. The bailer, rope, and well were cleaned thoroughly with first, potable and then, distilled water between each sampling.

The results of the chemical analyses are shown on Table 3. Eight values of toluene and one value of benzene exceeded 1 ppm. The distribution of the two compounds are shown on Figures 75 and 76 (Appendix VII).

Figure 75 shows the distribution of toluene in ground water at the Site. It is apparent that a discontinuous plume (or series of slugs) of toluene is present at the southern portion of the Site. The reason for the discontinuity may be in part due to intermittent discharges from as many as four sources. The four possible sources based on ground-water flow directions and toluene concentrations are as follows: (1) upgradient of SD-4 on the east flank of the hide burial ground; (2) upgradient of OW-16, just north of the trailer area; (3) on the southwest flank of the burial

TABLE 3

SHALLOW TEMPORARY WELL ANALYSIS
DURING BENZENE/TOLUENE SCREENING

Sample No. SD	Sample Date 1983	Concentration (ppb)	
		Benzene	Toluene
1	10/26	<10	31,000
2	10/26	<10	640
3	10/26	<10	290
4	10/26	15	4,200
5	10/26	<10	17
6	Not sampled		
7	10/27	<10	130
8	10/27	<10	250
9	10/27	46	880
10	10/27	<10	<10
11	10/27	<10	<10
12	10/28	ND*	<10
13	10/28	<10	10
14	10/28	<10	<10
15	10/28	10	11
16	12/7	<10	4,400
17	12/7	<10	2,100
18	12/7	<10	<10
19	12/8	<10	50
20	Not sampled		
21	12/8	<10	3,600
22	12/8	ND*	50
23	12/8	<10	<10
24	12/8	ND*	ND*
25	12/9	19	<10
26	12/9	38	<10
27	12/9	150	430
28	12/9	83	<10
29	12/12	<10	ND*
30	12/12	<10	ND*
31	12/12	<10	ND*
32	12/12	<10	ND*
33	12/12	<10	ND*
34	12/13	35	ND*
35	12/13	<10	ND*
36	12/13	<10	ND*
37	12/13	<10	ND*
38	12/13	<10	<10
39	12/14	97	<10
40	12/14	300	24
41	12/14	79	ND*
42	12/14	22	ND*
43	12/14	<10	ND*
44	12/14	ND*	ND*
45	12/15	<10	<10
46	12/15	ND*	110

TABLE 3 (continued)

Sample No. SD	Sampling Date 1983	Concentration (ppb)	
		Benzene	Toluene
47	12/15	<10	<10
48	12/15	<10	ND*
49	12/15	ND*	580
50	12/15	ND*	<10
51	12/15	ND*	ND*
52 (OW-19)	12/19	ND*	ND*
53 (OW-19A)	12/19	ND*	ND*
54	12/20	ND*	80
55+	12/20	36,000	8,200
56	12/20	16	1,200
57 (OW-20)	12/21	ND*	<10
58 (OW-20A)	12/21	ND*	<10
59	12/21	ND*	4,600
60	12/21	48	<10
61	12/21	380	61

* ND - not detected, limit of detection = 3 ppb

+ SD-55 This sample contained several unidentified components by GC analysis, sample was extremely odorous

ground near SD-46; and (4) in the developed area just south of Atlantic Ave.

The most concentrated slug of toluene is around OW-16 and is limited in extent, vertically and horizontally. The largest slug extends from SD-56, through SD-21, SD-59 and SD-55, in the developed area. No toluene was detected in SD wells around or immediately below the Chrome Lagoon area. Wells OW-12 (355 ppb) and OW-17 (203 ppb) appear to be picking up isolated slugs flowing from the direction of SD-55.

Figure 76 shows the distribution of benzene as determined by the source determination investigation. Benzene was not found significantly above the detection limit north of Atlantic Ave. or in the Chrome Lagoon area. The highest concentration of benzene is found upgradient of this point, so the area around SD-55 is believed to be the source of benzene. A narrow plume of benzene extends from SD-55 in the direction of ground-water flow towards SD-40 and OW-12. The next highest concentrations of benzene to SD-55 is at OW-12 where benzene was detected at 203 ppb. OW-17, further down valley, picked up benzene at 402 ppb.

No benzene or toluene were detected in wells downgradient of OW-12 and OW-17.

FINDINGS AND CONCLUSIONS

1. The Woburn Site is underlain by bedrock of low permeability. Unconsolidated deposits overlying bedrock are low permeability glacial till, permeable outwash sands, peat and miscellaneous fill deposits (including chemical wastes and hide residues).
2. The extent of the waste deposits on the Site has been defined both aerially and vertically. Approximately 100 acres of the Site contain waste deposits. These deposits were found to range from less than one to eight feet deep. In several areas, wastes have been piled on the ground up to forty feet above grade.
3. The area to the east of Commerce Way and its extension does not contain waste materials.
4. Waste deposits at the Site include animal hide residues, construction debris, and chemical waste containing the following metals: arsenic, barium, chromium, copper, lead and zinc with lesser amounts of mercury.

5. The stockpiles of hide residues and other wastes in the northern portion of the Site contain all of the metals identified in other areas of the Site.

6. Soil samples collected from pits and borings were analyzed for fourteen metals in Phase I and six metals in Phase II. The results can be summarized as follows:

(a) Zinc is the most widespread metal found at the Site and lead is the second most widespread. Lead, arsenic, and zinc are frequently found together in waste at the Site.

(b) There are approximately 29 acres of the Site where greater than 1,000 ppm of lead and/or arsenic are found and an additional 28 acres containing 100 ppm of lead and/or arsenic.

(c) Chromium is found on approximately 18 acres of the Site at levels greater than 1,000 ppm and on an additional 17 acres at greater than 100 ppm. Chromium is generally found in the same areas as the hide residues and in the Chrome Lagoon area.

- (d) Copper is also found across the Site at concentrations of greater than 100 ppm.
 - (e) Mercury was detected above 100 ppm at eight locations.
 - (f) During Phase I, no other metals were found in significant amounts (greater than 100 ppm) occurring independently of lead, arsenic, chromium, zinc, copper, barium and mercury.
7. Hide residues are found on approximately 13 acres of the Site. In some of this area, hide residues and associated chromium are mixed with other wastes containing lead, arsenic, zinc and copper.
8. The ground-water investigation conducted at the Industri-plex 128 Site has determined that there is no significant ground-water contamination problem resulting from the hide residues or lead/arsenic wastes at the Site. Metals such as lead, arsenic and chromium were not found to leach at significant concentrations into the ground water.

Metals that do not leach to the ground water are sorped onto clay particles and organic matter in the

upper part of the aquifer. Because of this, metals are attenuated and their migration is extremely limited.

Non-priority pollutant organic compounds, while found in or directly downgradient of hide residue burial areas, do not migrate very far, apparently due to sorption or biodegradation.

9. The only potentially significant ground-water contamination found during this investigation is benzene and toluene which have no known relation to waste deposit at the Site. These compounds are present in the buried valley immediately downgradient of the Site and will migrate through the aquifer at a significant rate.
10. A preliminary screening for organic compounds in Phase I soil samples identified several areas around the Site, particularly in the western portion, that registered greater than 1000 counts per gram. Specific organic compounds present were not identified by this screening technique.
11. Twenty-nine soil samples from ten locations within the high counts per gram areas (particularly the

the New Boston Street area) were analyzed for organic compounds in Phase II. The results indicated that low ppm concentrations of organic compounds, including benzene, toluene, and diethylene glycol are present in sediment samples. No particular source or sources can be identified (Diethylene glycol is used as antifreeze).

12. Waste materials and contaminated soil can be distinguished from natural sediments in the field by their physical characteristics (texture, color, odor).
13. Waste deposits can be distinguished from clean fill by observation of physical characteristics. However, positive determination of waste type must be made by chemical analysis.
14. The conductivity survey of the Site was useful in locating the best areas for subsurface exploration with pits and borings. The conductivity results were also helpful in insuring that waste deposits did not remain undetected in the subsurface.
15. Interpretation of the conductivity data shows a very good correlation with chemical analytical results.

Conductivity results did not prove to be helpful in mapping the bedrock surface with depth and only partially successful in defining areas of contaminated ground water.

16. The geologists could visually identify waste materials and fill from natural deposits. This was verified by analysis of 20 random samples determined as clean by the geologists in the field.
17. Test pits were dug and visually logged on the Boston Edison Easement below the Site. Significant fill deposits ranging from less than one foot to 10 feet in thickness were identified and resemble those contaminated with metals on the Site. An area containing hide residues was also identified and mapped.
18. Shallow ground-water flow patterns on the Site are complex, responding to topographic highs and lows and permeability differences in both the waste materials and in the natural sediments. The most prominent feature is a ground-water high or mound near the center of the Site, which is caused by a sharp contrast in permeability between an elevated bedrock knob and overlying waste materials.

19. The effects of the water-table mounding beneath the waste areas at the Site are to locally control ground-water flow and to keep the lower portions of the wastes saturated.

20. A portion of the shallow ground water at the Site discharges into the Aberjona River, its tributaries and surface water bodies. The remainder flows into the deeper portion of the buried valley, which is downgradient of the Site.

21. Ground-water flow on the Site ranges from 1 foot per year (Unit D) up to 5 feet per day (certain layers in Unit C) based on visual observations of core samples and measured gradients.

22. Based on specific capacity testing, measured gradients and visual observations, the ground-water flow rate in the buried valley is estimated to be 0.2 to 1 foot per day.

23. Ground water in the bedrock and overlying outwash sands flows from north to south into the thicker and more permeable sands of the buried valley south of the Site.

24. There are no potable supply wells in the Buried Valley downgradient of the Site within the area of investigation (north of Mishawum Road).
25. Ground-water samples collected from upgradient wells (north of the Site) contained a number of priority pollutant compounds.
26. Ground-water samples collected from the wells downgradient of the Site contained, in a few cases, lead, (OW-13 and OW-17), arsenic (OW-20A) and zinc (OW-18 and OW-19) in excess of drinking water standards.
27. In 1982 arsenic was found at 200 ppb in a sample from OW-5 which is lateral to the Site with respect to regional ground-water flow. In the 1983 sampling, no arsenic was found either in this well or in OW-15 which is located immediately upgradient.

The 1982 sample from lateral Well OW-10 also contained cadmium (28 ppb) at a concentration greater than the drinking water standard (10 ppb). Cadmium was not detected in this well in the 1983 sampling.

28. In 1982 lead was found at 120 ppb in a sample from Well OW-7 which is downgradient of the Site. No lead was detected in this well in the 1983 sampling.

29. Chromium was detected in two monitoring wells (OW-12 and OW-16) but is not present in the hexavalent state and thus not above drinking water standards. OW-12 is immediately downgradient of the chrome lagoon area and OW-16 is downgradient of the hide burial ground. No chromium was detected downgradient of OW-12 in the Buried Valley.

30. Metal concentrations in ground water beneath and downgradient of the Site are generally low and variable and do not suggest the presence of a discrete "plume" of contamination associated with waste deposits at the Site.

31. The variation in results between the 1982 and 1983 samplings suggest that the sources of the metals are probably multiple and sporadic. Therefore, it is logical that monitoring results would be somewhat variable. In addition, trends in ground-water quality cannot be determined with only two samples.

32. Since the wastes containing metals have been on Site for several decades, the low and sporadic concentrations currently found in the ground water indicate that the metals are of low solubility and not mobile in the aquifer. Conditions should not change significantly in the future.
33. Organic compounds, particularly benzene and toluene, found in ground water downgradient of the Site during the 1983 sampling appear to be originating on the Site or in developed areas adjacent to the Site.
34. Benzene and toluene are not generally associated with the hide residue wastes or metal wastes on the Site. Rather, the sources appear to be limited in extent and not associated with any particular portion of the Site.
35. Four possible sources based on concentrations and ground-water flow directions are as follows: (1) upgradient of SD-4 on the east flank of the hide burial ground; (2) upgradient of OW-16, just north of the trailer compound; (3) on the southwest flank of the burial ground near SD-46; and (4) in the developed area just south of Atlantic Avenue.

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36. Organic compounds such as benzene and toluene, unlike the metals, will migrate through the aquifer at a significant rate.

37. Organic compounds in the buried valley downgradient of the Site do not extend as far as OW-19 as of the most recent (1984) sampling.

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IV. GAS EMISSIONS

Program Objectives

During the Phase I Study a total of 12 bore holes were sampled, on two separate dates, to determine the quality of gases being emitted at the site. Valid VOC results were obtained for only two locations, due to complications in sampling technique and field contamination. However, non-VOC analytical results from the ten remaining bore holes indicated the presence of hydrogen sulfide at concentrations measuring from 0 ppm to 47,000 ppm. Based on these findings, it was determined that additional information should be collected concerning the quantity and quality of gaseous emissions at the Woburn site.

The Phase II air emission sampling program was tailored to determine more site specific information on the quantity and nature of the air emissions so that effective remedial action measures could be developed. Specific program objectives included:

- Identifying the areas within the site where organic materials were undergoing decomposition.
- Determining the locations where the greatest concentration of land-fill gases were generated, and the chemical components of these gases.
- Determining the rate at which gases were being released from the site.
- Validating the sensitivity of gas sampling and analysis of odorous chemical compounds found in the gases as determined by an independent odor survey.
- Generating sufficient information such that a plan to control the release of these gases so that a public nuisance did not occur and public health and safety were protected, could be developed.

The methodologies by which information were obtained to meet these objectives, and the extent to which these activities were successful, are addressed in the following discussion.

Bar Hole Investigation

Bar Hole Program Objectives

The bar hole investigation was conducted to screen the subsurface wastes identified in Phase I for combustible gas and hydrogen sulfide (H₂S). These measurements would identify areas that contained gaseous concentrations in the soil and identify areas for further study.

Sampling Methods

Samples during the bar hole program were collected by forcing a 1/2 inch diameter steel bar into the soil to a depth of 30 to 36 inches. The bar was extracted and a 1/4 inch diameter, hollow core steel pipe was inserted to the bottom of the hole. Gases were collected from the bottom of the hole, through the steel pipe and attached flexible tubing, to the intake of field analytical equipment.

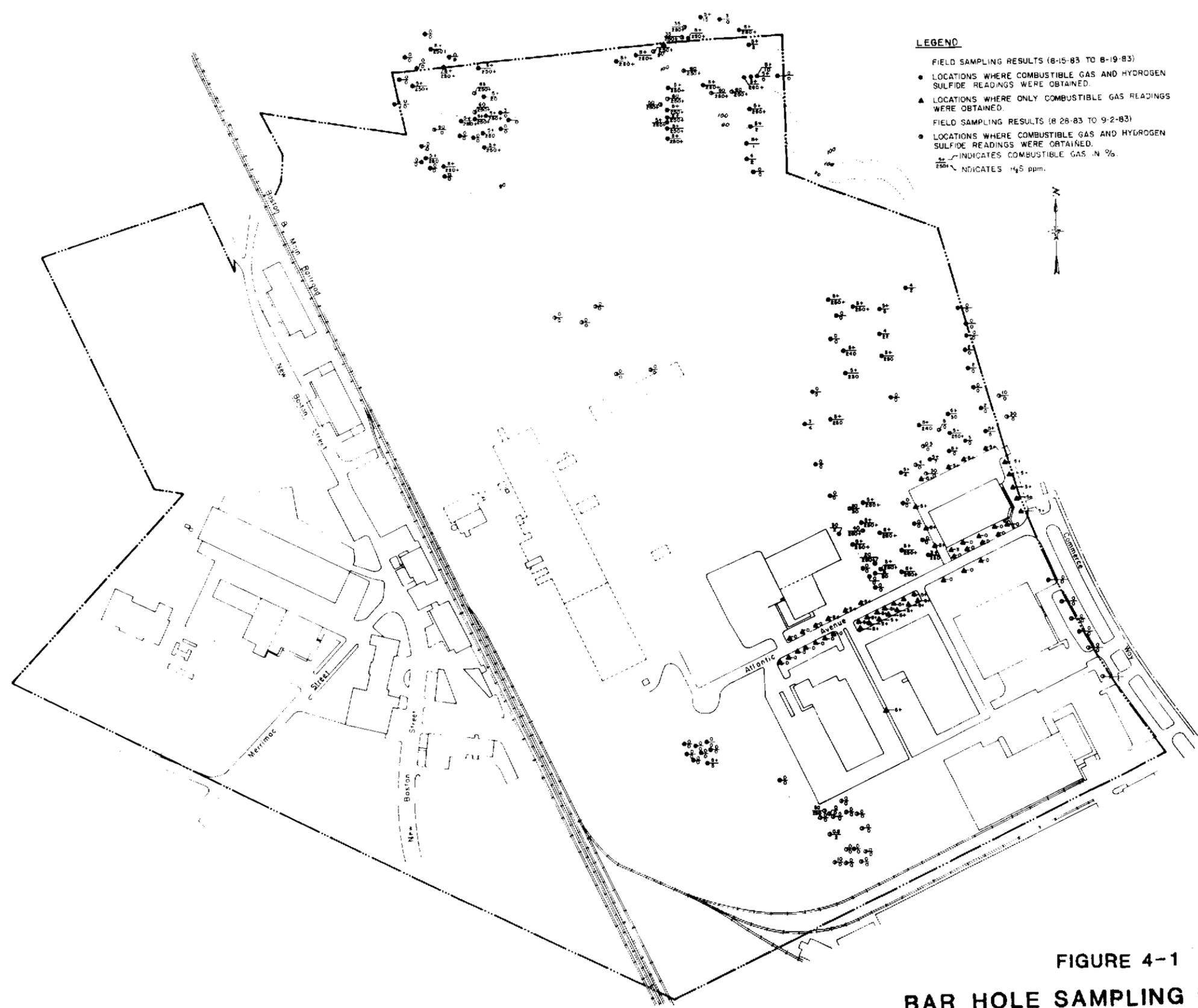
The field equipment consisted of two gas meters connected in series. The sample was first drawn through a MSA Model 60 Combustible Gas Indicator which measured combustible gas levels on a scale from 0 to 100 percent. The sample then passed through an Energetics Science 2000 Series Hydrogen Sulfide Analyzer which measured H₂S concentrations from 0.5 to 250 ppm. The internal suction pump of the Hydrogen Sulfide Analyzer, adjusted to a flow rate of 1.0 standard cubic feet per hour (SCFH), was used to extract the samples for analysis.

Bar Hole Sampling Results

A total of 370 samples were taken throughout the project area. The location and results from each sample are summarized on Figure 4-1.

The major areas screened during the bar hole program were termed the East Hide Pile, West Hide Pile, East-Central Hide Deposit, and South Hide Pile. These locations are identified on Figure 4-2. In addition, areas throughout the industrial park were sampled when readings at the site fenceline were positive or where vegetation appeared stressed. The site-specific bar hole findings are summarized by location below.

- The East Hide Pile: All samples within this area had combustible gas concentrations from 20 to 62 percent and hydrogen sulfide concentrations in excess of 250 ppm. Following sample introduction, a maximum reading of 250+ ppm almost instantaneously was registered and a 10 to 20-minute pumping period was required to purge the sample from the instrument.



LEGEND

FIELD SAMPLING RESULTS (8-15-83 TO 8-19-83)

- LOCATIONS WHERE COMBUSTIBLE GAS AND HYDROGEN SULFIDE READINGS WERE OBTAINED.
- ▲ LOCATIONS WHERE ONLY COMBUSTIBLE GAS READINGS WERE OBTAINED.

FIELD SAMPLING RESULTS (8-28-83 TO 9-2-83)

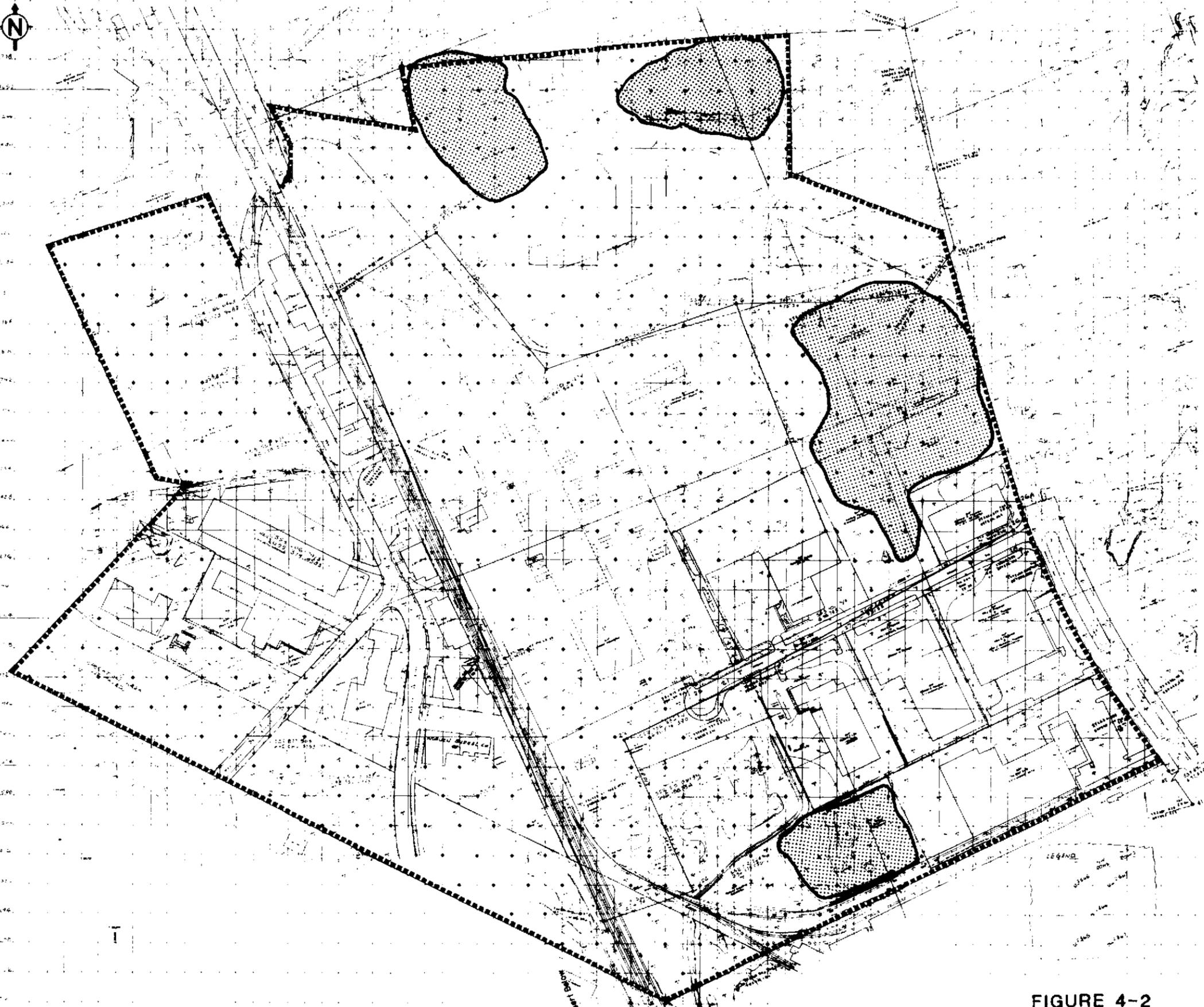
- LOCATIONS WHERE COMBUSTIBLE GAS AND HYDROGEN SULFIDE READINGS WERE OBTAINED.

~ INDICATES COMBUSTIBLE GAS IN %.

250+ INDICATES H₂S ppm.

FIGURE 4-1
BAR HOLE SAMPLING LOCATIONS
AND RESULTS

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STAMPER CHEMICAL CO.	
DATE	1954-08-07
BY	W. J. [unclear]
NO.	100
REV.	0
ISSUED	1954
BY	C

FIGURE 4-2
 HIDE PILE DEPOSIT
 LOCATION MAP

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- The West Hide Pile: Within this area, several separate and scattered locations were identified where hydrogen sulfide concentrations over 250 ppm and combustible gas readings of up to 60 percent were measured. Interval sampling (at 3-foot increments) resulted in sharp breaks between values of zero or over 250 ppm for H₂S. Generally, detectable readings were found in existing low areas or on the top edge of side sloped areas.
- East Central Hide Deposit: This area consisted of approximately four locations that registered readings for both combustible gas and hydrogen sulfide. Interval sampling at various locations again indicated sharp differences between readings at 3-foot intervals.
- South Hide Pile: Sampling in this area identified one location approximately 50 feet in diameter with measurable levels of H₂S and combustible gases.
- Off-Site Areas: Combustible gas levels of over 50 percent and H₂S concentrations greater than 250 ppm, respectively, were found on the properties owned by Anthony S. Femmino, Mary E. Fitzgerald and John J. Mulhern/Michael A. Howland, Woodcraft Supplies and Boston Edison Electric Company. The most extensive area (approximately 100 feet x 200 feet) was found approximately 1,500 feet south of the site on the Boston Edison Right-of-Way. Samples on the Mary E. Fitzgerald and John J. Mulhern/Michael A. Howland property and Anthony S. Femmino property were severely limited due to asphalt pavement.

Bar Hole Sampling Conclusions

Major areas were identified that displayed high concentrations of combustible gases and H₂S. The bar hole readings collected at 3-foot intervals showed extreme differences between measured values, suggesting that horizontal gas movement was limited. Based on the bar hole results, locations were selected for further investigation. These locations are summarized site specifically, below.

- The East Hide Pile: Consistently high concentration of gases were present on the East Hide Pile. A total of five borings were proposed to obtain samples for further analysis from this location.
- The West Hide Pile: Three areas were located that indicated the presence of measurable gaseous concentrations. Three borings were proposed for this area. The hide pile, however, did contain significant areas where gaseous emissions were not detected.
- East Central Hide Deposit: Sampling throughout the majority of this area did not indicate the presence of gas. When areas of detectable concentrations were encountered, readings became nondetectable over

time. It is believed that short horizontal movements caused this response. A total of nine sites were selected for borings.

- South Hide Pile: A single boring was proposed for the only location where gas was detected.
- Off-Site Areas: As stated previously, combustible gas levels of over 50 percent and H₂S concentrations greater than 250 ppm were measured on several properties off-site. Although the sampling was limited as a result of asphalt pavement, the concentrations measured indicate that it might be prudent for owners to review safety considerations for gas migration into their structures.

Bore Hole Sampling Program

Bore Hole Program Objectives

The bar hole sampling program described previously identified locations for further gas emission study. These areas were analyzed in detail to obtain flow rate and specific vapor-phase compound concentrations. The objectives of the bore hole program was to collect sufficient data to allow estimation of gas release rates and to determine the nature and extent of gaseous components.

Bore Hole Sampling Methods

The bore hole locations determined in the bar hole program are illustrated on Figure 4-3. At each bore hole location, a hole was augered into the ground and was excavated to the bottom of fill material. The auger was then extracted and a 4-inch diameter, 10-foot long plastic pipe was inserted into the hole. The pipe was positioned such that 2 feet extended above ground. The initial 2 feet of pipe wall below grade were solid and the remaining 6 feet were perforated to allow gas infiltration and exchange. The top of the pipe was then covered with plastic and a 1/4 inch hole drilled into the pipe one foot from the top for future sampling. Soil was compacted around the edge of the pipe extending above ground.

All of the bore holes were visually evaluated with respect to the release of gases. Following visual evaluations, plastic film 3 mils thick was placed over the pipes that were releasing gases to identify pressure gradients and to prevent air mixing before sampling. Plastic bags were placed on pipes to measure flow rates when a pressure gradient was observed. Seventeen bore holes were field measured for the release of gases. If the bag did not fill

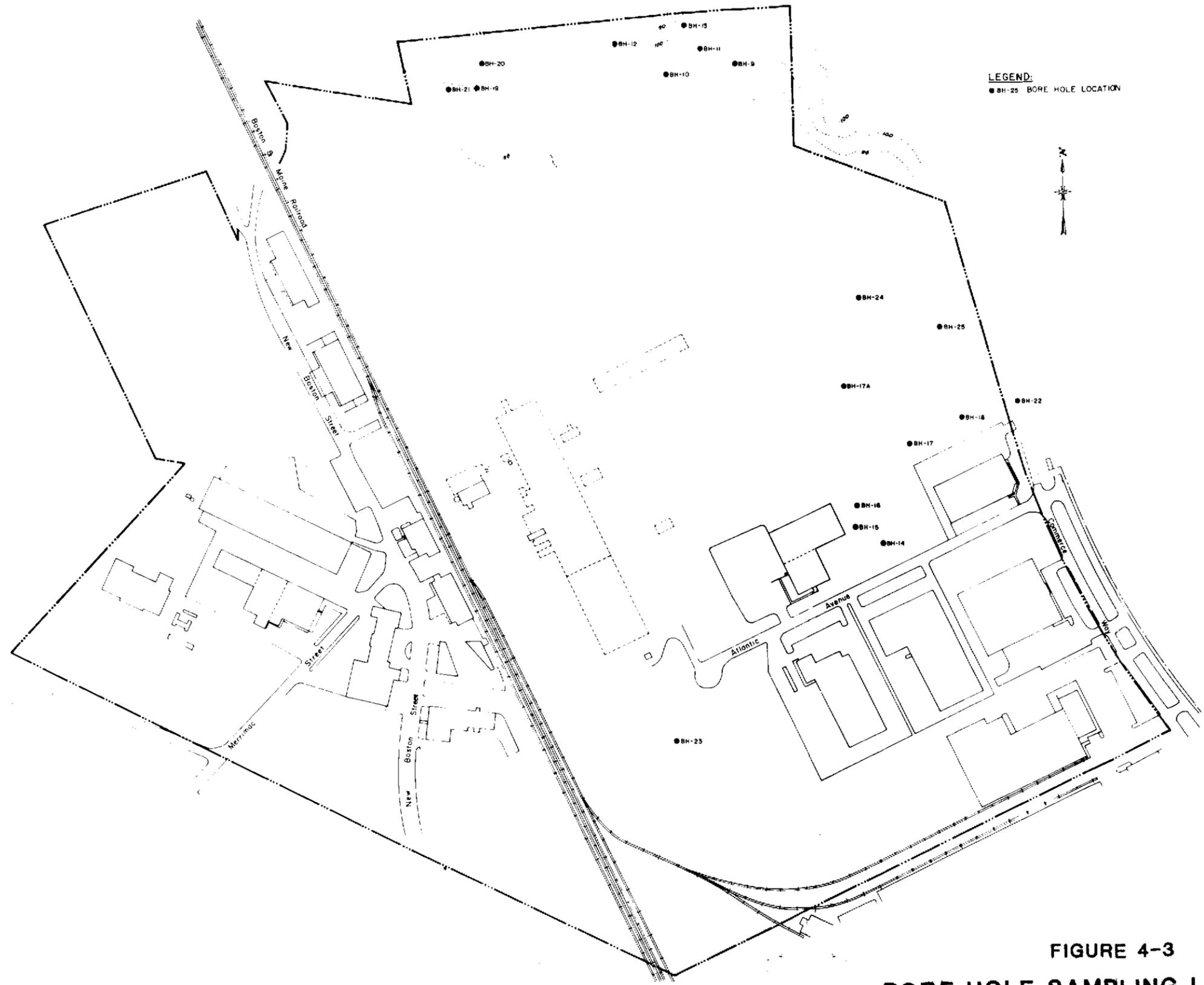


FIGURE 4-3
BORE HOLE SAMPLING LOCATIONS
AND RESULTS

over a 24-hour period, the bore hole release rate was considered insignificant. Based upon a bag volume of 4.2 ft^3 , this corresponds to a minimum detectable gas release rate of $0.0029 \text{ ft}^3/\text{min}$.

Samples for combustible gas and hydrogen sulfide were collected at the vents prior to and during the volume collection program.

Bore Hole Sampling Results

Table IV-1 summarizes gas generation rates at each bore hole location. Of the seven displaying measurable release rates, five (BH9 through 13) were located on the East Hide Pile (EHP). Bore Hole No. 10 was the most active location, releasing approximately 1.25 cubic feet per minute (cfm) of gas. The average release rate for the bore holes on the EHP was 0.36 cfm.

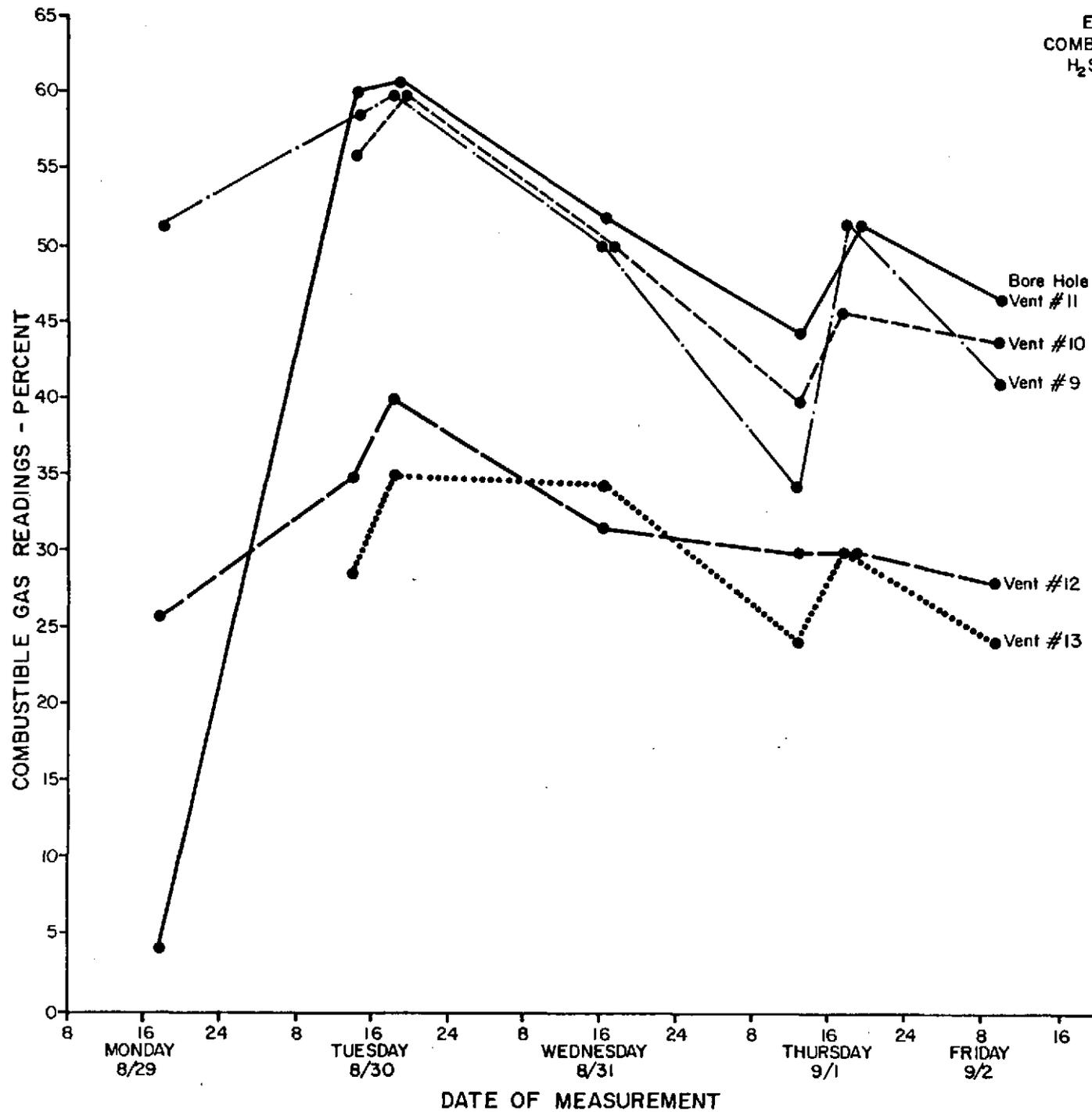
On the West Hide Pile (WHP), two of the three bore holes (BH20 and 21) had measurable release rates. Bore Hole No. 21 released approximately 0.65 cfm of gas, while Bore Hole No. 20 released approximately 0.0038 cfm.

Bore hole Nos. 14, 16 and 19 had visual signs of gaseous releases and indicated slight pressure gradients. However, the bags did not inflate over a 24-hour sampling period. All of the remaining bore holes (15, 17, 18, 22, 23, 24 and 25) did not show any indication of gaseous release. Plastic bag collections for 24-hour periods confirmed these observations.

Samples for combustible gas and H_2S were collected at the bore holes prior to and during the volume collection program. The measured concentrations over time are illustrated in Figures 4-4 through 4-7. Measured concentrations for specific compounds are summarized in Table IV-2.

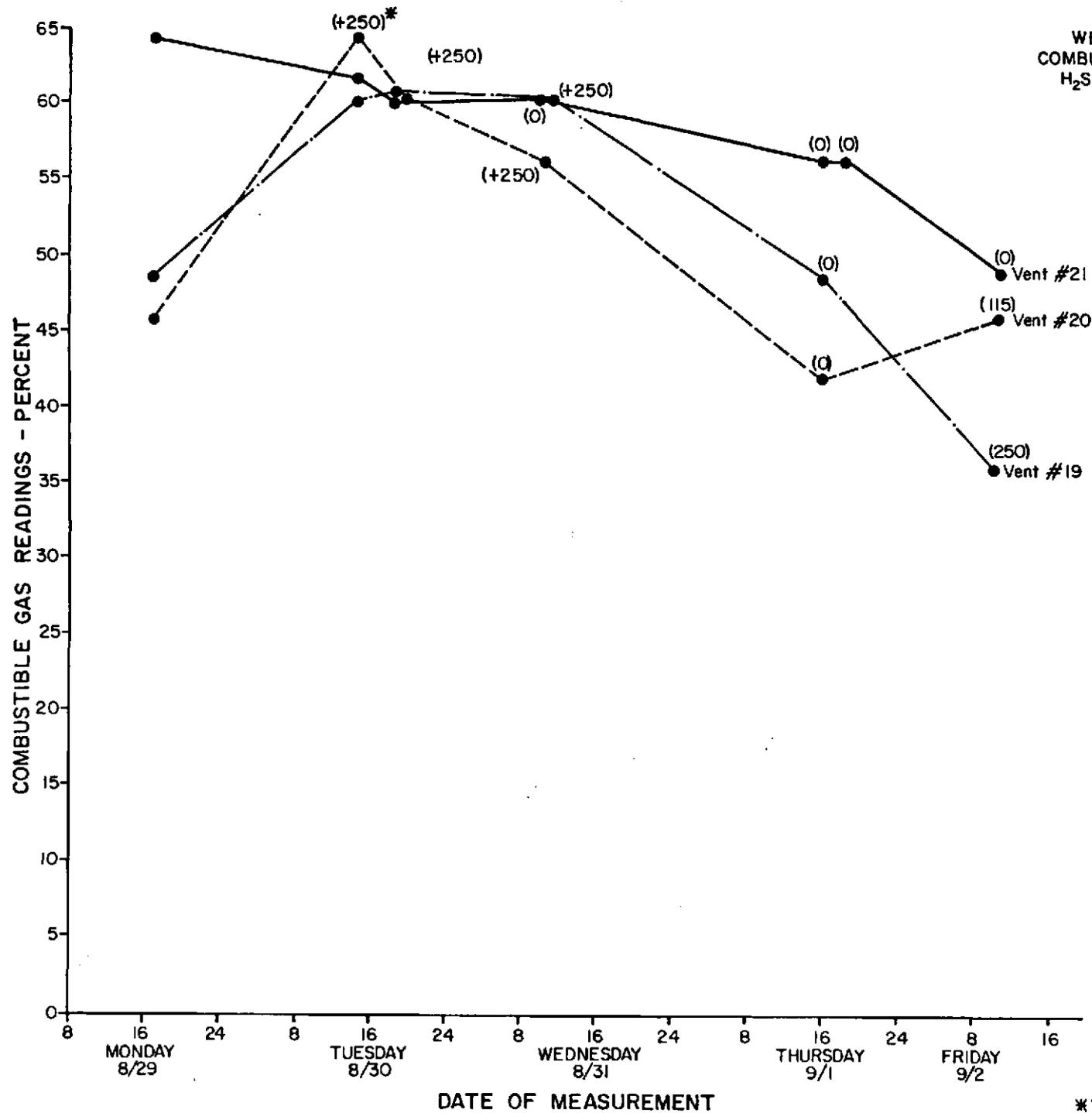
- The East Hide Pile: The results shown in Table IV-2 for Bore Hole Nos. 9 through 13 indicate hydrogen sulfide concentrations ranging from 5,600 ppm to 21,000 ppm. Additional compounds also were detected, but were mainly sulfur related and at concentrations considerably lower than those reported for H_2S .
- The West Hide Pile: Samples from Bore Hole No. 21 were highest for combustible gas, but lowest for H_2S , an unexpected result. During field sampling Bore Hole No. 21 always registered from 50 to 65 percent combustible gas, yet H_2S readings were nondetectable by field equipment. Laboratory analysis (Table IV-2) revealed values of 50 to 58 ppm which are relatively low. Bore Hole Nos. 19 and 20 did release gases containing H_2S concentrations over the 250 ppm upper limit of the field equipment on certain days. However, readings decreased to nondetectable levels on other occasions. Laboratory analysis indicated H_2S values of 200 ppm for Bore Hole No. 19 and 690 to 710 ppm for Bore Hole No. 20.

EAST HIDE PILE
COMBUSTIBLE GAS AND
H₂S MEASUREMENTS



All Samples Measured In
Excess Of 250ppm H₂S

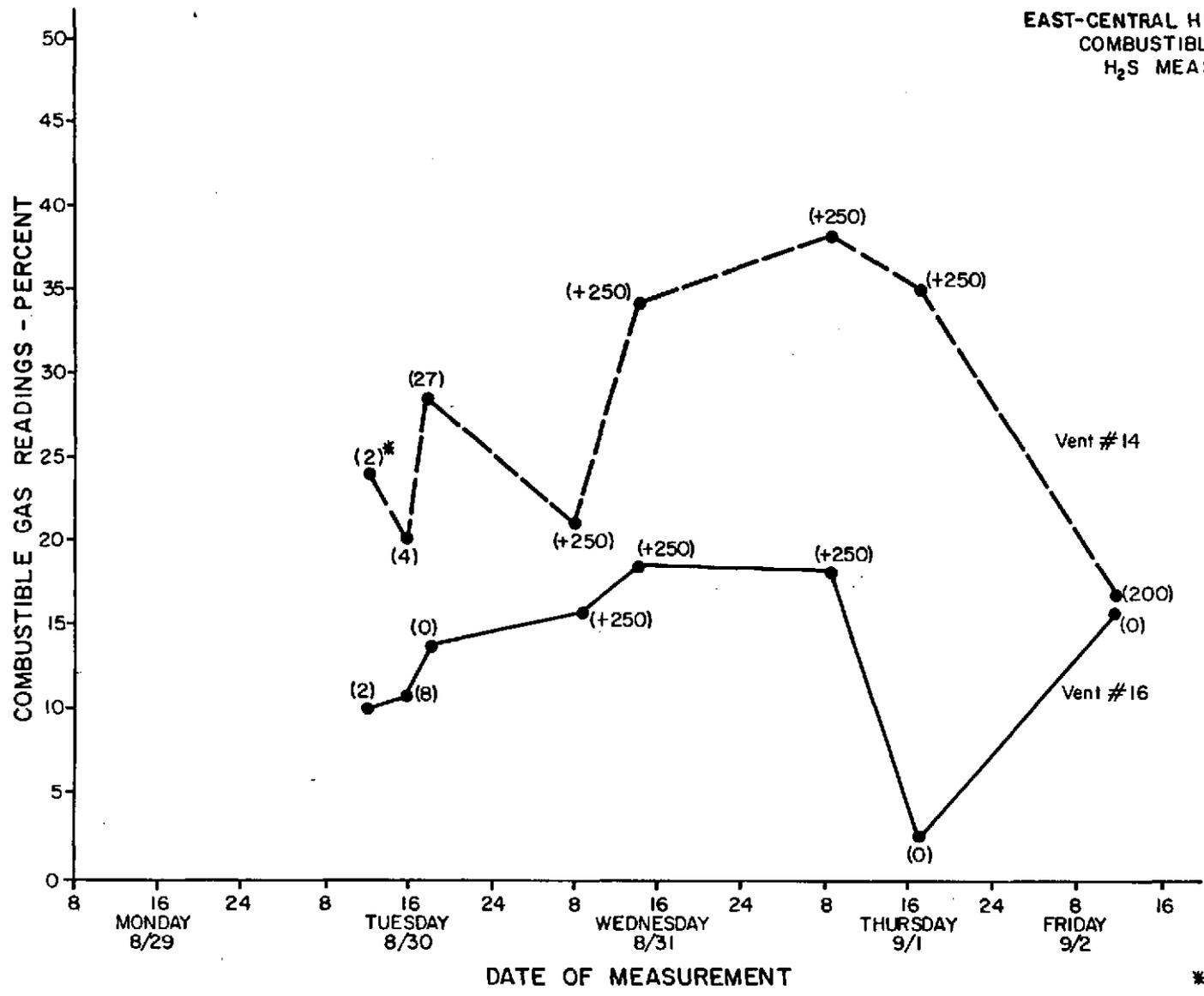
FIGURE 4-4



WEST HIDE PILE
COMBUSTIBLE GAS AND
H₂S MEASUREMENTS

* Values In Brackets Represent
H₂S Concentrations In ppm

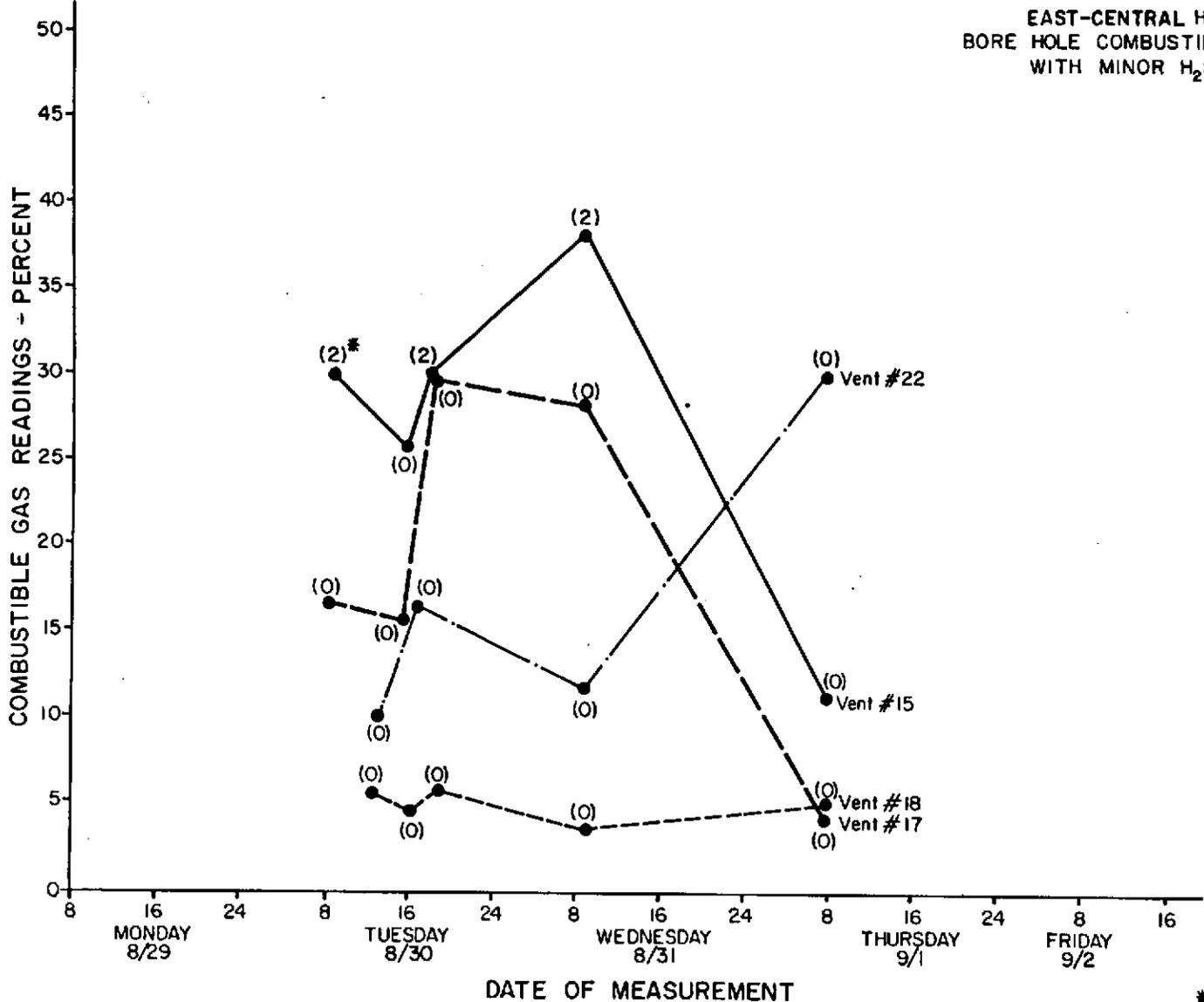
FIGURE 4-5



* Values In Brackets Represent H₂S Concentrations In ppm

FIGURE 4-6

EAST-CENTRAL HIDE PILE AREA
 BORE HOLE COMBUSTIBLE GAS MEASUREMENTS
 WITH MINOR H₂S CONCENTRATIONS



* Values In Brackets Represent H₂S Concentrations In ppm

FIGURE 4-7

TABLE IV-1
BORE HOLE GAS GENERATION RATES
 (Volume of Collection Bag = 4.2 Cubic Feet)

<u>Bore Hole Location</u>	<u>Test</u>	<u>Time to Fill (minutes:seconds)</u>	<u>Generation Rate (cfm)</u>	
9	1	18:00	0.23	
	2	16:45	0.25	
	3	13:00	0.32	
				Avg. 0.27
10	1	2:55	1.44	
	2	3:45	1.12	
	3	3:30	1.20	
				Avg. 1.25
11	1	21:30	0.20	
	2	26:30	0.16	
	3	22:15	0.19	
				Avg. 0.18
12	1	48:00	0.091	
	2	41:00	0.110	
				Avg. 0.101
13	1	182	0.023	
	2	210	0.021	
				Avg. 0.022
14	1	-	ND*	
15	1	-	ND	
16	1	-	ND	
17 - 17A	1	-	ND	
18	1	-	ND	
19	1	-	ND	
20	1	1114	0.0038	
21	1	6:35	0.64	
	2	7:50	0.54	
	3	5:35	0.76	
				Avg. 0.65
22	1	-	ND	
23	1	-	ND	
24	1	-	ND	
25	1	-	ND	

*ND = Nondetectable

TABLE IV-2
BORE HOLE AIR ANALYSIS

<u>Bore Hole</u>	<u>Location</u>	<u>Compound(s)</u>	<u>Concentration (ppm)</u>
9	52451	hydrogen sulfide	5700/5530 ⁽¹⁾
		2-propanethiol	180
		methanethiol	64
		2-butanethiol isomer	3.4
		ethanethiol	3.1
		methyl furan isomer	1.3
		trichlorofluoromethane	0.59
10	51411	hydrogen sulfide	1.8%/2.1% ⁽¹⁾
		methanethiol	50
		2-propanethiol	42
		ethanethiol	8
		carbon oxide sulfide	6.3
		benzene	1.1
11	52431	hydrogen sulfide	5800/5600 ⁽¹⁾
		2-propanethiol	42
		methanethiol	20
		ethanethiol	6.5
		carbon oxide sulfide	5.4
		2-butanethiol isomer	2.2
12	52381	hydrogen sulfide	1.9%/1.9% ⁽¹⁾
		methanethiol	150
		2-propanethiol	55
		ethanethiol	17
		carbon oxide sulfide	13
		benzene	11
		carbon disulfide	11
		dimethyl disulfide	7.5
		methyl furan isomer	1.4
		2-butanethiol isomer	1.1
		toluene	1.1
13	53423	hydrogen sulfide	2.0%/2.0% ⁽¹⁾
		2-propanethiol	180
		methanethiol	110
		ethanethiol	19
		carbon oxide sulfide	12
		dimethyl disulfide	7.8
		2-butanethiol isomer	5.5
		carbon disulfide	3.3
		benzene	1.5
		trichlorofluoromethane	0.63

TABLE IV-2
BORE HOLE AIR ANALYSIS (Cont'd)

<u>Bore Hole</u>	<u>Location</u>	<u>Compound(s)</u>	<u>Concentration (ppm)</u>
14	36532	hydrogen sulfide 2-propanethiol methanethiol	2000/1900 ⁽¹⁾ 9 2.4
16	37521	hydrogen sulfide 2-propanol 2-propanethiol methanethiol carbon oxide sulfide ethanethiol dimethyl disulfide	51/43 ⁽¹⁾ 20 6.6 4.3 4.1 4 1.1
17	39551	2-propanethiol methyl furan isomer ethanethiol	11 2.8 2
19	51301	hydrogen sulfide 2-propanethiol benzene toluene trichlorofluoromethane	200/200 ⁽¹⁾ 17 2.3 1.6 1.6
20	52301	hydrogen sulfide toluene	710/690 ⁽¹⁾ 0.73
21	51291	hydrogen sulfide benzene toluene	58/50 ⁽¹⁾ 1.2 0.76
22	40601	(nothing detected)	
23	29412	hydrogen sulfide 2-propanethiol methanethiol toluene ethanethiol bis(2-methylpropyl)disulfide	5300/4600 ⁽¹⁾ 47 18 3.9 2.5 1.9
24	44521	(nothing detected)	

TABLE IV-2
BORE HOLE AIR ANALYSIS (Cont'd)

<u>Bore Hole</u>	<u>Location</u>	<u>Compound(s)</u>	<u>Concentration (ppm)</u>
25	43571	hydrogen sulfide	240/250 ⁽¹⁾
		methanethiol	220
		ethanethiol	77
		dimethyl disulfide	1.6

Note:

1. Duplicate analyses, same sample.

- East-Central Hide Deposit: Measurements in this area were different from the those in the east hide pile and west hide pile areas. Bore Hole Nos. 14, 16 and 25 were the only locations to yield significant H₂S and/or combustible gas measurements, but these findings were not consistent. Values changed from nondetectable to 200 ppm for H₂S. Following the installation of Bore Hole Nos. 15, 17, 18 and 22, minimum or nondetectable readings were encountered. The areas adjacent to the bore holes were resampled with a bar hole and results indicated high levels of gases. The bore holes were relocated to new sites and again low or nondetectable readings were present. The bore holes were then adjusted by reinserting the perforated plastic pipe, but anticipated concentrations previously measured did not appear in the bore hole locations.
- South Hide Pile: Field samples were collected from Bore Hole No. 23 on four occasions with nondetectable results. The laboratory analysis indicated the presence of H₂S up to 5,300 ppm for this one sampling point.

Bore Hole Sampling Conclusions

The bore hole program was successful in obtaining data as to the nature and extent of gaseous compounds at bore hole locations. In addition, gas release rates were measured. The following conclusions for this program are reached:

- The East and West Hide Piles are the only locations actively releasing gases. Gas generation rates vary from bore hole to bore hole. The borings located within other areas did not exhibit gaseous release.
- Hydrogen sulfide readings varied considerably during measurements of adjacent areas. Whereas methane tends to diffuse through the soil and decrease in concentration over distance, hydrogen sulfide appears to collect and stay within a narrowly defined area.
- Several gaseous compounds were identified during the VOC analysis. The diversity indicates that hydrogen sulfide is not the only gaseous component of interest. These component and concentration results can be evaluated in the endangerment assessment to determine public risk.
- The gas release rates from the bore holes totalled 1.82 SCFM and 0.65 SCFM for the East and West Hide Piles, respectively. These findings can be evaluated in the selection of a design value for remedial action (see Gas Generation section in this chapter).

The following information represents the independent odor survey conducted by the firm of Arthur D. Little, Inc.

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ODOR EVALUATIONS OF BORE HOLE GASES
AT THE INDUSTRIplex 128 SITE
WOBURN, MASSACHUSETTS

A Report to
Stauffer Chemical Company
Westport, CT

By
S.E. Ellis
Arthur D. Little, Inc.
Cambridge, MA 02140

November 1983

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INTRODUCTION

On six days during the period 23 September through 3 November 1983, a team of trained odor analysts from the Chemical and Food Sciences Section of Arthur D. Little, Inc. conducted odor evaluations at the Woburn (Industriplex 128) site located in Woburn, Massachusetts using sensory evaluation techniques. The purpose of these evaluations was to validate the sensitivity of Stauffer Chemical Company's gas sampling and analyses to odorous chemical compounds found in the gases taken from each of 15 bore holes.

It had been identified during previous site evaluations that the primary odor types at the site were reduced sulfur species, primarily hydrogen sulfide (H_2S). In order to perform sensory evaluations on these highly odorous bore hole gases, an odor sample dynamic dilution system was developed which provided up to one million dilutions of each sample of concentrated bore hole gas. In order to identify other odorous species present in a concentrated H_2S gas sample, an odor adsorption system was used which excluded the H_2S and similar low-boiling compounds. The adsorbed odors were eluted for subsequent odor evaluations.

Throughout this study the odor team used specific chemical names to describe the observed odor when possible to do so. Use of these chemical names does not necessarily indicate the presence of that compound. Rather, it represents compounds with similar odor characteristics.

CONCLUSIONS

During direct analysis of the bore hole gasses, the characteristic odor of H_2S was identified as the principal odorant in 7 of the 15 bore

holes evaluated (including bore hole 9, 10, 11, 12, 13, 14, 23). These H₂S sources required 6.4 x 10⁴ to greater than 1 x 10⁶ dilutions with odor-free air to reduce to the recognition odor threshold of the professional odor team. In four of these seven bore holes the H₂S odor was accompanied by odors described as mercaptan, rubbery, sulfide, oniony, animal and fecal. The other three bore holes, all located at the east hide pile, were described as strictly H₂S in direct sensory analysis though other odors were revealed during the evaluation of the absorbed odors. No H₂S odors were found in the west hide pile.

Non-H₂S-related odors found during direct analysis included oniony, sulfide, cheesy sour, dimethyl sulfide, animal/horsey, phenyl acetic acid, musty, tarry, fecal and naphthalene. The odor strength of these bore hole gases as measured by odor threshold dilutions varied widely from 2 x 10³ to 5 x 10⁵. The most significant of these non-H₂S sources were Bore Hole No. 25 located on the center mound area and Bore Hole No. 16 located in the southeast corner of the site. The odors from both of these sources were described as fermented, cheesy sour.

Odors eluted from the adsorption medium included oniony mercaptan (similar to that of propyl- or butyl-mercaptan), fecal (skatole), rubbery, solventy (naphthalene or p-dichlorobenzene), tarry and musty. These odors were not quantitatively assessed during this program.

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APPROACH

During the period of September 28 to October 3, 1983, odorous gases from 15 bore holes located at the Woburn (Industriplex 128) site in Woburn, Massachusetts were evaluated by a team of 3 odor analysts. The approach used during these evaluations was developed for and modified during preliminary on-site evaluations during the week preceding the test period.

The three odor analysts used during these evaluations were trained in Arthur D. Little's Flavor Profile methodology. This objective technique makes use of trained personnel to describe odor in terms of descriptive character notes and to assign a defined intensity rating to the perceived odor. The following seven-point scale was used by the panelists to denote the total intensity of aroma, TIA:

- 0 = not detected
- 0.2 = threshold or barely detectable
- $\frac{1}{2}$ = very slight
- 1 = slight
- $1\frac{1}{2}$ = slight-to-moderate
- 2 = moderate
- $2\frac{1}{2}$ = moderate-to-strong
- 3 = strong

The character notes used by the panelists during their evaluations are descriptive only and are not intended to identify specific chemical species in the gases sampled. Rather, they represent compounds with similar odor characteristics. Certain compounds, such as hydrogen sulfide (H_2S), have unique characteristic odors while others, like methyl mercaptan, have odor characteristics such as mercaptan, sulfidy,

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decayed vegetation, cabbage, etc. Some of these characteristics are shared by other reduced sulfur species.

Direct Analysis of Bore Hole Gases

Odor analysis of each of the 15 bore holes was conducted by the odor team immediately following the bag sampling by a team of Stauffer Chemical personnel. The depth to refusal or ground water was measured by the Stauffer team and a 1/4 in. Teflon® sample line was lowered in to the bore hole to a depth of 1 to 2 feet less than the total depth. The final sample depth is included in Table 1. After connecting a small sample pump to the sample line and purging for approximately two minutes, the gas samples were collected for chemical analysis by the Stauffer team.

The Portable Dynamic Dilution System shown in Figure 1 was connected to the Teflon sample line for odor presentations to the panelist. This dilution system provides a constant flow of odor-free dilution air. The gas samples are metered in through a particulate filter. For this program the exhaust was closed in order to conserve the limited available sample volume.

Beginning at the maximum available dilution (1×10^6) with odor-free air, the sample gas concentrations were increased (dilutions decreased) until the odor was just perceptible by each panelist. The maximum dilution at which all panelists could describe the odor was taken to be the recognition dilutions-to-threshold value for each bore hole. This provides a basis for comparing the relative odor strengths of the bore holes.

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The odorant concentrations were increased by a factor of approximately two and again evaluated by each panelist who reported his observation of odor intensity and characteristics when odor was perceived. Due to the highly odorous background air at the Industriplex 128 site, the panelists breathed carbon-treated air between observations to minimize interference from extraneous odors.

The odor intensities were increased over the range of normal sensory acuity to establish the dose-response characteristics for each bore hole gas sample. The odor intensity responses for each dilution were averaged. Using the method of least squares, the best-fit line is established using the general form:

$$\text{Intensity (TIA)} = A \text{ Log Dilutions} + B$$

where A = slope and B = intercept.

Sample Collection and Evaluation

In order to assess the non-H₂S odors found in the gases from each bore hole, odors were collected on sorbent traps prepared at our Cambridge, Massachusetts odor laboratory. The sampling procedure involves passing approximately 500 L of the odorous gases through stainless steel cylinders containing 10 grams of XAD-2 sorbent resin. This material has very limited capacity for sorbing H₂S which aided in the identification of higher boiling species. No attempt was made to quantitatively evaluate these collected samples because the bore holes did not contain adequate volume to prevent dilution of the gases during sample collection.

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After collecting the odors on the sorbent, the tubes were reconnected in the dynamic dilution system as shown in Figure 2. The odorous compounds which could be air stripped were presented at a fixed dilution for qualitative odor assessment by the panelists.

The sorbent tubes were taken to a Stauffer's field laboratory located near the site where they were eluted with 10 mL of chromatographically pure, distilled-in-glass pentane. Each panelist conducted qualitative analysis on the odors released from a blotter strip containing the pentane and eluted odorous compounds.

RESULTS

The results of the direct sensory analysis are included in Table 2. Based on dilution-to-threshold, Bore Hole No. 10 on the east hide pile was the most odorous sample, requiring greater than one million dilutions (the equipment limit). The gases from this bore hole were described as H₂S only. The other two bore holes described as H₂S only (Nos. 12 and 13) were also located on the east hide pile - lower level.

H₂S was the most significant odor type found during the analysis, being identified in 7 of 15 samples. With the exception of the three holes discussed above, the H₂S characteristics were normally included with odors described as oniony, mercaptan, sulfide, rubbery, animal and fecal. While a number of chemical compounds could produce these odors the following are offered as possible candidates:

Oniony	=	propyl mercaptan, propylane sulfide
Mercaptan	=	any mercaptan
Sulfide	=	dimethyl sulfide (DMS) or dimethyl disulfide (DMDS)

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Rubbery = propyl mercaptan, butyl mercaptan
Animal = nitrogenous compounds, fatty acids such as
caprylic
Fecal = skatole
WWTP = wastewater treatment plant

In most cases the non-H₂S odor sources were more dilute. Two exceptions were found, Bore Holes No. 16 and 25, where the dilutions-to-threshold were 128,000 and 512,000, respectively. The gases from these bore holes were both described as cheesy or fermented sour and were easily recognizable even at near-threshold dilutions. Other odors described in these gases are included below with candidate chemical compounds:

Fermented = decaying protein
Cheesy = fatty acids, butyric and isovaleric
Garbagey = methacrylic acid or similar compounds
Burnt sweet = very dilute skatole or indole

Also included in Table 2 are the results of the dose/response analysis. These results are shown graphically in Figures 3 and 4. A significant point to be gained from these curves is that in those bore holes where H₂S predominated the slopes are significantly greater than when appearing blended with other odors (see Figure 4, curves 10 and 12). This suggests that impurities in the gases may serve to temper the odor impact of the gases at the supra-threshold level.

The dilutions required to reach a slight odor intensity (TIA = 1) for each of the dose/response curves are included in Table 2 for comparison of the supra-threshold odor strengths of the gases from the bore holes.

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This odor intensity has been used during some of our odor pollution programs as an indicator of complaint-intensity odors.

The characteristics of the air and solvent-eluted odors from the sorbent tube samples are included in Table 3. The prevalent odors collected on these tubes were oniony, horsey, animal, fecal, rubbery and dimethyl sulfide (DMS). Less frequently identified characteristics included burnt, and solventy. No attempt was made to quantitate these odors.

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TABLE 1

BOPE HOLE DATA

INDUSTRIALPLEX 128 (WILSON SITE)

<u>Bore Hole No.</u>	<u>Date Sampled</u>	<u>Sample Depth (ft.)</u>	<u>Bore Hole Location</u>
9	9/28	19	East hide pile - upper level
10	9/28	21	East hide pile - upper level
11	9/28	11	East hide pile - upper level
12	9/30	12.5	East hide pile - lower level
13	9/30	10	East hide pile - lower level
14	9/29	9	Southeast corner of site
16	9/29	9.5	Southeast corner of site
17	9/29	7	Southeast corner of site
19	10/3	15	West hide pile
20	10/3	18.5	West hide pile
21	10/3	13	West hide pile
22	9/29	5	Approximately 100 M north of main gate
23	10/3	9.5	Near chrome pit south of main gate
24	9/29	22	Center mound - upper level
25	9/30	13	Center mound - lower level

TABLE 2

DIRECT SENSORY EVALUATION OF BORE HOLE CASES

Dose/Response Analysis (2)

Bore Hole No.	Dilutions to Threshold (1)	-A Slope	B Int.	r Regr. Coef.	Dilutions to T1A = 1	<u>Odor Characteristics</u>
9	64,000	1.23	6.12	0.970	14,000	H ₂ S, X-SH, sour, fatty acid, fecal, oniony-SH, solventy
10	>1 x 10 ⁶	1.40	8.87	0.973	430,000	H ₂ S
11	256,000	1.12	6.29	0.994	50,000	H ₂ S, rubbery, sulfide, oniony
12	512,000	1.66	9.89	0.993	230,000	H ₂ S
13	512,000	1.21	6.99	0.947	86,000	H ₂ S
14	128,000	1.37	7.30	0.994	40,000	H ₂ S, trace fecal, trace sour
16	128,000	0.83	4.49	0.974	15,000	Cheesy sour, dirty sour, burnt sweet, trace fecal (butyric, propionic, and isovaleric acids)
17	8,192	0.73	3.35	0.989	2,000	Animal, sweet fragrance, fecal, DMS, musty, sulfidy (WWTP)
19	4,096	1.16	4.55	0.987	1,400	Sulfidy, sour, oniony-SH, tarry, fecal
20	32,000	0.97	4.53	0.994	4,200	Sour, oniony, SH, vegetable sulfide, rubbery, slightly fecal and H ₂ S, naphthalene (moth balls)
21	4,096	1.04	4.22	0.993	1,200	Oniony, sulfidy, animal, horsey, rubbery, tarry, fecal

IV-11a

TABLE 2 (Continued)

DIRECT SENSORY EVALUATION OF BORE HOLE GASES

Dose/Response Analysis⁽²⁾

Bore Hole No.	Dilutions to Threshold ⁽¹⁾	<u>Dose/Response Analysis</u> ⁽²⁾				Dilutions to TIA = 1	<u>Odor Characteristics</u>
		-A Slope	B Int.	r Regr. Coef.			
22	2,048	1.07	3.73	0.992	350	Horsey, animal, fecal, leathery, sulfide, oniony	
23	512,000	0.99	6.06	0.946	135,000	H ₂ S, trace oniony, oniony-SH, rubbery, animal, fecal	
24	2,048	0.83	2.93	0.967	200	Fecal, rubbery sulfide, vegetable sulfide, animal, musty, WWTP	
25	512,000	0.99	5.71	0.982	55,000	Fermented sour, cheeseey, garbagey	

(1) Recognized by 100% of the panel participants.

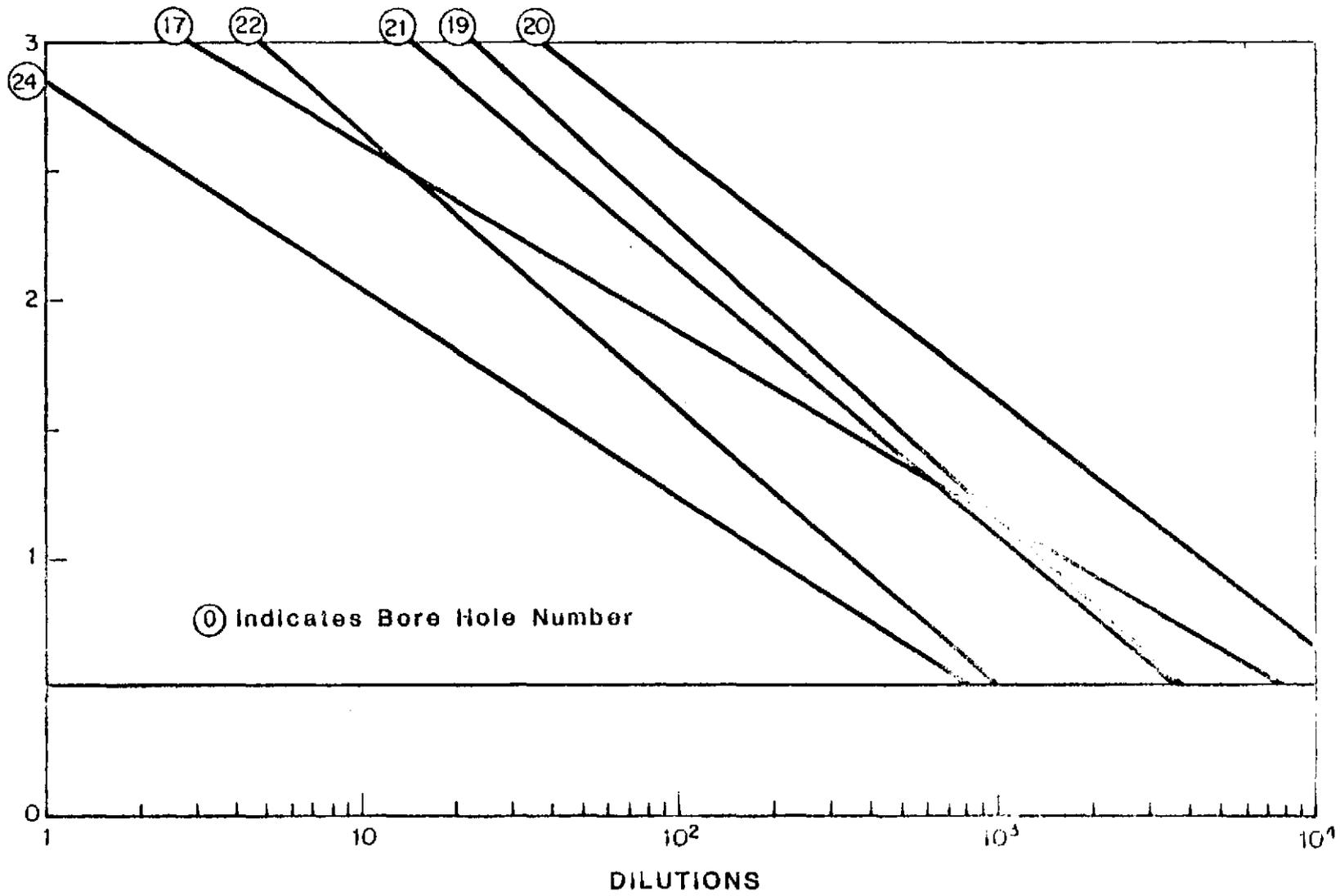
(2) Results of best fit for all data, TIA = A (log Dilutions) + B.

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TABLE 3
 SENSORY EVALUATIONS OF
 ADSORBED BORE HOLE ODORS

Bore Hole No.	Odor Characteristics	
	Air Eluted	Solvent Eluted
9	Oniony, sour, sulfidy, burnt oniony	Oniony (Pr or allyl-SH) fecal (skatole), solventy naphthalene)
10	Oniony, horsey, animal, fecal	(Me or ET)-SH, Pr-SH, fecal and fatty acid, rubbery
11	Oniony, fecal, rubbery, sulfide, DMS or DMDS	Oniony, (Pr or allyl-SH), fecal, p-dichlorobenzene
12	Oniony, horsey, DMS, animal	Oniony-SH, rubbery-SH (TBM), musty-earthly, horsey, trace skatole
13	Corny (DMS), barny, fecal, vegetable sulfide	-SH (TBM?), rusty, animal, fecal, skatole
14	Fecal, burnt sweet, animal	Rubbery-SH or sulfide, rusty- earthly, fecal (WWTP)
16	N/A	N/A
17	N/A	N/A
19	Oniony, garlicky, rubbery	-SH (Me or ET), tarry, oniony, WWTP
20	N/A	N/A
21	Trace acetic acid, sulfidy, horsey, animal	Sulfidy, fuel oil, WWTP
22	N/A	N/A
23	Oniony, sour, rubbery, animal, horsey, fecal	-SH, fuel oil WWTP, fecal,
24	N/A	N/A
25	Putrid, cheesey, garbagey fermented sour, trace fecal, coffee-like-SH	Cheesey, burnt, animal, fecal (WWTP), benzene-tarry (trace methyl benzene)

FIGURE 3

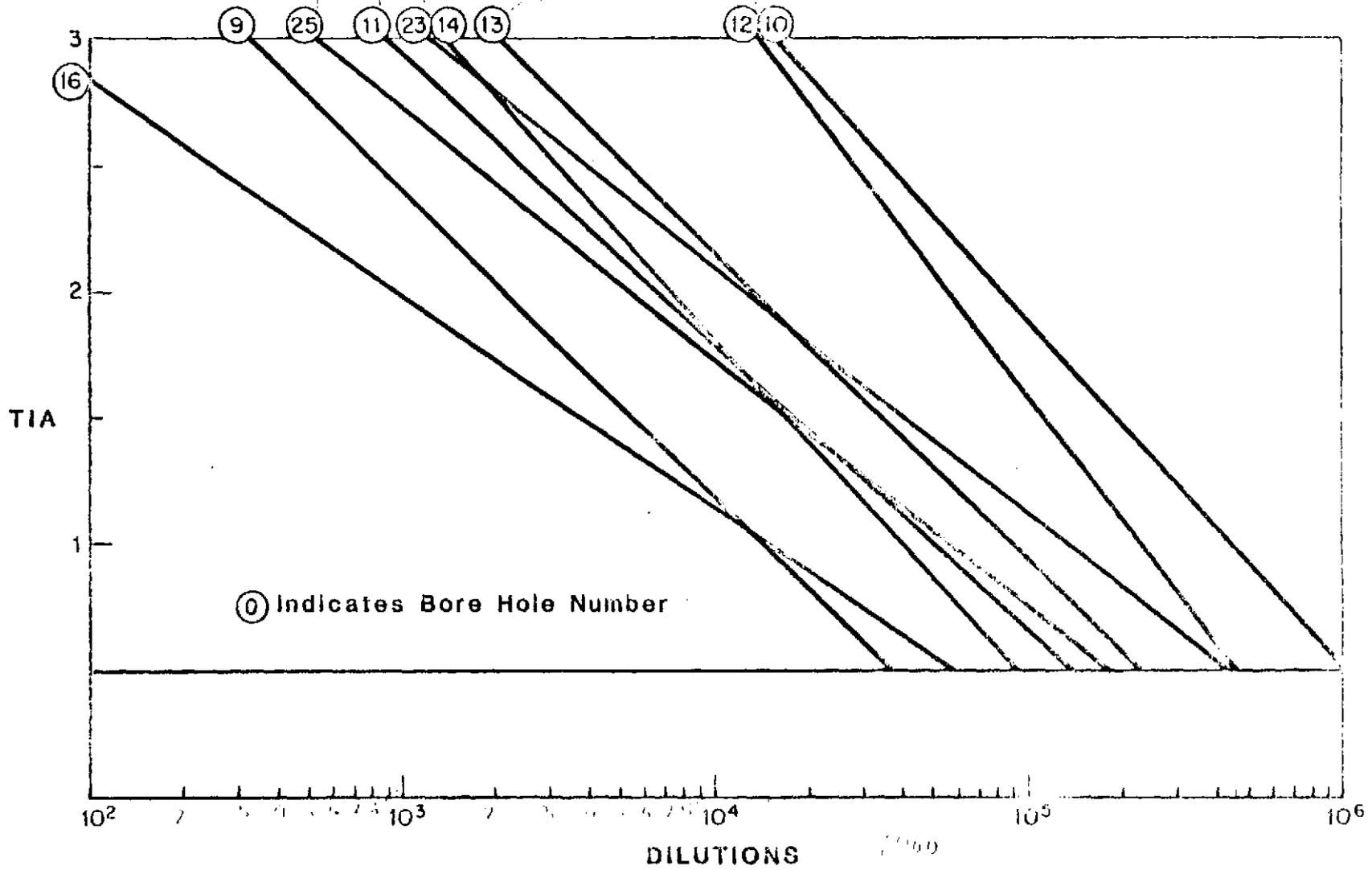


BORE HOLE DIRECT ANALYSIS DOSE/RESPONSE CURVES

IV-11a

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FIGURE 4



BORE HOLE DIRECT ANALYSIS DOSE/RESPONSE CURVES

IV-11a

Amersham Pharmacia Biotech Inc.

Gas Generation: Objectives

To determine the extent of remedial action required for odor abatement, a design value for gas generation/release must be defined. The value selected should take into consideration the measured bore hole release rates, gas generation rates from similar deposits, and gas production measured in other studies from anaerobically decomposing putrescible materials. Once a value for design is selected, the method of gas collection, dispersion/treatment, and cover requirements can be determined.

Factors Affecting Gas Production

Gas production from actively generating putrescible materials is dependent on several factors. These include:

- Volume and nature of decomposing material
- Moisture content
- Presence of biodegradation inhibitors
- Extent of anaerobic conditions

The organic nature of the animal hide deposits makes these materials amenable to anaerobic decomposition. Some of the deposits are situated below the water table and are provided with an immediately available moisture source. In addition, rainwater infiltration is a mechanism by which moisture is maintained in the hide piles. Deposits that are relatively deep in geometry have a more compact mass for developing and maintaining anaerobic conditions. High chromium and other heavy metal concentrations may tend to inhibit microbial degradation.

Gas production is a complex process incorporating several different bacterial populations requiring varying substrates. In many instances, the product from one group of organisms is required for decomposition by another. For example, methane formation and production is a result of two bacterial populations, acid-formers and methane-formers. The acid-formers convert certain substances into organic acids that are utilized by the methane-formers to produce methane gas. In addition, certain compounds that are toxic or inhibitory to one bacterial population may not necessarily be so to another. As a result of this complex bacterial interaction, and in light of the variable nature of the hide deposit components and materials, it should not be surprising that different hide deposits exhibit dissimilar generation rates and different gaseous components that are variable with time.

Based upon the above review of factors affecting gas production, it becomes evident that effective measures to reduce the rate of gas production include:

- Decreasing the potential for the hide deposits to be in contact with water
- Altering the extent of the anaerobic environment by spacial rearrangement or oxygen introduction
- Increasing the presence of anaerobic inhibitors

The extent to which these factors can be mediated and controlled is discussed in subsequent sections.

Factors Affecting Gas Release Rates

In a dynamic system of gas production and release as is characteristic of the animal hide deposits, several variables affect the observed release rate. These include:

- Gas production rate
- Nature and geometry of the material through which gases are migrating
- Prevailing climatic conditions

Factors affecting the gas production rate have been discussed previously. The type of material through which the gases migrate mediates the release based upon the soil permeability, porosity, depth and area. Climatic conditions affect release directly as a result of changing barometric pressure and precipitation. As barometric pressure decreases, gas release increases. This phenomenon was evident over a two to three-day period during the site investigation. As inclement weather approached and the barometric pressure fell, the on-site odor intensity increased significantly, suggesting that the hide pile emission rates increased. Rainwater infiltration displaces gas confined in the void space between soil particles (all of these phenomena are discussed in more detail in the determination of cover requirements in Chapter V).

Based upon the above discussion, a methodology to mitigate the gas release from the hide deposit is as follows:

- Select a design value for gas production rate

- Determine the cover requirements necessary to control release and rain water infiltration through a designed collection system
- Determine the extent of gas treatment required

The rationale for selection of a gas production rate follows. Methods for mitigating gas release and gas treatment options are included in Chapter V.

Selection of Gas Production Rate

To select an appropriate value for gas production rate, both measured and calculated rates were investigated. Calculated values are compared to the measured rates to determine agreement and to select a design rate.

Gas release rates for bore holes in the hide pile deposits were measured and reported previously. The intent of the following analysis is to identify deposits which are releasing gases and to quantify this release.

Based upon the Phase II bore hole sampling, two animal hide deposits were identified as actively releasing gases. These deposits are termed the East and West Hide Piles. An independent odor survey conducted by the firm of Arthur D. Little, Inc. revealed that the East Hide Pile was emitting the most objectionable odors and was identified as the major source of odors. Gas sample analysis yielded similar results; compounds with low odor thresholds such as hydrogen sulfide are emitted at concentrations at least one to two orders of magnitude higher at the East Hide Pile than at the West. Therefore, the selection of a gas production rate conservatively is focused upon the East Hide Pile. The measured gas release rate for the East Hide Pile, based on bore hole measurements (see Table IV-1), during Phase II was 1.8 SCFM.

As stated previously, the rate at which gases are released is dependent upon several factors, including pressure differential, temperature (Brock, T. D., Biology of Microorganisms, 3rd Ed., Prentice-Hall, Inc., 1979) and the thickness and porosity of the transfer medium. Drilling the bore holes to identify problem areas, to collect gases for analysis, and to determine empirical emission rates partially disturbed the dynamics of release from the current pile geometry. Therefore, the measured rates are compared to calculated rates to determine a design value.

For comparison, values for actively generating municipal landfills were investigated. Studies conducted at municipal landfills in California and

elsewhere in the U.S. indicated total gas release rates of 0.12 to 0.30 ft³/yd³/d can be expected (Moore, C. A. and I. Rai, "Design Criteria for Gas Migration Control Devices, Management of Gas and Leachate in Landfills, USEPA, Cincinnati, Ohio, 1977, EPA-600/9-77-026). Also, the predominant gas produced is methane. Assuming the bulk density of the animal hides is similar to municipal waste and employing a hide volume of 125,000 yd³, a production rate of 15,000 to 38,000 ft³/d (10 to 26 SCFM) is calculated.

Hide pile internal temperatures were measured during bore hole drilling and gas emission measurement during September 2 through September 4, 1983. Accordingly, these temperatures correspond to "worst case" ambient temperatures, and thereby promote anaerobic activity (i.e., high ambient temperatures promote high internal temperatures within the hide deposits). Temperatures ranged from 16 to 21 C (61 to 70 F) within the hide pile, which is well below the 35 C (95 F) temperature generally accepted as the optimum for organisms engaged in anaerobic decomposition, and below reported values up to 50 C found in municipal solid waste landfills. In general, the rate of biological activity decreases by 50 percent for every 10 C below this optimum temperature. As such, gas generation rates could be at least one-half of those measured at actively decomposing landfills. In addition, several other factors are apparent that would reduce the hide pile gas production rate below that measured at landfills, including:

- Much of the hide material is comprised of hair and wool remaining from hide glue tankage, which is insoluble fibrous animal protein. These materials are resistant to biological decomposition.
- The average age of the hide deposit, based upon production records, is 32 years. Municipal landfills place putrescible material daily to encourage methane production. Once landfills are closed, gas production decreases considerably over two to three decades.
- The hide pile material contains elevated concentrations of chromium, arsenic, and zinc. The combination of these heavy metals may inhibit anaerobic activity.

In review of the above factors, a gas generation rate of 5 SCFM seems reasonable. This value is one-half of the lower bound gas production rate for actively decomposing municipal landfills. Comparison of this value with the measured release rate during Phase II testing indicates that the predicted rate and the measured rate are the same order of magnitude. Therefore,

selection of a 5 SCFM gas production rate for design purposes, which is 250 percent of the value measured at the site, seems both appropriate and prudent.

Air Modeling

It is understood that the steady state gas production rates estimated previously may not necessarily reflect the current conditions at the site. It has been stated that unstable sideslopes, changes in barometric pressure, and gas displacement as a result of water infiltration may result in gaseous release rates greater than to those estimated for production. Accordingly, a "worst case" air model was employed to determine maximum downwind concentrations of measured compounds of particular interest in bore hole analysis.

To assess the extent of remediation required to mitigate odor complaints as a result of the decomposing animal hides, Massachusetts EPA/DEQE requested an estimate of existing/prior maximum downwind Woburn gas concentrations be made based on A. D. Little's November 13 and 16, 1981, off-site odor survey. It was acknowledged that because of lack of meteorological data, terrain and subjective nature of odor determination that it might be impossible to make a meaningful estimate of downwind gas concentrations.

Two air modeling consultants, Trinity Consultants and Form and Substance, Inc., together with D. Grasick of DEQE's air modeling section were contacted about improving the estimate based on ADL 1981 odor survey. All advised no valid estimate could be made at a distance of three miles in wooded terrain without meteorological data. Even with meteorological data a valid estimate probably could not be made without tracer studies to determine wind and terrain effects. Therefore, it was assumed a valid estimate of maximum downwind H₂S concentration could not be made based on the 1981 ADL odor survey.

It was decided a maximum downwind concentration should be made using the peak combined emission estimates based on field observations, barometric pressure fluctuations and water infiltration. The worst case unattenuated peak East Hide Pile emission rate of 80 cfm was assumed based on contributions from the following sources:

- 4 ACFM from sudden collapse of a 6-foot x 20-foot x 100-foot side-slope

- 9 ACFM from a sudden drop of 0.3 inch Hg in barometric pressure
- 16 ACFM from a 2-foot change in the water table during 24 hours
- 50 ACFM from infiltration of 0.25 inch of rain per hour

The peak existing East Hide Pile gaseous compound concentrations were assumed to be the maximum individual concentrations analyzed during Stauffer's 1982 and 1983 site studies. i.e., H₂S 5 percent, benzene 11 ppm, mercaptans 475 ppm and toluene 4 ppm. The estimated wind speeds and atmospheric stability classes during ADL's 1981 survey were used for the Texas Episodic Model Version 8 (TEM8) air model to predict ground level concentration of the various pollutants. Table IV-3 summarizes the modeling results. The values in Table IV-3 will be used in the endangerment assessment to determine the risk, if any, to the populace as a result of these gaseous emissions.

Summary and Conclusions

The Phase II bar hole program was successful in screening subsurface areas and determining locations for further bore hole analysis. Four major areas on-site (see Figure 4-2) were identified as displaying potential for gas emissions and odor. These locations are:

- The East Hide Pile located at the north end of the site. Five bore holes were located in this area.
- The West Hide Pile, also located at the north end of the site. Three bore holes were located in this area.
- The East Central Hide Deposit, located directly north and adjacent to the currently commercially developed area. Nine boreholes were located at this deposit.
- The South Hide Pile, located directly west and adjacent to the currently developed commercial area. A single borehole was installed at this location.

Gases were collected from these bore holes for gaseous component analysis and gas flowrates were measured.

At the same time, gases were collected from bore holes for an independent odor survey.

TABLE IV-3
 DOWNWIND GASEOUS COMPONENT CONCENTRATIONS⁽¹⁾
 BASED UPON WORST CASE CONDITIONS

Chemical Compound	Downwind Distance (Km)				
	0.1	0.7	1.0	1.5	2.0
Hydrogen Sulfide	1.35	.187	.139	.077	.055
Benzene	3.5×10^{-4}	4.0×10^{-6}	3.0×10^{-6}	2.0×10^{-6}	1.0×10^{-6}
Toluene	1.0×10^{-4}	$<5.0 \times 10^{-5}$	5.0×10^{-5}	5.0×10^{-5}	5.0×10^{-5}
Mercaptan	2.0×10^{-2}	$<5.0 \times 10^{-3}$	$<5.0 \times 10^{-3}$	$<5.0 \times 10^{-3}$	$<5.0 \times 10^{-3}$

Note:

1. All concentrations in parts per million (ppm).

The program was successful in identifying chemical compounds in the collected gases and in measuring gas flowrates under a particular set of conditions. Conclusions based upon gas emissions are as follows:

- Seven bore holes measured detectable gas emissions ranging from 0.004 to 1.25 CFM. Of these, five were located at the East Hide Pile and two at the West Hide Pile. The gas emissions totalled 1.82 and 0.64 CFM for the East and West Hide Piles, respectively.
- Gas emissions are a function of several factors. Therefore, the measured values imply which deposits are releasing gases, but may not necessarily indicate an absolute value that may be expected under all conditions. These values can, however, be compared to literature values and experience with actively generating landfills to determine a steady-state design value. Based on this additional information, a design value of 5 SCFM was selected.
- H_2S readings varied considerably during measurements of adjacent areas. Whereas methane appeared to diffuse and decrease in concentration over distance, H_2S seemed to collect and stay within a narrowly defined area, suggesting that all the hide deposits may not actively be generating gases, and localized "hot spots" from previous decomposition may exist.
- The gas component analysis indicated that hydrogen sulfide and methane were not the only gaseous components, although concentrations of other chemical compounds were two to three orders of magnitude less than these inorganics. The VOC results can be used in the endangerment assessment to determine what, if any, health effects can be expected from gases emitted from the boreholes. The estimated design gas emission rate can be utilized along with the concentration data to determine the chemical mass loadings from locations identified as actively releasing sources.

The odor survey was conducted on-site to determine the sensitivity of the collected gases to odorous chemical compounds found in these gases. Odors were analyzed for gases from each bore hole to determine:

- The number of dilutions required to effect a concentration at which the odor was just detectable by all of the three panelists.
- The number of dilutions required to reach qualitative judgement as to the intensity of the odor. These qualifications ranged from not detected to strong, and are termed total intensity of aroma (TIA). The odor panel suggested that the dilution TIA is an indicator of complaint/intensity of odor.

Both the TIA and the threshold dilution values can be reviewed to determine the relative magnitude of sources with regard to odor potential. The odor panel concluded:

11/1/77

- The characteristic odor of H_2S was identified as the principal odorant in 7 of the 15 bore² holes evaluated. These boreholes included all five on the East Hide Pile, one at the East-Central Hide Deposit, and the one bore hole on the South Hide Pile. The H_2S sources required 64,000 to greater than 1,000,000 dilution with odor-free air to reduce the sample concentrations to the recognition odor threshold of the professional odor team.
- Non- H_2S -related odor strength, as measured by odor threshold dilution,² varied from 2,000 to 500,000. The most significant of these odor sources, described as fermented and cheesy sour, were two bore holes on the East-Central Hide Deposit.

When ADL adsorbed bore hole gas on adsorption media and later eluted in the laboratory a solvent type odor (naphthalene or p-dichlorobenzene) was found, which ADL's site odor measurements and bore hole gas analysis had not detected. This is probable, since adsorption and elution could increase the concentration several fold over the bore hole concentration.

To determine the relative magnitude and to identify the source of odors at the Woburn site, the gas release and odor results were combined, by bore hole, to assemble Table IV-4.

It is evident from Table IV-4 that gas emission and odor potential, as judged by measurable gas emissions, dilutions to threshold, and TIA, is greatest at the East Hide Pile. Although the West Hide Pile had measurable gas release, no H_2S odors were identified and dilutions to threshold were 1 to 3 orders of magnitude less than the values determined for the East Hide Pile.

Two bore holes on the East-Central Hide Deposit and the bore hole on the South Hide Pile exhibited dilutions and TIA similar to those on the East Hide Pile. However, gas release rates were not detectable at these locations.

In summary, the data collected were sufficient to determine the major odor source(s) and to provide an estimate of gaseous component mass loadings from these sources. Although it is understood that release rates are dependent upon several factors and that those presented only are for a given set of conditions, these measurements did afford a comparison of the magnitude of gas emissions from different sources. The mass loadings can be used in the endangerment assessment and in determining the efficacy of individual remedial technologies.

TABLE IV-4

SUMMARY OF GAS EMISSIONS/ODOR PROGRAM

Bore Hole No.	Location	Gas Emission Rate (cfm)	Dilutions to Threshold	Dilutions to TIA = 1 ⁽¹⁾	Dilutions to TIA = 3 ⁽²⁾
9	East Hide Pile	0.27	64,000	14,000	350
10	East Hide Pile	1.25	>1,000,000	430,000	17,000
11	East Hide Pile	0.18	256,000	50,000	930
12	East Hide Pile	0.101	512,000	230,000	13,000
13	East Hide Pile	0.022	512,000	86,000	2,100
19	West Hide Pile	ND*	4,096	1,400	24
20	West Hide Pile	0.0038	32,000	4,200	40
21	West Hide Pile	0.65	4,096	1,200	15
14	East-Central Hide Deposit	ND*	128,000	40,000	1,600
16	East-Central Hide Deposit	ND*	128,000	15,000	60
17	East-Central Hide Deposit	ND*	8,192	2,000	3
22	East-Central Hide Deposit	ND*	2,048	350	5
24	East-Central Hide Deposit	ND*	2,048	200	<1
25	East-Central Hide Deposit	ND*	512,000	55,000	560
23	South Hide Pile	ND*	512,000	135,000	1,300

*ND = Not Detectable

1. TIA = 1:Slight odor

2. TIA = 3:Strong odor

SECTION V

PHASE II SAFETY AND HEALTH REVIEW

I. SUMMARY

A review of the Phase II exposure monitoring results shows that, other than for H₂S, there was insignificant potential for inhalation exposure to hazardous substances during site investigative activities. Although there was potential for exposure to H₂S, personnel real-time monitoring showed that the use of good work practices was effective in keeping actual employee breathing zone exposures below acceptable limits. The work practices and exposure monitoring program (Phase II Safety and Health Plan) were successful in assuring prevention of acute injury or any adverse impact on the health of personnel working on the site. In addition, the monitored site activities did not create any conditions which would have posed a health hazard to the off-site general public.

Based on personnel exposure monitoring and real-time dust measurements, peak dust exposure levels were typically less than 1 mg/m³ during trenching, boring, and drilling operations (well below the OSHA time-weighted average limit of 15 mg/m³), and no remedial control actions were required. Personnel exposure to the known heavy metals in the soil (lead, arsenic, and chromium) was typically at or near the limit of detectability. No elevated peak organic vapor levels above normal background levels, as measured by an Hnu organic vapor monitor, were encountered during investigative activities. Peak hydrogen sulfide breathing zone levels were typically less than 1 ppm, except during some activities on the waste piles. During these exceptions, H₂S breathing zone levels were within the OSHA acceptable ceiling and peak limits.

All personnel involved in site investigative activities wore protective coveralls and rubber boots as a precautionary measure. No site activity occurred which required additional special clothing for health protection of on-site personnel. Mandatory respirator use was not required and the exposure monitoring data affirmed that such a requirement was not necessary. Respirators were used on a voluntary basis, both for nuisance dust exposure and for objectionable odors when on the waste piles. Site personnel were trained in the use of the protective equipment and informed on the potential contaminants and their hazards. Boots were washed prior to leaving the site, and investigative personnel showered at the end of the day. All major equipment was steam cleaned prior to being taken off site.

II. RESPONSIBILITIES, SITE SECURITY, AND DECONTAMINATION

The site Project Engineer, Mel Beers, was responsible for Phase II safety and health. Two site Safety and Health Specialists, A. Kwan and V. Hutsko, were responsible for conducting air monitoring during site investigative activities, briefing M. Beers on work practices and protective equipment utilization, and reviewing the environmental sampling results.

As required in the S&H Plan, site access was restricted and controlled. All personnel going on site were required to wear rubber boots and to decontaminate them upon leaving. All equipment used on site was also decontaminated prior to being taken off site. Investigative personnel were required to shower at the end of the day.

III. USE OF PROTECTIVE EQUIPMENT

1. Protective Clothing

Protective clothing requirements as provided in the S&H Plan were followed. All personnel involved in site investigative activities wore protective coveralls and rubber boots as precautionary measures. As expected based on Phase I experience, additional special protective clothing was not required, other than rubber gloves worn by drillers.

2. Respiratory Protection

Exposure monitoring conducted during Phase I investigative activities had shown that potential personnel exposures to total particulate, heavy metals, and organic vapors were quite low. As a result, mandatory respirator use during investigative activities in Phase II was not required. Half-mask cartridge respirators and half-mask disposable respirators were available to all site personnel for use on a voluntary basis.

Both types were used by site personnel. Occasional use of dust respirators during trenching occurred, as well as use of organic vapor/nuisance odor respirators during some activities on the waste piles. Exposure monitoring conducted during Phase II investigative activities verified that potential personnel exposures were well below acceptable levels, and mandatory use of respirators was not required.

No site activities occurred which required the use of self-contained breathing apparatus.

IV. EXPOSURE MONITORING

1. Background

Phase I experience demonstrated that although potential personnel exposures for all investigative activities were low, the exposure potential during trenching was the highest. This was mainly due to the Backhoe Operator being fixed in a stationary position during digging and filling. In the event that the backhoe had to be positioned down wind of the trench, the operator would not be able to get out of the way of any dust being generated.

Eleven personnel exposure filter samples were collected on ten separate days of site investigative activity. Of the eleven, two were lost due to pump failure and one was lost during laboratory analysis (laboratory reported not receiving the sample filter). Six of the eight samples were collected on the Backhoe Operator. All of the samples were analyzed for total particulate. In addition, half were analyzed for lead and arsenic, and half were analyzed for total chromium. The results of the personnel samples are listed in Table I (attached).

In addition to the personnel samples, real-time peak monitoring was conducted for total particulate, H₂S, and total organic vapor. A GCA RAM-1 particulate monitor, Ecolyzer H₂S monitor, and E.nu photoionization organic vapor monitor were used for these determinations. Conditions were monitored both in the vicinity of the investigative personnel and down wind of the activity site.

2. Test Pit Digging

a. Total Particulate - Personnel Monitoring

Of the six personnel exposure samples collected on the Backhoe Operator during test pit digging, all but one showed non-detectable total particulate exposure levels (less than 0.2-0.3 mg/m³). The only detectable result of 1.03 mg/m³ occurred during a day when digging took place in particularly dry soil. All total particulate results were below the OSHA Permissible Exposure Limit (PEL) of 15 mg/m³ and the ACGIH recommended Threshold Limit Value (TLV) of 10 mg/m³.

b. Chromium, Arsenic, and Lead - Personnel Monitoring

The filter samples were also analyzed for either lead and arsenic, or for total chromium. The filters could not be analyzed for all three metals simultaneously because of analytical incompatibilities.

The highest of the three total chromium results, 3.1 ug/m³, was recorded on the filter sample that had a detectable total particulate level. The other two total chromium results were at non-detectable levels (less than 1.5 ug/m³). If it were assumed that all the chromium in the soil was in a hexavalent chromate form, the applicable OSHA PEL would be 52 ug/m³, expressed as chromium.

All three of the arsenic results were at non-detectable levels (less than 0.08 ug/m³). These were all well below the OSHA PEL of 10 ug/m³.

The highest of the three lead results was 2 ug/m³. All three results were well below the OSHA PEL of 50 ug/m³ and the "action level" of 30 ug/m³.

Although the filter sample that had a detectable total particulate level was not analyzed for lead or arsenic, a review of the soil sample heavy metal analyses for the areas being investigated on this day show that the chromium soil concentrations were approximately twice as high as the lead soil concentrations, and approximately eight times as high as the arsenic soil concentrations. Thus it is unlikely that either lead or arsenic exposure levels would have approached their respective OSHA PELs.

The review of the soil sample Heavy metal analyses also shows that on days when personnel samples were collected on the Backhoe Operator, digging occurred in site locations that had significant soil concentrations of lead, arsenic, and chromium. Although personnel samples were not collected on the Backhoe Operator during every day of the test pit digging, based on the levels measured during the six test days and the peak dust readings taken with the RAM-1 dust monitor on the other test pit digging days, it can be concluded that exposure to lead, arsenic, chromium, and total particulate was well within allowable limits during all test pit digging activities.

c. Real Time Monitoring - Total/Respirable Particulates

As mentioned above, in addition to the collection of personnel filter samples, real-time peak dust readings were taken during the digging of test pits. After the S&H Specialist became familiar with the operation, readings were often not taken when visual dust levels were low, such as when digging on rainy days or when digging in damp soil. The distribution of 113 total dust readings was:

< 1 mg/m ³	- 92 readings
1-2 mg/m ³	- 14 readings
2-5 mg/m ³	- 7 readings

A total of 41 respirable peak dust readings were all less than 0.5 mg/m³ (OSHA time-weighted average limit of 5 mg/m³). The highest reading recorded during the digging and filling of a test pit is included in these distributions.

All of the higher total dust readings occurred on the day when the 1.03 mg/m³ exposure level was measured on the Backhoe Operator. The peak readings correlate well with the filter sample results from this day and the other test days, and verify that dust exposures were low.

d. Real Time Monitoring - Organic Vapors

The H.nu organic vapor monitor was used on site only to warn of unexpected high organic vapor levels in the event that investigative activities would have uncovered a liquid organic deposit. The instrument could be consistently calibrated with isobutene in the 40-50 ppm range, but exhibited considerable instability in the 0-10 ppm range. Readings taken in the laboratory, in the ambient air well outside the site boundaries, and even with zero air (mixture of nitrogen/oxygen with non-detectable level of contaminants) varied from 0-10 ppm on a daily basis. Although the unit was returned to H.nu twice for repair during the project, it continued to exhibit the low level instability. Thus, although the unit was capable of providing warning of high levels, any actual levels less than 10 ppm were unreliable except to indicate that an elevated exposure condition did not exist. Readings taken during the digging of 197 test pits never exceeded 10 ppm on the instrument.

e. Real Time Monitoring - H₂S

The Ecolyzer H₂S monitor was worn on site during test pit digging activity. The alarm was set at 5 ppm and did not go off during these activities. Readings were recorded during the digging of 60 test pits. All were at non-detectable levels (less than 1 ppm).

3. Bore Hole Drilling/Sampling

a. Total Particulate - Personnel Monitoring

During bore hole drilling operations on 8/25/83, personnel samples for total particulate were collected on a Driller and a Geologist. Both sample results for total particulate were at non-detectable levels (less than 0.15 mg/m³).

b. Chromium, Arsenic and Lead - Personnel Monitoring

In addition to total particulate, the Geologist's sample was analyzed for total chromium. The total chromium exposure result was at a non-detectable level (less than 0.7 ug/m³).

In addition to total particulate, the Driller's sample was analyzed for arsenic and lead. The arsenic exposure level was non-detectable (less than 0.06 ug/m³). Based on the non-detectable total particulate exposure level and the other lead exposure results from Phase I & II samples, the Driller's lead result of 20.8 ug/m³ cannot be explained based on site conditions or activities. A more likely explanation would be that of laboratory contamination during analysis. In any case, the result should be viewed as an anomaly, and not indicative of actual lead exposure potential during the drilling operations.

c. Real Time Monitoring - H₂S

Based on Phase I activities, a potential for exposure to H₂S while drilling in the waste piles was anticipated. The applicable personnel exposure limits for H₂S are a 10 ppm time-weighted average TLV (recommended by the ACGIH), a 20 ppm ceiling limit (a 15 minute short term average OSHA PEL), and an OSHA maximum peak exposure limit of 50 ppm (for no more than 10 total minutes in an 8 hour period). Although the measured H₂S levels in the boreholes were as high as 5%, and levels measured just inside a hole immediately after drilling were sometimes greater than 1000 ppm, the applicable breathing zone personnel limits were not exceeded during the waste pile activities.

The H₂S monitor was set to alarm at 5 ppm during bore hole drilling and subsequent bore hole sampling activities. During drilling, H₂S levels were typically 1-2 ppm while the auger was in the soil. When the auger was removed and while a PVC vent pipe was hammered into the bore hole, peak levels as high as 15 ppm were measured. During these activities, site personnel typically wore respirators due to the objectionable odors.

After the PVC pipe was put in place, the hole was capped and allowed to equilibrate. During borehole sampling, although the sampling personnel were positioned upwind, peak levels as high as 30 ppm occurred immediately when the vent pipe was uncapped. As soon as the personnel backed away from the pipe, the levels would quickly drop below 20 ppm. Again, the sampling personnel typically wore respirators during these activities because of the odor.

H₂S concentrations also dropped off rapidly in the downwind direction. Concentrations were less than 5 ppm approximately 20-40 feet from the bore hole.

d. Real Time Monitoring - Organic Vapors

H.nu readings taken during bore hole drilling were all less than 10 ppm, indicating no potential for elevated organic vapor exposure.

4. Auger Drilling - Apportionment Sampling

Of 96 H₂S readings recorded during apportionment sampling, 86 were less than 1 ppm, 7 were at 1 ppm, and 3 were at 2 ppm. The higher readings appear to have resulted from zero drift near the end of the day. Of 58 H.nu readings recorded, all were less than 10 ppm, indicating no potential for elevated organic vapor exposure.

5. Summary and Conclusions

Exposure monitoring during Phase I investigative activities had shown very limited potential for exposure to heavy metals, reduced sulfur compounds, or organic vapors during trenching, boring, and drilling. Although elevated potential exposures were not anticipated for Phase II activities, real-time and personnel monitoring were required during Phase II investigative activities to confirm the insignificant potential for employee inhalation exposure and to assure that increased control measures were not required. Employee exposures to total particulate and heavy metals were, with minor exceptions, at or near the limits of detectability. The H₂S organic vapor monitor was capable of detecting inadvertent exposure to liquid organic deposits. Other than for this possibility, the potential for organic vapor exposure was very low. No potential for elevated organic vapor exposure was detected during site activities. Although waste pile bore holes contained elevated levels of H₂S, the use of good work practices during boring and subsequent sampling eliminated any potential for over exposures. All detected H₂S exposures were within acceptable limits. Although respirators were used periodically for odor and nuisance dust control, exposure monitoring documented that this respirator use was not required for reducing adverse health effects or for regulatory control purposes.

Section VI
Analytical Procedures

1. Modifications in Analytical Procedures Used for Phase II Investigation

The analytical procedures used in the Woburn Phase II program were detailed in the "Woburn Environmental Studies Sampling and Analysis Manual, Phase II Investigation," which was submitted to the Agency in May, 1983 by Stauffer. During the course of the investigation, only minor modifications in the procedures proposed were required to complete the analysis.

The analytical methods for the determination of metals in soils were not specified but were to be carried out either by atomic absorption spectrometry (AAS) or inductively coupled argon plasma spectrometry (ICAP). The six site-specific metals studied in the Phase II program were analyzed as follows:

arsenic	-	ICAP
copper	-	ICAP
chromium (total)	-	ICAP
lead	-	AAS
mercury	-	cold vapor - AAS
zinc	-	ICAP

With the exception of mercury, all metals were determined in a dry-ground soil core sample as specified in the analytical procedures. It was found in the preparation of quality assurance samples that mercury in spiked samples was lost in the drying procedure at 105°C. Attempts to retain the mercury by drying at 60°C also resulted in low recoveries of mercury spikes. It became necessary to modify the proposed procedures for soil metals analysis to obtain valid mercury results as follows:

Before sample drying in the Stauffer site laboratory a representative subsample of the original was collected in a 40 mL vial. This sample was then submitted to the contract lab, GCA, for mercury analysis and loss-on-drying along with a portion of the dried bulk sample for the remaining five metal analyses. Results for all metals were then reported for each sample on a dry basis as originally planned.

The remaining procedures required for analysis on Woburn samples were those originally described in the analytical manual.

2. Determination of Hexavalent Chromium in Woburn Soils

Stauffer agreed to conduct an investigation of the presence of hexavalent chromium (Cr VI) in Woburn soils as part of the Phase II program. Since validated procedures for Cr VI in soil containing high levels of trivalent chromium (Cr III) were not available, studies were carried out to determine the applicability of available EPA methods (Appendix III-C, Ref. 1).

Soils samples were collected in the vicinity of Stauffer's Eastern Research Center in Dobbs Ferry, New York for this investigation. These samples represented a natural matrix. A non-interfering sample matrix, sand, was also studied. Three sets of experiments were performed to validate the EPA procedures.

- o Soil samples were spiked with Cr VI only at levels ranging from 50 - 1000 ppm. The samples were digested according to EPA method 3060 (Appendix III-C, Ref. 2) and analyzed by extradition and atomic absorption spectrometry according to EPA method 7197 (Appendix III-C, Ref. 3).
- o Sand was spiked with Cr VI alone, Cr III and Cr VI mixed and with Cr III alone. The samples were again analyzed as above.
- o Samples were spiked with an excess of Cr III at levels equivalent to 0.04 to 20% in soils, without the addition of Cr VI. The samples were again analyzed according to the EPA procedures described earlier.

From these experiments it was found that:

- o The recovery of Cr VI from soils decreased rapidly at spiking levels less than 500 ppm, to 16% at the 50 ppm spike level. This was attributed to organic interferences in the soil which reduced Cr VI to Cr III, thus, no Cr VI could be detected using the EPA method if it would have been present.

- o Recovery of Cr VI spikes added to sand were approximately 100% at the 50 ppm level. There was no evidence that the Cr VI was reduced to Cr III. The excellent recovery was attributed to the lack of matrix interferences.
- o Spikes of Cr III alone to sand or soils produced a positive interference resulting in an apparent reading of Cr VI at between approximately 0.3 to 6 ppm. Since the final analytical determination of Cr VI in the EPA method is not selective to only Cr VI, it is possible that traces of Cr III can be carried through the procedure resulting in a false positive result.

It was reported in the literature (Appendix III-C Ref. 4) that oxidized manganese present in moist soils could oxidize Cr III to Cr VI. This was investigated as a possibility for the false positive results for Cr VI obtained in the analysis of spiked samples containing only Cr III. Using procedures outlined in the reference it was determined that the amount of oxidized manganese present in the soil and sand samples was not high enough to account for the false positive Cr VI results obtained (Appendix III-C, Ref. 5).

The major source of chromium in the Woburn soils is from hides tanned with Cr III compounds. From these studies, it was found that the EPA methods were not suitable for use to determine the presence of Cr VI in Woburn soil samples, since the methods can not recover Cr VI in the presence of high organic concentrations and give false positive results in the presence of high levels of Cr III compounds.

X-ray diffraction (XRD) and electron spectroscopy for chemical analysis (ESCA) were investigated as possible alternatives for the EPA Cr VI procedures (Appendix X, Ref. 6). Soil samples were spiked with known amounts of Cr VI as CrO_3 or $\text{K}_2\text{Cr}_2\text{O}_7$ and Cr III as $\text{Cr}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ at levels up to 4%.

XRD analysis of the spiked samples was found to be too insensitive for the purpose of the Woburn study. No signal for Cr VI compounds could be detected in spiked samples at the 4% level.

ESCA was also found to be unsuitable for the soil CR VI analysis even though it was found to be able to distinguish Cr III from Cr VI at approximately 0.5% in laboratory samples. Exposure of the sample to x-rays during the ESCA analysis converted some CR VI to Cr III and relatively high levels of Cr III in the samples made it impossible to detect trace amounts of Cr VI because of overlapping signals.

The use of argon etching to obtain depth profiles of Cr VI in soil samples was not possible, since it converted Cr VI to Cr III rapidly.

Based on the results of these studies, Stauffer and EPA agreed to drop the determination of Cr VI in soil samples due to the lack of a suitable analytical method.

3. Determination of Volatile Emissions in Woburn-Site Borehole Samples

The procedures for the determination of volatile emissions from the Woburn-site boreholes were outlined in Section 14.00 of the "Woburn Environmental Studies Sampling and Analysis Manual, Phase II Investigation." The original analytical procedures included determination of volatile organics by EPA method 8340, GC/MS and reduced sulfur compounds by gas chromatography using a flame photometric detector in the sulfur mode.

With the addition of the Arthur D. Little (ADL) odor panel study to the program, changes were made in the analytical procedures. EPA requested that the feasibility to measure higher boiling compounds in air by the bag method should be determined. It was suspected that additional compounds could be indicated as being present by the odor panel survey. The range of compounds studied was increased to include several semi-volatile organic priority pollutants and reduced sulfur compounds.

Experiments were conducted at Stauffer's contract laboratory, GCA, under Stauffer's direction to validate the gas sampling bag method for selected semi-volatile compounds. Several target compounds, chosen from earlier ADL odor surveys at the Woburn site, were selected including: isovaleric acid, phenyl acetic acid, trimethylamine, nitrobenzene, methanethiol, ethanethiol, 1-propanethiol and dimethyl disulfide. Detection limits could not be established for isovaleric acid or phenyl acetic acid in air at spike levels up to 50 ppm due to their low volatility.

Trimethylamine was not detected at spike levels up to 50 ppm presumably due to reaction with the acid compounds. Of the other compounds, all could be detected at levels below 1 ppm except for nitrobenzene which had a lower limit of detection of 3 ppm.

From the validation studies conducted, it was determined that the gas sampling bag method would be best suited for the more volatile compounds expected at the Woburn site, such as H₂S and thiols. Higher boiling compounds such as fatty acids were not expected to be detected by the bag method even though they were previously suspected as being present by odor.

The results of the Stauffer sampling and analysis of borehole air samples were supportive of the ADL odor survey, conducted simultaneously at the site. The major odorous components present in the boreholes were H₂S and thiol compounds.

As expected, the primary difference between the ADL odor survey and the GCA analysis was in ADL's detection of odorous high-boiling compounds such as skatole (methyl indole) and fatty acids (phenyl acetic acid, valeric acid, isovaleric acid, etc.). In a few instances, GCA detected low levels of compounds that were not indicated by ADL's odor survey. This was attributed to odorous materials and the presence of compounds at concentrations below their odor threshold.

Odors similar to dichlorobenzene and naphthalene were noted by ADL in boreholes 11 and 20. Neither of these compounds were detected by analysis at GCA, and no lower limit of detection had been previously established. Both of these compounds are high boiling and the bag method would not be expected to be ideal for their measurement in borehole air.

Additional experimental work was initiated at Stauffer's Eastern Research Center to establish a lower limit of detection for naphthalene and dichlorobenzene by the bag method. Since ADL could not confirm the existence or determine the actual level of either compound in borehole air by odor, the bag method lower limit of detection would then serve as an upper limit for either compound's concentration, if actually present. Using an equivalent experimental procedure, the lower limit of detection of dichlorobenzene and naphthalene in air by the bag method was estimated to approximately 1 ppm and 10 ppm respectively (Appendix I, Table 4.2.2).

Quality Assurance

A quality assurance (QA) program was incorporated into the Woburn Phase II investigation to evaluate the quality of the data and detect potential analytical problems in sampling and analysis. The elements of the program were fully described in the "Woburn Environmental Studies Sampling and Analysis Manual, Phase II Investigation." In summary, the key elements of the program included:

1. Written sampling and analysis procedures referenced to the regulatory/technical literature.
2. Chain of custody for all samples from point of collection through the contract laboratory where analyzed.
3. QA samples added to all sample batches sent to the contract labs to establish recovery and reproducibility data for all analyses.
4. A Stauffer QA supervisor on-site for the entire program to oversee the sampling and sample preparation activities and review analytical data from the contract labs.

QA samples were added to the Woburn samples as follows:

1. Soil Samples

- a) Blanks (library) - Soil collected from an off-site location with low levels of the metals was used to monitor potential contamination at the contractor's lab.
- b) Blank Spike (library) - Several samples were prepared by spiking the blank sample with known amounts of the specific metals studied at Woburn. The spikes were prepared at several different levels that were expected on-site. These samples were used to establish the recovery of analytes by the contract lab's procedures.

Both samples (a and b) were prepared as "library" samples at Stauffer's Eastern Research Center and analyzed in triplicate to establish reference values for each metal.

- c) Duplicate - One sample from each batch of 15 was selected as a blind duplicate and submitted for analysis. This sample was used to determine the within-the-batch reproducibility for each metal analysis.
- d) Prior (duplicate) - One sample from a previously analyzed batch was selected and included with each batch of 15 samples. These results were used to calculate the reproducibility of analyses between batches.
- e) Prior - One previously analyzed sample from the site was spiked with all site-specific metals, except mercury, and included with each batch of 15 samples. Mercury could not be spiked in these samples since it was determined that it was lost in the sample drying step and would therefore not be a valid spike. The prior spike sample was used in a site-specific matrix.

Samples c, d and e were selected and prepared at the Stauffer site laboratory and included with each batch of samples with the two library samples.

2. Borehole Air, Water and Soil Organics Samples

Minor modifications were made in the type of QA sample sent out for these categories. Prior and prior spike samples could not be used for these samples, since the holding times for these analyses prevented use of retain samples. Instead blanks, blank spikes, duplicates and duplicate spike samples were submitted to the contract laboratories. Adjustment of the spike levels to approximately double the concentration of the analytes in the duplicate spikes was not possible as in the soil prior spikes, since data was not available at the time of QA sample preparation. Best estimates for spike levels were made based on available data.

Following completion of the analyses, all analytical data was reviewed and QA sample results evaluated. Recovery and reproducibility of the analyses were calculated over the course of the entire investigation. This data has been summarized for each batch submitted for analysis (Appendix III, Table 1-4).

DATA QUALITY

The elements of the Quality Assurance Program are described in "Woburn Environmental Studies Sampling and Analysis Manual, Phase II Investigation."

As in previous hazardous waste-site studies, i.e. Love Canal, a major problem was the difficulty matching sample spikes to the amount of analyte actually found in the sample. The recovery of the spike was often not measurable because it's concentration was a magnitude lower than the actual analyte level. However, the study yielded a sufficiently large data base of acceptable QA values so that the overall quality of the analytical data could be judged as excellent.

SOIL SAMPLE ANALYSIS

1. Metals

The results of the Quality Assurance data for metal analysis in soil are considered excellent in relation to the matrix variation encountered and the relevance of the measured concentration in regard to remedial actions. With few exceptions (See Appendix III) all analytes were detected and recoveries found excellent in ranges significant for remedial action. For instance, a low of 83% to a high of 94% average recovery was obtained in the prior spiked samples for all metals analyzed. The reproducibility of the mercury analysis was lower than for other analytes since the sample for mercury analysis could not be dried and ground to obtain a homogenous sample. In general, the reproducibility of the metal analysis was good. It was observed that duplicate analysis performed by the contracted laboratory on the same day were generally in better agreement than those performed on different days. The contracted laboratory was audited by Stauffer personnel and was found to have complied with the required QA Standards (See Appendix III).

2. Organics

The quality of the data obtained for organics in soil are comparable to other hazardous waste site studies. The Love Canal report (Environmental Monitoring of Love Canal, Volume 1-EPA-600/4-82-030A, May 1982) page 257, refers specifically to the difficulties to add a known amount of Q.A. spikes to soil: "As was mentioned in the section on Limits of Detection/Quantitation, it is very difficult to add a known amount of an analyte or analytes to a soil, sediment, or biota sample and simulate the natural sorption or uptake processes. Therefore, known additions (spikes) are often superficial and do not rigorously test an analytical method. Alternatively, a spike may rapidly and (nearly) irreversibly sorb to a solid particle and the failure to recover it may not be indicative of laboratory performance." With these limitations, the results were found acceptable.

GROUND WATER VOC

The overall quality of the analytical data obtained is good in light of the quality assurance data. This is particularly true when the QA results obtained in this study are compared to the results of a major, frequently quoted round robin study on effluent analysis carried out by the EPA in cooperation with the chemical industry (Analysis of Chemical Plant Waste Waters for the EPA Priority Pollutants, 9/20/79, Radian Corporation).

BORE HOLE AIR ANALYSIS

Based on the limited scope of the air sampling, a bag sampling method was proposed and agreed upon. Considering the inherent limitations of this sampling method for determining gas mixture of trace levels, the results are considered acceptable.