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RCRA FACILITY INVESTIGATION (RFI) GUIDANCE

VOLUME IV OF IV

CASE STUDY EXAMPLES

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ABSTRACT

On November 8, 1984, Congress enacted, the Hazardous and Solid Waste Amendments (HSWA) to RCRA. Among the most significant provisions of HSWA are § 3004(u), which requires corrective action for releases of hazardous waste or constituents from solid waste management units at hazardous waste treatment, storage and disposal facilities seeking final RCRA permits; and § 3004(v), which compels corrective action for releases that have migrated beyond the facility property boundary. EPA will be promulgating rules to implement the corrective action provisions of HSWA, including requirements for release investigations and corrective measures.

This document, which is presented in four volumes, provides guidance to regulatory agency personnel on overseeing owners or operators of hazardous waste management facilities in the conduct of the second phase of the RCRA Corrective Action Program, the RCRA Facility investigation (RFI). Guidance is provided for the development and performance of an investigation by the facility owner or operator based on determinations made by the regulatory agency as expressed in the schedule of a permit or in an enforcement order issued under § 3008(h), § 7003, and/or 53013. The purpose of the RFI is to obtain information to fully characterize the nature, extent and rate of migration of releases of hazardous waste or constituents and to interpret this information to determine whether interim corrective measures and/or a Corrective Measures study may be necessary.

DISCLAIMER

This document is intended to assist Regional and State personnel in exercising the discretion conferred by regulation in developing requirements for the conduct of RCRA Facility Investigations (RFIs) pursuant to 40 CFR 264. Conformance with this guidance is expected to result in the development of RFIs that meet the regulatory standard of adequately detecting and characterizing the nature and extent of releases. However, EPA will not necessarily limit acceptable RFIs to those that comport with the guidance set forth herein. This document is not a regulation (i.e., it does not establish a standard of conduct which has the force of law) and should not be used as such. Regional and State personnel must exercise. their discretion in using this guidance document as well as other relevant information in determining whether an RFI meets the regulatory standard.

Mention of company or product names in this document should not be considered as an endorsement by the U.S. Environmental Protection Agency.

RCRA FACILITY INVESTIGATION (RFI) GUIDANCE

VOLUME IV

CASE STUDY EXAMPLES

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LIST OF ACRONYMS

AA	Atomic Absorption
AI	Soil Adsorption Isotherm Test
ASCS	Agricultural Stabilization and Conservation Service
ASTM	American Society for Testing and Materials
BCF	Bioconcentration Factor
BOD	Biological Oxygen Demand
CAG	EPA Carcinogen Assessment Group
CPF	Carcinogen Potency Factor
CBI	Confidential Business Information
CEC	Cation Exchange Capacity
CERCLA	Comprehensive Environmental Response, Compensation, and Lability Act
CFR	Code of Federal Regulations
CIR	Color Infrared
	Corrective Measures
CMI	Corrective Measures Implementation
CMS	Corrective Measures Study
COD	Chemical Oxygen Demand
COLIWASA	Composite Liquid Waste Sampler
DNPH	Dinitrophenyl Hydrazine
DO	Dissolved Oxygen
DOT	Department of Transportation
ECD	Electron Capture Detector
	Electromagnetic
EP	Extraction Procedure
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FID	Flame Ionization Detector
Foc	Fraction organic carbon in soil
FWS	U.S. Fish and Wildlife Service
GC	Gas Chromatography
GC/MS	Gas Chromatography/Mass Spectroscopy
GPR	Ground Penetrating Radar
HEA	Health and Environmental Assessment
HEEP	Health and Environmental Effects Profile
HPLC	High Pressure Liquid Chromatograhy
HSWA	Hazardous and Solid Waste Amendments (to RCRA)
HWM	Hazardous Waste Management
ICP	Inductively Coupled (Argon) Plasma
ID	Infrared Detector
Kd	Soil/Water Partition Coefficient
Koc	Organic Carbon Absorption Coefficient
Kow	Octanol/VVater Partition Coefficient
LEL	Lower Explosive Limit
MCL	Maximum Contaminant Level
MM5	Modified Method 5
MS/MS	Mass Spectroscopy/Mass Spectroscopy
NFIP	National Flood Insurance Program
NIOSH	National Institute for occupational Safety and Health

LIST OF ACRONYMS (Continued)

NPDES	National Pollutant Discharge Elimination System
OSHA	Occupational Safety and Health Administration
OVA	Organic Vapor Analyzer
PID	Photo Ionization Detector
pKa	Acid Dissociation Constant
ppb	parts per billion
ppm	parts per million
PUF	Polyurethane Foam
PVC	Polyvinyl Chloride
QA/QC	Quality Assurance/Quality Control
RCRA	Resource Conservation and Recovery Act
RFA	RCRA Facility Assessment
RfD	Reference Dose
RFI	RCRA Facility Investigation
RMCL	Recommended Maximum Contaminant Level
RSD	Risk Specific Dose
SASS	Source Assessment Sampling System
SCBA	Self Contained Breathing Apparatus
SCS	Soil Conservation Service
SOP	Standard Operating Procedure
SWMU	Solid Waste Management Unit
TCLP	Toxicity Characteristic Leaching Procedure
TEGD	Technical Enforcement Guidance Document (EPA, 1986)
TOC	Total Organic Carbon
TOT	Time of travel
TOX	Total Organic Halogen
USGS	United States Geologic Survey
USLE	Universal Soil Loss Equation
	Ultraviolet
VOST	Volatile Organic Sampling Train
VSP	Verticle Seismic Profiling
WQC	Water Quality Criteria

14.0 INTRODUCTION

14.1 Use of case studies

This document Volume IV of the RCRA - Facility Investigation of (RFI) Guidance, contains case studies selected to illustrate various concepts and procedures presented in Volumes I, II, and Ill. These case studies are provided to explain, through example, how various tasks can be conducted during RFls. The case studies also identify some of the potential problems that can occur if the RFI sampling and analytical programs are not carefully designed and executed. The case studies, however, should not be used as the primary source of guidance for RFI program design and conduct. Instead, Volumes I, II and Ill should be consulted. The studies do not necessarily address details specific to individual facilities, and omission of certain RFI tasks should not be interpreted as an indication that such tasks are unnecessary or of less significance. Most of the case studies are based on actual sites. In some cases, existing data have been supplemented with hypothetical data to iilustrate a particular point.

14.2 Organization of Volume lV

The case studies are organized primarily by the order in which the subject matter was presented in Volumes I, II and III. In some cases, individual case studies present materials relevant to more than one topic or media. Table 14-1 lists the points illustrated and identifies the case studies-which provide information relevant to these points.

The following general format was used as appropriate for each case study

- Title
- Identification of points illustrated
- introduction/Background
- Facility description
- Program design/Data collection
- Program results/Data analysis
- Case discussion.

TABLE 14-1

SUMMARY OF POINTS ILLUSTRATED

POINTS ILLUSTRATED	CASE STUDY NUMBER
SELECTION OF MONITORING CONSTITUENTS	
● Use of 40 CFR Part 261 Listing Background Documents in selecting monitoring constituents	1
● Consideration of degradation as a factor in identifying monitoring constituents	2
SAMPLING SCHEMES	
● Selection of a sampling scheme that appropriately characterizes soil contamination	3
● Evaluation of the effectiveness of a sampling scheme using statistical analyses	3
● Use of release monitoring leachate collection to characterize wastes when the actual waste stream is inaccessible, as in the case of buried drums	4
QUALITY ASSURANCE AND CONTROL	
● Use of quality assurance and control and data validation procedures	5
DATA PRESENTATION	
● Techniques for presenting data for facility investigations involving multimedia contamination	6
WASTE CHARACTERIZATION	
● Correlation of a contaminant release with a specific waste management unit using ground-water data	7
● Use of site topographic information to select test boring and monitoring well locations at facilities where large volumes of waste have been disposed.	8
● Use of waste stream information to select indicator parameters and monitoring constituents in a ground-water monitoring program to minimize the number of constituents that must be monitored	9
● Use of information on possible waste reaction products in designing a ground-water monitoring program	10
CORRECTIVE MEASURES INCLUDING INTERIM MEASURES	
● Use of biodegradation and removal for interim corrective measures	2
Corrective action and the implementation of interim corrective measures	11
AERIAL PHOTOGRAPHY	
● Use of aerial photographs to identify actual and potential waste migration routes and areas requiring corrective action	12
● Identification of a ground-water contaminant plume using infrared aerial photography	13
● Use of historical aerial photographs and facility maps to identify old waste disposal areas and ground-water flow paths	14

TABLE 14-1

SUMMARY OF POINTS ILLUSTRATED (continued)

POINTS ILLUSTRATED	CASE STUDY NUMBER
SOIL	
● Use of soil characteristics to estimate mobility of contaminants in soil	15
● Effects of degradation in determining the fate of a contaminant in soil	2
● Use of leaching tests to predict potential impacts of contaminated soils on ground water	16
GROUND WATER	
● Use of split-spoon sampling and organic vapor monitoring to select screened intervals for ground-water monitoring	17
● Development of a two-phase boring program to investigate ground-water contamination	18
● Use of basement monitoring to estimate contaminant migration	19
● Use of mathematical models to determine locations of ground-water monitoring wells	20
● Monitoring and characterization of ground-water contamination when two liquid phases are present	21
● Methodology for construction of vertical flow nets	22
SUBSURFACE GAS	
● Design of a phased monitoring program to adequately characterize subsurface gas migration	23
● Use of predictive models to estimate extent of subsurface gas migration	24
AIR	
● Use of dispersion modeling and meteorological/emissions monitoring data to estimate downwind contaminant concentrations	25
● Design of an upwind/downwind monitoring program when multiple sources are involved	26
SURFACE WATER	
● Use of existing site-specific data to design a surface water monitoring program	27
● Use of bioassays and bioaccumulation studies to assess potential biological effects of off-site contaminant migration	28
● Use of sediment sampling to indicate off-site contaminant migration via surface runoff	29
● Design of a sampling program to account for three-dimensional variations in contaminant distribution	30
● Use of dispersion zone concepts in the design of a surface water monitoring program	31

15.0 CASE STUDIES

CASE STUDY 1: USE OF THE 40 CFR 261 LISTING BACKGROUND DOCUMENTS FOR SELECTING MONITORING CONSTITUENTS

Point Illustrated

- The 40 CFR 261 Listing Background Documents can be of direct help in selecting monitoring constituents.

Introduction

The RCRA Hazardous Waste Listing Background Documents developed for the identification and listing of hazardous wastes under 40 CFR Part 261 represent one source of potential information on waste-specific constituents and their physical and chemical characteristics the documents contain information on the generation, composition, and management of listed waste streams from generic and industry-specific sources. In addition to identifying hazardous constituents that are present in the wastes, the documents may also provide data on potential decomposition products. In some background documents, migratory potential are discussed and exposure pathways are identified.

Appendix B of the Listing Document provides more detailed information on the fate and transport of hazardous constituents. Major physical and chemical properties of selected constituents are listed, including molecular weights, vapor, pressures and solubilities, octanol-water partition coefficients, hydrolysis rates, biodegradation rates, and volatilization rates. Another section of the appendix estimates the migratory potential and environmental persistence of selected constituents--based on a conceptual model of disposal in an unconfined landfill or lagoon.

The appropriate uses and limitations of the Listing Documents are outlined in Table 15-1. A case study on how the Documents may be used in investigating a release follows.

TABLE 15-1

USES AND LIMITATIONS OF THE LISTING BACKGROUND DOCUMENTS

Uses	Limitations
● Identifies the hazardous constituents for which a waste was listed	● Applicable only for listed hazardous wastes
● In some cases, provides information on additional hazardous constituents which may be present in a listed waste	● Industry coverage maybe limited in scope (e.g., the wood preserving industry). Listing Documents only cover organic preservatives, not inorganics(15 percent of the industry), such as inorganic arsenic salts
● In some cases, identifies decomposition products of hazardous constituents	● Data may not be comprehensive (i.e., not all potentially hazardous constituents may be identified). Generally, limited to the most. toxic constituents common to the industry as a whole
● Provides overview of industry; gives perspective on range of waste generated (both quantity and general characteristics)	● Data may not be specific. Constituents and waste characteristic data often represent an industry average which encompass many different types of production processes and waste treatment operations
● May provide waste-specific characteristics data such as density, pH, and leachability	● Listing Documents were developed from data/reports available to EPA at the time, resulting in varying levels of detail for different documents
● May provide useful information the migratory potential, mobility, and environmental persistence of certain hazardous constituents	● Hazardous waste listings are periodically updated and revised, yet this may not be reflected in the Listing Documents
● May list physical and chemical properties of selected constituents	● Listing Documents for certain industries (e.g., the pesticides industry) may be subject to CBI censorship due to the presence of confidential business information. In such cases, constituent data may be unavailable (i.e., expurgated from the document)

Facility Description

The facility is a wood preserving plant located in the southeast. The facility uses a steaming process to treat southern pine and timber. Contaminated vapors from the wood. treating process are condensed and transported to an oil/water separator to reclaim free oils and preserving chemicals. The bottom sediment sludge from this and subsequent waste water treatment units is a RCRA listed hazardous waste: K001.

Use of Listing Background Documents

Due to the presence of small, but detectable, levels, of phenolic compounds in the ground water of an adjacent, property, a RCRA Facility Assessment (RFA)was conducted and it was determined that a release from the facility, had occurred. The owner was instructed to conduct a RCRA Facility Investigation (RFI). Before embarking on an extensive waste sampling and analysis program, the owner decided to explore existing sources of information order to better focus analytical efforts.

The owner obtained a copy of the Wood Preserving Industry Listing Background Document from the RCRA Docket at EPA Headquarters. He also had available a copy of 40 CFR Part 261, Appendix Vll, which identifies the hazardous constituents for which his waste was listed. For K001, he found the following hazardous constituents listed: pentachlorophenol, phenol, 2-chlorophenol, p-chloro-m-cresol, 2,4 dimethylphenyl, 2,4-dinitrophenol, trichlorophenols,

fluoranthene, benz(b)fluoranthene, benz(a)pyrene, ideno(1,2,3-cd) pyrene, benz(a)anthracen, dibenz(a)anthracene, and acenaphthalene.

From the Summary of Basis for Listing section in the, Listing Document, the owner found that phenolic, compounds are associated with waste generated from the use of pentachlorophenol-based wood preservatives, and that polynuclear aromatic hydrocarbons (PAHs) (i.e., chrysene through acenaphthalene in Appendix, Vll) are associated with wastes from the use of creosote-based preservatives. Examining the facility records, he determined that pentachlorophenol had been the sole preservative used; moreover, it had come from a single manufacturer. Based on a demonstrable absence of creosote use, the owner felt confident in excluding creosote and PAHs.

To help focus on which phenolics might be present in his waste, the owner turned to the Composition section of the Listing Document. In Table 4, he found typical compositions og commercial grade pentachlorophenol. The sample from his manufacturer contained 84.6 percent pentachlorophenol, 3 percent tetrachlorophenol, and ppm levels of polychlorinated dibenzo-p-dioxins and dibenzo-furans. The owner was surprised by the absence of the other phenoiics mentioned in Appendix Vll, and he was concerned by the presence of dioxins and furans. Reading the text carefully, he discovered that the majority of the phenolic compounds listed as hazardous constituents of the waste are actually decomposition products of penta- and tetrachlorophenol. He also learned-that while the Agency had ruled out the presence of tetrachlorodibenzo(p)dioxin (TCDD) in the listed waste (except where incinerated), it had not ruled out the possibility that other chlorinated dioxins might be present: “... chlorinated dioxins have been found uncommercial pentachlorophenol and could therefore be expected to be present in very small amounts in some wastes. ” Due to their extreme toxicity and because his facility had historically used the commercial pentachlorophenol, with the highest concentration of dioxins and furans, the owner thought it prudent to include a scan for dioxins in his waste analysis plan.

The owner found no further data in the Composition section to help him narrow the list of phenolics; however, Table 6 gave a breakdown of organic compounds found in different wood preserving plants (i.e., steam process vs. Boneton conditioning, but only two phenolics were listed. A note in the text highlights one of the limitations of using the Listing Document: "The absence in this table (Table 6) of certain components . . . probably indicates that an analysis for their presence was not performed rather than an actual absence of the component. It should be kept in mind that the waste analyses in the Listing Background Documents are not comprehensive and that they are based, as the Agency acknowledges, on data available at the time. In the absence of more detailed waste-specific data, the owner decided to include pentachlorophenol, tetrachlorophenol, unsubstitued phenol, and the six listed decomposition-product phenolic compounds in his waste analysis plan.

In reading the Listing Documents, the owner found useful information for other phases of the RFI. In the Migratory Potential Exposure Pathways section, he learned that pentachlorophenol is highly bioaccumulative, with an octanol/water partition coefficient of 102,000. Tetrachlorophenol, tri-chlorophenol, and dichlorophenol are likewise bioaccumulative, with octanol/water coefficients of 12,589, 4,169, and 1,380, respectively. He also learned that the biodegradability of pentachlorophenol is concentration limited.

In Appendix B of the Listing Background Documents; Fate and Transport of Hazardous Constituents, the owner found data sheets for six out of nine phenolic compounds, also some for dioxins and furans. Information on water chemistry, soil attenuation, environmental persistence, and bioaccumulation potential were listed along with chemical and physical properties such as solubility and density.

Case Discussion

Although the Listing Background Document did not provide the owner with enough specific data to fully characterize his waste, it did help him refine the list of monitoring constituents, alert him to the potential presence of dioxins, and gave him physical and chemical waste characteristic data which could be useful in predicting contaminant mobility.

CASE STUDY 2: ESTIMATION OF DEGRADATION POTENTIAL OF CONTAMINANTS IN SOIL

Point Illustrated

- Degradation, either chemical or biological, can be an important factor in determiningcthe fate of a contaminant soil, and can also be a factor in identifying constituents to monitor. The. degradation rate can also be accelerated as a means of conducting interim or definitive corrective measures.

Introduction

Degradation of contaminants in the environment can occur through several mechanisms, and can be a factor in identifying monitoring constituents. Under natural conditions, these processes are often very slow, but studies have shown that chemical and biological degradation can be accelerated in the soil by modifying soil conditions. Parameters such as soil moisture content and redox condition can be altered to encourage contaminant degradation in soils.

Site Description

The site is situated in an arid region that was used during the 1970s by aerial applicators of organochlorine and organophosphate pesticides. The applicators abandoned the site in 1980 and homes were built in the vicinity. The site can be divided into three areas based on past use. The most contaminated area, the “hot zone”, is a 125 feet by 50 feet area at the north end of the site that was used for mixing, loading, and unloading the pesticides. Soil samples from this area contained toxaphene, ethyl parathion, and methyl parathion at concentrations up to 15,000 mg/kg. The present residential area was used as a taxiway and an area to rinse tanks and clean planes. Soils from this zone were low in parathion but toxaphene concentrations ranging from 20 to 700 mg/kg were found. This area is approximately 1.7 acres in size and located immediately south and west of the hot zone. The runway itself was approximately 10 acres in size and south of the residential zone. Soil sample results from the runway area had low concentrations of all three pesticides.

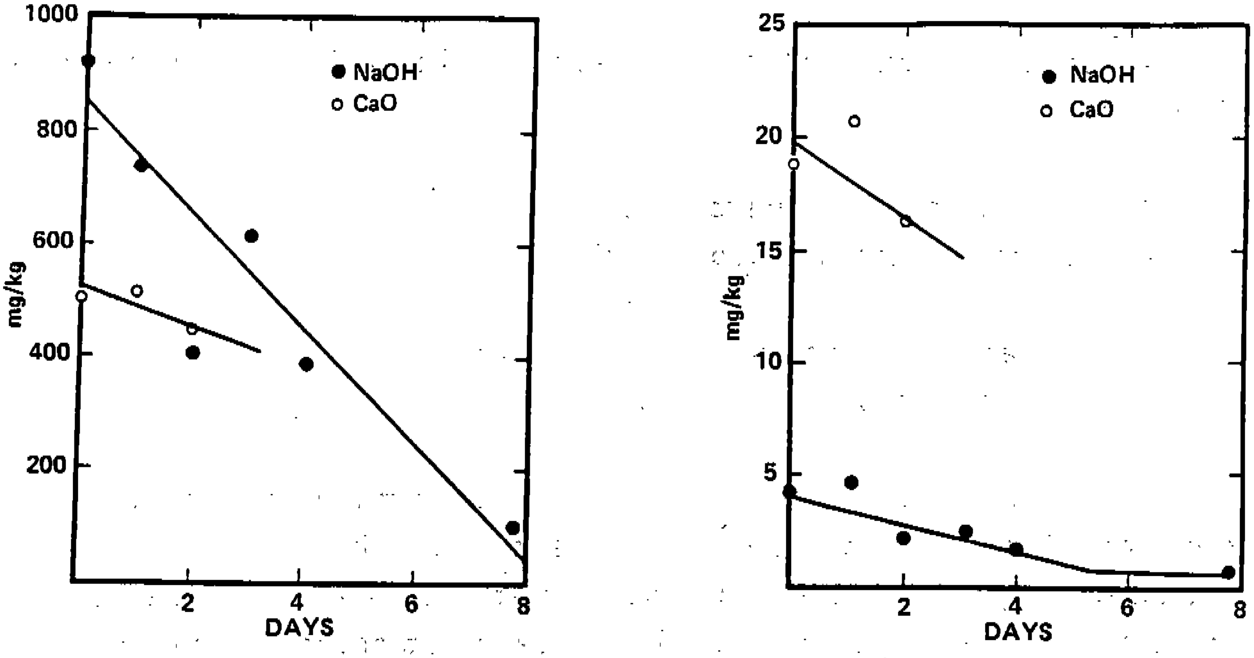
A number of factors influence degradation of organic compounds in soils. These include:

- chemical nature of the compound
- organic matter content of the soil
- soil pH
- oxidation/reduction environment of the soil
- concentrations of the compound.

At the subject site, the soils were low in moisture content, were oxidizing, and exhibited soil pH values of 6.8 to 8.0. Under such conditions, parathion can be degraded slowly by alkali catalyzed hydrolysis reactions. The rate of these reactions increases with increasing soil pH. Parathion can also be biodegraded to 0,0-Diethyl phosphoric acid. At a nearby site, it was shown that toxaphene will degrade anaerobically if reducing conditions can be achieved in the soil. It has also been observed that the loss of toxaphene by volatilization is enhanced by high soil moisture content. Other data indicated that toxaphene will degrade in the presence of strong alkali, by dechlorination reactions. This information can be used in identifying monitoring constituents and in performing interim and definitive corrective measures.

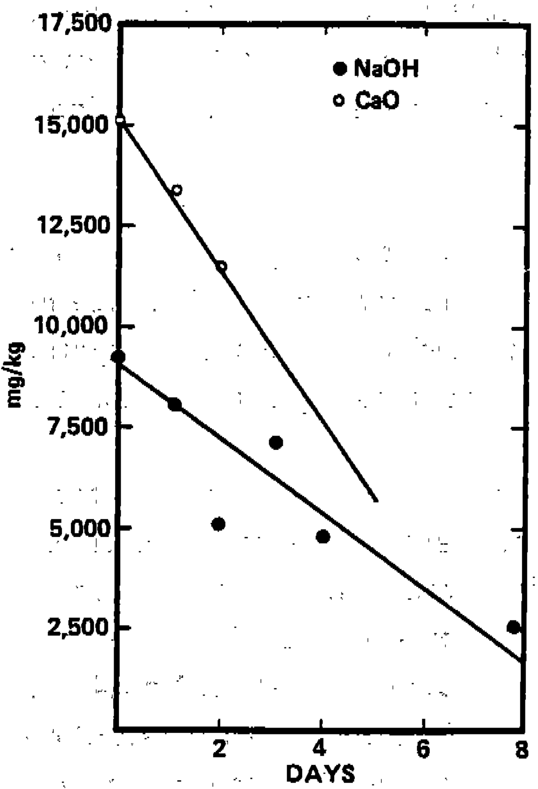
To test the feasibility of chemically degrading the contaminated soil, in situ, laboratory bench-scale tests were performed. Two treatments were evaluated, application of calcium oxide (quicklime) and sodium hydroxide (lye). Figure 15-1 shows that the pesticides were degraded by both of these strong alkalis.

Those responsible for the remedial measures felt that the hot zone was too contaminated for in situ treatment to be effective over" reasonable time periods. The upper 2 feet of soil from this area was excavated and transported to an approved landfill for disposal. However, the 1.7-acre residential area was treated in situ. To promote degradation, approximately 200 g/ft^2 of sodium hydroxide was applied using a tractor with a fertilizer-spreading attachment. A plow and disc were used to mix the sodium hydroxide into the soil to a depth of 1.5 feet. At 70 days after the application; concentrations of ethyl parathion had decreased by 76 percent, methyl parathion by 98 percent, and toxaphene by 45 percent.



Laboratory Bench Test, Ethyl Parathion Degradation

Laboratory Bench Test, Methyl Parathion Degradation



Laboratory Bench Test, Toxaphene Degradation

Figure 15-1. Results of Laboratory Bench Test for Pesticide Degradation

Source: (from King et al., 1985).

Case Discussion

Knowledge of the properties of a contaminant as well as its environment are important in assessing the potential for degradation, and this information can be used to identify monitoring constituents and conduct interim or definitive corrective measures. It may be possible to alter the site's physical or chemical characteristics to enhance degradation of contaminants. Under appropriate conditions, in situ treatment of contaminated soils can be an effective corrective measures method.

Reference

King, J., T. Tinto, and M. Ridosh. 1985. In Situ Treatment of Pesticide Contaminated Soils. Proceedings of the National Conference of Management of Uncontrolled Hazardous Waste Sites. Washington, D.C.

CASE STUDY 3: SELECTION AND EVALUATION OF A SOIL SAMPLING SCHEME

Points Illustrated

- Sampling methodologies must be properly selected to most appropriately characterize soil contamination.
- Statistical analyses can be used to evaluate the effectiveness of a chosen sampling scheme.

Introduction

Selection of a sampling scheme appropriate for a soil contamination problem is dependent on the objectives of the sampling program. A grab sampling scheme may be employed; however, grab sampling can produce a biased representation of contaminant concentrations because areas of gross contamination are most often chosen for sampling. Random sampling can provide an estimate of average contaminant concentrations across a site, but does not take into account differences due to the proximity to waste sources and soil or subsurface heterogeneities. A stratified random sampling scheme allows these factors to be considered and, thus, can be appropriate for sampling. Depending on the site, additional sampling using a grid system may be needed to further define the areas of contamination.

Facility Description

The example facility operated as a secondary lead smelter from World War II until 1984. Principal operations at the smelter involved recovery of lead from scrap batteries. Air emissions were not controlled until 1968, resulting in gross contamination of local soils by lead particulates.

Land use around the smelter is primarily residential mixed with commercial/industrial. A major housing development is located to the northeast and a 400-acre complex of single family homes is located to the northwest. Elevated blood lead levels have been documented in children living in the area.

Program Design/Data Collection

Initial soil sampling was conducted at the lead smelter and in the surrounding area to document suspected contamination. Sample locations were selected based on suspected areas of deposition of airborne lead and in areas where waste dumping was known to have occurred. High lead concentration were documented in samples collected from these sources. Because data obtained in the exploratory sampling program (grab sampling) were not adequate to delineate the areal extent of contamination, a stratified random sampling scheme was developed.

Based on wind rose data and the behavior of airborne particulate matter, a sampling area was selected encompassing a 2-mile radius from the smelter. Specific sampling sites were selected using a stratified random sampling scheme. The study area was divided into sectors each 22.5 degrees wide and aligned so that prevailing winds bisected the sectors. Each sector was further divided into approximately one-tenth mile sections. A random number generator was used to select first the direction and then the section. Random numbers generated were subject to the following restrictions: two-thirds of the sites selected had to fall in the major downwind direction; both residential and non-residential sites had to exist in the sector; sampling sections were eligible for repeat selection only if they were geographically within 1/2 mile of the smelter or if the section contained both residential and non-residential sites. Sites that were biased towards lead contamination from other than the lead smelter were not sampled (e.g., gas stations and next to roads). A total of 20 soil sampling locations were selected, 10 at residences and 10 at non-residential sites such as schools, parks, playgrounds and daycare centers.

Sample cores were collected using a 3/4-inch inner diameter stainless steel corer. Total sample depth was 3 inches. A minimum of four and maximum of six samples were collected at each sampling location within a 2 ft radius. Cores were divided into 1 inch increments and the corresponding increments were composite from each depth to make up one sample. This approach provided data on lead stratification in the top 3 inches of soil. All samples were analyzed for total lead.

The results of the stratified random sampling indicated several acres with over 2,000 ppm lead in the soil. To further define the extent of these areas, a grid sampling plan was designed. Seven hundred and fifty foot increments were used. The grid was oriented along the axis of the release. Both residential and non-residential areas were sampled. At each grid point, four 3-inch cores were collected 30 m from the grid point in each major compass direction. The cores were composited by depth as discussed above.

Program Results/Data Analysis

Analytical results from the soil sampling program indicated significant lead contamination within the study area. Maximum concentrations observed were 2,000 ppm lead with a background level of 300 ppm. Krieging of the data from the grid sampling plan was used to develop a contour map as shown in Figure 15-2. Lead concentrations were highest northwest and southwest of the smelter.

Case Discussion

Because of the large area potentially affected by lead emissions, development of a sequential sampling plan was necessary to determine the maximum soil lead concentrations surrounding the smelter and the areas having elevated concentrations. A grab sampling scheme was first used to confirm that soil contamination existed. A stratified random sampling scheme was developed to provide representative data throughout the study area. This type of sampling allowed consideration of prevailing wind directions and the need to sample both residential and non-residential areas. To further define areas of contamination, a grid sampling plan was developed. From these data, lead isoconcentrations maps were prepared delineating areas with elevated concentrations.

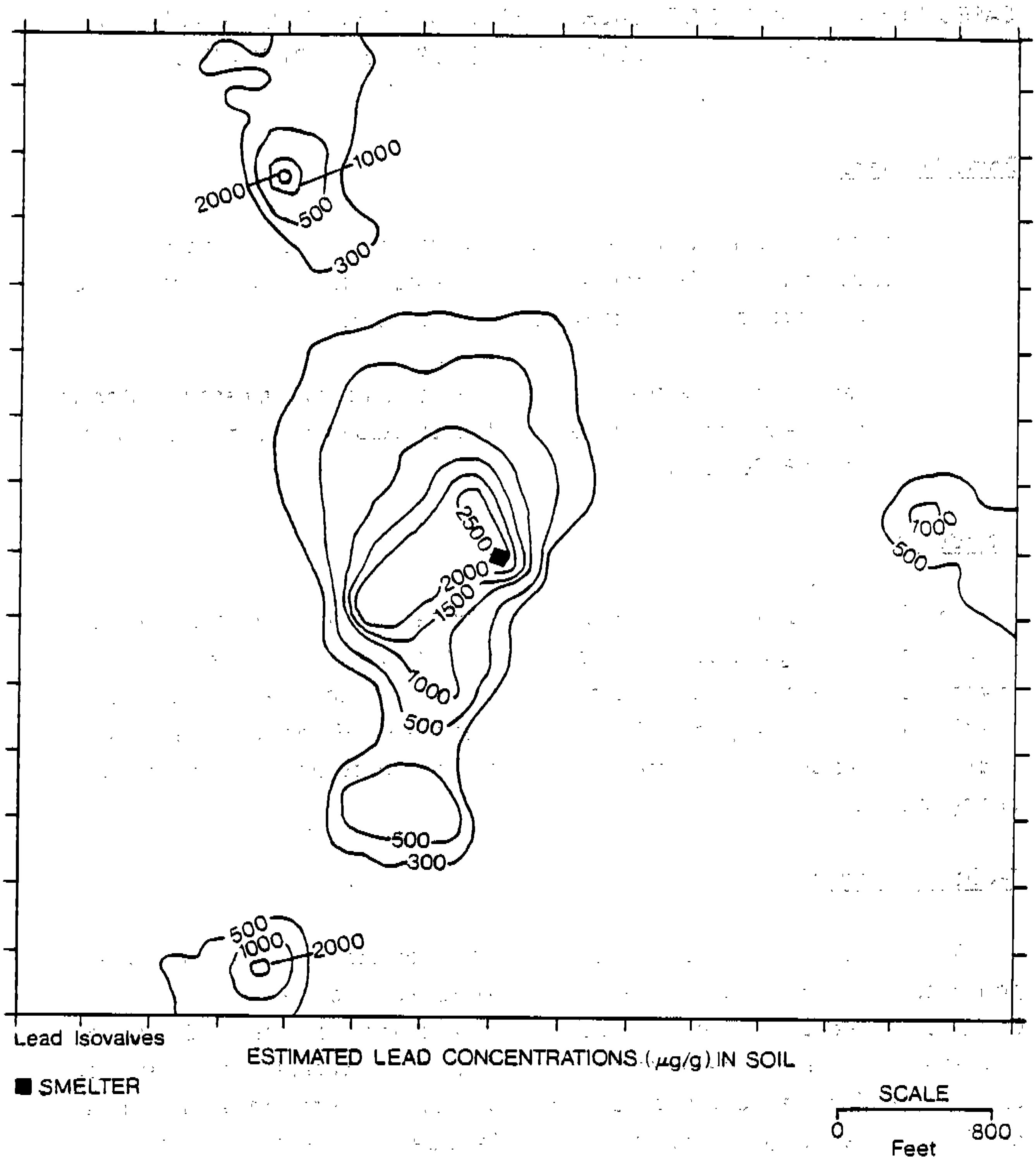


Figure 15-2. Isoconcentration Map of the Lead Concentrations in ppm Around the Smelter

CASE STUDY 4: SAMPLING OF LEACHATE FROM A DRUM DISPOSAL AREA WHEN EXCAVATION AND SAMPLING OF DRUMS IS NOT PRACTICAL

Points Illustrated

- It is not always possible to perform waste characterization prior to establishing the RFI monitoring scheme because the waste may not be directly accessible, as in the case of buried drums.
- When direct waste characterization is not practical, release monitoring should be performed for the constituents listed in Appendix B of Volume I of the RFI Guidance.

Introduction

Insufficient waste characterization data existed for a former drum disposal facility that was suspected of releasing contaminants into the subsurface environment. Leachate within the disposal pit was sampled and analyzed for all constituents listed in Appendix B of Volume I of the RFI Guidance. The resulting information was used to determine the major waste constituents to be monitored during the RFI.

Facility Description

The unit of concern was a pit containing an estimated 15,000 drums. Due to poor recordkeeping by the facility operator, adequate information regarding the contents of the drums was not available. It was also not known if the drums were leaking and releasing contaminants to the environent. Because insufficient data existed regarding the drum contents, it was not known what constituents should be monitored in nearby ground and surface waters. Due to the risk to workers and the potential for causing a multi-media environmental release, excavation and sampling of the drums to determine their contents-was not considered practical. Instead, it was decided that leachate around the perimeter of the drum disposal pit would be sampled to identify constituents which may be of concern.

Program Design/Data Collection

To determine the physical extent of the buried drums, a geophysical survey was conducted using a magnetometer. Borings were located at positions having lower magnetometer readings than surrounding areas in order to minimize the potential for drilling into drums.

Soil borings were drilled around the perimeter of the drum disposal pit, as defined by the magnetometer survey. Drilling was accomplished using a hydraulic rotary drill rig with a continuous cavity pump. Water was used as the drilling fluid. To prevent surface runoff from entering the borehole and to control gaseous releases from the borehole, primary and secondary surface collars were installed. These consisted of 5-foot sectitons of 4-inch steel pipe set in concrete. A device to control liquid and gaseous releases from the borehole was threaded onto the collars to form a closed system (Figure 15-3)

Drilling was performed using a wireline operated tri-cone roller bit with a diamond tipped casing advancer (Figure 15-4). Water was pumped down inside the casing and out the drill bit, returning up the borehole or entering the formation. The use of water to aid in drilling also helped reduce the escape of gases from the borehole. Air monitoring showed no releases. Split-spoon samples were collected at 5-foot intervals during the drilling and a leachate monitoring well was installed at each boring location.

The soil and leachate samples were analyzed for the compounds contained in Appendix B of Volume I of the RFI Guidance.

Program Results/Data Analysis

The leachate samples were found to contain high levels of volatile organic compounds including 2-butanone, 4-methyl-2-pentanone, and toluene. Concentrations were higher on the downgradient side of the pit.

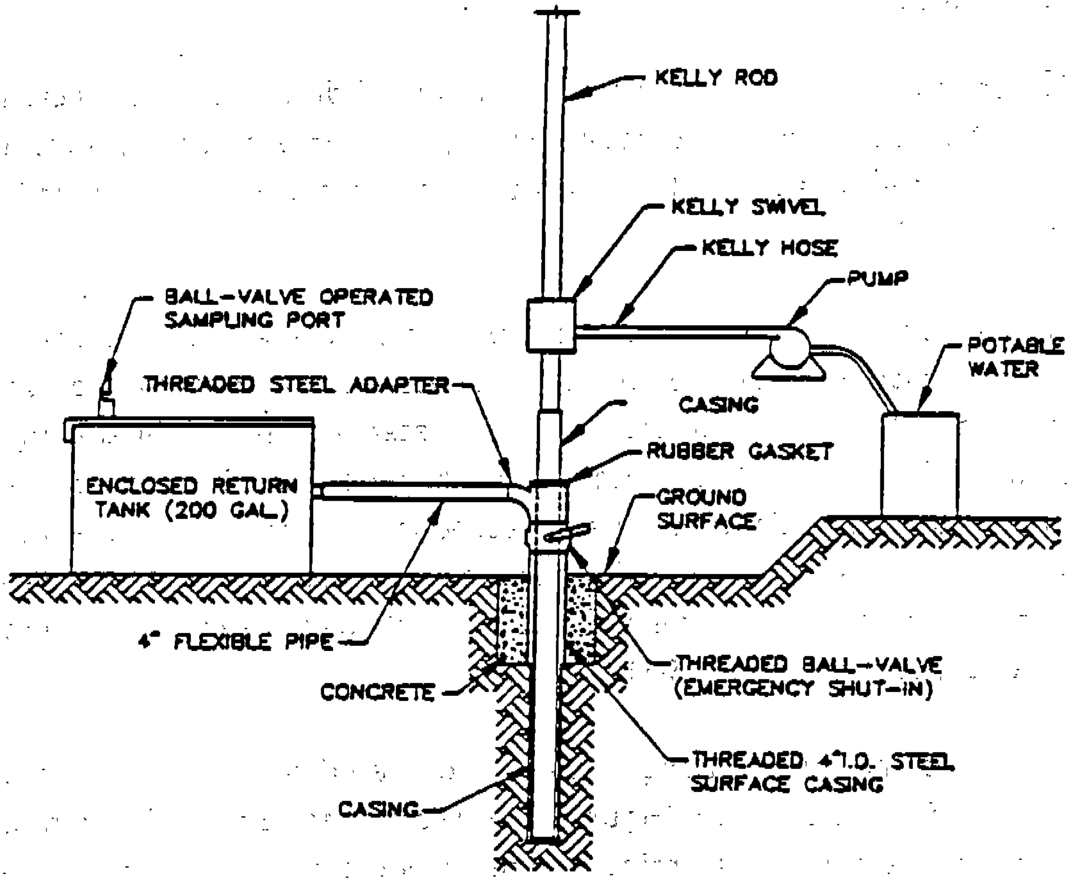


Figure 15-3. Schematic Diagram of Gas Control System Utilized at Pit

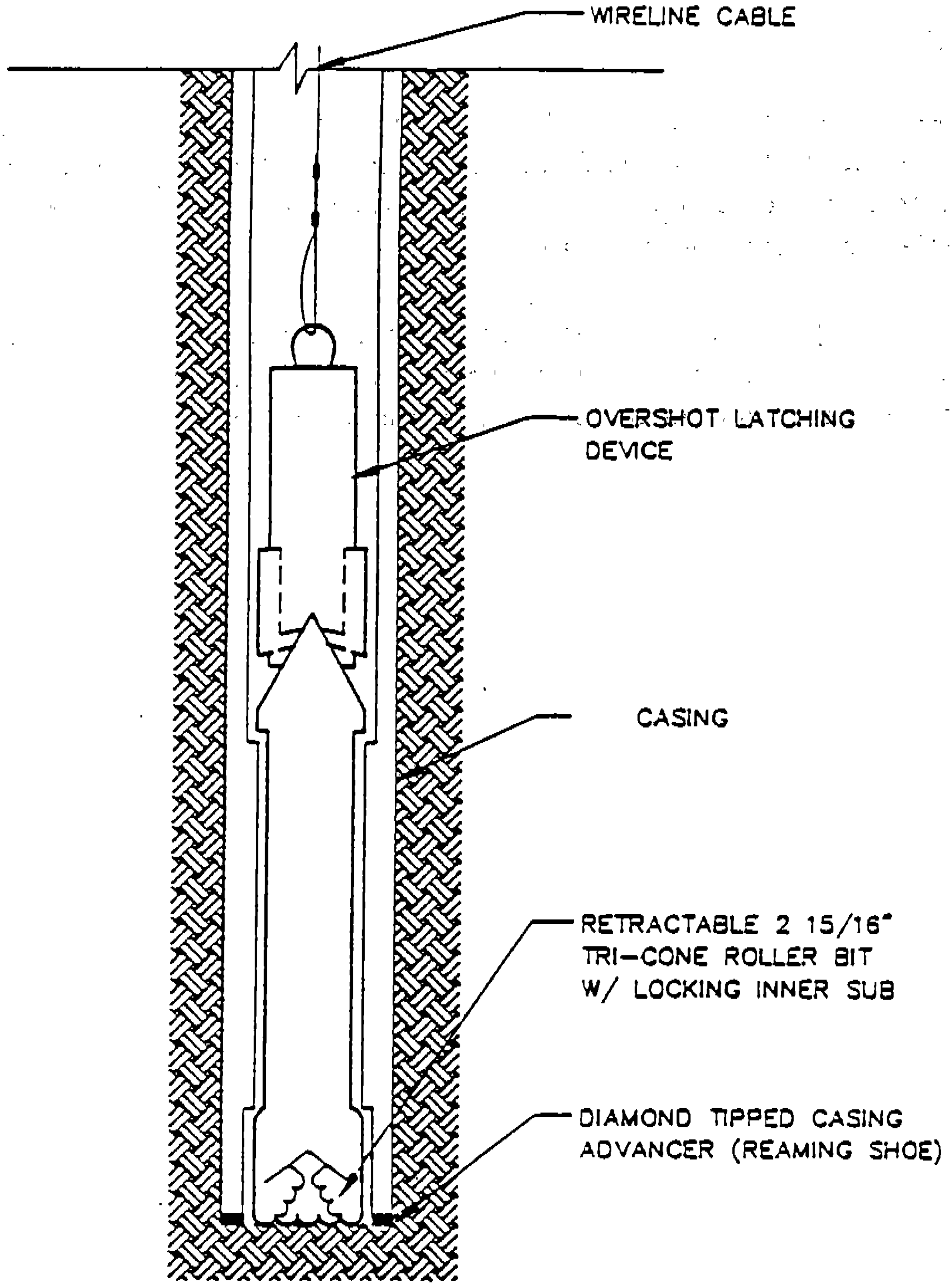


Figure 15-4. **Schematic Drawing of Wireline Drill Bit and Reaming Shoe**

Case Discussion

Leachate sampling can be useful in determining whether buried drums are leaking and to identify materials that are being released. This methodology can be safer than excavation and sampling of individual drums. It can also identify the more soil-mobile constituents of the leachate.

The data gathered in this case study were used in designing a monitoring program, and the contaminants found were used as indicator compounds to link downgradient ground-water contamination to this waste disposal unit.

CASE STUDY 5: USE OF QUALITY ASSURANCE/QUALITY CONTROL (QA/QC) AND DATA VALIDATION PROCEDURES:

Points Illustrated

- A comprehepsive field and laboratory QA/QC program is necessary for assessing the quality of data collected during an RFI.

- Timely validation of laboratory data can uncover problems correctable by reanalysis or by resampling, thus preventing data gaps.

Introduction

A company in the mining and smelting industry sampled domestic wells and surface soils in the vicinity of a tailings pile to monitor possible leaching of metals into the aquifer and possible soil contamination due to wind-blown dust. Because the data would be used to assess corrective measures alternatives and to conduct a health and environmental assessment, the company chose to conduct both its sampling and analysis efforts under a formal QA/QC Project Plan and to subject all laboratory data to rigorous data validation procedures.

Facility Description

At this facility, a tailings pond had received smelter waste for many years. Local water supply wells were potentially at risk due to percolation of water through the pile and possible leaching of heavy metals. Local surface soils in nearby residential areas (e. g., yards, public playgrounds) were also subject to contamination from wind-blown dust originating from the pile during dry windy weather.

Sampling Program

Before sampling began, a set of documents were drafted following U.S. EPA guidelines (U.S. EPA 1978, 1980a, 1980b, 1981, 1982, 1985a, 1985b) that specified in detail sampling sites and parameters to be measured, field and laboratory procedures, analytical laboratory protocols, and all field and laboratory QC checks including frequencies, and corrective actions. The important elements of each document are described below.

Standard Operating Procedures (SOPs)--

This document contained step-by-step procedures for the following items:

- Calibration, operation, and maintenance of all instruments used in the field and laboratory.
- Equipment decontamination.
- Ground water and soil sampling, including compositing.
- Use of field notebooks and document control.
- Sample packaging, shipping and chain-of-custody.

Field Operations Plan (FOP)--

This document included the following:

- Rationale for choice of sampling locations, sampling frequency, and analytes to be measured
- List of sampling equipment and S0Ps to be used for each sampling event.
- List of field QC checks to be used and their frequency for each sampling event.
- Health and safety issues and protective measures for field personnel.
- Sampling schedule.

Laboratory Analytical Protocol (LAP)--

This document included the following:

- Sample size, preservation, and analysis protocol for each analyte.
- List of laboratory QC checks, QC statistics to be calculated and their control limits, and corrective actions for QC checks outside control limits.
- Detailed list of deliverable documents and their formats.
- Procedures for sample custody, independent audits, and general laboratory practices.

QA/QC Project Plan (QAPP)--

This document gathered into one place the overall data quality objectives for the sampling and detailed QC procedures needed to attain those objectives. Included were:

- Quality assurance objectives in terms of precision, accuracy, completeness, comparability, and representativeness.
- Procedures for the screening of existing data.
- Data management, reduction, validation, and reporting.
- Overview of both field and laboratory QC checks and their frequencies, control limits, and corrective actions.
- Data assessment procedures.

Results

Five surface soil samples were taken in high traffic areas of two playgrounds and three residential yards. Five tap water samples were collected at two public drinking fountains at the playgrounds and at the three private residences. The analysis results, as received from the laboratory, are shown in Table 15-2. The data indicated that a soil hot spot existed for cadmium, that elevated lead occurred at all five soil stations, and that all of the domestic wells showed elevated levels of mercury.

The laboratory data package was subjected to a thorough data validation, as detailed in the QA Project Plan. The following information and QC results were checked by examination of original documents or photocopies of the documents.

Sampling, Sample Shipping, Chain-of-Custody--

Copies of field and field laboratory notebook pages were examined to insure that all SOPS were correctly followed, that there were no notations of anomalous circumstances (such as sample spillage) that may have affected analysis results, and that the samples were correctly preserved, packaged, and shipped. Copies of all chain-of-custody forms, bills-of-lading, and sample analysis request forms were examined to insure that chain-of-custody was not broken and that samples arrived intact at the laboratory.

Laboratory Raw Data--

The QAPP had specified that one of the deliverables from the laboratory was copies of all instrument readouts and laboratory notebook pages. The digestion raw data were checked to insure that no holding time violations had occurred. This is important for mercury because the holding time is only 28 days for aqueous samples.

All raw calibration data were recalculated and tested against instrument-calculated sample results. Recoveries of calibration verification standards and continuing calibration standards were checked to-insure that all instruments were correctly calibrated, were not drifting out of calibration, and were correctly calculating raw analysis results.

TABLE 15-2

RESULTS OF ORIGINAL SURFACE SOIL AND TAP WATER ANALYSES :

Sample[a]	Cd	Cu	Pb	Hg	Zn
SOIL-1	14	5200	800	NA[b]	1200
SOIL-2	7	2400	400	NA	190
SOIL-3	<20[c]	720	4530	NA	70
SOIL-4	19	680	350	NA	350
SOIL-5	1200	1080	460	NA	420
WATER-1	<50	NA	<30	1.5	NA
WATER-2	<50	NA	<30	1.3	NA
WATER-3	<50	NA	<30	1.0	NA
WATER-4	<50	NA	<30	1.4	NA
WATER-5	<50	NA	<30	1.2	NA

[a] Soils in units of mg/kg, water in µg/L.
[b] Not analyzed.
[c] Undetected at detection limit shown.

Final analysis results were recalculated from raw data using dilution and digestion factors, as summarized in the lab notebooks, and compared to the data summary sheets. No transcription errors were found. However, the cadmium result for SOIL-5 contained a calculation error, and the correct final result was 12 mg/kg instead of the 1200 mg/kg reported.

Laboratory QC Checks--

The QAPP had specified that the laboratory had to analyze pre-digestion duplicates and spikes, U.S. EPA laboratory control samples, and reagent blanks. The laboratory QC results are summarized in Table 15-3 and indicated accuracy and precision well within U.S. EPA guidelines. The mercury preparation blank also indicated that the tap water results were not due to laboratory digestion reagents or procedures.

Field QC Checks--

As specified in the QAPP and FOP, the follgwing field QC samples were included with each of the soils and tap water samplings: bottle blank, field blank, standard reference material (SRM), triplicate, and an interlaboratory split to a "reference" lab. The results are summarized in Table 15-4.

Although no U.S. EPA control limits or corrective actions exist for field-generated QC checks, the results of their analysis can aid in the overall assessment of data quality. The triplicate, SRM, and interlaboratory split analyses indicated good overall analysis and sampling precision and accuracy. The field blanks indicated the possibility of mercury contamination from one of the four possible sources: the pre-cleaned bottles, the preservation reagent, the distilled water used in the field, or an external contamination source such as dust. The high positive mercury result in the water bottle blank eliminated all of these sources except the first because the bottle blanks remained sealed throughout the sampling effort.

The laboratory was immediately called and, upon personal inspection, the laboratory manager discussed the remnants of a broken thermometer bulb in the plastic tub used to acid-soak the bottles. An unused bottle from the same lot and

TABLE 15-3

LABORATORY QC RESULTS

Analyte	Duplicate RPD[a] (%)		Spike Recovery[b] (%)		LCS[c] (%)	Soil Preparation Blank[d]	Water Preparation Blank[e]
	SOIL-2	WATER-4	SOIL-2	WATER-4			
Cd	18	NC[f]	100	98	101	<50[g]	<50
Cu	5	NA[h]	93	NA	97	<100	NA
Pb	14	NC	110	92	106	<200	<30
Hg	NA	NC	NA	103	NA	NA	<0.20
Zn	7	NA	85	NA	99	<150	NA

[a] RPD = relative percent difference = (difference/mean) xl 00. Control limits = ± 35% for solids and ± 20% for aqueous samples.

[b] Spike Recovery = (spike + samle result) - (sample result) x100. Control limit = 75-125%
(spike added)

[c] LCS = laboratory control sample. Control limit- 90-1, 10%. ‘”

[d] mg/kg.

[e] µg/l.

[f] NC = not calculated-due-to one or both concentrations below detection limit.

[g] Undetected at detection limit shown.

[h] NA = not analyzed.

TABLE 15-4

FIELD QC RESULTS

Analyte	Triplicate Cv[a] (%)		SRM Recovery[b] (%)		Interlab. RPD[e] (%)		Field Blanks[f]		Bottle Blanks[g]	
	SOIL-1	WATER-1	BCSS-1[c]	U.S. EPA[d]	SOIL-1	WATER-1	SOIL-1	WATER- 1	SOIL-1	WATER-1
Cd	22	NC[h]	83	105	-12	NC	<50[i]	<50	<0.5	<0.5
Cu	3	NA[j]	94	NA	o	NA	<I00	NA	<1	NA
Pb	7	NC	97	101	14	NC	<200	<200	<0.5	<0.5
Hg	NA	18	NA	103	NA	19	NA	1.1	NA	0.8
Zn	1	NA	110	NA	24	NA	<150	NA	<1	NA

[a] CV = coefficient of variation = (mean/standard deviation) Xl 00.
[b] Recovery = (certified value/result) X100.
[c] National Research Council of Canada marine sediment.
[d] U.S. EPA Trace Metals I, Concentration #1.
[e] RPD = relative percent difference = [(analytical lab result - ref. lab. result)/mean] X100.
[f] Distilled water. Units = µg/L.
[9] Empty containers rinsed with digestion, reagents at lab. Units = total µg.
[h] NC = not calculated due to at least one sample result below detection limits.
[i] Undetected at detection limit shown.
[j] NA = not analyzed.

still at the laboratory as well as two bottles washed in previous lots were analyzed. The bottles previously washed contained no detectable mercury, and the bottle from the same lot as used in the sampling effort contained 0.75 µg. The water mercury data were rejected, and a second sampling effort using new bottles was conducted. All of the new samples contained no detectable mercury.

Discussion

This case study demonstrates the need for the establishment of a formal QA/QC program that not only specifies field QC protocols but also incorporates thorough data package validation. In this instance, a potential hot spot was found to be due to a calculation error, and potential mercury contamination of domestic well water was found to be a result of using contaminated sample containers. In the latter case, timely QA/QC review allowed for a speedy resampling effort which could be done at this site. In situations where resampling is not possible, adequate QA is crucial.

References

U.S. EPA. 1978 (revised 1983). NEIC Policies and Procedures. EPA-330/9-78-001-R. U.S. EPA, National Enforcement Investigations Center, Denver, CO.

1978 (revised 1983). NEIC Policies and Procedures. EPA-330/9-78-001-R. U.S. EPA, National Enforcement Investigations Center, Denver, CO.

U.S. EPA. 1980a. Interim guidelines and specifications for preparing quality assurance project plans. QAMS-005/80. U.S. EPA, Office of Monitoring Systems an- Quality Assurance, Washington, DC. 18 pp.

U.S. EPA. 1980b. Samplers and sampling procedures for hazardous waste streams. EPA-600/2-80-018. U.S. EPA, Municipal Environmental Research Laboratory, Cincinnati, OH.

U.S. EPA. 1981. Manual of groundwater quality sampling procedures. EPA-600/2-81-160. Robert S. Kerr Environmental Research Laboratory, Ada, OK. 105 PP.

U.S. EPA. 1986. Test methods for evaluating solid waste. SW-846. 3rd ed. U.S. EPA, Office of Solid Waste and Emergency Response, Washington, DC.

U.S. EPA. 1985a. Contract laboratory program statement of work. Inorganic analysis, multi-media, multi-concentration. S.OW. NO. 785. July, 1985. U.S. EPA, Environ-mental Monitoring Support Laboratory, Las Vegas, NV.

U.S. EPA. 1985b. Laboratory data validation. Functional guidelines for evaluating inorganic analysis. October, 1985. U.S. EPA, Office of Emergency and Remedial Response, Washington, D.C.

CASE STUDY 6: PRESENTATION OF DATA COLLECTED DURING FACILITY INVESTIGATIONS

Point Illustrated

- Techniques for presentation of data for facility investigations involving multimedia contamination.

Introduction

Data acquisition and interpretation are integral parts of facility investigations. Depending on the size, complexity, and hazards posed at a particular site, significant quantities of meteorologic, hydrologic, and chemical data can be collected. To make the best use of these data, they should be presented in an easily understood and meaningful fashion. This case study focuses on widely used and easily implemented graphical techniques for data presentation.

Site Description

The site is a former copper smelter that ceased operation in the early 1980s. During the operation of the smelter, large quantities of mine tailings were slurried to tailings ponds that remain today (Figure 15-5). The tailings contain high solid phase concentrations of inorganic contaminants such as copper, zinc, lead, cadmium, and arsenic. In the Smelter Hill area, flue dust and stack emission deposition have contaminated surficial soils. Numerous other units were operated at the complex including an experimental plant designed to leach copper using ammonia. The copper leach plant is shown in Figure 15-6. Three disposal ponds (I, II, and Ill), received wastes slurried from the plant.

As a result of smelting and waste disposal practices, multimedia contamination of ground water, surface water, and soils has occurred. Also, episodes of air contamination have been documented due to entrainment of tailings during windy periods.

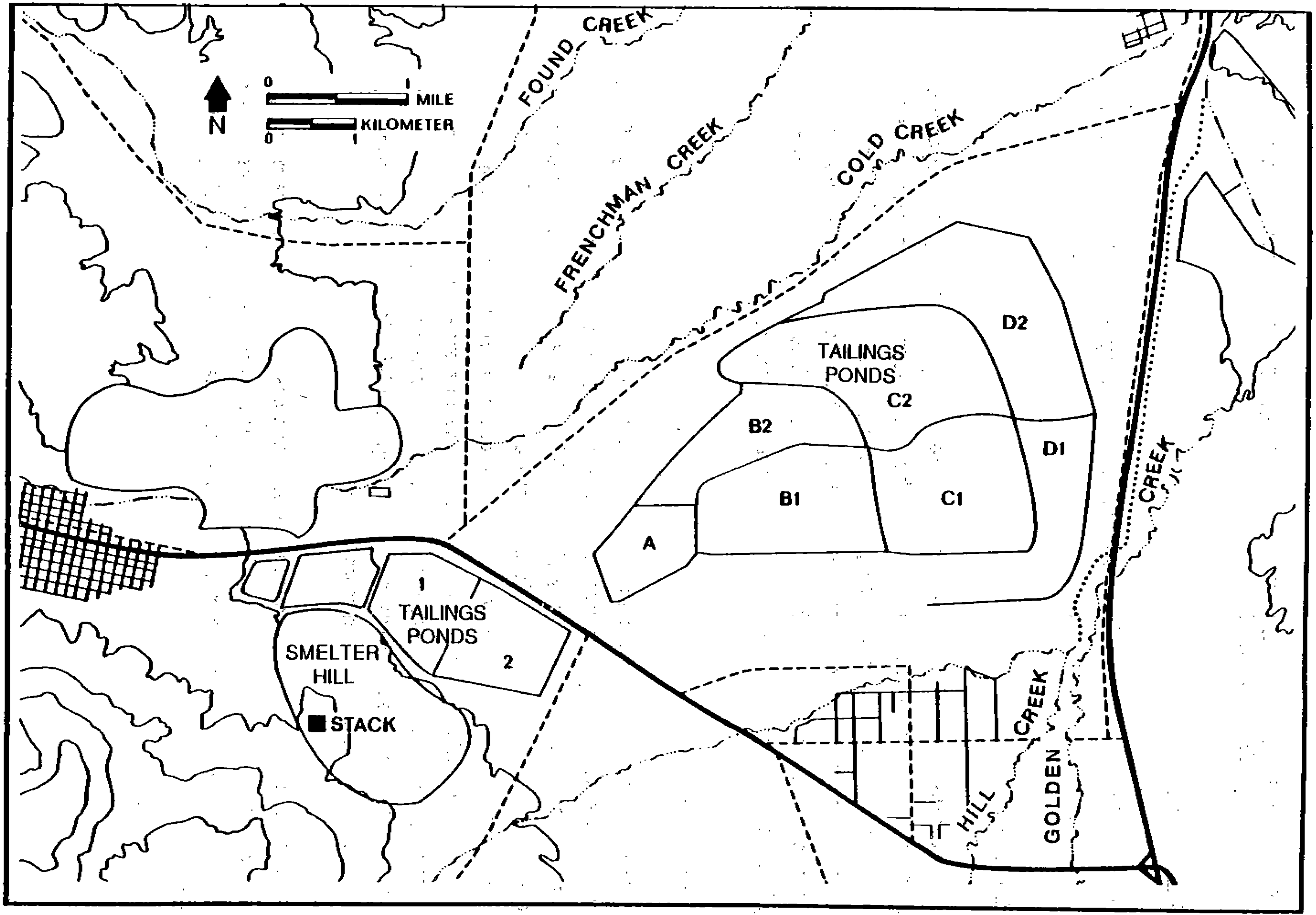


Figure 15-5. Map of the Smelter Site and Associated Tailings Ponds

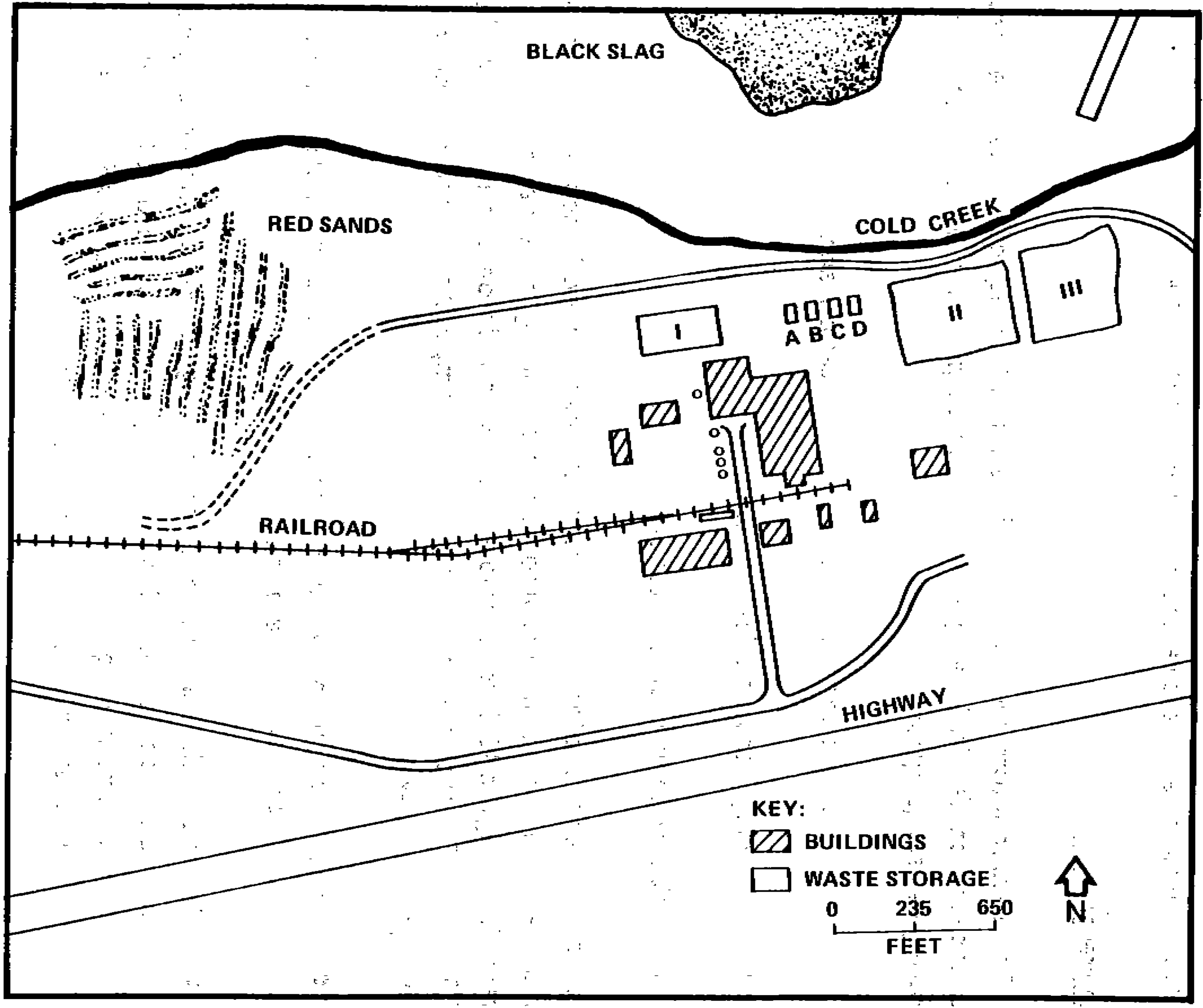


Figure 15-6. Locations of Copper Leach Plant and Waste Storage Ponds

Field Sampling and Data Collection

Data collection activities at this site were comprehensive. Over 100,000 pieces of data were collected in the categories shown in Table 15-5.

Data Presentation

This section illustrates a number of graphical techniques that can be used to present data from facility investigations. Graphical presentations are useful for the following general purposes:

- Site feature identification, source identification, and mapping;
- Hydrologic characterization; and
- Water quality characterization.

For large sites, aerial photography is often very useful for defining the locations and boundaries of waste deposits, and for establishing time variability of site characteristics. Figure 15-6, for example, was developed from aerial photographs at a 1:7800 scale. Types of information obtained by comparing this photograph to one taken 10 years earlier include:

- Pond III was originally constructed earlier than Ponds I and II, and was not lined. Ponds I and II were lined.
- The red sands (a slag deposit) shown in Figure 15-6 are present only north of the railroad tracks. Earlier photographs showed that the red sands extended to the highway, but were leveled and covered with alluvium during construction of the copper leach plant.

This type of photographic information is valuable for locating waste deposits, estimating quantities of wastes, and determining waste proximity to sensitive areas.

TABLE 15-5

SUMMARY OF DATA COLLECTED

Category	Parameters
Ground Water	Water level elevations, potentiometric heads Concentration of Al, Sb, As, Ba, Be, Bo, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Hg, Mo, Ni, K, Se, Ag, Na, Sn, V, Zn, P, Cl, F, SO_4, pH, 0_2, Ec, Eh, Alkalinity, TDS
Surface Water and Sediment	Flow rates, bed particle size distributions, suspended solids concentrations, dissolved concentrations of same inorganic parameters as ground water
Alluvium[a]	Moisture content, soil, pH, Ec, Sb, As, Cd, Cu, Fe, Pb, Mn, Se, Ag, Zn, particle-size distribution
Soil[a]	Cd, Cu, Fe, Pb, Mn, Ni, Zn, Sb, As, Cd, Cr, Hg, Se, Ag, Zn, particle-size distribution, Eh, S, TOC
Tailings[a]	Sb, Ar, Be, Cd, Cu, Fe, Pb, Mn, Ag, Se, Zn, particle size, moisture, pH, Ec, sulfur, carbonate
Slag and Flue Dust[a]	Sb, As, Cd, Cu, Fe, Pb, Mn, Se, Ag, Zn, SO_4, Ec, pH, alkalinity
Miscellaneous	Meteorology, aerial photographs and other photographic documentation, well log data, surface topography, volumetric surveys of waste piles

[a] Element data are solid phase.

For sites with complex hydrologic interaction, it is often helpful to graphically represent the flow system. Figure 15-7 illustrates the surface water system at the site. The diagram is useful because it shows the-hydrologic interconnections of the drainage system.

For the ground-water system, flow direction and velocities provide information needed for contaminant transport predictions. This information is generated by plotting water levels on a site map, and then drawing contours through points of equal elevation. An example is shown in Figure 15-8. Because the contours form a relatively simple pattern in this case, they were drawn by hand. However, computer-based contour packages exist that could be used to plot more complicated contour patterns.

Inferred flow directions are also shown in Figure 15-8. From a knowledge of the hydraulic gradient, hydraulic conductivity and effective porosity, the average linear velocity can be calculated as shown in the upper left hand corner of the figure. A velocity of 79 m/yr is calculated, for example, which means that approximately 126 years would be required lot conservative solutes to move across the site (approximately 10,000 meters).

Water quality data can be presented as shown in Figure 15-9. This figure shows the spatial distribution of calcium, sulfate, and TDS at key surface water stations. This data preservation method provides a broad areal view of these parameters

Time series plots are useful for showing temporal variations in water quality. For example, time trends of $S0_4$ at three ground-water monitoring locations are shown in Figure 15-10. Well 19 is slightly downgradient from the source, and the high $S0_4$ levels reflect that the well is receiving solutes generated within the source. Wells 26 and 24 are further upgradient, and reflect better water quality conditions. The plot indicates that variability between stations generally is more significant than time variability at a given location. One exception is at well 24 where a temporary increase in sulfate levels was noted in 1975-76.

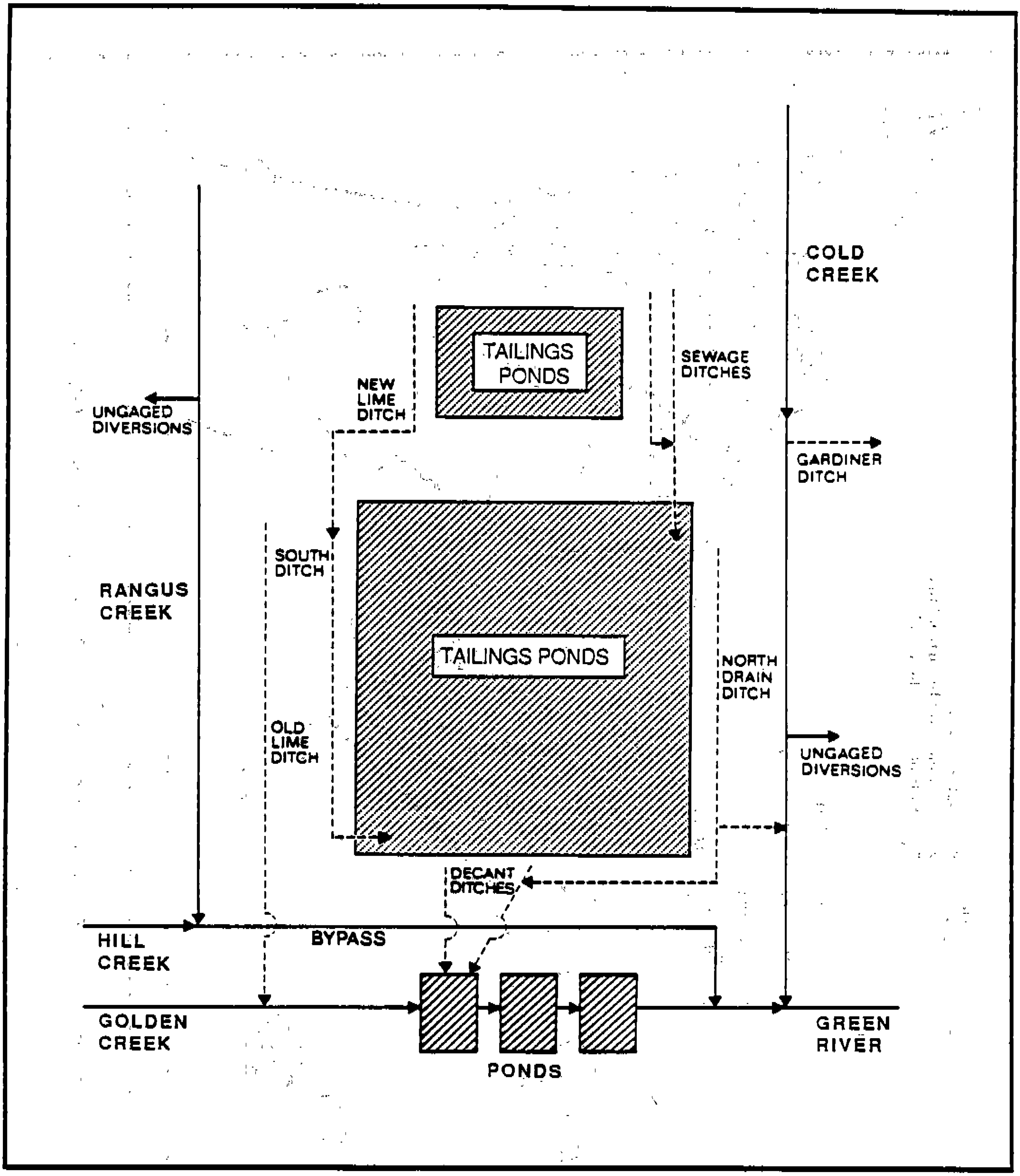
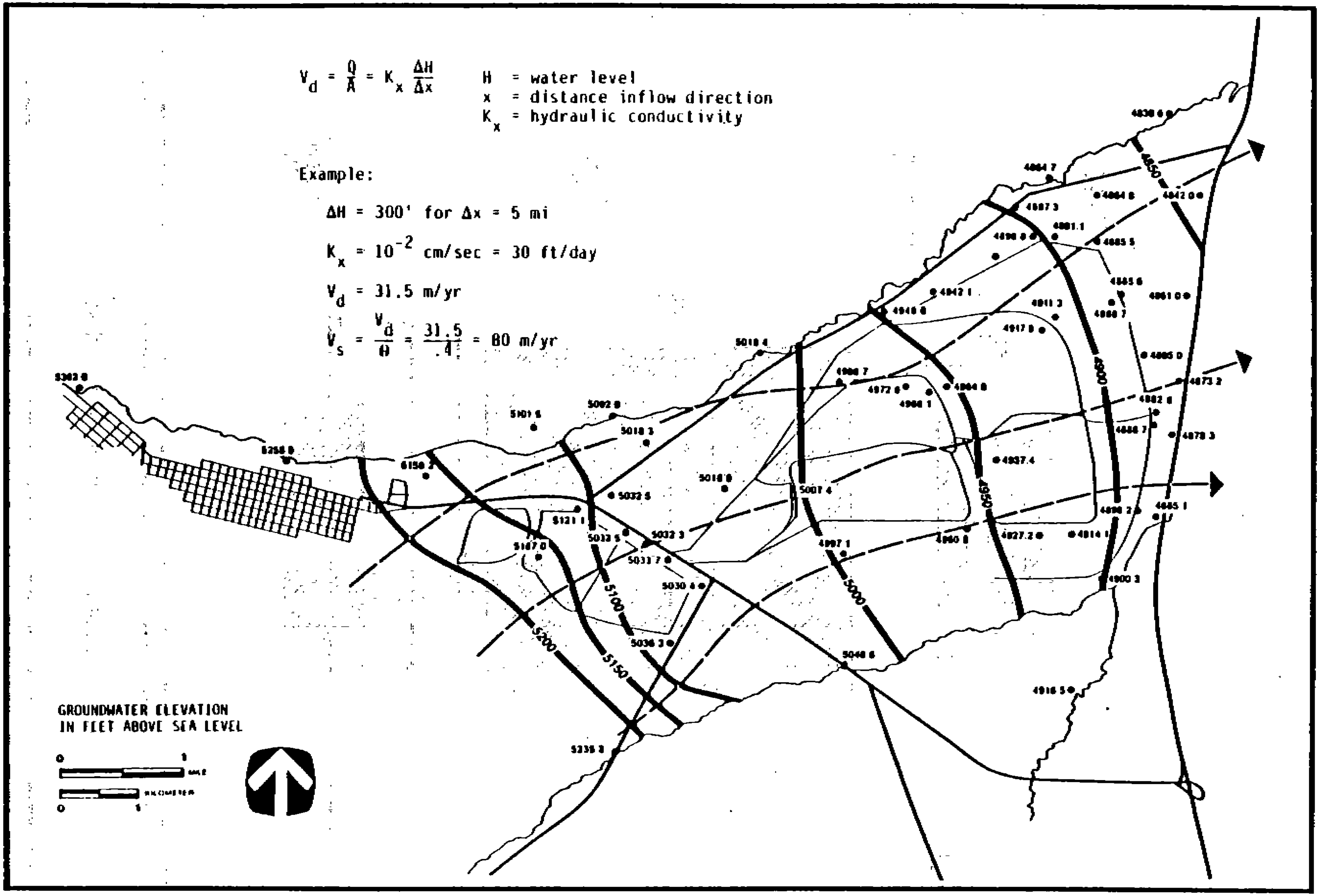


Figure 15-7. Schematic of Surface Water System



$$V_d = \frac{Q}{A} = K_x \frac{\Delta H}{\Delta x}$$

H = water level
x = distance inflow direction
K_x = hydraulic conductivity

Example:

$\Delta H = 300'$ for $\Delta x = 5$ mi

$K_x = 10^{-2}$ cm/sec = 30 ft/day

$V_d = 31.5$ m/yr

$$V_s = \frac{V_d}{\Theta} = \frac{31.5}{.4} = 80 \text{ m/yr}$$

Figure 15-8. Ground-Water Flowlines Based on Measured Water Levels

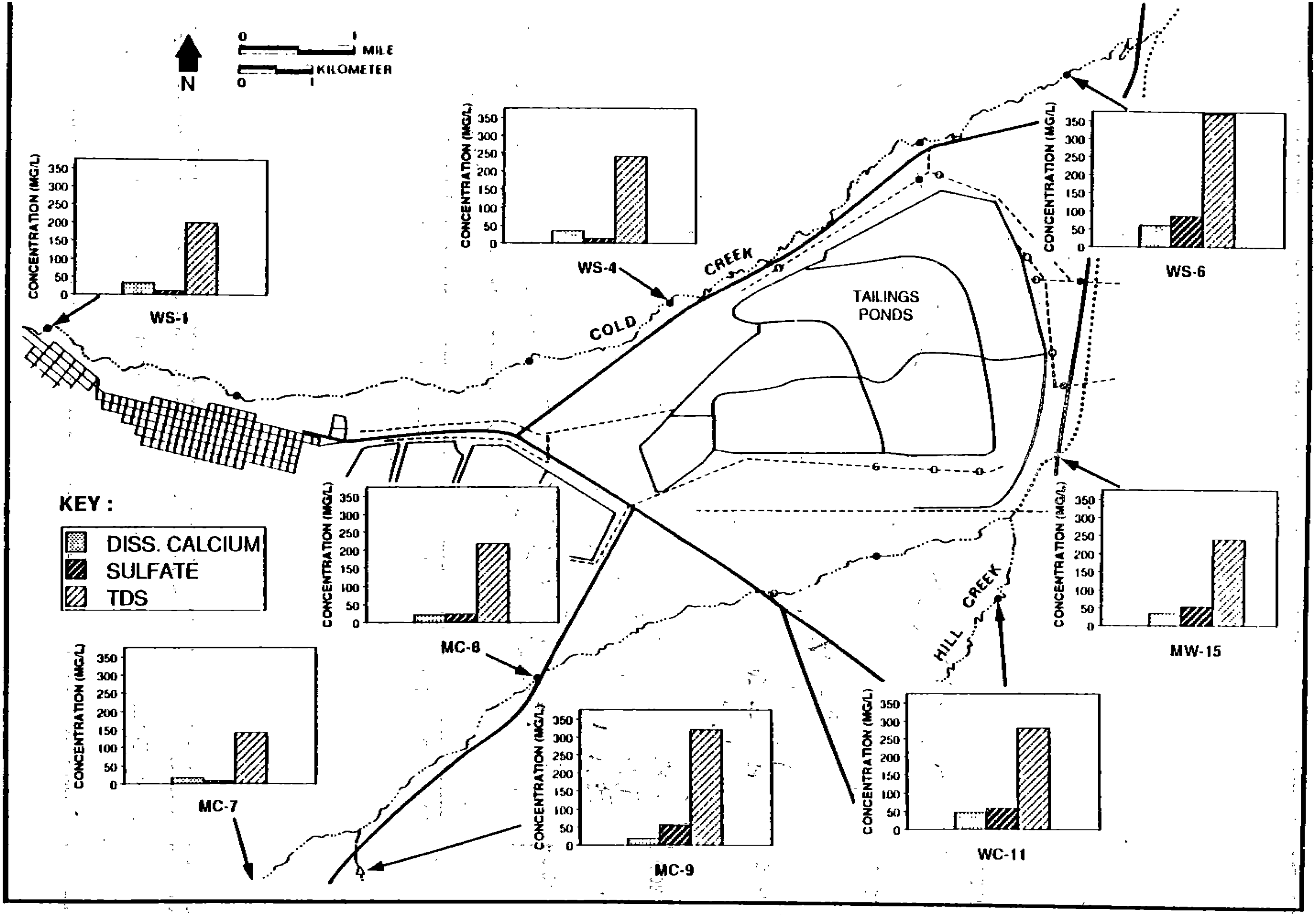


Figure 15-9. Selected Surface Water Quality Parameters at Key Stations

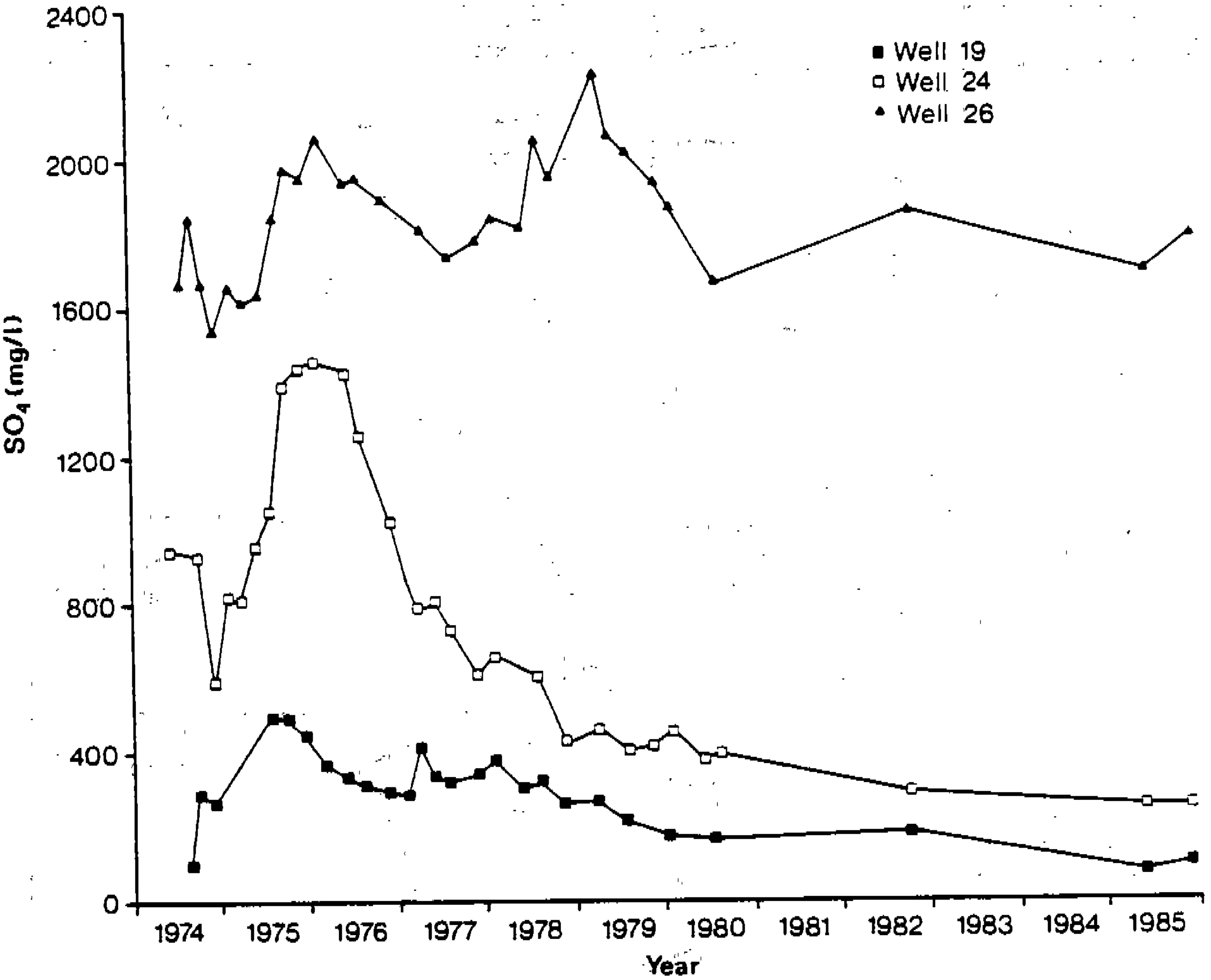


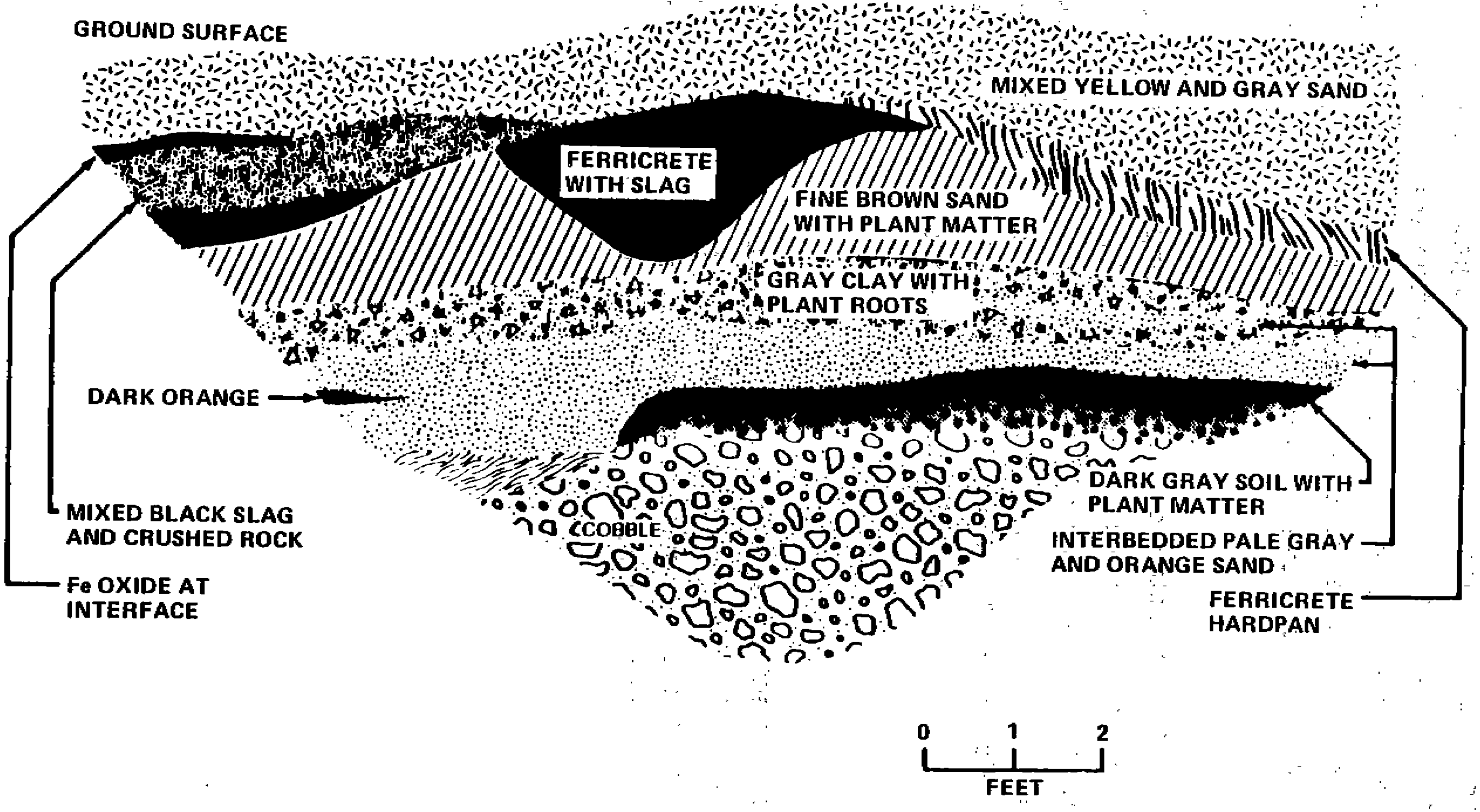
Figure 15-10. Changes in Sulfate Over Time at Selected Wells Located Within the Site

To identify leachate and soil interactions beneath a waste site, trenches may be dug. The trench walls are then logged and photographed. Detailed sampling may be done at closely spaced intervals to confirm that reactions such as precipitation have occurred. Figure 15-11 shows a cross-section of a tailings deposit that was developed based on a trench excavated through the tailings into the underlying alluvium. The plot shows the demarcation between wastes and natural alluvium.

Figure 15-12 shows the detail of the chemical composition of one borehole through the tailings and into the underlying alluvium. The chemical composition is shown to vary significantly with depth. These types of plots contain a wealth of chemical information that can help to explain the geochemical processes operative in the tailings. Figure 15-12 also shows the marked contrast between the composition of the tailings (in the top 16 feet)and the underlying galluvium.

Summary

The graphical presentations illustrated in this case study are a few of the many techniques available. With the proliferation of graphical packages available on microcomputers, scientists and engineers have a wide range of tools available for data presentation. Some of these tools are summarized inTable 15-6.



Notes: A BLUE-GREEN PRECIPITATE FORMED ON THE EXPOSED SURFACE OF TOP 6 INCHES OF ALLUVIUM. THIS PRECIPITATE WAS NOT THERE WHEN TRENCH FIRST DUG.

Figure 15-11. Field Sketch of Tailings Trench T-3

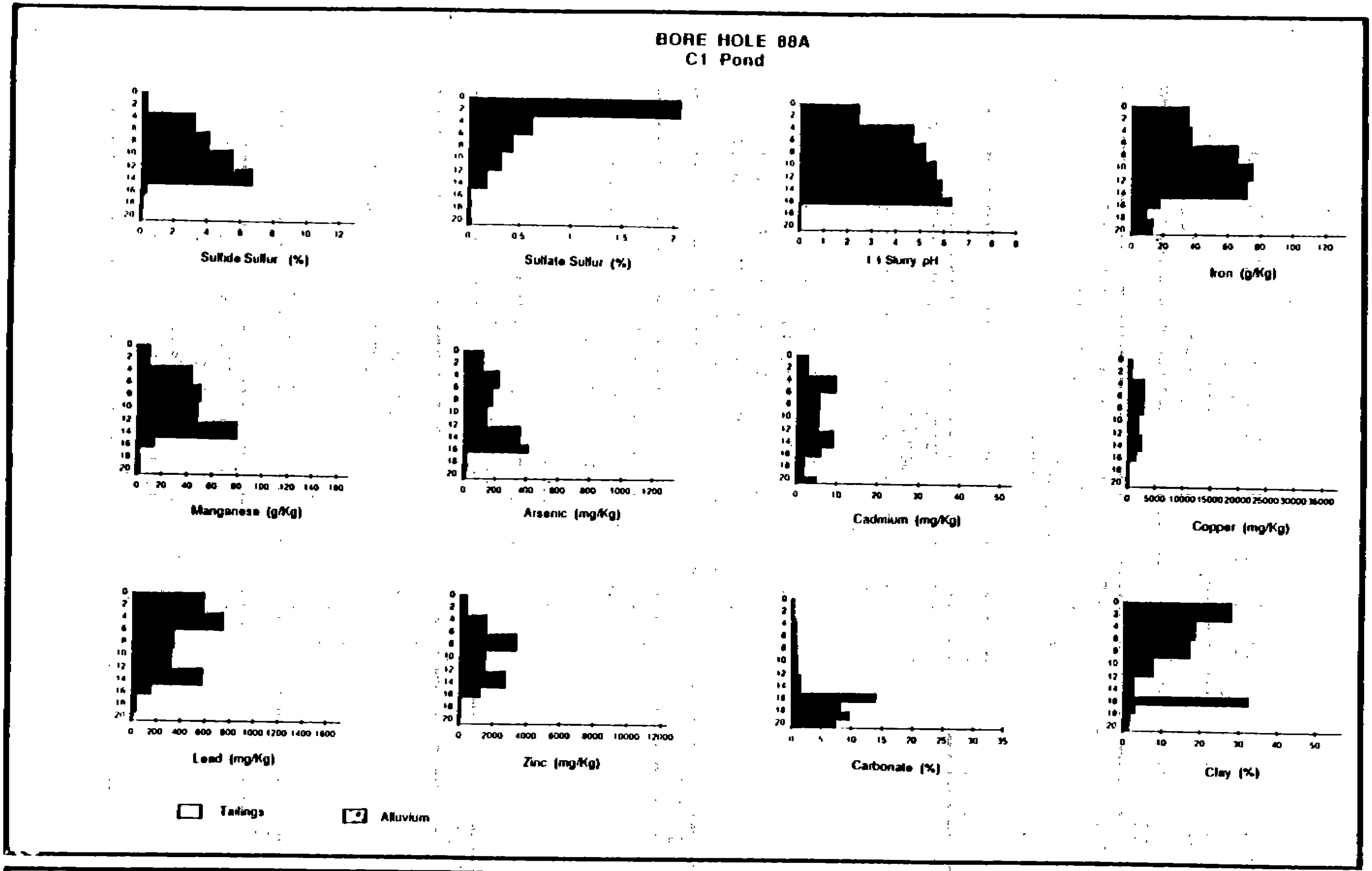


Figure 15-12. Depth vs. Concentration Profiles for Selected Variables for Borehole 88A

TABLE 15-6

TYPICAL METHODS FOR GRAPHICALLY PRESENTING DATA COLLECTED DURING FACILITY INVESTIGATIONS

Data	Graphical Presentation Methods
METEOROLOGIC DATA	
Wind speed and direction	● Wind rose showing speed, direction and percent of observations for each 10° increment
Air temperature	● Bar chart, by month
Precipitation	● Bar chart, by month
Evaporation	● Bar chart, by month
SURFACE WATER DATA	
Flow rates	● Hydrographs; distance profiles, cumulative frequency distributions, flood frequency plots ● Hydrologic network depiction and water budgets
Water quality	● Trilinear diagram ● Stiff diagrams ● Contour showing vertical concentration or temperature variability in two deep water bodies ● Time history plots showing daily/annual variability ● Bar charts of major cations/anions or contaminants at multiple locations shown on a single map
GEOHYDROLOGIC DATA	
	● Geologic map of site and vicinity ● Stratigraphic cross-sections of site in direction of and perpendicular to ground water flow ● Well logs ● Cross-sections near waste deposits ● Solid phase chemical analyses by depth at borings near waste deposits and into alluvium
GROUND-WATER DATA	
	● Water level contours ● Flow directions and velocities ● Time history of water table at important locations ● Stiff diagrams ● Trilinear diagrams ● Contaminant plumes, showing isopleths
MISCELLANEOUS	
	● Figures with important site features, including waste sources, storage ponds, disposal areas, buildings, sampling locations, well locations ● Operational aspects for special sampling equipment (e.g., lysimeters)

CASE STUDY 7: CORRELATION OF CONTAMINANT RELEASES WITH A SPECIFIC WASTE MANAGEMENT UNIT USING GROUND-WATER DATA

Point Illustrated

- Development of an effective ground-water monitoring program can tie releases of contaminants to specific waste mangement units.

Introduction

Documentation of a release from a specific waste management unit may require the development of a comprehensive ground-water monitoring program coupled with an extensive hydrogeologic investigation. Determination of ground-water flow direction and horizontal and vertical gradients are necessary to assess the direction of potential contaminant migration. Historical data on wastes disposed in specific units can provide information on contaminants likely to be detected downgradient.

Facility Description

Chemicals were manufactured at a lOOO-acre facility for over 30 years.The facility produced plastics including cellulose nitrate, polyvinyl acetate, polyvinyl chloride and polystyrene, and other chemicals such as phenols and formaldhyde. Wastes produced in the manufacturing process were disposed on site in an unlined liquid waste impoundment and in two solid waste disposal areas. Readily combustible materials were incinerated in four burning pits. Ground-water contamination has been documented at the site. Figure 15-13 shows, the facility plan and locations of ground-water monitoring wells.

The site is located in a glacial valley and is adjacent to a major river. A minor tributary runs through the southwestern portion of the facility and drains into the river. Approximately 200 dwellings are located downgradient of the site.

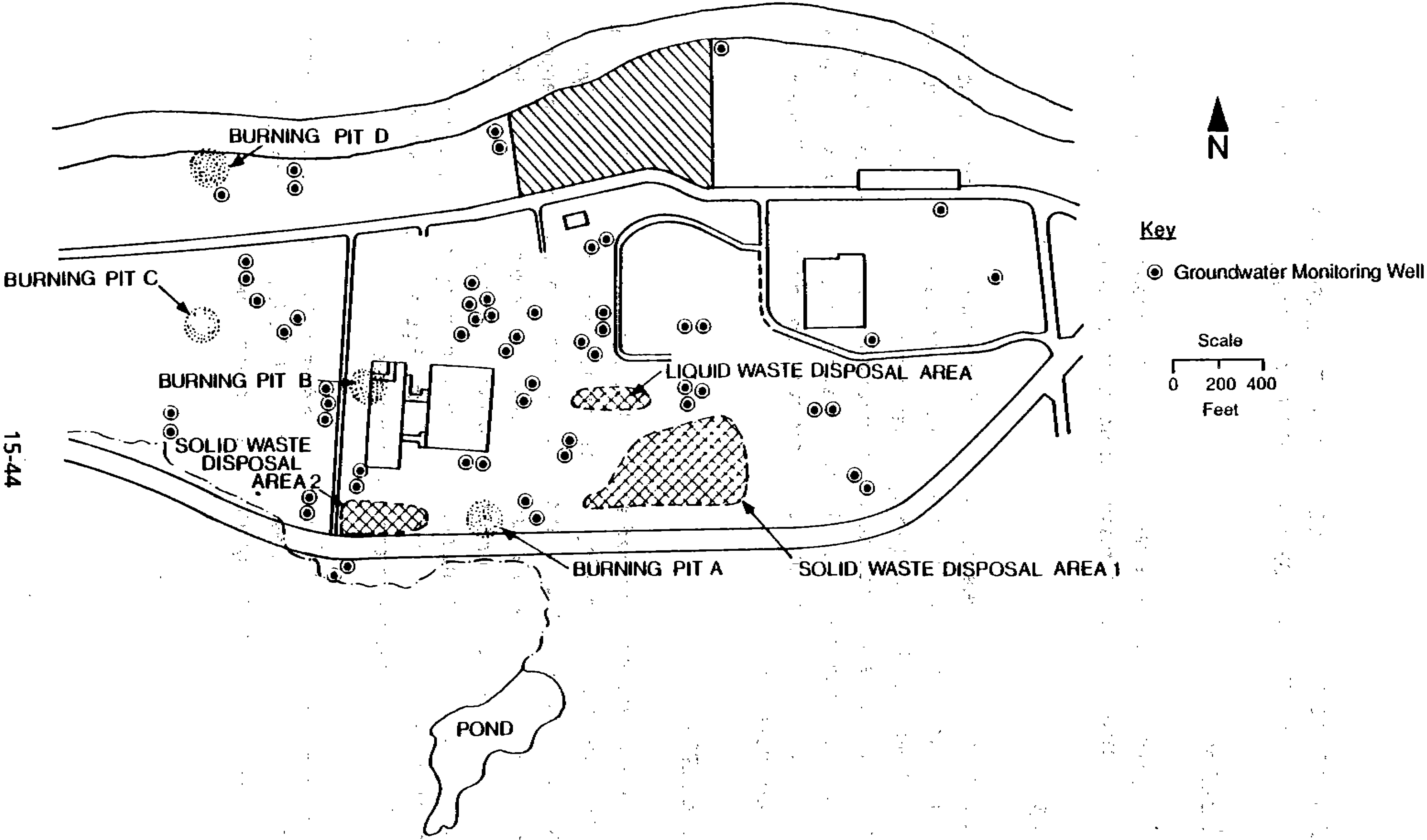


Figure 15-13. Location of Ground-Water Monitoring Wells

Data Collection

Initial studies to assess the extent of ground-water contamination began in 1981. Studies focused on ground water in the vicinity of various wasted disposal units. A limited numberof monitoring wells were installed in 1983. These wells provided general data on the direction of ground-water flow and chemical constituents that had entered the ground water. In 1984, a two-phased approach was developed to define the areal and vertical extent of contamination and to identify, contaminant, releases from specific waste management units. The first phase involved the characterization of facility geologic and hydrogeologic conditions using historical data, determination of the chemical nature of contaminants in the ground water using existing monitoring wells and development of a contaminant contour map delineating horizontal boudaries of contamination. Based on this data, 33 soil borings were drilled in Phase 2. The goals of the second phase were to 1) detail subsurface geologic characteristics, vertical and horizontal water flow patterns, contaminant migration, and site-specific chemical contaminants; and 2) install wells that would be used to monitor contaminants being released from ail units of concern at the faciiity.

Continuous split spoon samples were collected in each boring and headspace analyses for volatile organic compounds (VOC) were conducted on-each sample. Chemical constituents were identified using a field gas chromatograph. Confirmational analysis by GC/MS were conducted on selected samples. Geotechnical analyses were also conducted on the split spoon samples.

Chemical and hydrogeologic data (direction of flow, gradients) obtained from the borings were used to select appropriate ground-water monitoring well locations and screen depths. Fifty-two (52) nested monitoring wells were if installed at 25, locations upgradient and downgradient of each waste management unit, and near the river and its, tributary. Screen depths were determined by the depth of maximum VOC contamination observed in the borings and the permeability of soil layers.

Data Analysis

Ground-water contamination data from new wells. coupled with historical waste disposal data allowed releases from three specific waste management areas to be defined. Sample analyses showed organic solvents in nearly all locations. However, more unusual constituents associated with specific manufacturing progesses were detected in some samples, allowing them to be correlated with releases from specific waste management units The two situations below illustrate how these correlations were accomplished:

1) PCBs detected in some samples were correlated with Solid Waste Disposal Area #1. This area received construction debris, resins, plastics, metals, drums, and PCB containing transformers. Records indicated that this unit was the only location where transformers were disposed onsite. PCBs could not be associated with any of the other waste management units.

2) The solvent dimethylformamide (DMF) detected in some samples was correlated with Burning Pit B. It was discovered that the building that housed this unit had been used to tint windshields and that DMF is a component of the dye used in this process. DMF could not be tied to any of the other waste management units. A leachfield in which waste dyes had been disposed was discovered under the building and the contamination was traced back to that source.

Case Analysis

An extensive hydrogeologic investigation of the facility was completed and, in conjunction with historical, data, was used to develop a comprehensive ground-water monitoring program. Placement of the monitoring wells of the screens was essential in providing data that unequivocally linked contaminant releases to specific waste management units and manufacturing processes.

CASE STUDY 8: WASTE SOURCE CHARACTERIZATION FROM TOPOGRAPHIC INFORMATION

Points Illustrated

- Mapping of changes in site topography can support the selection of locations for test borings and monitoring wells.

- This technique is especially useful at sites where large volumes of waste have been disposed of over several years.

Introduction

Topographic surveys conducted prior to and at different times during the operation of a waste management facility can be used to help characterize the vertical and horizontal extent of waste disposal areas. Because the resolution of this technique is limited, it is most-useful when large volumesof waste are involved.

Facility Description

This facility is the same as discussed in Case Study 7 above.

Topographic Survey

In 1984, a topographic survey measuring elevations in feet relative to mean sea level was conducted for the areas shown in Figure 15-14. These elevations were plotted on a map of appropriate horizontal scale and contoured in 2-foot intervals. This topography was transferred to an existing site plan (horizontal scale 1” to 200’). Topographic maps from 1935 (showing the natural topography before waste deposition) to 1960 (showing the topography in the earlier stages of the facility operation) were compared to the 1984 map. By examining the changes in elevations which occurred over time, contours were developed showing’ the estimated changes in vertical and horizontal units of the liquid waste and solid waste disposal areas.

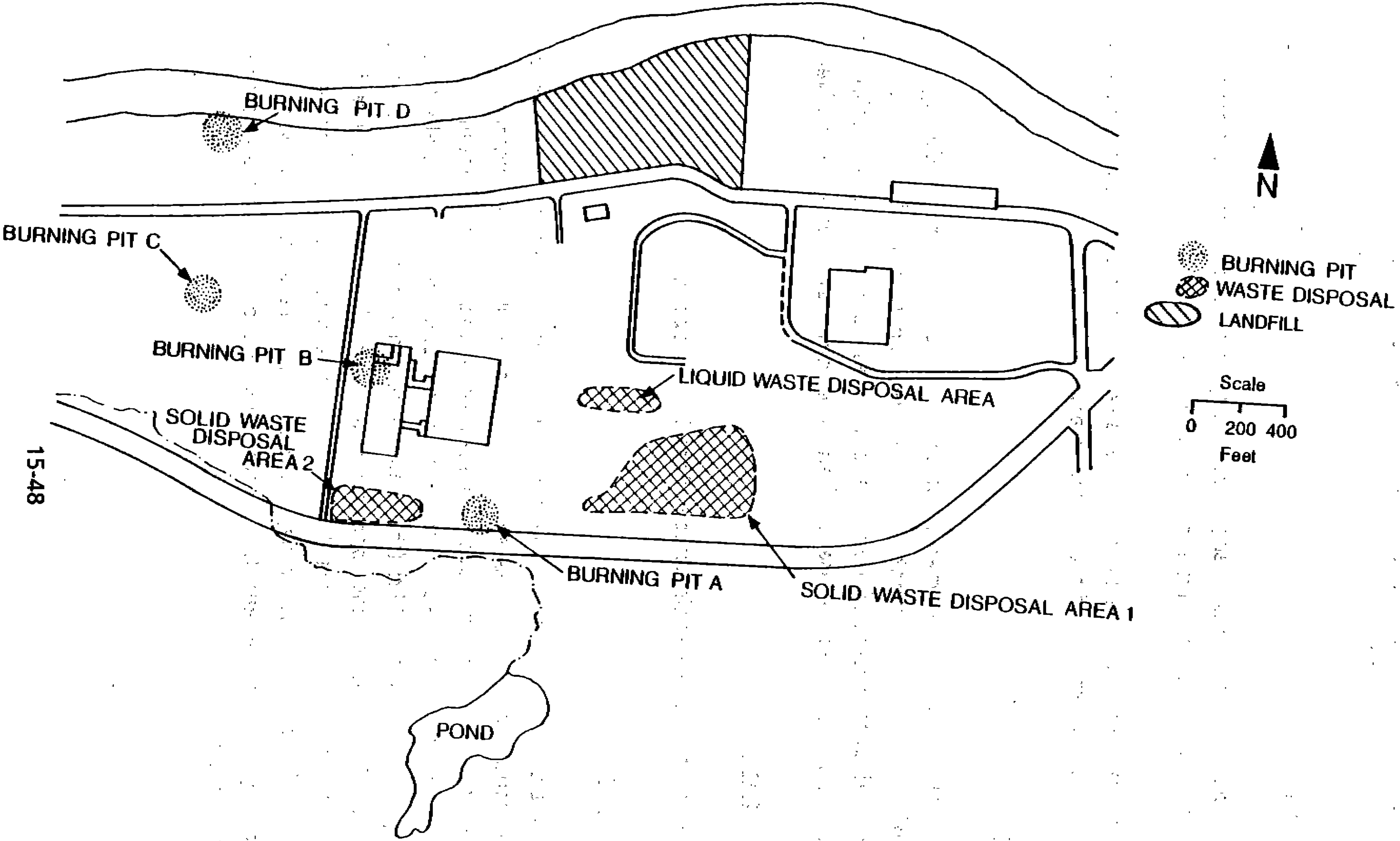


Figure 15-14. Site Map Showing Waste Disposal Areas

Results

From the analysis, it was apparent that the deepest portion of Solid Waste Disposal Area (SWDA) No. 1 (Figure 15-14) was approximately 48 feet, and the Liquid Waste Disposal Area (LWDA) was approximately 30 feet deep. The horizontal limits of the disposal areas were also defined in part by this review, but other field surveys provided more accurate information on the horizontal boundaries of the waste disposal areas.

Case Discussion

Topographic surveys can provide useful information for characterizing disposal areas. The results of these studies can facilitate the selection of appropriate test boring locations, and may reduce the number of borings necessary to describe the subsurface extent of contamination. It should be noted that techniques such as infrared aerial photography and topographic surveying are approximate in their findings. They are useful methods in the early phases of an investigation, but do not replace the comprehensive characterization of the environmental setting needed for the full investigation.

CASE STUDY 9: SELECTION OF GROUND-WATER MONITORING CONSTITUENTS AND INDICATOR PARAMETERS BASED ON FACILITY WASTE STREAM INFORMATION

Points Illustrated

- Waste stream information can be used to identify potential contaminants and thus to select appropriate ground-water monitoring constituents and indicator parameters.
- The number of initial monitoring constituents analyzed may be significantly reduced from the 40 CFR Part 261 Appendix Vlll list when detailed waste stream information is available.

Introduction

Hazardous waste treatment, storage, and disposal facilitity subject to RCRA are required to identify all waste streams managed the facility, waste volumes, concentrations of waste constituents, and the waste management unit in which each waste type is disposed. Ground-water monitoring programs should be developed to adequately monitor contaminant migration from each unit. Constituents to be analyzed in the ground-water monitoring program should be established prior to sample collection. When waste stream data are not available, the full set of Appendix VIII monitoring constituents may be required to characterize ground-water contamination. Knowledge of the waste streams managed by a facility simplifies the selection of monitoring constituents and indicator parameters because potential contaminants and their likely reaction and degradation products can be more easily identified.

Facility Description

The 600-acre facility is a permitted waste disposal site operated since 1980. Solid waste management units occupy 20 acres of the site and include four surface impoundments and one container storage area subject to RCRA. Until 1985, three units (two surface impoundments and one solids disposal unit) not subject to RCRA were used for geothermal waste disposal. However, the two surface impoundments were replaced by a RCRA regulated landfill. RCRA wastes managed by the facility include metals, petroleum refining-wastes, spent non-halogenated solvents, electroplating wastewater treatments sludge, spent pickle liquor from steel finishing operations, and ignitable, corrosive, and reactive wastes. Ground-water monitoring wells have been installed downgradient of each waste mangement unit.

Program Design

Prior to disposal, each load of waste received is analyzed in an on-site laboratory to provide a complete characterization of waste constituents. Periodic sampling of the waste management units is, also conducted to identify waste reaion products and hazardous mixtures. Even though the incoming wastes have been characterized, the facility owner also analyzed initial ground-water samples from each monitoring well far all Appendix, Vlll constituents. The resulting data were used to establish existing concentrations for each constituent and to select a set of monitoring constituents and indicators parameters to identify migration of waste to the ground-water system. Table 15-7 includes a list of the indicator parameters analyzed at the facility. Rationale for indicator parameter selection are included in this table. A separate list of hazardous constituents to be monitored was also developed based on the waste analysis.

Because the facility accepts only a limited number of 40 CFR Part 261 Appendix Vlll constituents and initial monitoring verified the absence of many constituents, the facility owner or operator was able to minimize the total number of constituents monitored in ground water. The process of constituent elimination is dependent on the actual wastes received by the facility and the physical and chemical properties of these constituents that influence their migration potential (e.g., octanol/water partition coefficients, volubility, absorptivity, susceptibility to biodegradation).

Non-halogenated solvents have relatively low partition coefficients (K_{ow}: benzene = 100; toluene = 500) and are not readily retained by soils. Conversely, polycyclic aromatic hydrocarbons, constituents of petrochemical wastes, have very high partition coefficients (e.g., chrysene = $4x10^5$) and are generally immobile in soils. Migration rates of metals are also influenced by the exchange

TABLE 15-7

INDICATOR PARAMETERS

Parameter	Citeria for Selection
Total Organic Carbon (TOC)	Collective measure of organic substances present
Total Petroleum Hydrocarbons	Indication of petroleum waste products
Total Organic Halogen (TOX)	Halogenated organic compound are generally toxic, refractory, and mobile
Nitrates	Mobile contaminant, degradation product of nitrogen compounds
Chloride	Plating solution constituent, highly mobile in ground water, Early indicator of plume arrival
Sulfides	Toxic biodegradation by product, strong reducing agent, may immobilize heavy metals
pH	Good indicator of strongly acidic or alkaline waste leachates close to sources.
Total phenols	Collective measure of combounds likely to be in waste. Even small concentrations can cause olfactory problems following water treatment by chlorination.

capacity of the soil. Different metal species are sorbed to different extents. Following an assessment of the migration potential of each waste constituent, the need for analysis of that constituent can be prioritized.

Case Discussion

Waste stream information was used to determine appropriate monitoring constituents and indicator parameters. The use of the existing initial ground-water quality data and the incoming waste analyses allowed for prediction of contaminants of concern in ground water and reduced the number of constituents requiring analysis.

CASE STUDY 10: USING WASTE REACTION PRODUCTS TO DETERMINE AN APPROPRIATE MONITORING SCHEME

Point Illustrated

- It is important to consider possible waste reaction products when developing monitoring procedures.

Introduction

Volatile organic priority pollutants have been detected in ground water at various areas across the country. These compounds, widely used as solvents, are generally considered environmentally mobile and persistent. Increasing evidence, however, indicates that chlorinated solvents can be degraded under anaerobic conditions by reductive dehydrochlorination. The sequential removal of chlorine atoms from halogenated 1 and 2 carbon aliphatic compounds results in formation of other volatile priority pollutants which can be detected during investigations of solvent contamination.

Facility Description

The facility is a small municipal landfill sited on a former sand and gravel quarry. In addition to municipal wastes, the landfill accepted trichloroethane and tetrachloroethene contaminated sludge from a local fabrication plant until 1975. In 1983, a municipal well located downgradient of the landfill tested positive for dichloroethane, dichloroethene isomers, and vinyl chloride. This prompted the city to investigate the cause and extent of the problem.

Site Investigation

According to records kept at the facility, some of the compounds found in the municipal well were not managed at the facility. This prompted the city to request that a monitoring program be developed to determine whether another source was causing well contamination. A careful search of the city records, however, failed to indicate a credible alternative source of the compounds. Suspecting that the landfill was the source of the well contaminants, five monitoring wells were installed (Figure 15-15) and water samples were analyzed for halogenated compounds using EPA Method 601. The results, given in Table 15-8, show an increase in degradation products of trichlorciethane and tetrchloroethene with increasing distance from the landfill. Using these data, supported by hydrogeologic data from the monitoring wells, the munitipal landfill was shown to be the source of the observed contamination.

TABLE 15-8
RESULTS OF MONITORING WELL SAMPLING

	WELL NUMBER (See Figure 15-15 for well locations)				
	1	2	3	4	5
Chlorinated Ethanes					
(1) Trichloroethanes	10(3)	68	ND(4)	ND	ND
(2) 1,1-Dichloroethane	71	240	130	11	13
1,2-Dichloroethane	ND	12	21	ND	ND
Chloroethane	ND	21	18	160	ND
Chlorinated Ethenes					
(1) Tetrachloroethene	80	13	ND	ND	ND
Trichloroethene	12	100	62	ND	ND
(2) 1,2-Dichloroethenes	ND	990	950	150	ND
1,1-Dichloroethene	ND	ND	ND	ND	ND
Vinyl Chloride	ND	120	59	100	ND

(1) Parent Compounds
(2) Degradation Products
(3) All Concentrations In Micrograms/L
(4) ND means < 10 Micrograms/L

Case Discussion

Based on the compounds found in the municipal well, the city believed that the municipal landfill could not be the source of the contamination. If this reasoning had been followed, then a system of monitoring wells might have been needlessly installed elsewhere in the attempt to find an alternate source of the

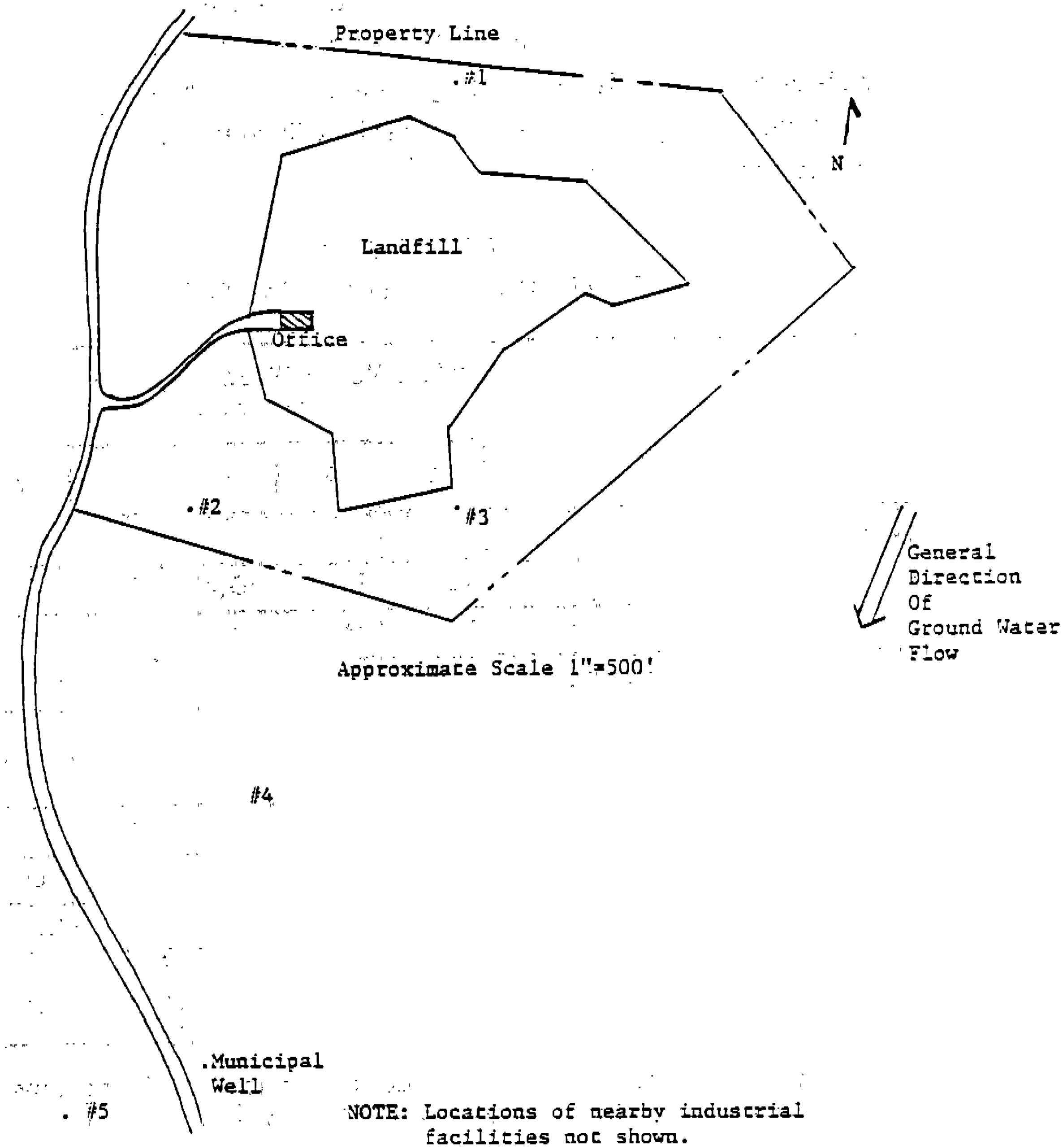


Figure 15-15. Site Map and Monitoring Well Locations

contamination. Instead, after carefully researching local industriesj it was determined that the landfill was the most reasonable source of the contamination and that the observed well contaminants were probably degradation products of the Iandfilled solvents. The progressive dehalogenation of chlorinated.ettiaries-a~~ ethenes, as shown in Table 15-8, is commonly encountered in situations where chlorinated solvents are subjected to anaerobic conditions (Wood, 1981). Different degradation reactions may occur when pesticides are subjected to acidic or alkaline conditions or biological degradation. Therefore, it is important to keep reaction products in mind when designing any monitoring scheme or interpreting contamination data.

Reference

Wood, P. R., R.F. Lang, I.L. Payan, and J. DeMarco. 1981. Anaerobic Transformation, Transport and Removal of Volatile Chlorinated Organics in Ground Water.’” First International Conference on Ground Water Quality Research, October 7-.1:0,’:1981”, Houston, Texas.

CASE STUDY 11: CORRECTIVE: MEASURES STUDY AND THE IMPLEMENTATION OF INTERIM MEASURES

Points Illustrated

- Interim corrective measures may be necessary to protect human health or the environment.
- The evaluation of the need for definitive corrective measures.

Introduction

The development and implementation of a comprehensive Corrective Measure Study can be a time-consuming process. Between the time of the identification of a contaminant release and the completion of definitive corrective measures, existing conditions or contaminant migration can endanger human health or the environment. Under such conditions interim measures may be necessary. The case study presented below illustrates the implementation of interim measures to reduce contaminant migration and to remove the imminent threat to the nearby population from exposure to contaminants in drinking water, and also illustrates the decision making process as to whether definitive corrective measures may be necessary.

Facility Description

The facility in this case study is an underground tank farm located at a pharmaceutical manufacturing plant. The tank farm encompasses an area approximately 140 feet by 260 feet and contains 30 tanks ranging in size from 12,000 to 20,000 gallons. The tanks are used to store both wastes and raw materials for the various batch manufacturing processes performed at the plant. Typical wastes include carbon tetrachloride, acetonitrile and chloroform. At the time of the release, the tank farm had no cap to prevent the infiltration of rainfall or runoff. It also did not have berms to provide containment for surface spills. No leak detection or leachate collection systems were present.

Geologlcal and Hydrological Setting

The site is underlain by silty soil overlying limestone. The weathered limestone beneath the site is very: permeable (up to 210 ft/day) due to the solution of rock along joints and bedding planes in the limestone. Depth to the limestone varies from 3 to 80 feet beneath the tanks and from 15 to 190 feet downgradient of the site.

The ground-water system beneath the site consists of two aquifers. The uper one, an unconfined limestone aquifer, is about 300 feet below the surface. The deep aquifer is an artesian aquifer, in another limestone formation about 200 feet below the land surface. Ground-water flow in the upperaquife is controlled by both the regional flow system and local channelized flow through solution conduits. The upper aquifer discharges to a canal 3 miles north of the site. Figure 15-16 shows the ground-water elevation contours in the vicinity of the site. Regional average ground-water flow velocity was estimated at 4ft/day, but ground-water velocities on the order of 50 ft/day have been measureci in some channelized areas. Channlized flow is also is responisible for Iocal deviatiorrs in flow direction.

Release Characerization

A contaminant release from the tank farm was discovered when one of the tanks used for waste storage was found to be empty. The waste sored in the tank was predominately carbon tetrachloride (CCl_4) (a carcinogen with an MCL of 0:005 mg/l, with some acetonitrile (a systemic toxicant with a water-based health, criterion of 200 µg/l) and chloroform (a systemic toxicant with a water-based health criterion of 400 µg/l) reference dose (RfD) is 0.4 mg/l). Approximately 15,000 gllons of waste liquids had been routed to the tank before the leak was discovered. Excavation of the tank revealed ruptures in at Ieast three locations. Initial ground water monitoring after the tank rupture was discovered identified CCl_4 in a well 2500 feet downgradient of the site, at concentrations above the MCL for CCl_4 of 0.005 mg/l.

Contaminants from the leaking tank were found to have dispersed laterally within a two-foot-thick sand bed which underlies the tanks. The contaminated area

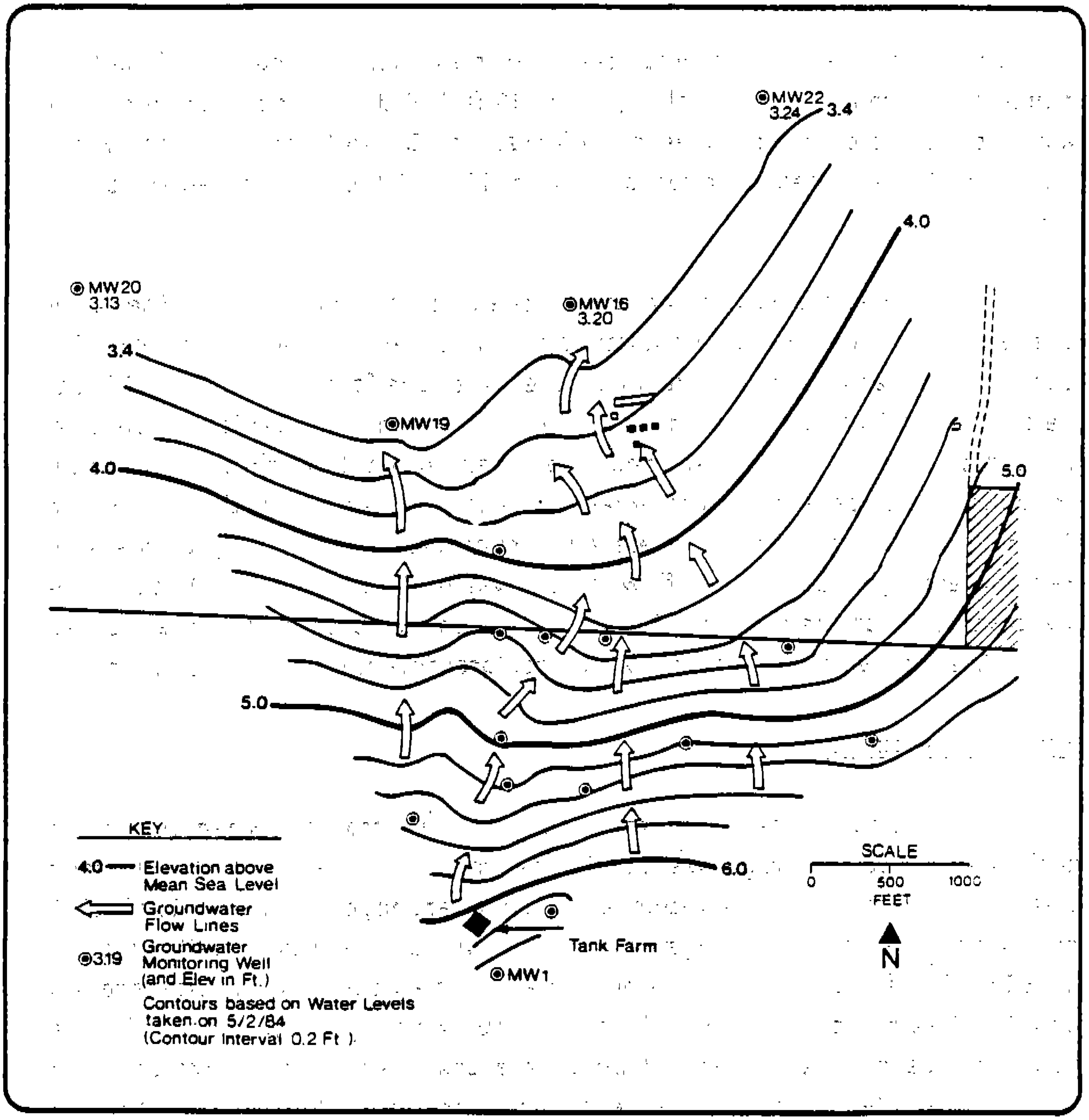


Figure 15-16. Ground-Water Elevations and Flow Directions in Upper Limestone Aquifer

was approximately 5600 ft^2. High levels of CCl_4 were found throughout the sand layer. Concentrations of CCl_4 in the natural soil ranged between undetected and 2200 mg/kg. Observed consentrations were well above the soil RSD for CCl_4 (2.7 mg/kg). Concentrations generally decreased with depth due to adsotptioh onto the clay particles in the soil. Carbon tetrachloride apparently moved downward with little lateral dispersion until reaching the soil-limestone interface. Upon reaching the unsaturated limestone, the contaminants then appeared to have rapidly dispersed over an area of about 12 acres before entering the aquifer.

Interim Corrective Measures

Immediate action to contain the release in the aquifer was taken. This involved pumping the well where CCl_4 had been found continuously at its full capacity of 450 gpm.

All drinking water in the vicinity of the release was obtained from wells installed in either the shallow or artesian aquifer. Immediately after the detection of the release, all domestic and industrial wells north of the facility were tested for CCl_4 contamination. Test results showed contamination of several shallow water supply wells. Based on this information and the inferred ground-water flow direction to the north-northeast, wells serving two small communities and a nearby motel were closed. The facility operator hired all mobile water tanks available and supplied water for immediate needs until a temporary water supply could be implemented. Water from an unaffected artesian well was then used to supply water to these communities.

The design and operation of the tank farm was altered in an attempt to avoid similar problems in the future. A fiber-reinforced concrete cap was installed over the tank farm to prevent the infiltration of rainfall and runoff, thus minimizing further contaminant migration in the soil. The ruptures were repaired, and a tank monitoring system was also developed and implemented at the site.

Definitive Corrective Measures: Saturated and Unsaturated Zones

A comparison of CCl_4 concentrations within the ground water to the MCL for CCl_4 (0.005 mg/l) indicated that definitive corrective measures may be necessary.

Due to the high mobility of CCl_4 within the unsaturated zone, and the potential for continued inter-media transfer, from this zone to the ground water, definitive corrective measures for both the saturated (ground water) and unsaturated zones should be evaluated in a Corrective Measures Study (CMS).

Case Discussion

The development and implementation of definitive corrective measures at a site may take a substantial length of time. Depending on the nature and severity of the release and the proximity of receptors, interim measures, such as alternative water supplies, were required to minimize the effects on human health and the environment. Comparison of constituent concentrations with health and environmental criteria indicated that definitive corrective measures may be necessary and that a Corrective Measures Study (CMS) should be initiated.

CASE STUDY 12: USE OF AERIAL PHOTOGRAPHY TO IDENTIFY CHANGES IN TOPOGRAPHY INDICATING WASTE MIGRATION ROUTES

Points Illustrated

- Aerial photographs can be used to obtain valuable data on facility related topographic features, including type of waste management activity, distance to residences and surface waters adjacent land use and drainage characteristics.

- Detailed interpretation of aerial photographs can identify acual and potential waste migration routes and areas requiring corrective action.

Introduction

Stereoscopic pairs of historical and current aerial photographs were used to assist in the analysis of waste management practices at a land disposal facility. Stereo viewing enhances the interpretation of aerial photographs because vertical as well as horizontal spatial relationships can be observed, and because the increased vertical resolution aids in distinguishing various shapes, tones, textures, and colors within the study area. Typical items that should be noted include pools of unknown liquid that may have been released from buried materials which could. migrate off site through drainage channels. Soil discoloration, vegetation damge or enhanced vegetation growth can also be indicative of contaminant migration.

Facility Description

The site contains an active land disposal facility which receives bulk hazardous waste, including sludges and contaminated soil for burial, and liquid waste for disposal into solar evaporation, surface impoundments. Operations at the facility began in 1969. Historical and current aerial photographs were reviewed to asses waste management practices and to identify potential contaminant migration pathways requiring further investigation and corrective action.

Data Collection and Anaysis

Low altitude color aerial photographs of the facility (scale = 1:8400) were obtained in October 1983 and February 1984. The photos were interpreted by an aerial photo analyst at the U.S. EPA Environmental Monitoring and Support Laboratory at Las Vegas, Nevada. Figure 15-17 shows the analyzed photograph. The interpretation code is givin in Figure 15-18. Analysis of the photograph indicates several areas of seepage at the base of the surface impoundments. This seepage indicates that either the impoundments are not lined or the liners have failed. Drainage from the western portion of the facility which contains most of the impoundments flows into a drainage reservoir formed by a dam across the main drainage. Drainage from the northeast portion of the facility where seepage was also observed appears to bypass this reservoir and enter the main drainage which flows offsite. Besides possible surface contamination, this seepage also indicates potential subsurface contamination.

The aerial photograph obtained in February 1984 (Figure 15-19) indicates the continued existence of see page from the surface impoundments. There is evidence of possible discharge from the drainage reservoir to a stream channel, as a pump and piping were observed. Additional material in the solid waste disposal area has altered the dranage pattern. At the south end of this area, seepage is evident in association with damaged vegetation. Drainage from this area enters a drainage system and appears to be diverted offsite.

Case Discussion

Analysis of aerial photographs of the land disposal facility enabled investigators to identify potential contaminant sources and migration, pathways. This information was used by investigators to identify areas for surface water, sediment, soil, and subsurface sampling.

Figure 15-17. October 1983 Aerial-Photograph of Land Disposal Facility

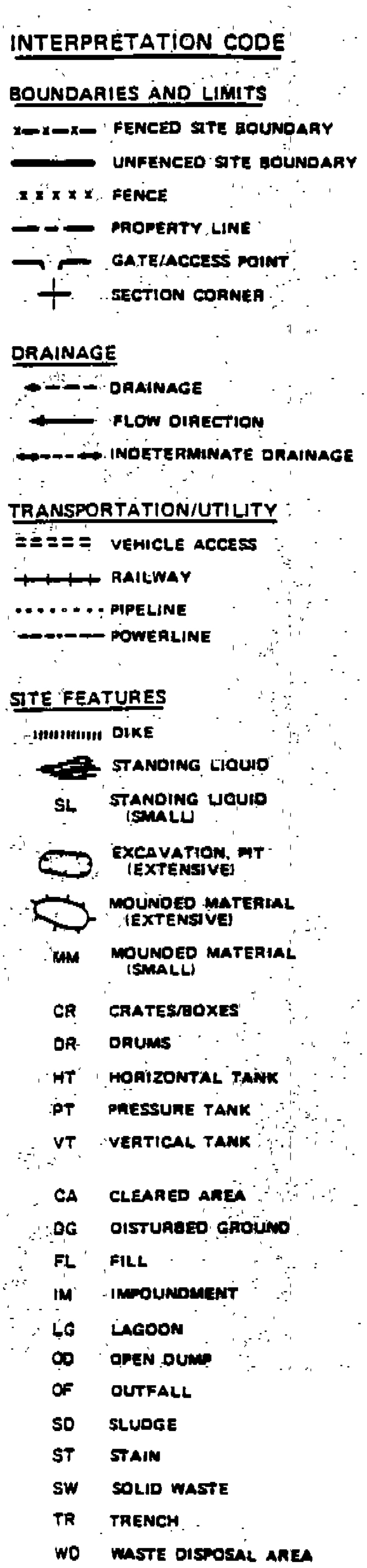


Figure 15-18. Aerial Photograph Interpretation Code

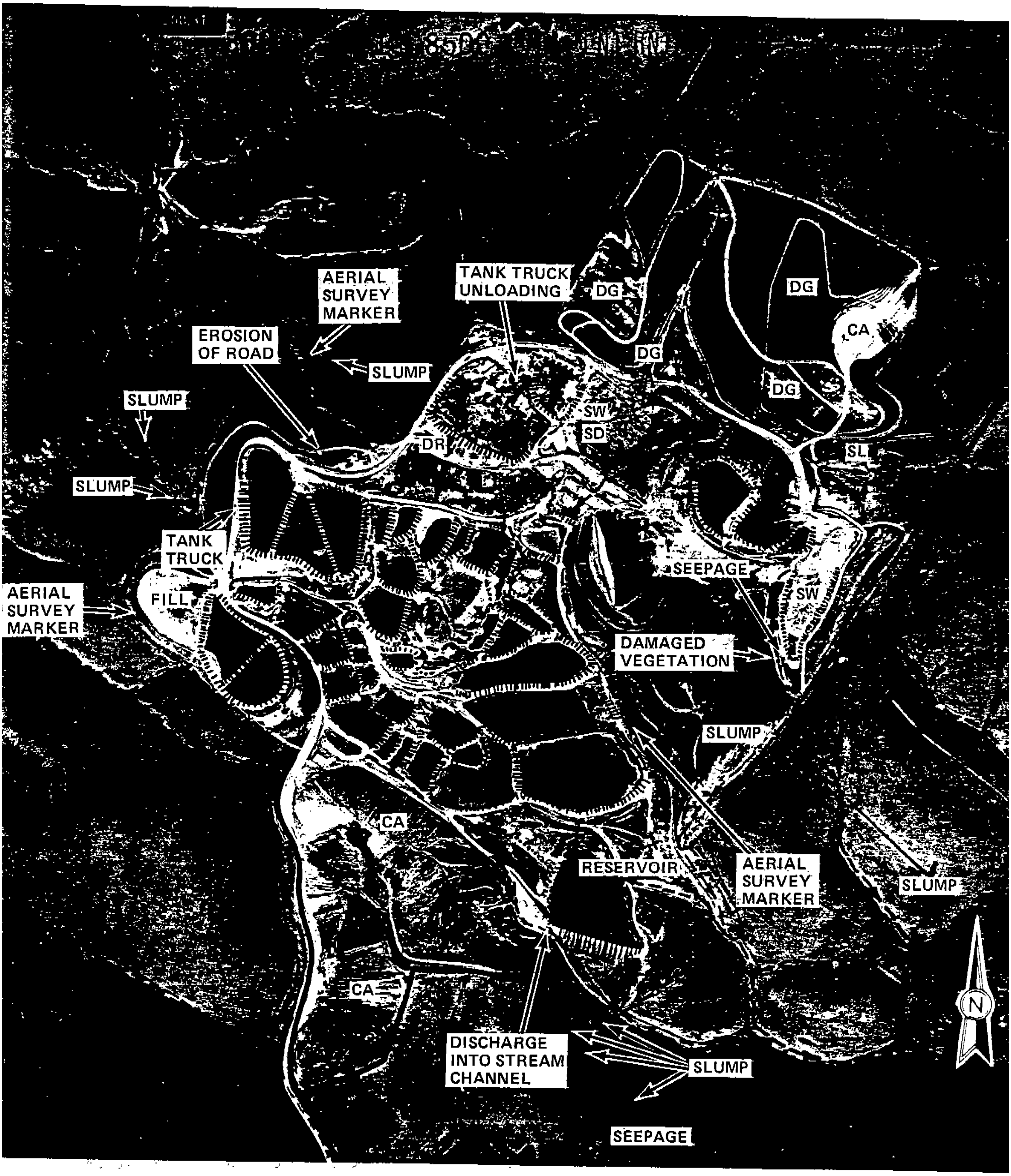


Figure 15-19. February 1984 Aerial Photograph of Land Disposal Facility

CASE STUDY 13: IDENTIFICATION OF A GROUND-WATER CONTAMINANT PLME USING INFRARED AERIAL PHOTOGRAPHY

Point Illustrated

Infrared photography can assist in identifying contaminant plumes and in locating monitoring wells by showing areas of stressed vegetation and contaminated surface water.

Introduction

Infrared aerial photography can assist in identifying contaminant plumes at sites where little or no monitoring has been conducted. By identifying areas of stressed vegetation or contaminated surface water, it may be possible to focus on contaminant discharge points and roughly define the extent of a release. Hydrogeologic investigations and surface water sampling can then be performed to further characterize the release. Infrared photography offers the potential to increase the efficiency of a sampling program.

Facility Description

The facility is a municipal solid waste landfill which has served a population of 22,000 for 30 years. The facility covers an area of 11 acres, holding an estimated 300,000 tons of refuse. The majority of waste in the landfill was generated by the textile industry. Until July 1978, the facility was operated as an open dump with sporadic management. City officials indicated that original disposal occurred in open trenches with little soil cover. After July 1978 the facility was converted to a well-operated sanitary landfill. Figure 15-20 shows the facility.

Geologic Setting--

The landfill is located on a sandy to silty till varying in thickness from 23 feet at the hill crest to 10 feet on the side slope. A swamp is present at the base of the hill at about 255 feet above sea level. There is a dam at the southern drainage outlet

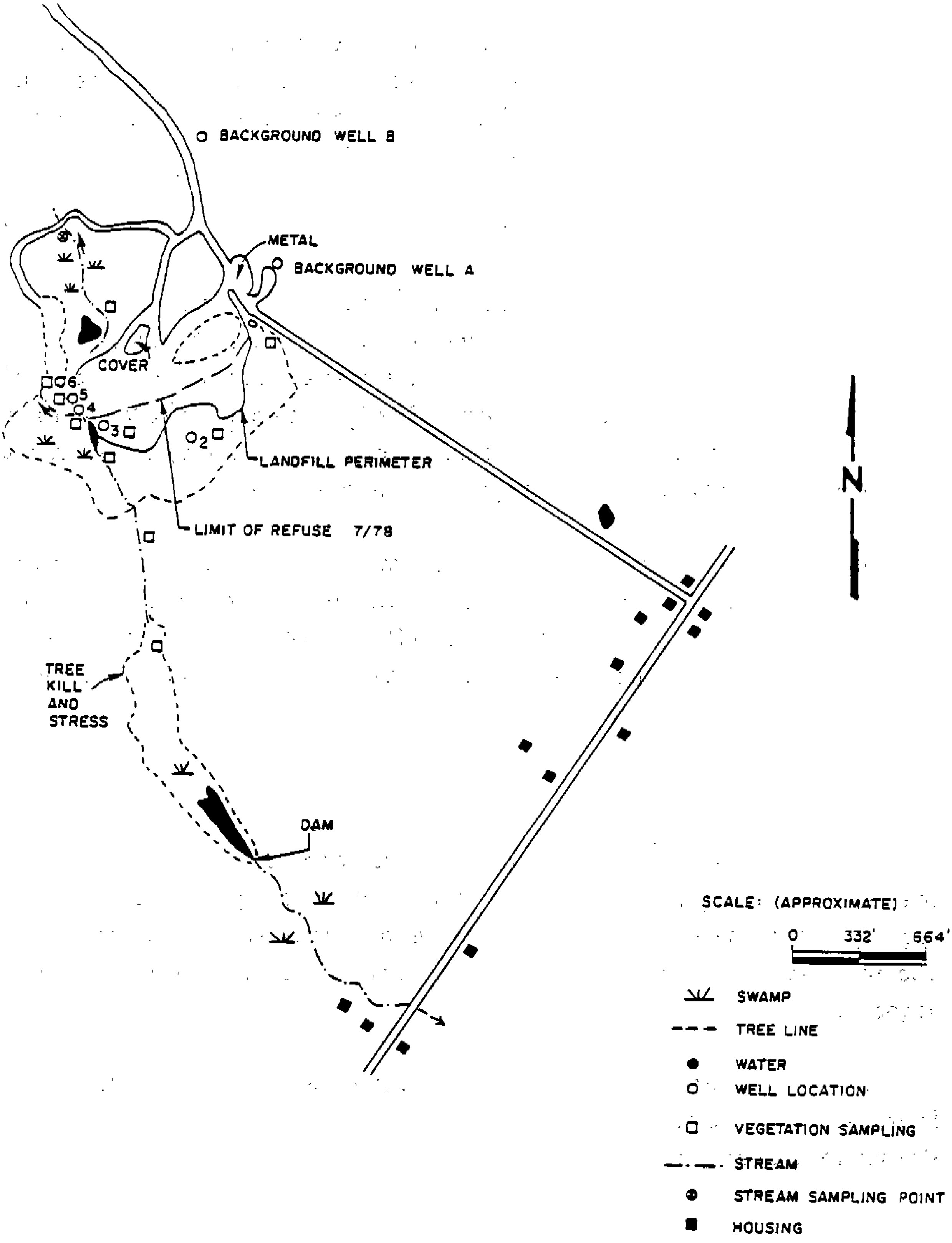


Figure 15-20. Facility Plan View

of the swamp, a distance of 2,500 feet from the landfill. Ground water is approximately 20 feet below the surface at the crest of the hill, while on the slope it is approximately 6 feet below the surface. The swamp at the foot of the hill is the surface expression of the ground water (Figure 15-21).

Aerial Photograhy and Sampling Program

Figure 15-22 shows the infrared aerial image of the site. The landfill corresponds to the light area in the northwest portion of the photograph (Figure 15-21). The dark area to the south of the site is stressed vegetation, and the-light area within it is contaminated swamp water. The 33-acre area of tree kill and stress is clearly visible in the original photograph. Plants, under stress may be detected by infrared photography because of changes in infrared reflectance.

Ground-water monitoring wells and vegetation sampling points are shown in Figure 15-20. Data collected from the wells indicated elevated levels of chromium, manganese, iron, and total organic carbon (TOC). Table 15-9 lists the average concentrations of the parameters tested. The vegetation study indicated an accumulation of heavy metals.

Case Discussion

The vegetative stress apparent in the infrared photography was confirmed by the data from the ground water and vegetation sampling. However, the site requires further characterization to determine the vertical extent of contamination and to assess the potential for impact beyond the present area of stressed vegetation.

It should be emphasized that infrared photography is not a substitute for hydrogeologic characterization. However, it is a useful tool for identifying areas of stressed vegetation that may be associated with releases from waste disposal sites.

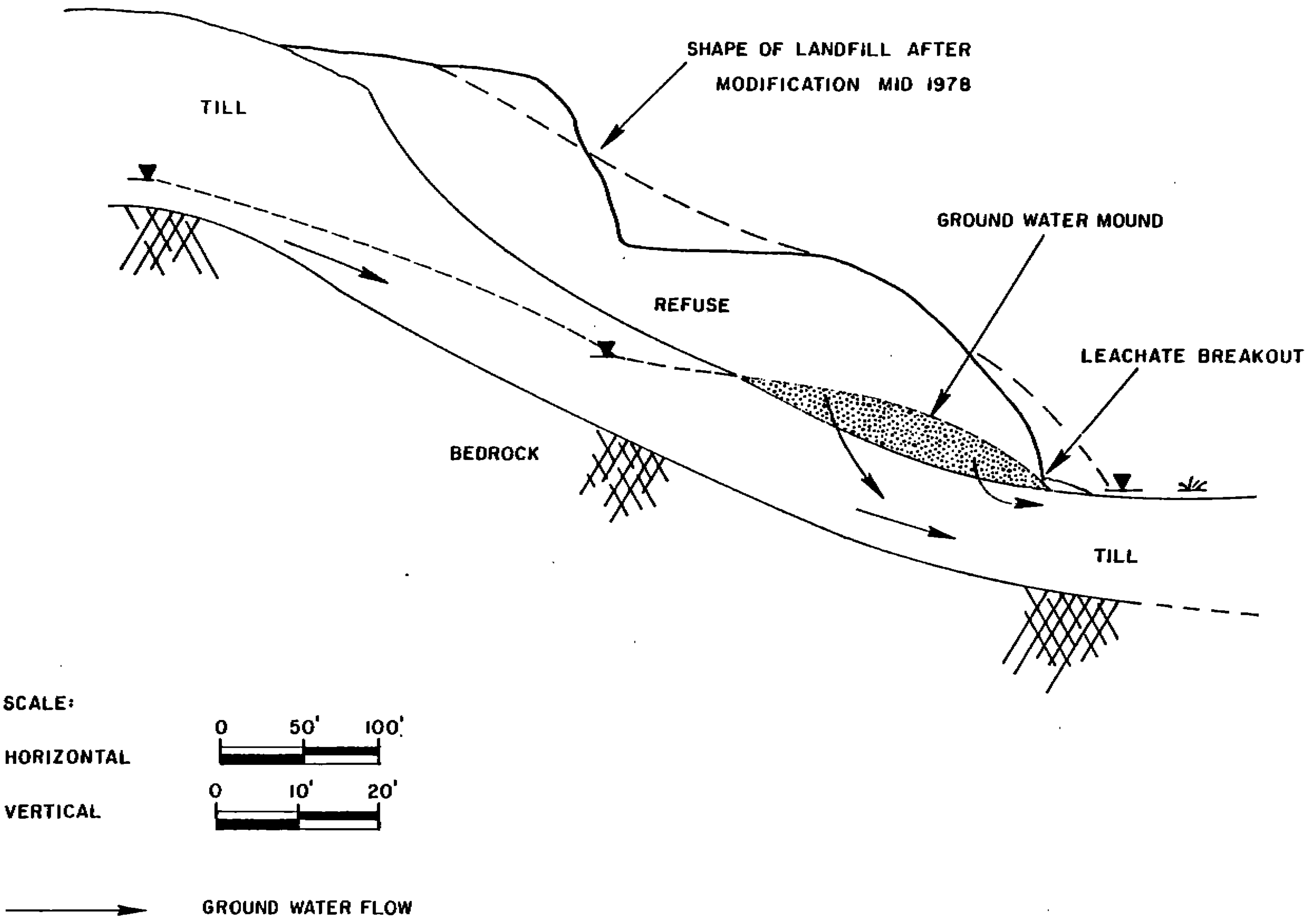


Figure 15-21. Generalized Geologic Cross-Section

Figure 15-22. Infrared Aerial Photograph of the Site

TABLE 15-9

AVERAGE VALUES OF PARAMETERS INGROUND WATER AND STREAM SAMPLES[1]

	BOD_5	TOC	TKN	NH_3	NO_3 =	Tot.P	Fe	Mn	Hardness	Cl	ClBD	Cr	TDS	Cd	pH
Background[2]	<10	/	/	/	/	1.73	2.7	0.4	18.2	5.2	102	/	98	0.05	/
Well #2	<20	119	1.7	0.54	0.48	0.11	108.8	4.2	525.6	67.3	1000	0.03	828.5	1	2.9
Well #3	<20	56	5.5	3.9	0.10	0.15	39.6	16.3	414.2	103.5	450	0.02	230	---	5.5
Well #4	/	300	2.5	<0.01	<0.01	0.13	27	9.4	1	980		0.02	/	/	5.4
Well #5	20	45.5	0.6	1.22	0.15	0.18	71.6	3.8	353	74.7	240	0.03	863.0	1	5.8
Well #6	19	45.5	3.4	2.47	<0.1	1.5	177	7.65	659.9	120	1300	0.71	780	/	5.7
Stream	<20	72.5	43.7	49.7	0.05	0.10	18.4	1.73	230	76.7	1300	0.017	817	/	6 8

[1] All values as mg/l, except conductivity (µmhos) and pH (standard units)

[2] Average of background wells A and B

/ = Not Analyzed

CASE STUDY 14: USE OF HISTORICAL AERIAL PHOTOGRAPHS AND FACILITY MAPS TO IDENTIFY OLD WASTE DISPOSAL AREAS AND GROUND-WATER FLOW PATHS

Points Illustrated

- Aerial photographs taken over many years in the life of a facility can be used to locate old solid waste management units (SWMUs).
- Historical aerial photographs can be used to identify geologic/topographic features that may affect ground-water flow paths.

Introduction

In gathering information pertaining to investigation of a release, historical aerial photographs and facility maps can be examined and compared to current aerial photographs and facility maps. Aerial photographs can be viewed as stereo pairs or individually. Stereo viewing, however, enhances the interpretation because vertical as well as horizontal spatial relationships can be observed. The vertical perspective aids in distinguishing various shapes, tones, textures, and colors within the study area.

Aerial photographs and facility maps can be used for the following:

- Providing evidence of possible buried drums. Historical photographs can show drums disposed of in certain areas where later photographs show no indications of such drums, but may show that the ground has been covered with fill material.
- Showing previous areal extent of landfill or waste management area. Earlier photographs might show a much larger waste management area than later photographs.
- Showing areas that were dry but now are wet, or vice versa, indicating a possible release from an old waste management area.

- Showing changes in land use patterns (e.g., a landfill in an early photograph could now be a park or be covered by buildings).

- Soil discoloration, vegetation damage, or enhanced vegetative growth can sometimes be detected, indicating possible contaminant migration.

- Geologic/hydrologic information, such as faults, fracture or joint systems, old stream courses (channels), and the contact between moraines and outwash plains.

Facility description

This facility is the same as previously described in Case Studies 7 and 8.

Data collection and analysis

Over the past 50 years aerial photographs were taken of the facility area. Interpretation of the photographs produced important information that is shown diagramatically in Figure 15-23. Solid Waste Disposal Area 2 (SWDA-2)was lower in elevation in 1940 than it is now. In fact, the area appears to have been leveled and is now covered by vegetation, making it difficult to identify as a SWMU at ground level. Another area was identified as a possible waste disposal area from a historical review of photos. Further study of photographs, facility maps and facility files revealed this to be a former Liquid Waste Disposal Area (LWDA), designated as LWDA-2 on Figure 15-23.

The use of these historical photographs also revealed geologic features that could affect the ground-water flow system under the facility. In this case, monitoring well data indicated a general northwesterly ground-water flow direction, in addition to a complex flow pattern near LWDA-1 and SWDA-1 (Figure 15-23). Recent photographs were analyzed, but because of construction and other nearby activities (e.g., cut and fill, sand and gravel mining) conclusions could not be drawn. A review and analysis of old photographs revealed the existence of a buried stream channel of the river (Figure 15-23). This buried stream channel was identified as a preferential path for ground water and consequently contaminant

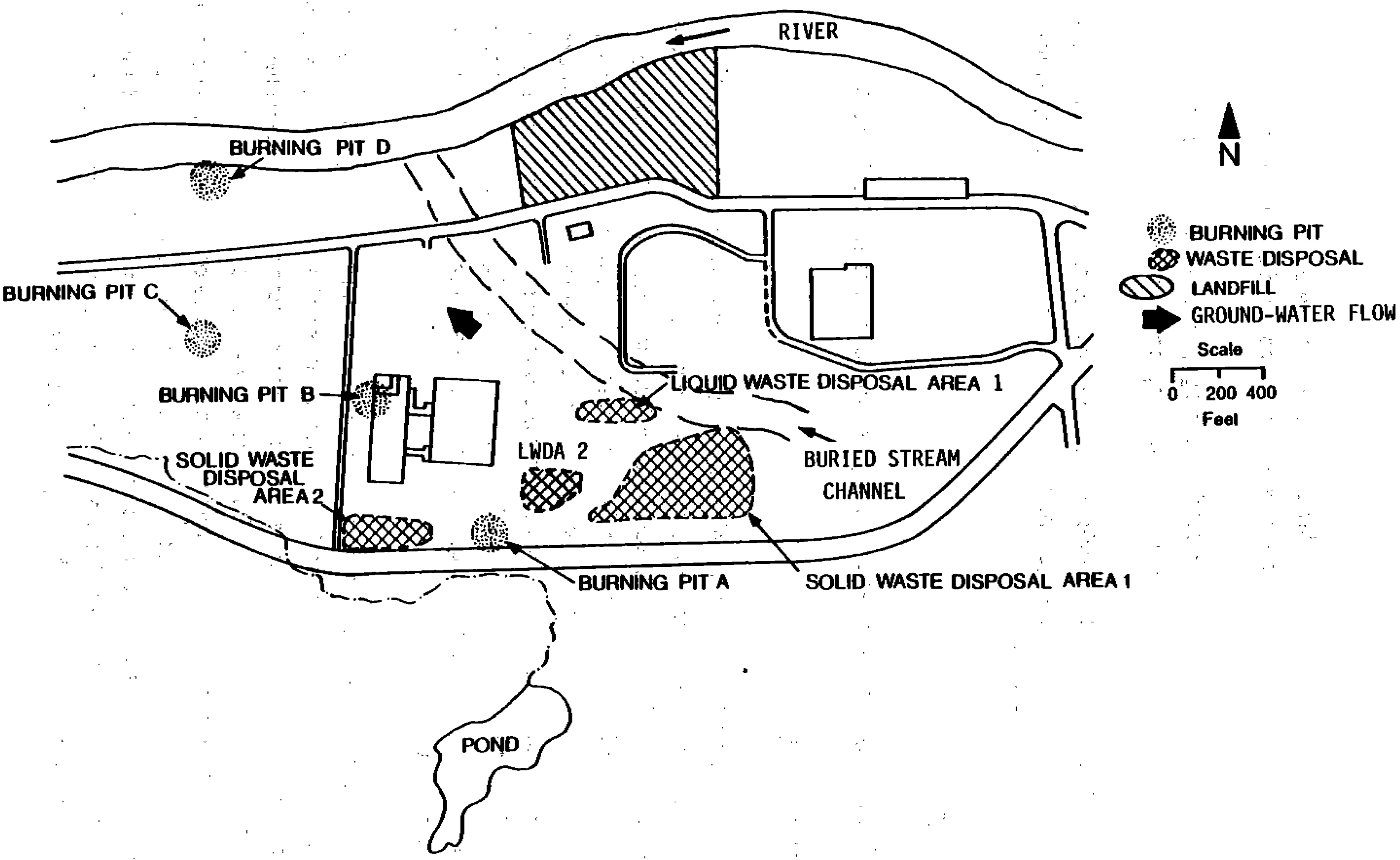


Figure 15-23. Site Layout. LWDA-2, SWDA-2 and Stream Channel Identified Through Use of Aerial Photograph Analysis

migration. Additional monitoring data and further analysis of subsurface geologic data is needed to determine the full impact of the buried stream channel on the ground-water flow regime.

Case Discussion

Analysis and interpretation of a series of historical aerial photographs and facility maps spanning a period of over 50 years enabled facility investigators to identify the following:

(1) Location of waste disposal areas (e.g., old SWMUs);

(2) Changes in topography (related to earlier disposal activities); and

(3) Possible preferential pathways (e.g., old stream channel) for migration of ground water and contaminants.

This information was used to identify areas for more detailed sampling and analysis.

Analysis of historical facility maps and historical aerial photographic interpretation can be a very powerfull tool in a RCRA Facility Investigation, but should be used in combination with other investigative techniques to result in a thorough characerization of the nature, extent, and rate of contaminant migration.

CASE STUDY 15: USING SOIL CHARACTERISTICS TO ESTIMATE MOBILITY OF CONTAMINANTS

Point Illustrated

- Information on soil characteristics can be used to estimate the relative mobility of contaminants in the surface environment.

Introduction

The relative mobility of contaminants can be estimated using soil characteristics and aquifer hydraulic characteristics. Although metals do precipitate at higher concentration, at the levels encountered in most subsurface environments, sorption is the dominant attenuation process. The degree to which a metal sorbs onto soil particles depends on the soil pH, the percent clay, the percent soil organic matter, the presence of particular coatings (e.g., iron, manganese, and aluminum oxide/hydroxides) and, to a lesser extent, the type of clay present. For organic contaminants, there are several processes which may be important in predicting their fate in soils. These include sorption, biodegradation, hydrolysis and, to a lesser extent, volatilization. The sorption of a given organic compound can be predicted based on its octanol-water partition coefficient, the percent organic carbon in the soil, and the grain-size distribution of the soil.

Determining the relative mobility of contaminants can be helpful in selecting appropriate sampling locations. For example, if wastes containing metals were present in an impoundment, samples to determine the extent of any downgradient metal contamination would normally be collected within a short distance of the impoundment. On the other hand, for fairly mobile waste constituents such as trichloroethylene (TCE), samples could be taken over a much larger downgradient distance. The case study presented below illustrates how contaminant mobility can be estimated.

Facility Description

A 17-acre toxic waste dump was operated in a mountain canyon for 16 years. The facility received over 32 million gallons of spent acids and caustics in liquid form. These wastes were placed in evaporation ponds. Other wastes sent to the facility included solvents and wastes from electroplating operations containing chromium, lead, mercury and zinc. Pesticides including DDT had been disposed of in one corner of the site.

Site Description

The site was underlain by alluvium and granitic bedrock (Figure 15-24). The bedrock, as it was later discovered, was fractured to depths of between 50 and 100 feet. Ground water occurred in the alluvial deposits at depths of 10 to 30 feet. Several springs existed in the upgradient portion of the site. A barrier dam was built across part of the canyon at the downgradient edge of the site in an effort to control leakage. Because of the extensive fracture system, this barrier was not effective. Instead, it appears to have brought the ground-water table up into the wastes and, at the same time, pressurized the underlying fracture system, thereby creating seepage of contaminated water under the dam.

Estimation of Contaminant Mobility

Because of the variety of constituents accepted at this site, an estimate of their relative mobility was needed prior to designing the remedial investigation. The first step was to estimate the average linear velocity using the following equation:

$$\bar{v} = \frac{Ki}{\eta_e}$$

where

$\bar{v}$ = horizontal seepage velocity, ft/day
K = hydraulic conductivity, ft/day
i = ground-water gradient
η_e = effective porosity, decimal fraction.

The hydrogeologic data needed were obtained from existing site assessment reports. The alluvium underlying the site had an average hydraulic conductivity of 0.8 ft./day and an estimated effective porosity of 11 percent. The average ground-

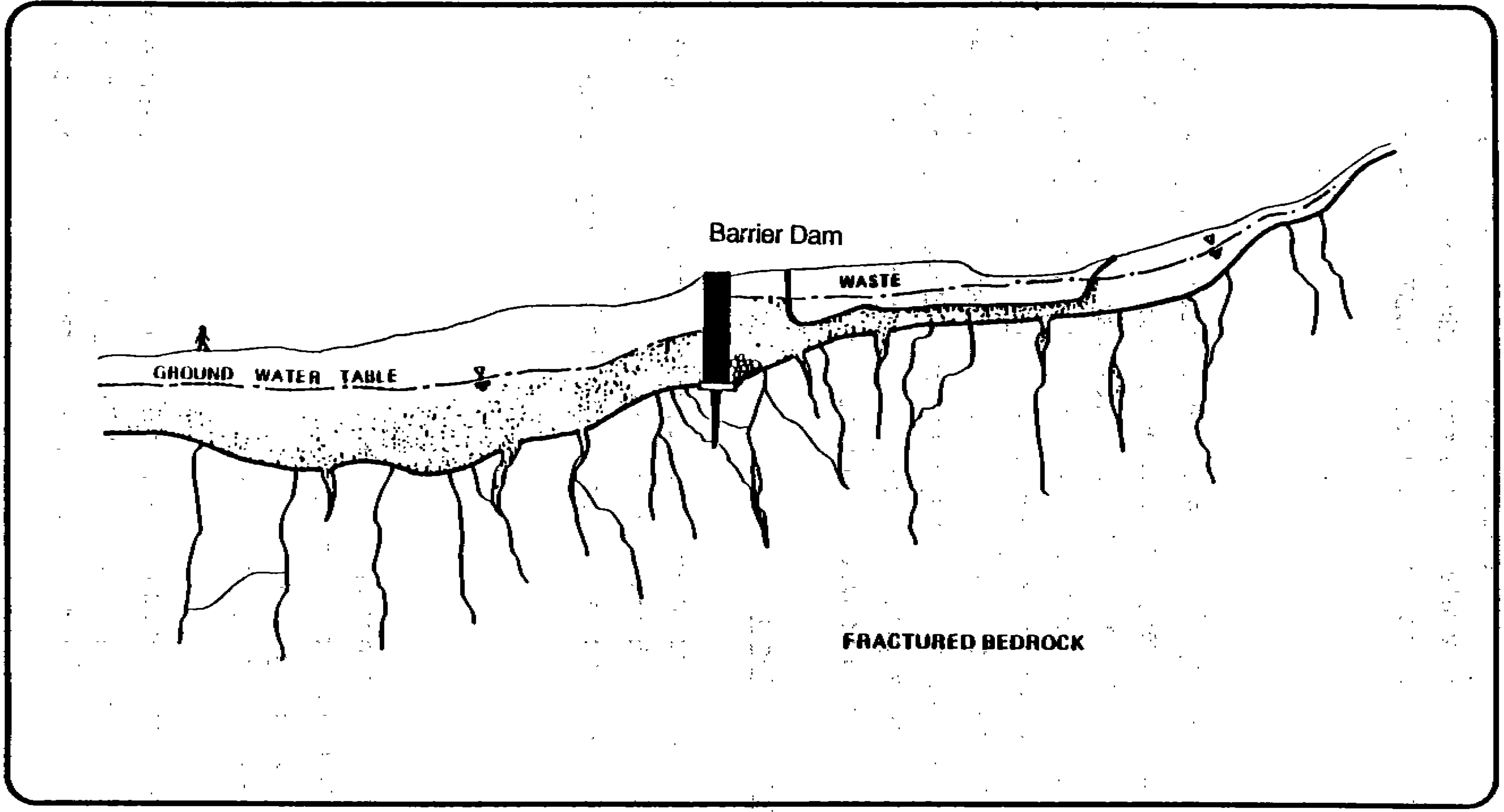


Figure 15-24. Schematic Cross-Section of Waste Disposal Site

water gradient below the site was 0.06. Using the above equation, the average linear velocity was estimated to be 160 ft/yr. This represents the average velocity at which a conservative constituent would migrate downgradient along the centerline of the plume. Examples of such constituents include chloride and bromide. As shown in Table 15-10, nitrate and sulfate also behave conservatively in many cases. Due to the absence of highly weathered, sesquioxide soils, sulfate behaved conservatively at this site. Using the above average linear velocity, an estimate was made of the distance a conservative solute would travel in a given time (T) using $d = \nu \cdot T$. Limited water quality data were available for 1980. Wastes were first disposed at this site in 1956. The average extent of plume migration along the centerline was thus estimated to be 3800 feet.

With respect to metals, additional data were needed to estimate their fate including soil pH, presence of carbonates, organic ligands, and percent soil organic matter and clay. At this site, the soil PH varied from less, than 3.0 within 400 feet of the acid ponds to 7.2 at a distance 2000 feet downgradient. As shown in Figure 15-25, the partition coefficients for metals are dependent on pH and organic matter content. For example below a pH of 5.6, for the types of soil encountered at the site, the partition coefficient (Kp) for cadmium is about 10 ml/g. At a pH of 7.2, Kp is about 6500 ml/g, (Rai and Zachara, 1985). The relative mobility of attentuated constituents can be estimated as follows (Mills et al., 1985):

$$V_A = \nu / R_d$$

where

V_A = average velocity of attenuated consitutent along centerline of plume, ft/day

ν = average linear velocity as defined above, ft/day

R_d = retardation factor (unitless)

and

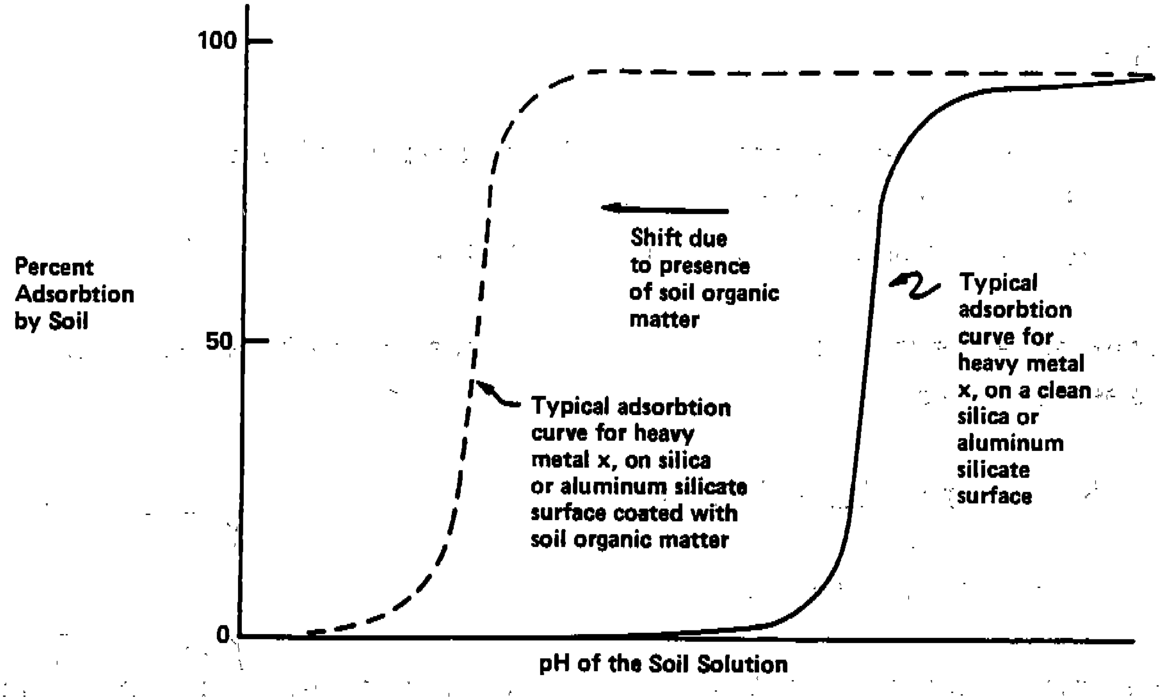
$$R_d = 1 + \frac{K_p \rho B}{n_e}$$

TABLE 15-10

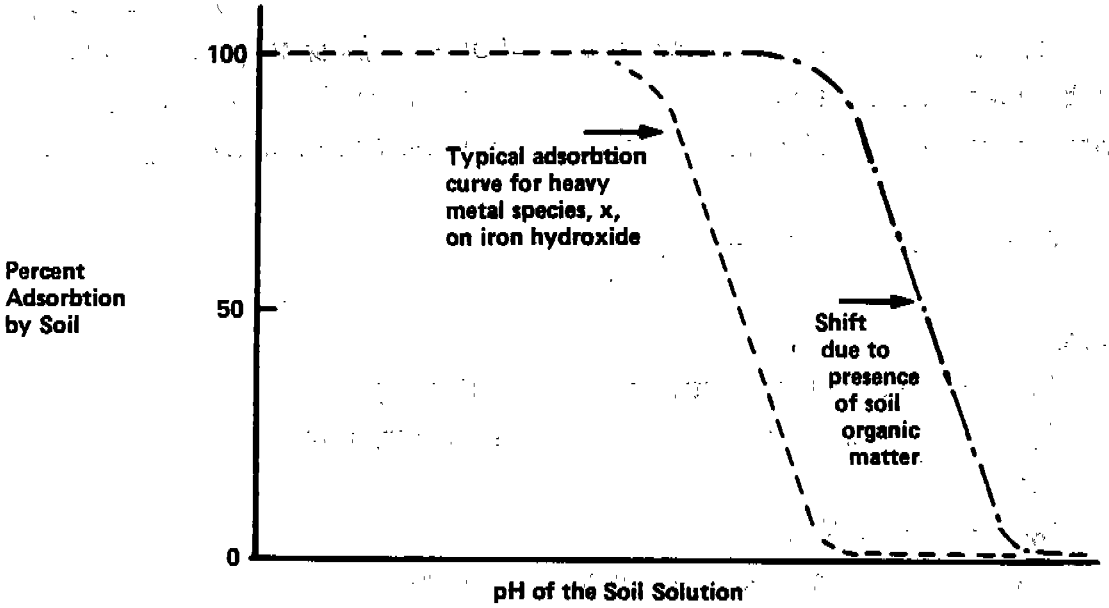
RELATIVE MOBILITY OF SOLUTES

Group	Examples	Exceptions	Master Variables*
Conservative	TDS CL^- BR^- NO_3^- SO_4^{2-}	 Reducing conditions Reducing conditions and in highly weathered soils coated with sesquioxides	ν
Slightly Attenuated	B TCE	Strongly acidic systems Anaerobic conditions	ν, pH, organic matter ν, organic matter
Moderately Attenuated	Se As Benzene		ν, pH, Fe hydroxides ν, pH, Fe hydroxides ν, organic matter
More Strongly Attenuated	Pb Hg Penta-chlorophenol		ν, pH, SO_4^{2-} ν, pH, C1 ν, organic matter

* Variables which strongly influence the fate of the indicated solute groups. Based on data from Mills et al., 1985 and Roi and Zachara, 1984.



a) Generalized Heavy Metal Adsorbtion Curve for Cationic Species (e.g., $CuOH^+$)



b) Generalized Heavy Metal Adsorbtion Curve for Aniotic Species (e.g., CrO_4^{2-})

Source: (Mills et al., 1985).

Figure 15-25. Hypothetical Adsorption Curves for a) Cations and b) Anions Showing Effect of pH and Organic Matter where

K_p = soil-water partition coefficient for solute of concern, ml/g
ρB = soil-bulk density, g/mL
η_e = effective soil porosity (decimal fraction).

For example, the relative mobility of cadmium at a pH of 7.2 was estimated for this site as shown below:

$$R_d = 1 + \frac{6500(1.7)}{0.11} = 100,456$$

$$V_A = 160/100,000 = 0.002 \text{ ft/yr}$$

This estimate was consistent with the field data which indicated that the metals migrated only until the pH of the contaminant plume was neutralized, a distance of about 2000 feet. Cadmium concentrations decreased from 1.3 mg/l at a distance of 1400 feet from the ponds to below detection (<0.1 µg/l) at a distance of 2000 feet.

Estimates of mobility for organic contaminants which sorb onto soil particles can be made in an analogous manner. The partition coefficient for organic constituents can be calculated using the following equation (Mills et al., 1985):

$$K_p = K_{oc}[0.2(1-f)X^s_{oc} + fX^f_{oc}]$$

where
K_p = soil-water partition coefficient, ml/g
K_{oc} = organic carbon partition coefficient, ml/g
and
K_{oc} = $0.63\ K_{ow}$
K_{ow} = octanol-water partition coefficient
f = $\dfrac{\text{mass of silt and clay } (0<f<1)}{\text{mass of silt, clay and sand}}$
X^s_{oc} = organic fraction of sand ($X^s_{oc} < 0.01$)
X^f_{oc} = organic-fraction of silt-clay ($0 < X^f_{oc} < 0.1$).

For example, the solvent trichloroethylene (TCE) has a K_{ow} valueof200. Using the above equation and site data (f = 0.1, X^{s}_{oc} = 0.001, X^{f}_{Oc} = 0.01), the partition coefficient K_p was estimated to be 0.2 ml/g. The relative mobility of TCE at the site was then estimated to be approximately 40 ft/yr (R_d = 4 and V_A = 40 ft/yr). Methods for considering-additional processes influencing-the fate of organics (e.g., hydrolysis and biodegradation) are presented in the manual entitled Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Ground Water (Mills et al., 1985).

Case Discussion

As shown in Figure 15-26, contaminants downgradient of a waste disposal site may migrate at different speeds. Using the methods illustrated above, estimates of the relative mobility of constituents can be made. Such estimates can then be used to locate downgradient monitoring wells and to assist in the interpretation of field data.

References

Mills, W.B., D.B. Porcella, M.J. Ungs, S.A. Gherini, K.V. Summers, L. Mok, G.L. Rupp, and G.L. Bowie, 1985 Water Quality Assessment: A Screening Procedure' for Toxic and Conventional Pollutants in Surface and Ground Water. EPA/600/6-85/002a, Vol. I, II and III.

Rai, D. and J.M. Zachara. 1984. Chemical Attenuation Studies: Data Development and Use. Presented at Second Technology Transfer Seminar: Solute Migration in Ground Water at Utility Waste disposal Sites. Held in Denver, Colorado, October 24-25,1985.63 pp.

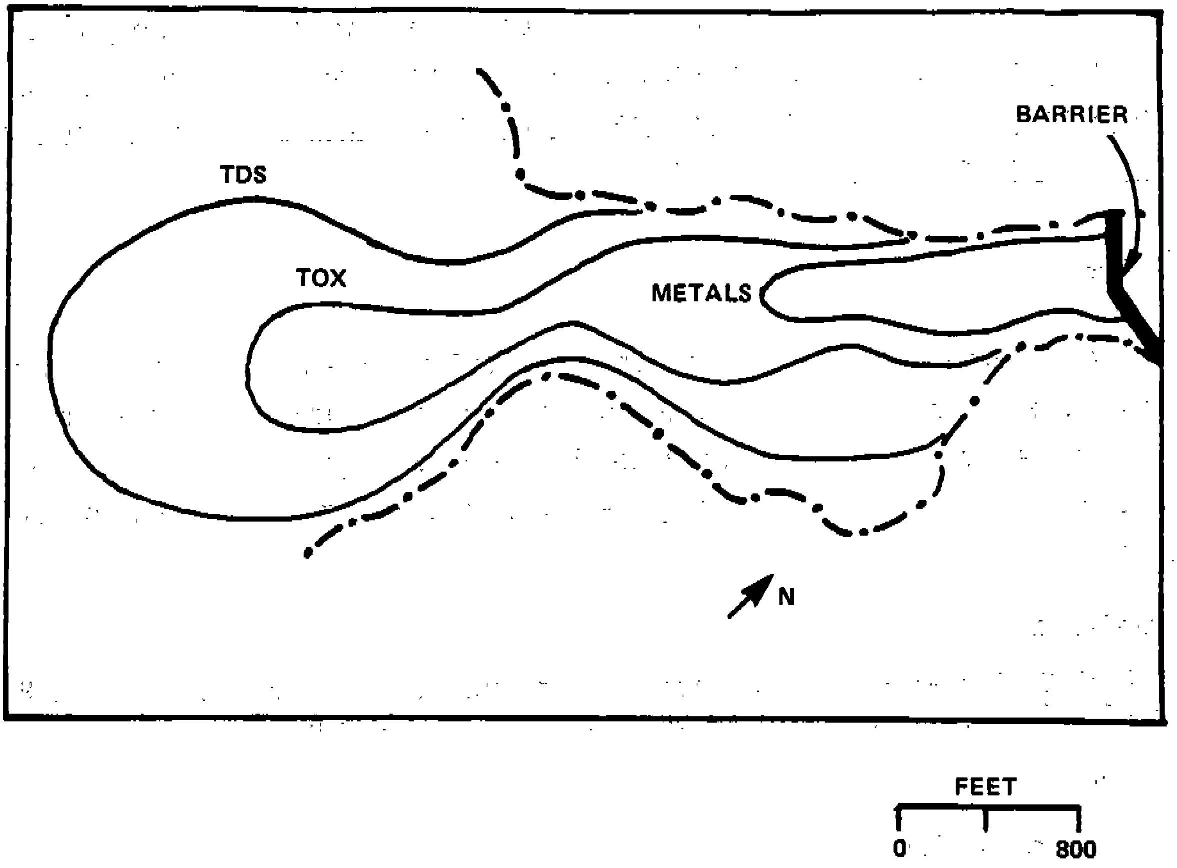


Figure 15-26. Schematic Diagram Showing Plumes of Total Dissolved Solids (TDS), Total Organic Halogens (TOX) and Heavy Metals Downgradient of Waste Disposal Site

CASE STUDY 16: USE OF LEACHING TESTS TO PREDICT POTENTIAL IMPACTS OF CONTAMINATED SOIL ON GROUND WATER

Point illustrated

- Soil leaching tests can be used in conjunction with waste and site-specific factors to predict potential impacts on ground water.

Introduction

Contaminated soil, whether deep, or surficial in nature, has the potential to impact ground water, primarily through leaching. In many cases, soil contamination has already lead to contamination of the ground water and decisions can be made regarding clean-up of the contaminated soil and ground water based on the constituent concentrations observed in these media. However, in cases where contaminated soil has not yet resulted in contaminated ground water, but has some potential to do so, decisions need to be made regarding the contaminated soil and whether it should be removed or some other action-should be taken because of the soil's potential to contaminate ground water above levels of concern. This evaluation may be especially critical in those cases where only deep soils are contaminated, or where constituent concentrations within surficial soils do not exceed soil ingestion criteria. Both theoretical (mathematical) and physical (leaching test) models can be used in this evaluation, as well as or in conjuration with a qualitative evaluation of release and site-specific factors. This case illustrates the, use of leaching tests and consideration of release and site-specific factors to determine whether contaminated soil has the potential to contaminate ground water above levels of concern.

Facility Description

The facility is an industrial chemical and solvent facility located on a leased 2.5 acre site within the corporate limits of a major city in the north-central United States (see Figure 15-27). Periodic overtopping of the surface impoundment, which is now empty, and suspected contamination of the soil with organic solvents from the surface impoundment, resulted in an RFI in which the facility was directed to characterize the nature, extent and rate of release migration.

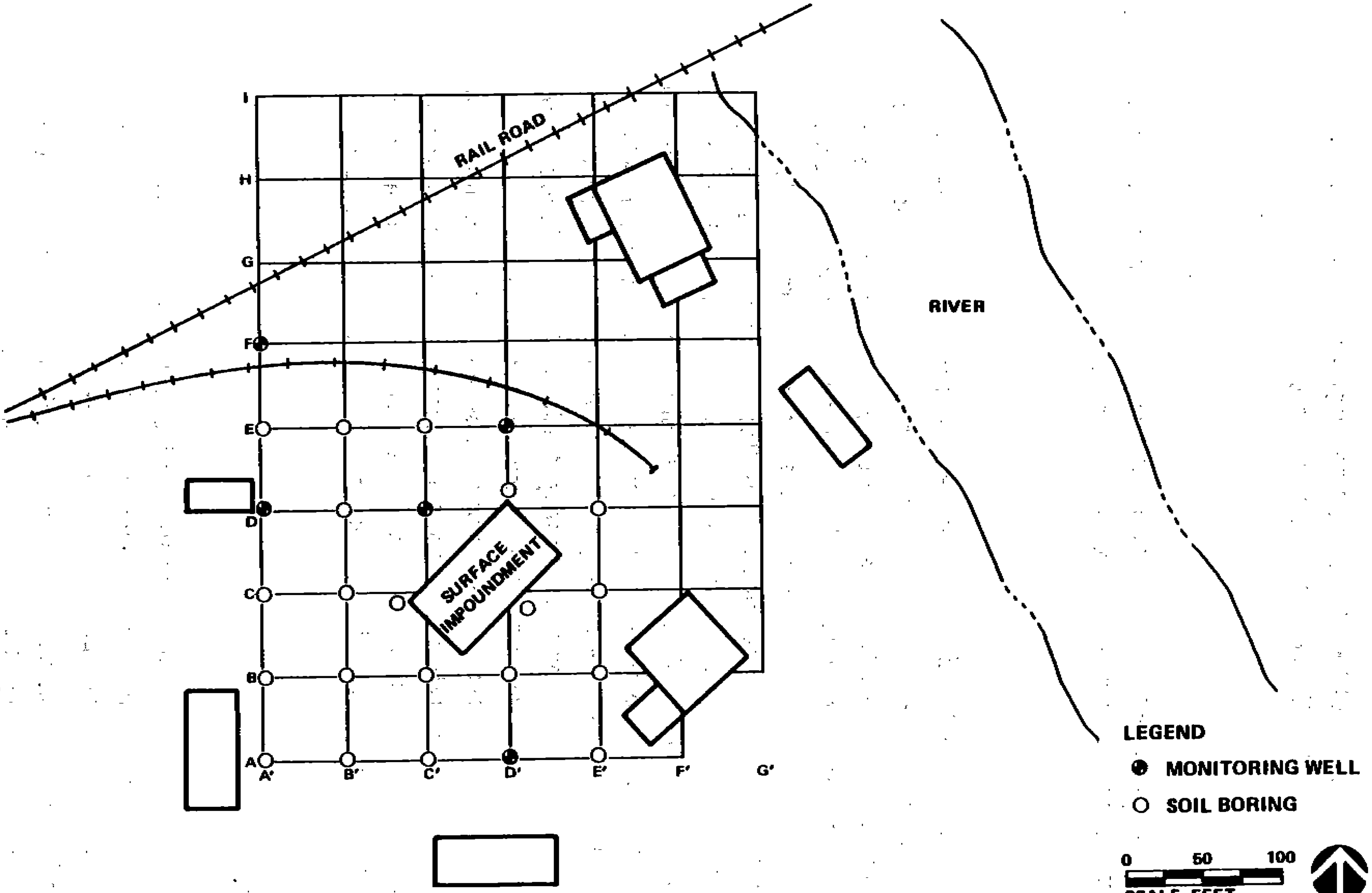


Figure 15-27. Facility Map Showing Soil Boring And Well Installation

Release characterization revealed that the soil surrounding the surface impoundment, which was mostly fine sand and silt with some clay, was contaminated with tetrachloroethylene and 1,1,1 -trichloroethane at concentrations ranging from 0.05 to 0.10 and 2 to 20 mg/kg, respectively. This contamination was observed at depths of up to 5 feet, which was approximately 20 feet above the water table (i.e., the water table was approximately 25 feet, below the land surface). The soil beneath the site was relatively permeable, with a hydraulic conductivity of approximately $9x10^{-4}$ cm/sec.

Ground-water monitoring conducted during the RFI showed no current contamination of the ground water, which flows in a northerly direction and eventually intersects the river (Figure 15-28). The river is used for irrigation and drinking at downstream locations. Grab. samples taken from the river and river sediments showed no contamination.

The soil in the immediate vicinity of the railroad spur also showed isolated pockets of mercury contamination ranging in--concentration from 1 to 2 mg/kg, and to a depth of 1 foot below the land surface. The source of the mercury contamination could not be determined.

Contamination Evaluation

The relevant health and environmental (HEA) criteria, the constituent concentrations observed at the site, and selected physical/chemical properties for the three constituents are shown in Table 15-11. Although comparison of the HEA criteria for ingestion with the consituent concentrations observed at the site showed no exceedances, the regulatory agency overseeing the RFI was concerned that leaching of the contaminated soil could lead to eventual contamination of the underlying ground water. This concern was based on the relatively high permeability of the soils beneath the site and the relatively high mobility of the two organic constituents detected. The facility obtained the regulatory agency's approval to conduct a leaching evaluation using EPA's Method 1312 (Synthetic Acid Precipitation Leach Test for Soils).

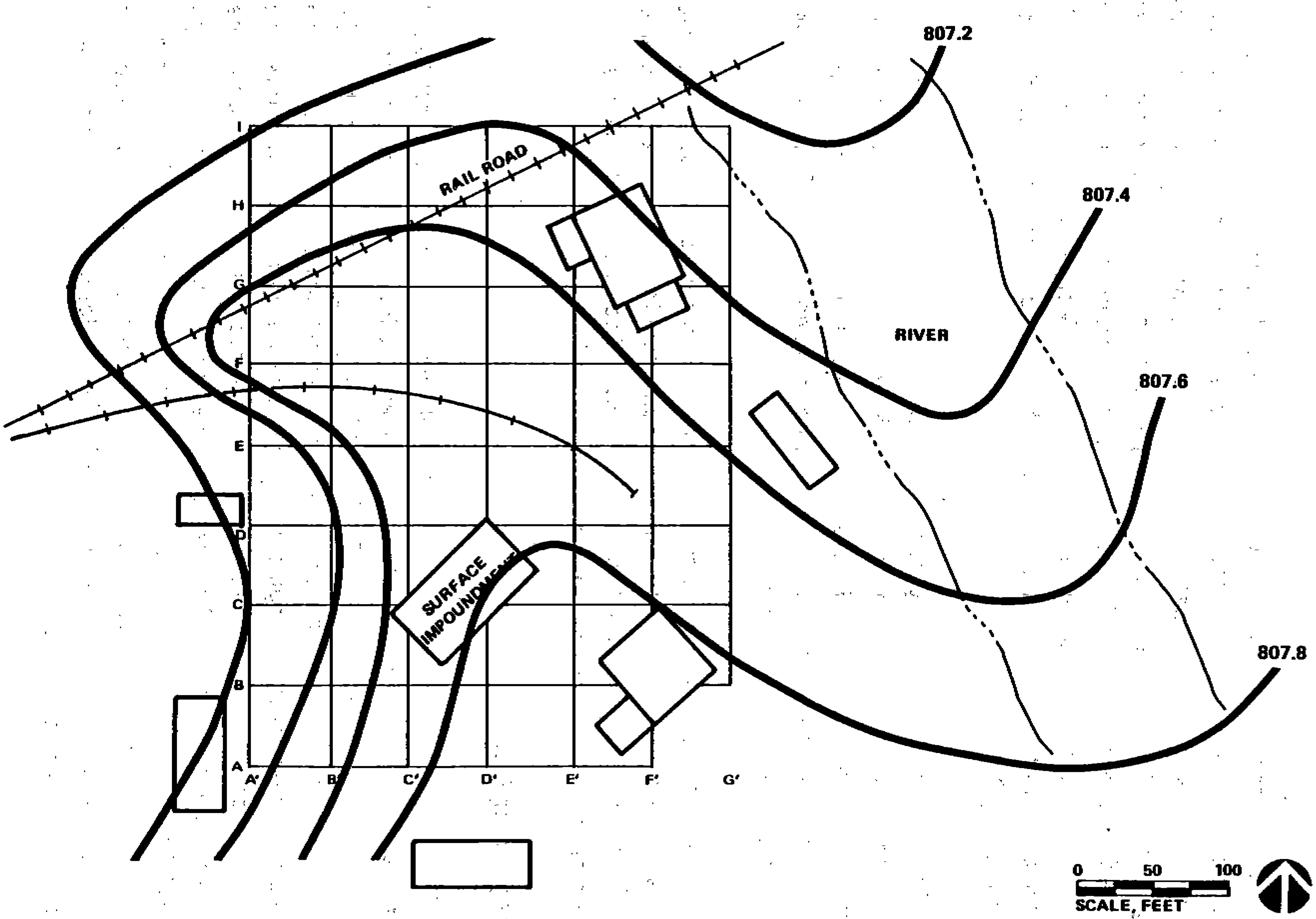


Figure 15-28. Facility Map Showing Ground-Water Contours

TABLE 15-11

HEA CRITERIA, CONSTITUENT CONCENTRATIONS AND RELEVANT PHYSICAL/CHEMICAL PROPERTY DATA FOR CONSTITUENTS, OBSERVED AT SITE

Chemical	CAS No.	HEA Criteria (Ingestion) (mg/kg)	H_2O Sol (mg/l)	HEA Criteria (Water) (mg/l)	Constit. Conc. (mg/kg)	Koc (mg/l)	Log Kow	Det. Limit* (mg/l)
Tetrachloroethylene	127 -18-4	69	150	0.0069	0.10	364	2.6	0.01
1,1,1-Trichloroethane	71-55-6	2,000	1500	0.2	20	152	25	0.01
Mercury	7439-97-6	- -	- -	0.002	2	Low	- -	0.0004

* Detection limits presented are those for water. Detection limits for soil vary greatly, but may be assumed to be approximately 1 mg/kg.

Leaching Evaluation

Prior to collecting samples and applying the leaching test, the facility first decided to determine if the contaminated soils could possibly result in leaching test (extract) concentrations that exceed the relevant HEA criteria (See Table 15-11). To do this, the facility calculated the maximum theoretical extract concentration by assuming that 100 percent of the constituents would leach from the soil. The

$$\begin{array}{l}\text{Maximum Theoretical}\\ \text{Extract Concentration(mg/l)}\end{array} \qquad \frac{\begin{array}{c}\text{Concentration of Toxicant}\\ \text{in Soil (mg/kg)}\end{array}}{20}$$

where 20 refers to the liquid to solid ratio applied in EPA Method 1312.

Using this simple equation, the facility determined that the maximum leachate concentration for tetrachloroethylene was, in fact, below the HEA criteria for water (see Table 15-11), and that the level could not possibly be exceeded even if 100 percent of the contaminant leached from the waste. For 1,1,1-trichloroethane and mercury, however, it was determined that the HEA criteria level could be reached if only a portion of the contaminant present leached from the soil, and that application of the leaching test would be necessary. Using this screening-type evaluation, the facility was able to reduce the number of constituents that would need to be analyzed when applying the leaching test, from three to two.

Samples of the contaminated soil were then collected at selected locations (i.e., those expected to produce the more heavily contaminated samples) and Method 1312 applied. Total constituent analyses were also conducted in order to ensure that the samples represented the more heavily contaminated areas of the site. Analyses of the soils and leaching test extract were conducted for 1,1,1-trichloroethane and mercury. The results are shown in Table 15-12.

The leaching test results for 1,1,1-trichloroethane and mercury showed extract concentrations above the respective HEA criteria (action levels) for these

TABLE 15-12

LEACHING TEST RESULTS (mg/l)*

Constituent	D-C′	C-C′	C-B′
1,1,1-Trichloroethane	0.3	0.2	0.5
Mercury	0.002	0.002	0.003

* Resampled at locations close to original sampling point. Samples analyzed are result of composite of three grab-samples. All samples were taken from the top 0-1 ft of the soil surface.

constituents, indicating that there might be a basis to require some sort of corrective action. The facility, however, presented arguments to show that mercury would be attenuated in the soil column as the leachate percolates towards the water table, and that 1,1,1-trichloroethane would be degraded to below the level of concern in the ground water. Below is a synopsis of the two arguments.

Mercury: The facility first examined theoretical Eh-pH fields of stability for the various aqueous mercury species, determined that the predominant mercury species would be elemental mercury, and further predicted (using Eh-pH diagrams) that the maximum equilibrium concentration of elemental mercury in water would be 0.025 mg/l. The facility interpreted the substantially lower leaching test concentration to indicate that attenuation processes such as sorption play a major role in restricting the mobility of elemental mercury. The facility cited high soil/water partition coefficients (i.e., Kd values), and several scientific studies to further support their contention that mercury would strongly sorb to both organic and inorganic components of the soil before any leachate reached the ground water.

1,1,1-Trichloroethane: The facility recognized that due to its high solubility (1500 mg/l) and low Kd (0.011 ml/g), 1,1,1-trichloroethane would not be attenuated appreciably as the leachate percolates towards the water table. The facility argued, however, that abiotic hydrolysis would significantly degrade 1,1,1-trichloroethane during leaching. Several environmental half-life studies were cited which indicated that the half life for 1,1,1-trichloroethane ranged between 0.5 and 2.5 years. Based on these studies, the facility predicted that 1,1,1-trichloroethane would be degraded to below levels of concern within one to three years. Using additional site information and simple time of travel calculations, the facility predicted that concentration levels for 1,1,1-trichloroethane would be decreased to below the level of concern well before reaching any potential receptors.

The regulatory agency’s evaluation of the facility’s arguments is presented below:

Mercury: The facility’s argument with respect to mercury is essentially correct if it can be assumed or proven that the mercury originally present at the site is inorganic in nature. If, however, the mercury present is organic in nature (e.g., methyl mercury), the potential for migration of the mercury is, substantially increased. Organic mercury compounds generally have higher volatility, higher solubility, and much lower Kd values, than inorganic mercury compound. It should also be noted that even if the original release was of inorganic mercury, biotransformation (i.e., biomethylation) of elemental mercury may occur. The facility should be required to determine the actual form(s) of mercury present at the site.

1,1,1-Trichloroethane: The facility's argument with respect to 1,1,1-trichloromethane raises many technical questions. For example, the facility uses published data, on the half life of 1,1,1-trichloromethane, which may not be applicable to the facility's soil and ground-water environment. As another example, the half-life degradation, rate argument may only be applicable for ground-water transport. The facility does not address degradation in soil or effects on surface water (assuming that contaminated ground-water will eventually migrate to the river). Most important, however, is the fact that the facility did not address the degradation products of 1,1,1-trichloroethane, one of which is 1,1-dichloroethylene, which is also a hazardous constituent. 1,1,1-trichloroethane should be assumed to pose a threat to ground water.

Conclusions

The next step in the RFI process would be to determine if interim corrective measures or a Corrective Measure Study was warranted for the release. Although none of the soil ingestion HEA criteria were exceeded at the site, application of the leaching evaluation indicated that 1,1,1-trichloroethane could leach to ground water and result in exceedance of the HEA criterion for water. On, this basis, the facility should be directed to perform a Corrective Measures Study.

To prevent further contaminant migration, the application of interim corrective measures may also be considered. Construction of a temporary cap over the contaminated area is one option Perhaps a more appropriate measure would be to remove the contaminated soil. Such an action, taken as an interim corrective measure, may negate the need for a formal Corrective Measures Study.

Case Discussion

Leaching tests and similar evaluations (e.g., application of validated mathematical leaching models) can be used to identify potential problems due to leaching of contaminated soils. In this case; application of a leaching evaluation was instrumental in identifying a potential threat to ground water as a result of leaching of contaminated soil. This finding was particularly significant as HEA ingestion criteria were not exceeded.

It should be noted, however, that in some cases leaching tests may provide result that are difficult to interpret. For example, consider what would have happened if the soil underlying the facility was predominantly clay with a permeability on the order of 10^{-8} cm/sec. In this case, demonstrating” that leaching will most likely occur within the foreseeable future may be difficult. As another example, if the soil underlying the facility were predominantly sand, leaching would be probable. In both these cases, application a leaching test may not provide any more useful information than is already available. Careful consideration of release and site-specific information is always warranted prior to application of leaching tests.

CASE STUDY 17: USE OF SPLIT-SPOON SAMPLING AND ON-SITE VAPOR ANALYSIS TO SELECT SOIL SAMPLES AND SCREENED INTERVALS FOR MONITORING WELLS

Point Illustrated

- HNU and OVA/GC screening can provide a relative measure of contamination by volatile organics. It can be used to select soil sample locations and can assist in the selection of screened intervals for monitoring wells.

Introduction

On-site vapor screening of soil samples during drilling can provide indications of organic contamination. This information can then-be used to identify apparent hot spots and to select soil samples for detailed chemical analyses. In this manner, the use of higher powered laboratory methods can be focused in an effective way on the analysis of samples from critical locations and depths. The vapor analyses on site can also be helpful in selecting screened intervals for monitoring wells.

Facility Description and History

Manufacturing of plastics and numerous other chemicals has occurred at the site over the past 30 years. Some of the major products included cellulose nitrate, polyvinyl acetate, phenol, formaldehyde, and polyvinyl chloride. The entire site covers l,OOO acres. The location of the buildings and waste disposal areas are shown in Figure 15-29. This is the same facility as used in Case Studies 7,8 and 14.

Three disposal methods are known to have been employed at the site. Readily combustible materials were incinerated in four burning pits, while non-combustibles were either disposed of in landfills or in a liquid disposal area. All on-site disposal operations were terminated in 1970, and monitoring programs have been implemented to identify contaminants, define and monitor ground-water contaminant plumes, and assess the resulting environmental impacts.

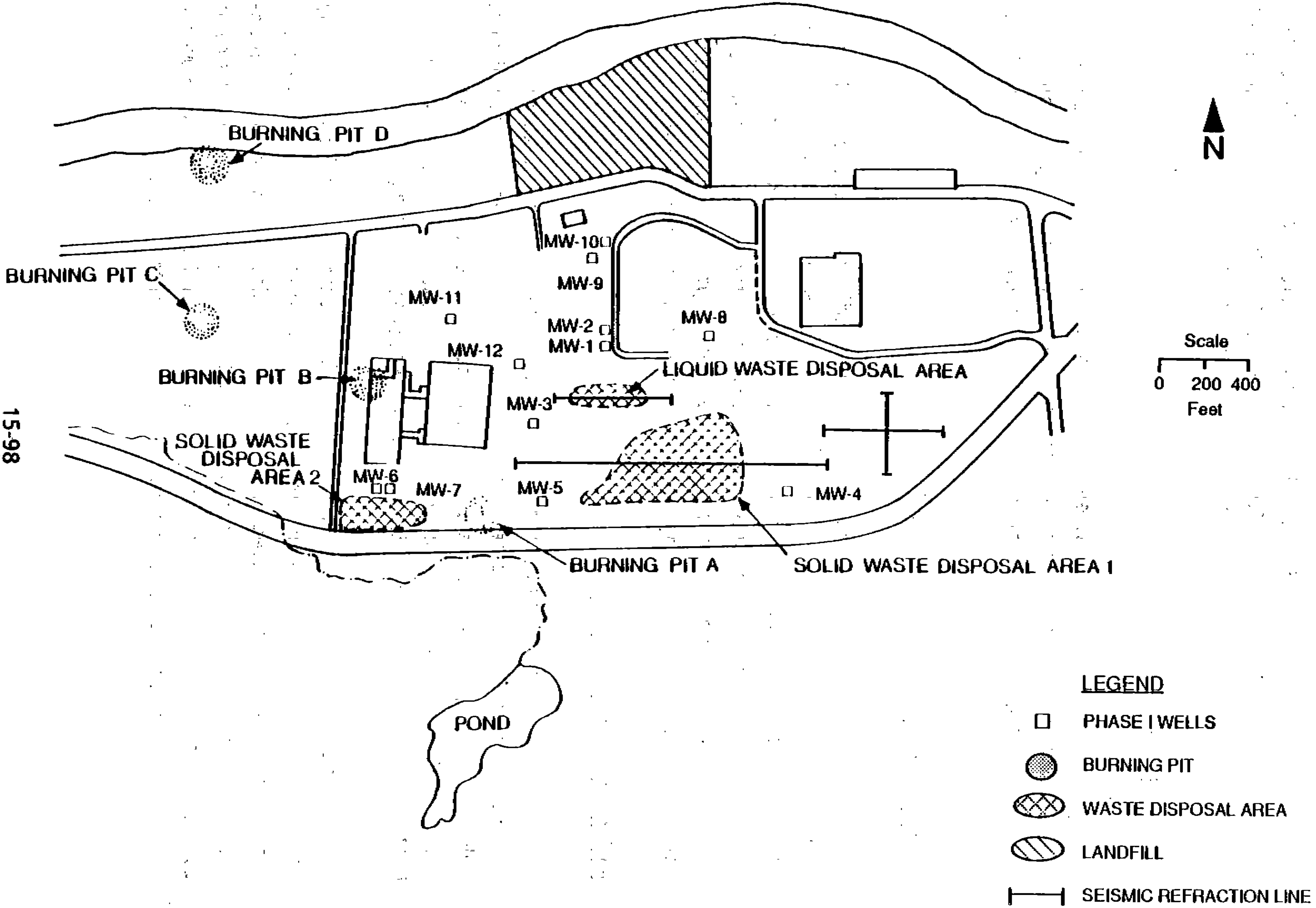


Figure 15-29. Site Plan Showing Disposal Areas and Phase I Well Locations

Geologic and Hydrologic Setting

The site is located in a well-defined glacial valley, adjacent to a river. Three major units underlie the site, consisting primarily of sand and gravel outwash deposits; fine-grained lacustrine sands; and till. The middle sand unit contains lenses of silt, clay and till. Only the deep till formation appears to be continuous across the site. A geologic cross-section beneath two of the disposal areas is shown in Figure 15-30.

The ground-water flow direction at the site is to the northwest. However, there appears to be a buried stream channel running across the site which strongly influences the local ground-water flow regime (see Figure 15-31). Ground water from the site is thought to discharge to the river. The depth to ground water varies from 10 to 40 feet.

Sampling Program

As part of the remedial investigation at this site, 33 borings were drilled using a hollow-stem auger rig. Continuous soil samples were collected using split-spoon samplers. Samples for laboratory chemical analysis were selected based on the volatile organic concentrations detected by initial vapor screening of the soil samples in the field.

This field screening was achieved by placing a portion of each sample core in a 40 ml glass headspace vial. An aliquot of gas was extracted from the vial and injected directly into a portable OVA gas chromatography (OVA/GC). The chromatography was equipped with a flame. ionization detector to identify hydrocarbons. Each sample was also screened using an HNU photoionization detector because of its sensitivity to aromatic hydrocarbons, particularly benzene, toluene and the xylenes. Following completion of drilling, gamma logs were run on ail boreholesi

An example of the vapor screening results (HNU and OVA/GC) and geological and gamma logs for one of the boreholes are shown in Figure 15-32. The data shown demonstrate the differential sensitivity of the HNU and OVA/GC detectors. Because the OVA/GC is more sensitive to the organics of interest (aliphatics),

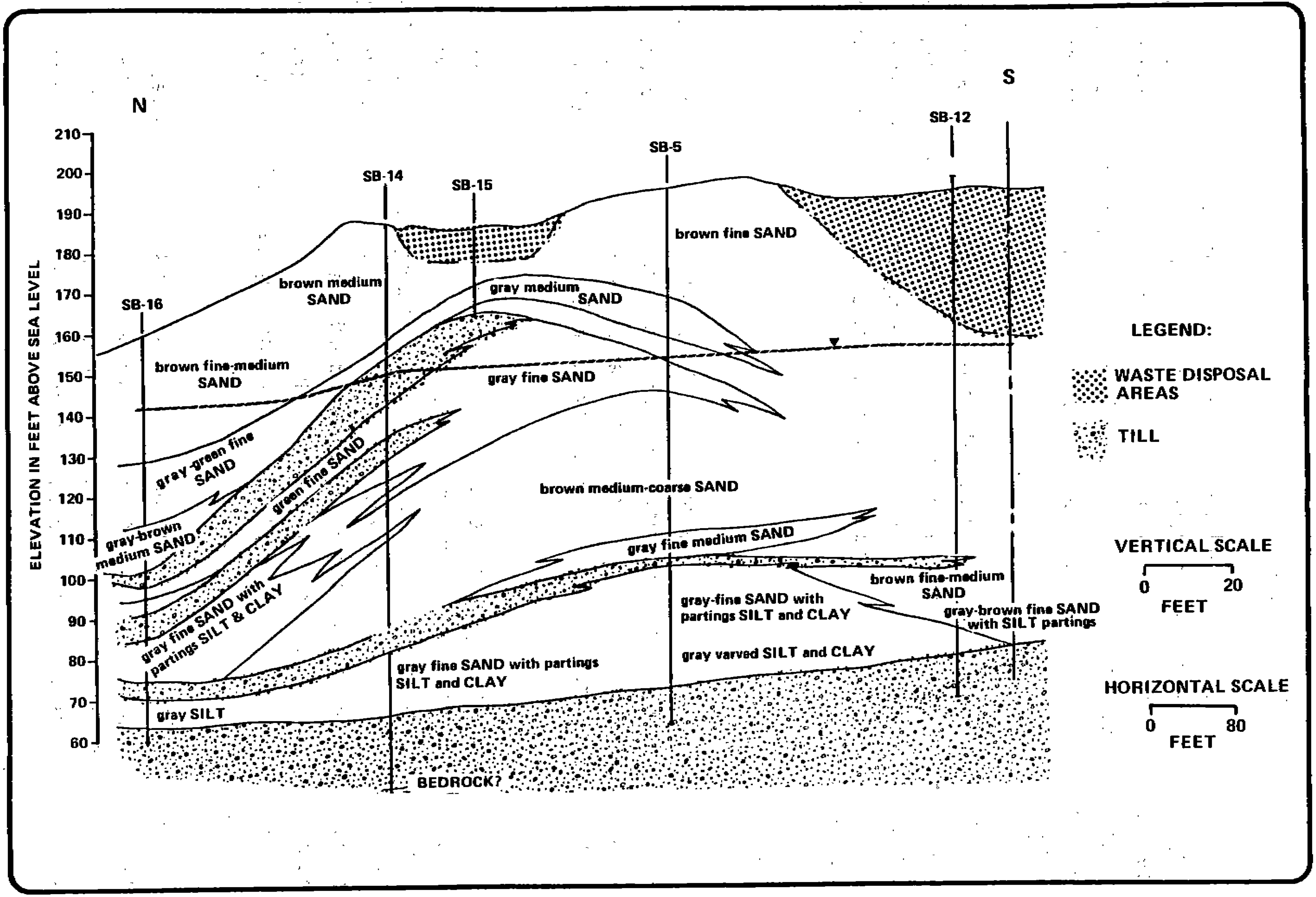


Figure 15-30. Geologic Cross-Section Beneath Portion of Site

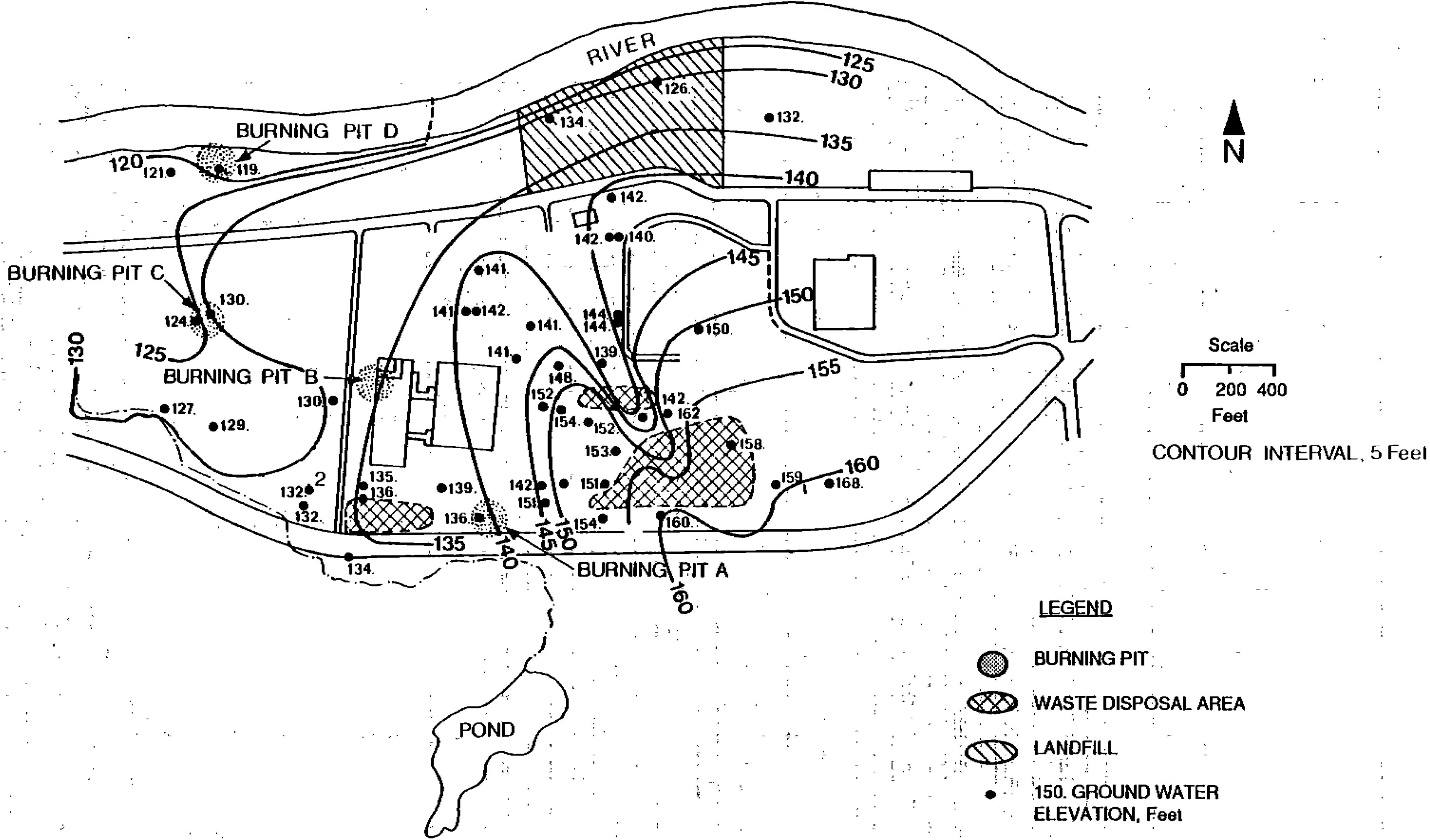
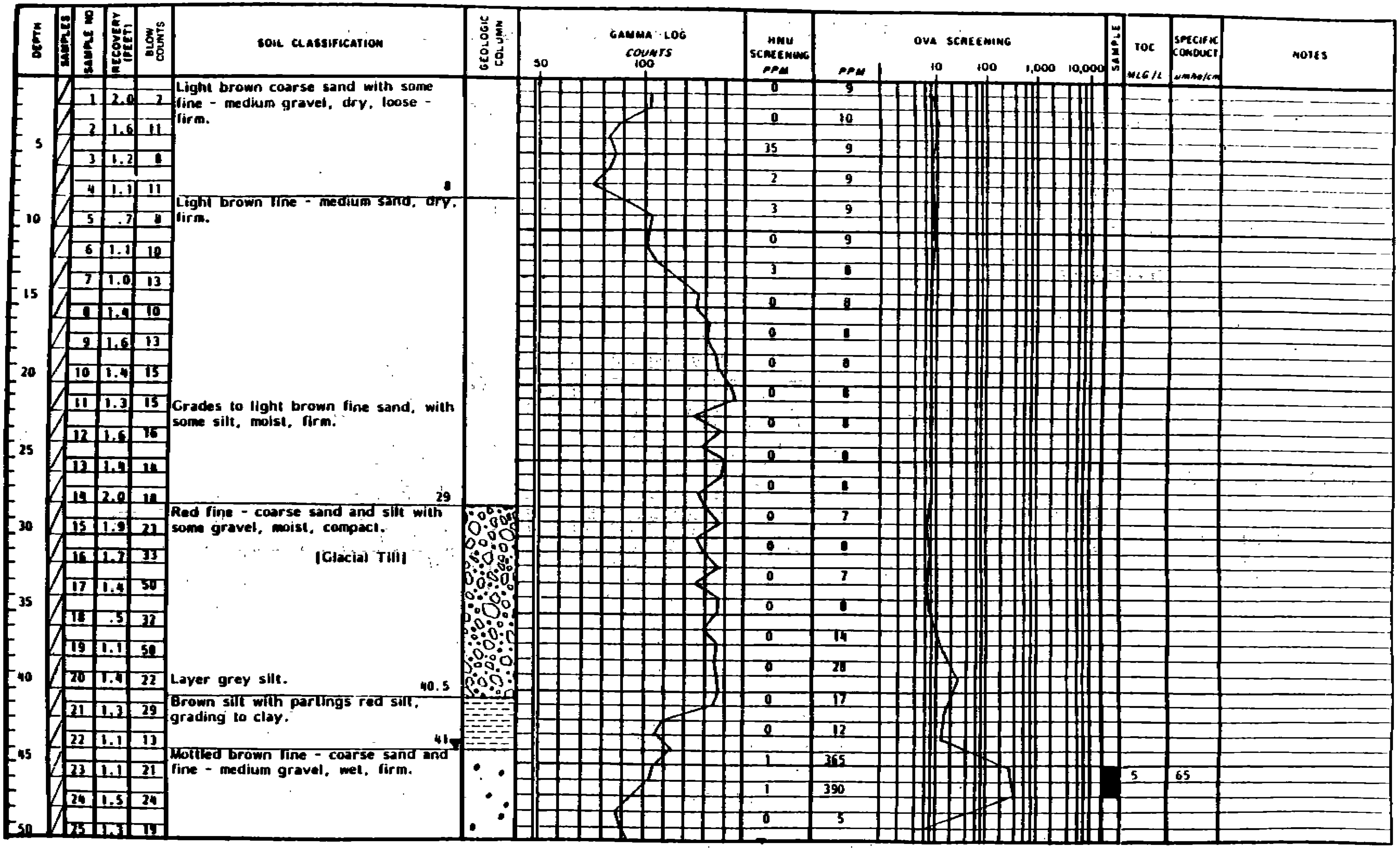


Figure 15-31. Ground-Water Elevations in November 1984



SAMPLE NO	RECOVERY (FEET)	BLOW COUNTS	HNU SCREENING PPM	OVA SCREENING PPM	TOC MLG/L	SPECIFIC CONDUCT umho/cm
1	2.0	2	0	9		
2	1.6	11	0	10		
3	1.2	8	35	9		
4	1.1	11	2	9		
5	.7	8	3	9		
6	1.1	10	0	9		
7	1.0	13	3	8		
8	1.4	10	0	8		
9	1.6	13	0	8		
10	1.4	15	0	8		
11	1.3	15	0	8		
12	1.6	16	0	8		
13	1.9	14	0	8		
14	2.0	18	0	8		
15	1.9	21	0	7		
16	1.7	33	0	8		
17	1.4	50	0	7		
18	.5	32	0	8		
19	1.1	50	0	14		
20	1.4	22	0	28		
21	1.3	29	0	17		
22	1.1	13	0	12		
23	1.1	21	1	365	5	65
24	1.5	24	1	390		
25	1.3	19	0	5		

SOIL CLASSIFICATION

Light brown coarse sand with some fine - medium gravel, dry, loose - firm.

8

Light brown fine - medium sand, dry, firm.

Grades to light brown fine sand, with some silt, moist, firm.

29

Red fine - coarse sand and silt with some gravel, moist, compact.

(Glacial Till)

Layer grey silt.

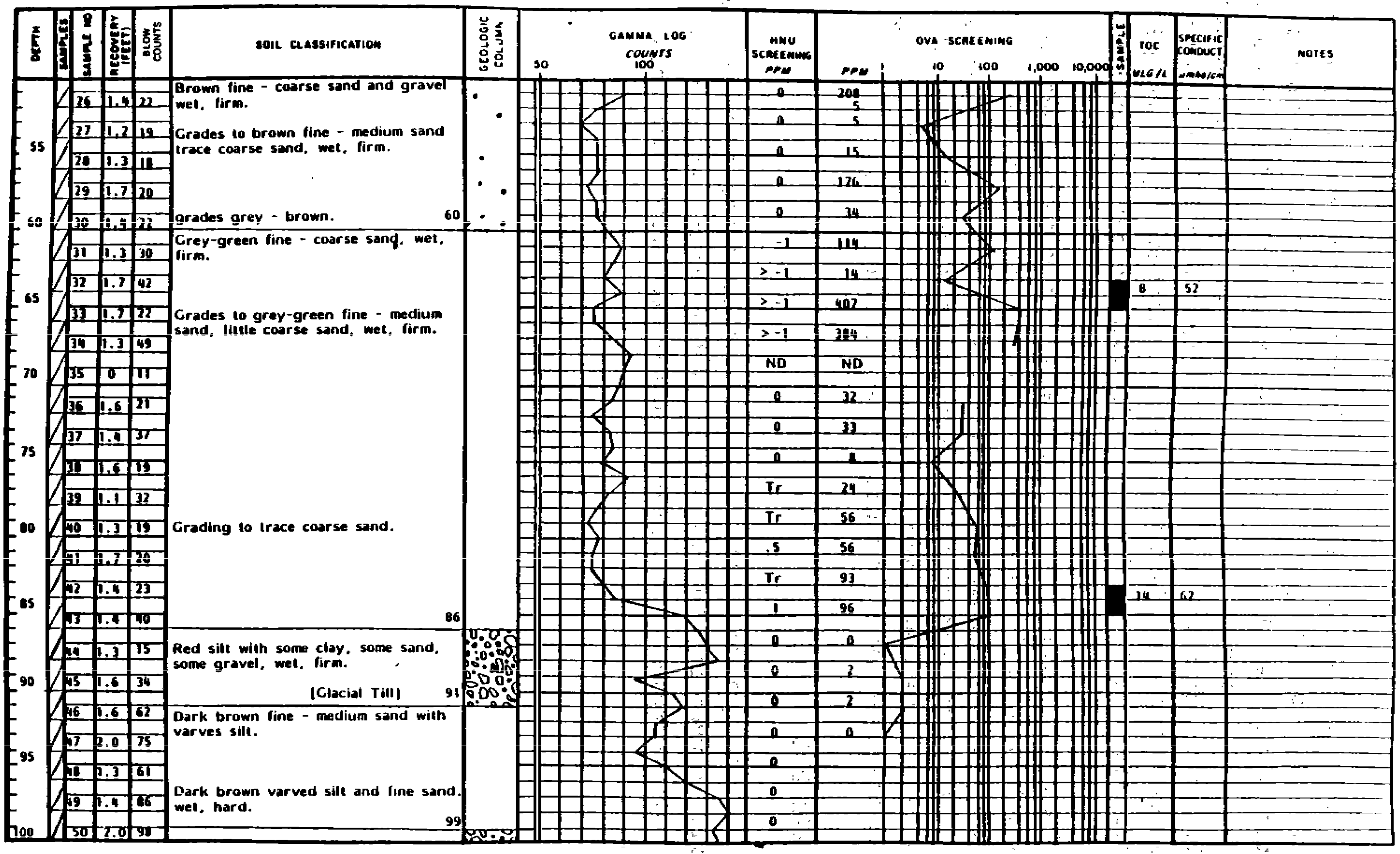
40.5

Brown silt with partings red silt, grading to clay.

41

Mottled brown fine - coarse sand and fine - medium gravel, wet, firm.

Figure 15-32. Example of Borehole Data Including HNU and OVA/GC Screening



Depth	Sample No	Recovery (Feet)	Blow Counts	Soil Classification	HNU Screening PPM	OVA Screening PPM	TOC MG/L	Specific Conduct µmho/cm
	26	1.4	22	Brown fine - coarse sand and gravel wet, firm.	0	208 5		
	27	1.2	19	Grades to brown fine - medium sand trace coarse sand, wet, firm.	0	5		
	28	1.3	18		0	15		
	29	1.7	20		0	176		
60	30	1.4	22	grades grey - brown. 60	0	34		
	31	1.3	30	Grey-green fine - coarse sand, wet, firm.	-1	114		
	32	1.7	42		> -1	14	8	52
	33	1.7	22	Grades to grey-green fine - medium sand, little coarse sand, wet, firm.	> -1	407		
	34	1.3	49		> -1	384		
70	35	0	11		ND	ND		
	36	1.6	21		0	32		
	37	1.4	37		0	33		
	38	1.6	19		0	8		
	39	1.1	32		Tr	24		
80	40	1.3	19	Grading to trace coarse sand.	Tr	56		
	41	1.7	20		.5	56		
	42	1.4	23		Tr	93	14	62
	43	1.4	40	86	1	96		
	44	1.3	15	Red silt with some clay, some sand, some gravel, wet, firm.	0	0		
90	45	1.6	34	[Glacial Till] 91	0	2		
	46	1.6	62	Dark brown fine - medium sand with varves silt.	0	2		
	47	2.0	75		0	0		
	48	1.3	61		0			
	49	1.4	86	Dark brown varved silt and fine sand. wet, hard. 99	0			
100	50	2.0	98		0			

Figure 15-32. Example of Borehole Data Including HNU and OVA/GC Screening (continued)

these results were used to select samples for detailed chemical analysis in the laboratory. As shown in Figure 15-32, samples in zones with OVA/GC readings of 365 ppm (45 feet deep), 407 ppm (65 feet deep), and 96 ppm (85 feet deep) were selected. In the laboratory, samples were first analyzed for total organic carbon (TOC). The ten samples with the highest TOC levels were then analyzed for purgeable organics using EPA Method 50-30 and extractable organics using EPA Method 82-,50 (U.S. EPA, 1982 - Test Methods for Evaluating Solid Waste, SW 846).

The OVA/GC results were also used to select well screen intervals. Examination of the data in Figure 15-32 show that the highest levels of volatile organics (by OVA/GC) were found a depth of 65 feet. In addition, the gamma and geologic logs indicated that the permeable medium at that depth was coarse sand which would be a suitable location for the placement of a well screen. Thus, a 5-foot stainless steel screen was set over the depth interval of 62 to 67 feet. -

Case Discussion

This sampling program incorporated field techniques that detect the presence of volatile organics and allow on-site, rapid identification of likely contaminant “hot spots’’ for detailed laboratory analysis and to select depths for monitoring well screens.

CASESTUDY 18: CONDUCTING A PHASED SITE INVESTIGATION

Points Illustrated

When ground-water contamination is known or suspected at a site, a set of initial borings is typically made to determine site hydrogeologic characteristics and to identify areas of soil. and ground-water contamination (Phase I).

- These findings are then used to select well locations to fully delineate the extent of contamination (Phase II.

Introduction

To identify the extent ground-water contamination in an efficient manner, information is needed on the ground-water flow regime. Phase I investigations typically focus on determining site geologic characteristics and ground-water flow directions and velocities: Waste sources are also identified. The Phase I results are then used in planning the Phase II investigation to determine the extent of contamination and to refine estimated rates of contaminant migration.

Facility and Site Description

Descriptions of the facility and site geologic characteristics were included in Case Studies 7, 8, 14 and 17.

Sampling Program

The Phase I sampling program included geophysical surveys, water level monitoring, soil sampling, and ground-water quality sampling. Three seismic refraction lines were run to estimate the depth to the top of the deep till. The top

Available historical data indicated that the general ground-water flow direction was to the northwest across the site. The ground water was thought to discharge to the river. This information and historical drawings and maps of known disposal areas were used to locate the Phase I borings (see Figure 15-29 in Case Study 17). One well (MW4) was located on the suspected upgradient side of the site. The other wells were located near waste sources to determine which sources appeared to be contributing contaminants to the ground water. For example, two wells (MW6 and 7) were immediately downgradient of solid waste disposal area #2. To determine the presence, of vertical gradients, three two-well clusters were drilled--each with one well screened just below the water table and a second well screened considerably below that at the base of the till.

The results of the Phase I investigation indicated that all the wells contained solvents. Thus, investigations of the waste sources and contaminant plumes were continued in Phase II. The highest solvent concentrations were found in wells located near the liquid waste disposal area where downward vertical gradients were present. The contaminants had migrated down to depths of 75 feet in this portion of the site. The Phase I data confirmed the general northwest ground-water flow direction but showed a complex flow pattern near the buried stream channel. A second concern was whether observed lenses of fine-grained till under the site were producing localized saturated zones which could be contaminated.

Based on the Phase I results, a Phase II monitoring program was designed to determine the extent of contamination around the major disposal sites. Typically, two soil borings were made - one up- and one downgradient of the waste source. Because of the high solvent concentrations observed in the wells downgradient of the liquid disposal area, a more intensive field investigation of this area was included in Phase II. instead of two borings per waste source at the liquid disposal area, 11 soil borings and five new monitoring wells were drilled. This represented one-third of the total effort for the entire 1,000 acre site. The total number of Phase II soil borings was 33 (Figure 15-33) and the total number of Phase II wells was 15 ,(Figure 15-34). The phase II data indicated. that most of the solvent contamination originated, from the liquid disposal area and not from solid waste disposal area #1 which is upgradient of the liquid disposal area. The Phase II data did identify PCBs from solid waste disposal area # 1 but not from any of the other sources. This was consistent with site records indicating that transformers had been disposed at this area.

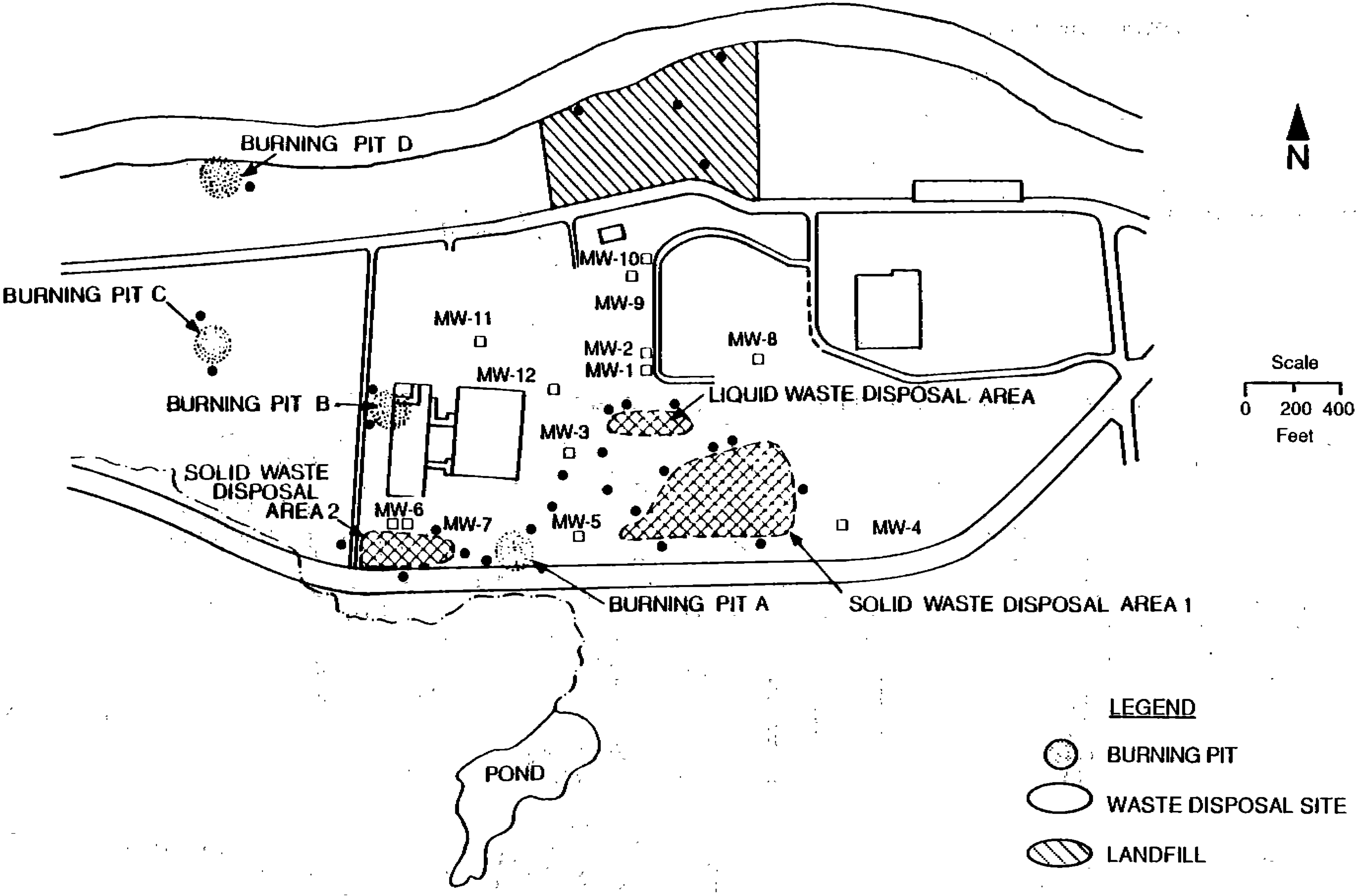


Figure 15-33. Proposed Phase II Soil Borings

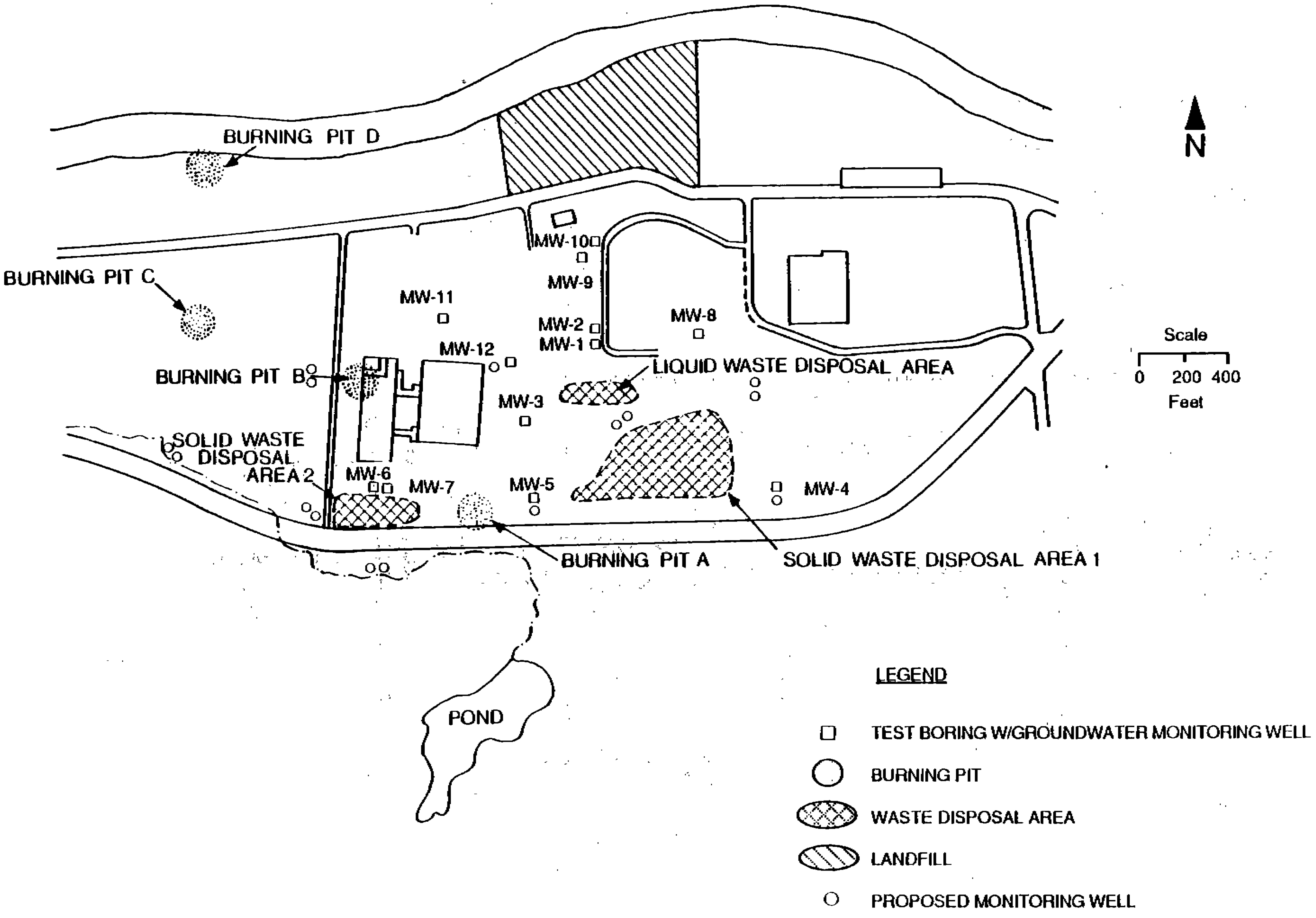


Figure 15-34. Proposed Phase II Monitoring Wells

Case Discussion

Investigation of a large complex site is commonly conducted sequentially. Basic information is needed on site geologic characteristics and ground-water velocities and directions to appropriately locate wells for determining the extent of contamination. Thus, the initial installation of a limited number of exploratory borings and wells can provide the data needed to design a complete and effective investigation. Results from the latter investigation can then be used to determine the need for remedial action and to evaluate alternative remediation methods.

CASE STUDY 19: MONITORING BASEMENT SEEPAGE

Point Illustrated

- Basement monitoring can be used to estimate the extent of contaminant migration.

Introduction

Leachate produced in a landfill can be transported downgradient in ground water by advection and dispersion. Shallow ground water may surface and seep into basements.

Site Description

A channel, originally constructed as part of a hydroelectric power generation system, was used as a disposal site for a variety of chemical wastes from the 1920s through the 1950s. More than 21,000 tons of waste were dumped in and around the site before its closure in 1952. After closure, homes and a school were construed on and around the site. In the 1960s, residents began complaining of odors and residues. During the 1970s, the local water table rose, and contaminated ground water seeped into nearby basements.

Geologic and Hydrologic Setting

Figure 15-35 shows a cross-section of the site. The site has both a shallow and a deep aquifer. The shallow aquifer consists of approximately 5 feet of interbedded layers of silt and fine sands overlying beds of clay and glacial till. The deeper aquifer is a fractured dolomite bedrock overlying a relatively impermeable shale. Travel times from the shallow to the deeper aquifer are relatively long. Contamination has occurred in the shallow aquifer because of the “bathtub effect”. The impermeable channel filled because of infiltration, and leachate spilled over the channel sides. The leachate contaminated the shallow ground water and was transported laterally in this system.

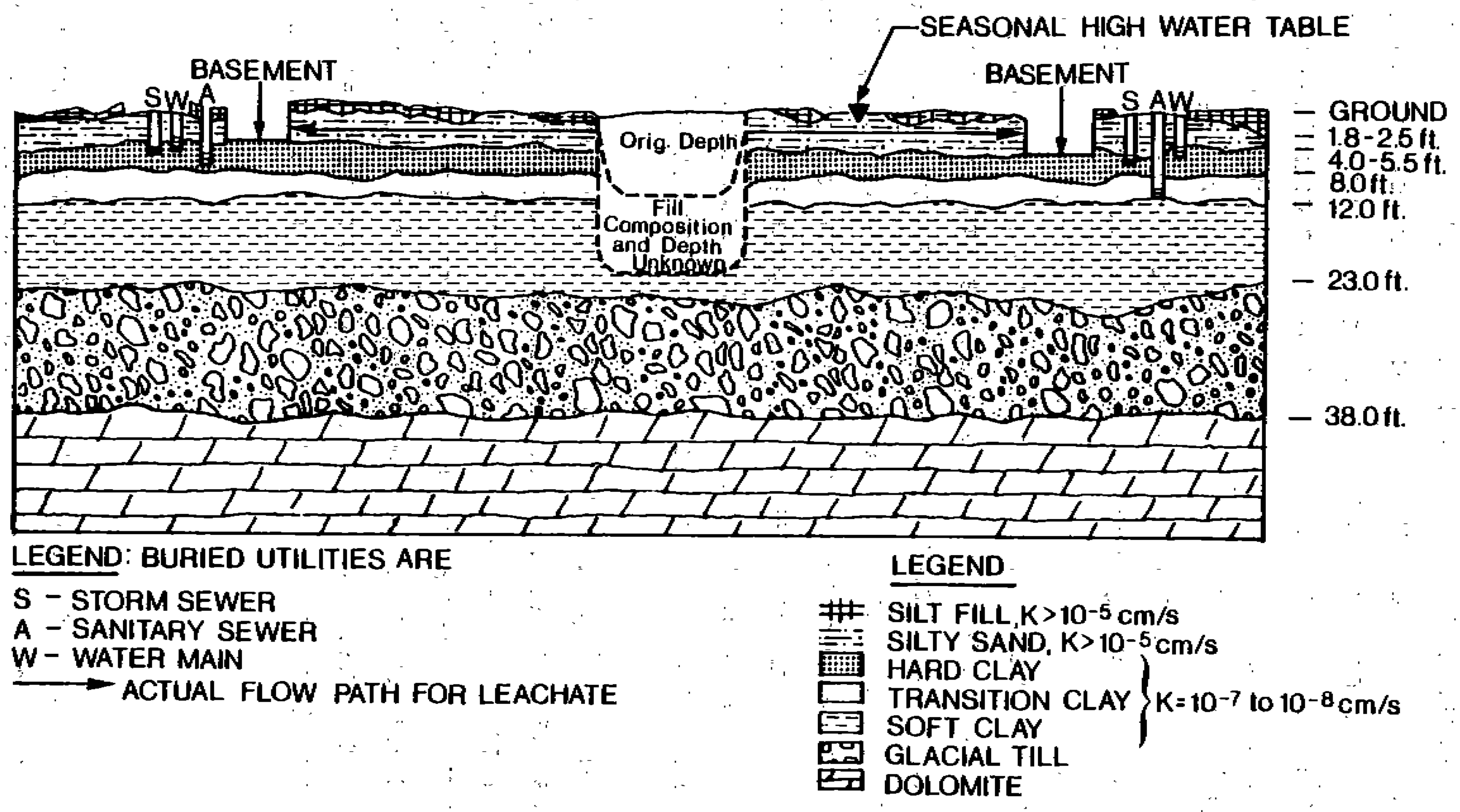


Figure 15-35. Geologic Cross-Section Beneath Site

Sampling Program

The houses surrounding the channel were grouped into three sets (upgradient, downgradient, and on-site) based on preliminary data on the underlying strata and ground-water flow directions. Four houses from each group were selected for sampling for a total of 12 houses. Samples of water and sediments were collected, from the sump pump wells in each basement. Water samples were collected when the sump pumps were running and 24 hours after pumping had ceased. Water and sediment samples were analyzed for purgeable and extractable organics. Benzene, carbon tetrachloride, chloroform, and trichloroethylene (TCE) were found in the water samples. Water samples taken while the sump pumps were running had higher concentrations of volatile organics. Sediment samples contained PCBs and dioxin, possibly due to cosolvation. Relatively immobile organics can become dissolved in another more mobile solvent. The mobile solvent containing traces of other organics can be advected along with the water. This process (cosolvation) is one facet of enhanced transport which has recently been proposed as a possible mechanism for the observed mobility of otherwise immobile organics. Samples of water and sediment from storm drains were also collected and analyzed to determine if discharge from the sumps to the storm drains were a significant source of organics in the storm runoff.

In addition to determining water quality, indoor and outdoor air quality was measured in the basements at each house. Tenax and polyurethane foam tubes were placed in air monitoring systems in each basement to measure 12-hour average concentrations of volatile organics (e.g., carbon tetrachloride, benzene, and TCE) and semi-volatile-organics (e.g., pesticides). Volatile organics were present in the indoor air samples but semi-volatile organics were not detected. The highest volatile organic concentrations were observed when the sump, pumps were operating.

Case Discussion

At sites where hydrogeologic factors favor shallow lateral ground-water flow, initial site characterization may involve sampling of basements. Results from such an initial site characterization can provide information on contaminant migration which can be used in the design and implementation of detailed soil and ground water monitoring programs.

The results of the sampling program described above led to the evacuation and destruction of a number of homes. A system of monitoring wells has been installed to replace the basement sump sampling sites. The shallow aquifer is being pumped and treated to arrest contaminant migration.

CASE STUDY 20: USE OF PREDICTIVE MODELS TO SELECT LOCATIONS FOR GROUND-WATER MONITORING WELLS

Point Illustrated

- Simple mathematical models can be used to estimate the longitudinal and transverse spread of a contaminant plume. Wells can then be located in areas expected to have elevated contaminant concentrations and in areas thought to be both up-and downgradient of the plume.

Introduction

The use of mathematical models to estimate the migration of contaminants can be helpful for several reasons, including: 1) fewer wells may be needed to delineate a contaminant plume, and 2) wells can be rationally located in an attempt to determine the maximum concentrations in a plume, its furthest extent, and locations where concentrations should beat background levels.

Facility Description

The site was an electronics manufacturing plant that had been in operation for 20 years. Four large diameter, rock-filled "dry wells” had been used to dispose of solvents and process wastes. These disposal units were between 35 and 60 feet deep. Depth to ground water was over 460 feet. Disposal Units 1 and 2 had received paint wastes and solvents, including trichloroethylene (TCE) and tetrachloroethylene, between 1964 and 1979. Disposal Units 3 and 4 had been used to dispose of plating solutions and spent acids between 1971 and 1977. These solutions contained copper, chromium, nickel, lead and tin. All the disposal units were closed in 1982. Exact quantities of wastes disposed are not known.

Geologic and Hydrologic Setting

The site is located in a large alluvial basin in an arid region. The basin alluvium is over 1,000 feet thick and consists of an upper sand and gravel unit, a middle silty-clay unit, and a lower sand and gravel unit. Granitic bedrock underlies the unconsolidated formations. Prior to large withdrawals of ground water, the upper unit had been saturated. At present, the silty-clay unit acts as an aquitard so that water beneath it is under confined conditions. The potentiometric surface is now 350 feet below the land surface. In addition to a drop in water level elevations, the ground-water flow direction has changed over the years from east to north in response to changing pumping regimes. Estimated horizontal flow velocities have varied from 10 to 40 feet/year.

Site Investigation

In 1982, city water officials discovered TCE in water samples from wells within 3 miles of the site. On its own initiative, the site owner began a pre-remedial investigation, and then later a remedial investigation, to determine whether his site could be a source of the TCE. The pre-remedial investigation provides an example of how simple models can be used to determine well locations. The pre-remedial investigation included sampling nearby wells and drilling a single deep sampling well (over 500 feet deep).

Original plans called far locating the deep monitoring well between the waste disposal units in an attempt to determine whether solutes had contaminated the underlying ground water. However, site constraints, including an overhead power transmission line, underground power lines and major manufacturing buildings, necessitated that the monitoring well site be moved. The next step was to determine an appropriate location for this well. Because of the changing ground-water flow direction at this site, it was decided to use a simple mathematical model to predict the areal extent of contamination from the disposal units. The results would then be used in selecting a new location for the deep monitoring, well. Data were collected to determine historical hydraulic gradients, pumping histories, and aquifer hydraulic characteristics (e.g., conductivity, porosity). Following data collection, a vector analysis model “the method of Mido” (1981) was used to predict plume evolution. The results showed that the major plume migration was to the north (Figure 15-36). Thus, the well was located north of the disposal units at a distance of 60 feet from Unit 4.

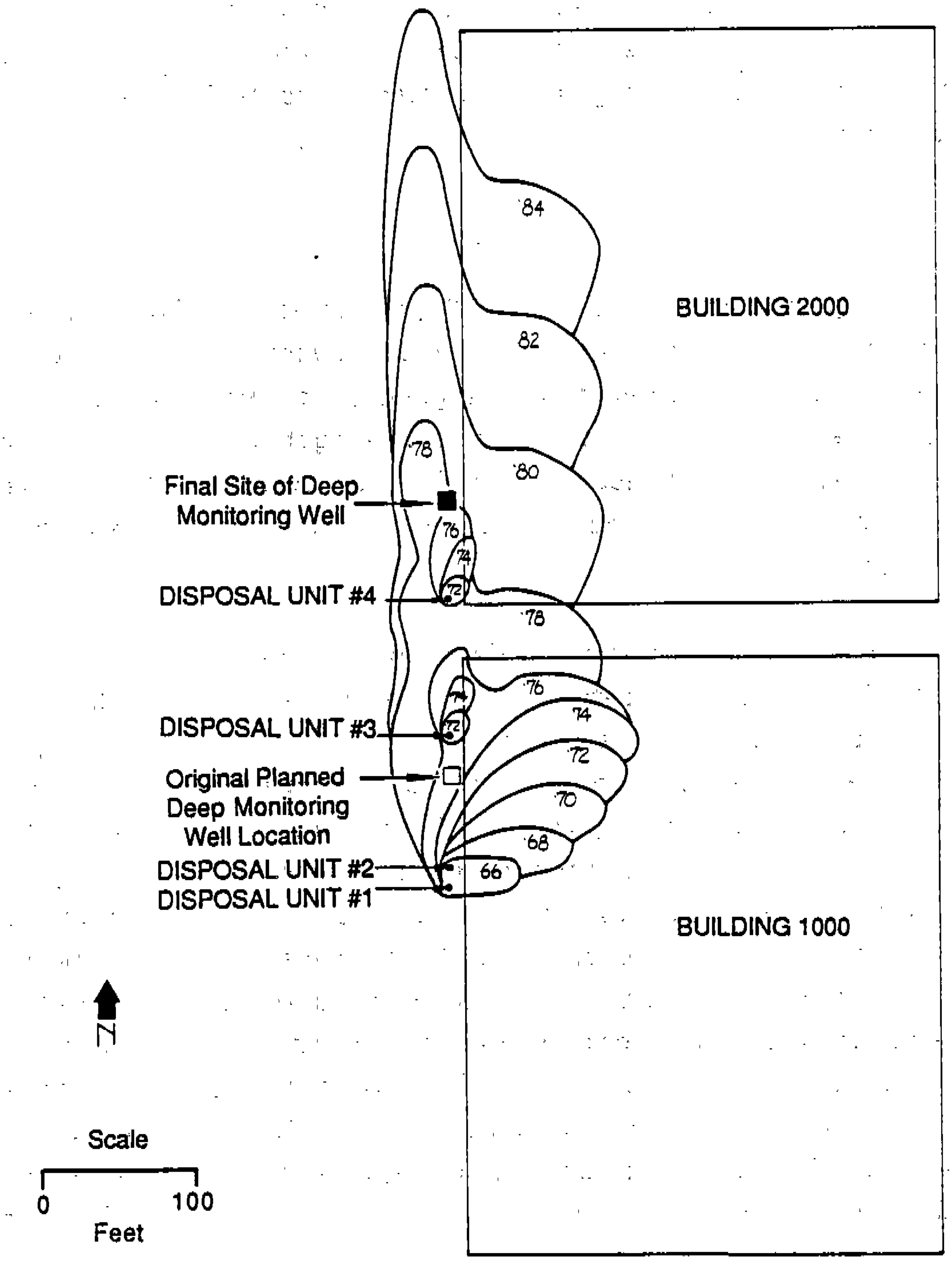


Figure 15-36. Estimated Areal Extent of Hypothetical Plumes from Four Wells

Case Discussion

Use of a model to predict potential plume migration at this site provided a means of evaluating the long-term consequences of changing ground-water flow directions and velocities. Thus, the pre-remedial investigation deep monitoring well could be sited in the direction of net plume displacement, rather than at a location which might have had a low probability of intercepting contaminated ground water. A concentration below the detection limits from a well located beyond the expected plume boundaries would have been inconclusive (for example, see Figure 15-37). However, the deep monitoring well was located close to the disposal units and in the direction of plume migration. Additional wells are now being planned for the full-scale remedial investigation.

Reference

Mido, K.W. 1981. A economical approach to determining extent of ground water contamination and formulating a contaminant removal plan. Ground Water, Vol. 19, No. 1, pp. 41-47.

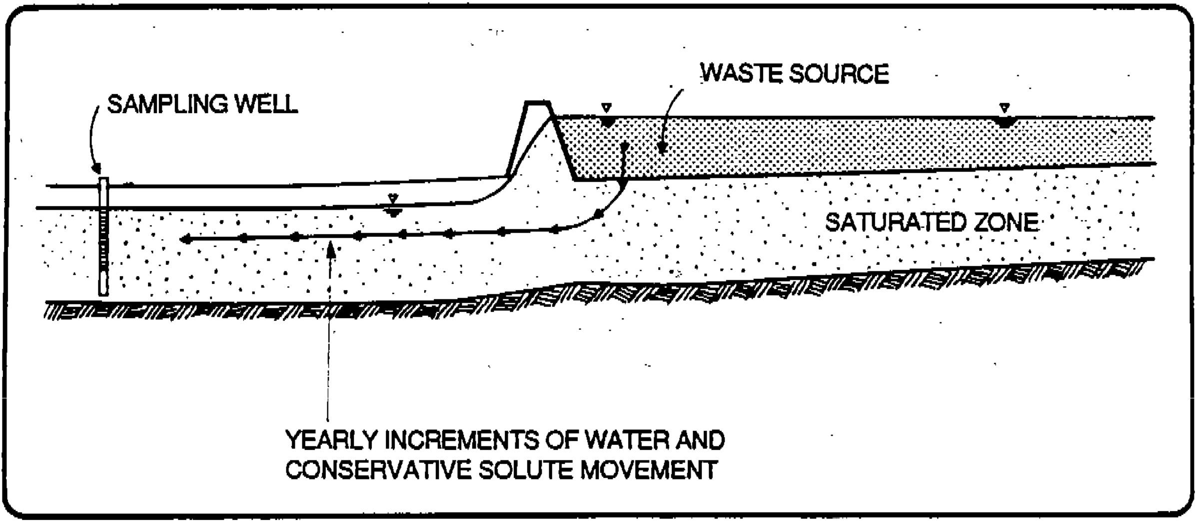


Figure 15-37. Consideration of Solute Migration Rates in Siting Sampling Wells.

If a monitoring well is sited farther downgradient than solutes could have traveled in the time since disposal, low concentrations in the well would certainly not prove that ground-water contamination had not or was not occurring. Prior to locating a well, average linear velocities should be estimated($v = Ki/n_e$ where v = average linear velocity for conservative solutes, K = hydraulic conductivity, i = ground-water gradient, and n_e = effective porosity). Using these estimates, and the age of the disposal unit, T, an approximate migration distance, D, can be computed (D = T/v) for conservative solutes associated with the waste. For soil interactive solutes, migration distances will be less. Methods for estimating these distances are given by Mills et at. (1985).

CASE STUDY 21: MONITORING AND CHARACTERIZING GROUND-WATER CONTAMINATION WHEN TWO LIQUID PHASES ARE PRESENT

Point Illustrated

- Monitoring and characterizing ground-water contamination when two or more liquid phases are present requires knowledge of the physical and chemical properties of each phase.

Introduction

Ground-water supplies are susceptible to contamination by immiscible organic liquids. Organic liquids such as PCB-contaminated transformer oils, petrochemical solvents, and motor fuels, because of their nature, often form a second liquid phase. This separate liquid, in either the vadose or saturated zone, represents a problem in multiphase flow. It is necessary to understand how these separate phases behave where designing monitoring and sampling programs for sites contaminated with such liquids. Techniques commonly used for single-phase flow systems may not be appropriate.

Site Description

The facility is a transformer manufacturing plant which experienced a major discharge of polychlorinated biphenyls (PCBs) and trichlorinated benzenes (TCBs). The discharge resulted from a break in a buried pipeline, but surface spillage may have also occurred during production. The volume and duration of the subsurface discharge is not known; neither is the quantity released by above ground spillage.

Geological and Hydrologic Setting

The site is comprised of 10 feet of fill over lacustrine clay which varies in thickness from 20 to 30 feet. Fractures with openings of approximately 0.1 cm have been observed in the clay. Below the clay lies a thin silt layer. Below that is a 40- to 60-foot-thick layer of glacial till composed of fine sand near the top, and gravel, sand, and silt below.

Perched water about 3 feet deep flows laterally in the fill. The permanent water table, located in the till, is partially confined. Potentiometric levels in this latter system are between 25 and 30 feet below the land surface.

Sampling Program

Over 1000 soil samples were taken as part of the site investigation. A mobile atmospheric pressure chemical ionization mass spectrophotometer (APCI/MS) was employed for rapid, on-site characterization of soil samples. This instrument can detect PCBs down to a minimum concentration of 100 mg/kg. About 20 percent of the PCB analyses were replicated by conventional gas chromatography.

Granular dry materials were sampled from an auger with care taken in cleaning sampling equipment to avoid cross-contamination. In taking samples from the clay, special effort was made to sample the surfaces of obvious fractures. This was done to maximize the changes of detection of PCBs in largely uncontaminated soil. Due to dilution, large bulk samples can prevent the detection of contaminant migration through fractures in low permeability soils.

Vertically, the soil sampling program showed PCBs to be distributed in a non-homogeneous pattern within the clay zone. Concentrations of PCBs greater than 500 mg/kg PCBs were detected. The lateral spreading of PCBs throughout the fill was much more extensive than the vertical movement. This could be due to the nature of the discharge/spillage, pressure from the broken pipe, or the fact that the fill is more permeable than the clay. The PCBs appear to have formed a layer along the fill/clay interface. Movement of PCBs more than 300 feet laterally from the original spill site has been confirmed.

Based on the soil sampling results, 12 well locations.(Figure 15-38) were chosen to further characterize the site. Four boreholes were drilled into the till aquifer. One well, 686-B, was placed upgradient of the spill site with a screened interval between depths of 45 and 50 feet. The three downgradient wells in the till aquifer were screened over different, intervals to increase the possibility of detecting a separate organic liquid layer. The screened intervals used were at depths 45 to 50 feet (well 686-A), 50 to 55 feet (well 686-C), and 55 to 60 feet (well 686-D). Eight

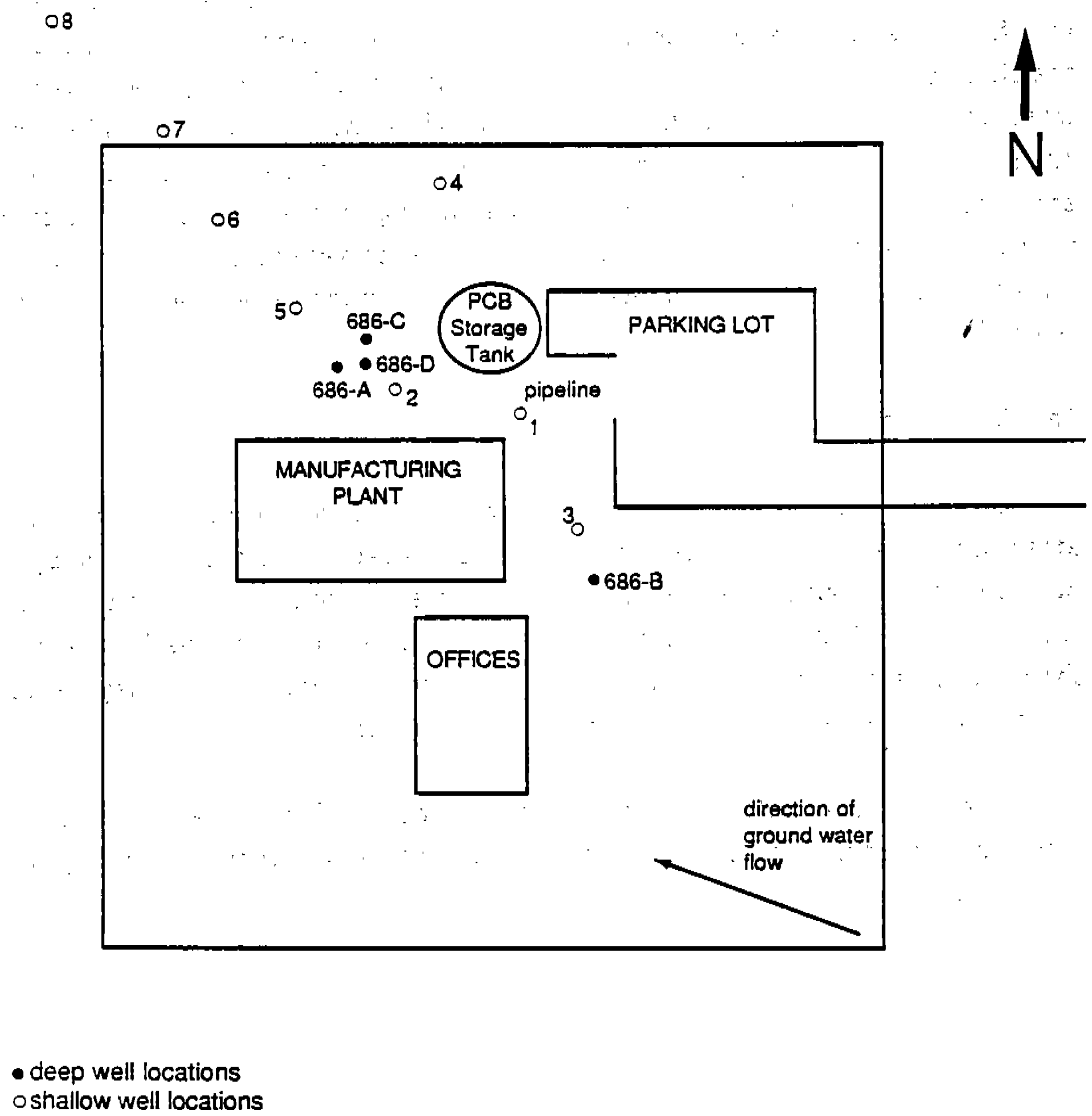


Figure 15-38. Well Locations and Plant Configuration

shallow wells were also placed in the fill to monitor the perched water. The fill is approximately 10 feet deep and a layer of PCBs was suspected at the fill/clay interface. The depth of the perched water fluctuates between 7 and 8 feet. Six of the eight wells in the fill, 1, 3, 4, 6, 7, and 8, are screened from 7 to 10 feet. Samples from wells 1, 6, 4, and 7 showed PCB levels much higher than the volubility limits. The sampling results suggest that two separate liquid layers exist at these locations and that the liquids are being mixed during sampling. Wells 2 and 5 were screened from 5 to 8 feet to determine if a floating liquid layer was present. Again, samples having concentrations far in excess of volubility limits indicated the existence of a layer of organic liquid.

Ground-water systems contaminated with immiscible liquids require special attention. Well screen intervals should be placed to intercept flow along boundaries between soil layers of differing hydraulic conductivities and at water table surfaces. Sampling results must also be interpreted properly. Samples showing contaminant concentrations far in excess of volubility limits may indicate that two layers of different liquids are being pumped and mixed.

Finally, Figure 15-39 is offered as an illustration of the types of complexity which can be encountered with immiscible liquids having densities both greater than and less than water.

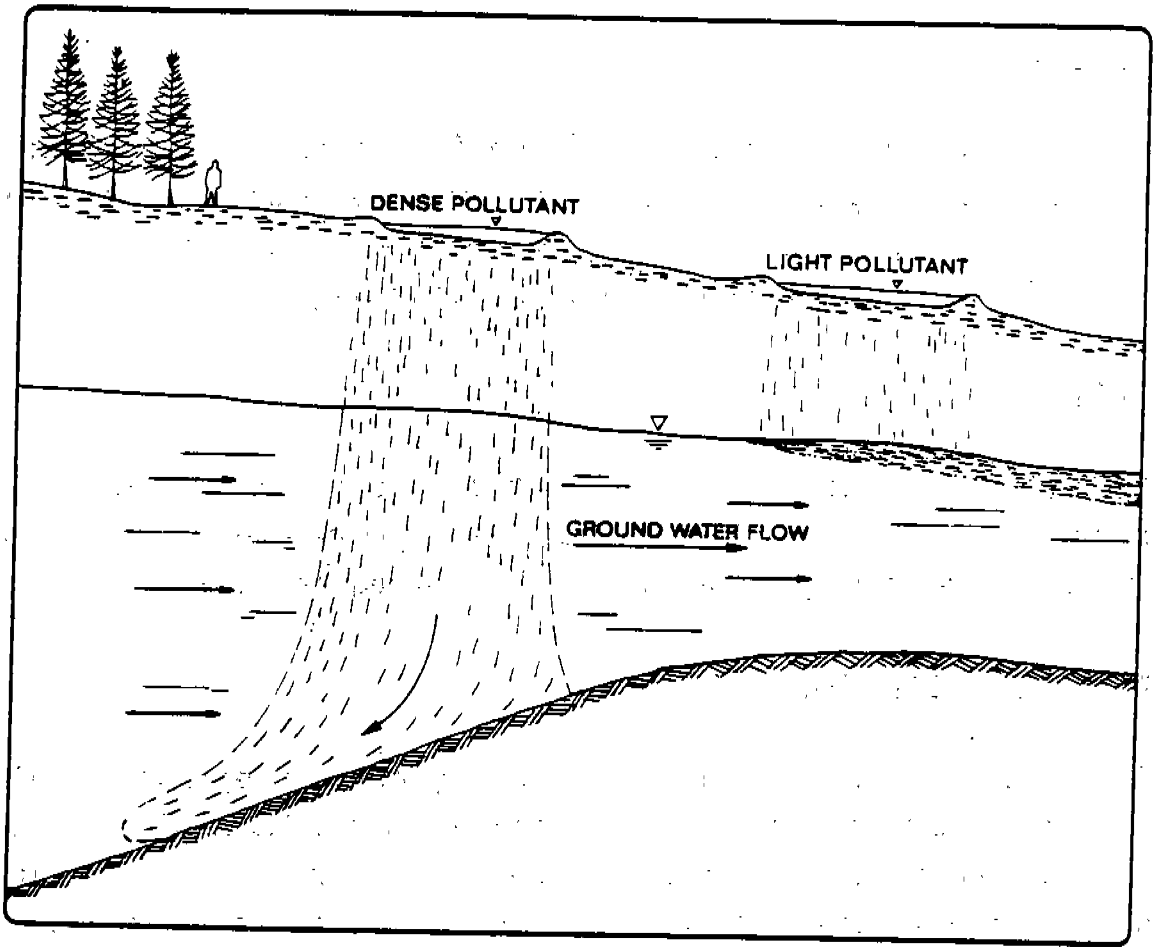


Figure 15-39. Behavior of Immiscible Liquids of Different Densities in a Complex Ground-Water Flow Regime

CASE STUDY 22: METHODOLOGY FOR CONSTRUCTION OF VERTICAL FLOW NETS

Point Illustrated

- Construction of a vertical ground-water flow net can be a valuable tool for evaluating ground-water (and contaminant) pathways and for determining additional actions that may be necessary to accurately delineate the ground-water flow regime at a facility.

Introduction

Constructing a vertical flow net at a facility provides a systematic process for analyzing the accuracy of ground-water elevation and flow data, and can therefore foster a better understanding of the ground-water flow regime at the site.

Facility Description and History

The site contains a large chemical manufacturing facility of approximatley 300 acres located beside a major river in the northeastern United States. The site has been used for chemical manufacturing by different companies since 1904 and has a Icing history of on-site waste management. Several solid waste management units have been identified at the facility. This is the same facility as discussed in Case Studies 7,8,14,17 and 18.

Geologic and Hydrologic Setting: At depths of 150 to 200 feet the site is underlain by bedrock identified as arkosic sandstone. Above this bedrock are glacial deposits consisting of a thick bed of hard till, overlain by lacustrine sediments and deltaic and outwash deposits. Discontinuous lenses of till were identified within the deltaic deposits. A trough cut into the thick-bedded till and trending approximately southeast to northwest has been identified. See Figure 15-40.

The river beside the facility flows westward and discharges into the main stem of a larger river approximately 4 miles west of the facility. A small tributary (brook) borders the facility to the southwest and west. Swamp-like areas are present near

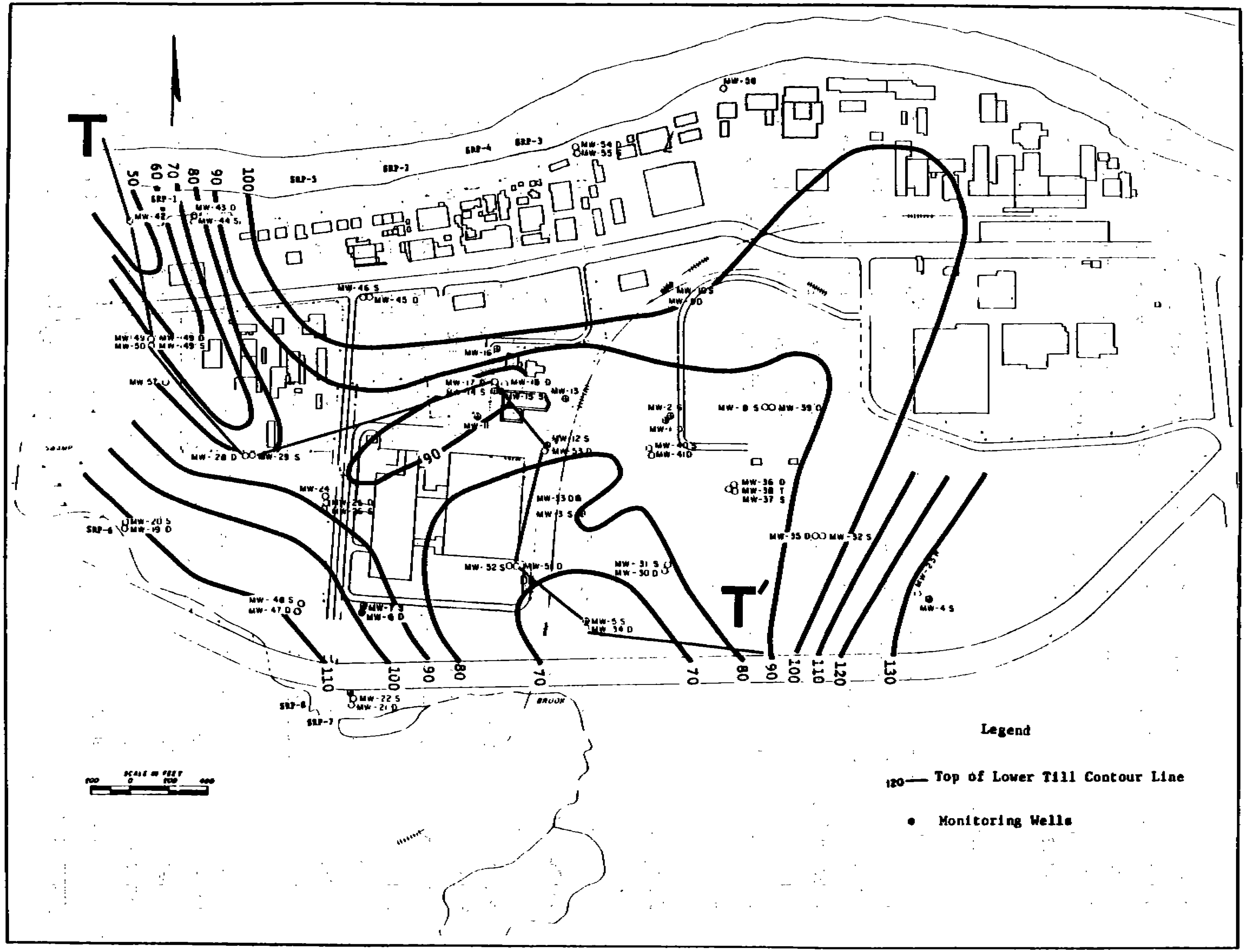


Figure 15-40. Top of Lowest Till Contour Map and Location of Vertical Flow Net

the tributary. It is suspected that the arkosic sandstone outcrops in the river adjacent to the facility. Whether this visible rock is a large glacial erratic or an outcrop of the arkosic sandstone bedrock is an issue identified during previous investigations and may be important in characterizing the ground-water flow regime at the facility.

Program Design

The site was investigated in two phases. Phase I (1981-1984) included the installation and monitoring of wells MW-1 through MW-12, while Phase II (1984-1985) consisted of 34 soil borings, installation of wells MW-13 through MW-57, and monitoring and sampling of all wells. This two-phased approach allowed the use of the initial monitoring well data and soil boring data to determine the placement of the Phase II monitoring wells. Further discussion of this two-phased approach is provided in Case Studies 7 and 18.

Data Analysis

Evaluation of the data was conducted based on information provided by the owner or operator, including the water-level elevation data presented in Table 15-13. Well locations and water-level elevations in the wells were mapped and compared to elevations of the midpoint of the well screens to show relative hydraulic head differences from well to well. Vertical gradients are a reflection of different head values at different elevations. For each well, the head can be determined at the elevation of the midpoint of the well screen by measuring the water-level elevation in the well. Different head values corresponding to different screen elevations were used to evaluate vertical gradients. During the plotting of this map, anomalous data were identified and marked for further investigation.

The geology of the site and the depositional processes forming the aquifer were studied to determine what sorts of hydrogeologic phenomena might be expected. Glacial outwash deposits exhibit trends in sediment size and sorting. Sediment size decreases and sorting increases from the marginal to the distal portions of the deltaic/lacustrine deposits.[1] It is expected that this tendency will be

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[1] Mary P. Anderson, "Geologic Facies Models: What Can They Tell Us About Heterogeneity," presented to the American Geophysical Union, Baltimore, May 18,1987.

TABLE 15-13

GROUND-WATER ELEVATION SUMMARY TABLE PHASE II

Well Number	Ground Elevation (ft)	Well Depth (ft)	Midpoint of Well Screen Elevation[1]	Screen Length (ft)	Water Level Elevation 9/1/82
MW-1	162.80	76.50		3	
MW-2	162.50	22.50		3	
MW-3	174.20	31.00	145.7	3	150.54
MW-4	201.90	54.00	150.4	3	156.85
MW-5	186.30	47.50	141.3	3	149.95
MW-6	144.30	39.50	107.3	3	135.78
MW-7	144.60	19.50	127.6	3	135.94
MW-8	155.10	24.00	133.6	3	149.04
MW-9	160.50	61.00	135.0	3	141.53
MW-10	160.40	30.00	132.9	3	144.62
MW-11	154.70	27.00	130.2	3	140.57
MW-12	159.50	26.50	135.5	3	141.05
MW-13	162.20	29.00	139.2	10	141.22
MW-14	162.10	29.00	139.1	10	140.66
MW-15	162.00	29.00	139.1	10	140.67
MW-16	162.00	29.00	135.5	3	140.87
MW-17	162.00	71.00	104.5	25	140.52
MW-18	161.90	72.00	103.4	25	140.53
MW-19	137.10	24.00	116.6	5	127.83
MW-20	137.20	17.00	123.7	5	127.82
MW-21	141.40	26.50	118.4	5	135.39
MW-22	141.60	15.10	13.0	5	135.35
MW-23	204.30	225.50	-10.2	20	184.98
MW-24	143.90	70.00	76.4	5	136.47
MW-25	143.80	39.00	107.3	5	130.20
MW-26	143.80	24.00	123.2	5	130.17
MW-27*					
MW-28	142.70	46.00	100.2	5	127.86
MW-29	142.80	23.00	123.3	5	127.88
MW-30	172.00	85.50	90.0	5	152.70
MW-31	172.20	24.85	150.8	5	151.68
MW-32	203.10	61.00	145.6	5	154.78
MW-33	174.20	94.00	83.7	5	150.49

*Not installed.

[1] Assumes screens are installed one foot above the bottom of the well.

TABLE 15-13 (continued)

Well Number	Ground Elevation (ft)	Well Depth (ft)	Midpoint of Well Screen Elevation	Screen Length (ft)	Water Level Elevation 9/1/82
MW-34	186.20	75.80	113.9	5	149.72
MW-35	203.20	106.25	100.4	5	144.31
MW-36	189.40	101.20	91.7	5	143.22
MW-37	189.50	48.00	145.0	5	150.51
MW-38	189.30	135.30	57.5	5	145.04
MW-39	154:90	68.00	90.5	5	142.45
MW-40	173.80	47.50	129.8	5	146.59
MW-41	173.70	75.30	101.9	5	141.95
MW-42	134.20	64.00	73.7	5	117.62
MW-43	133.50	32.10	80.9	5	117.24
MW-44	139.50	28.00	115.0	5	119.62
MW-45	144.32	35.00	112.8	5	128.97
MW-46	144.15	25.00	122.6	5	126.48
MW-47	141.50	34.00	111.0	5	131.91
MW-48	141.60	17.00	128.1	5	131.74
MW-49	143.00	72.20	74.3	5	123.22
MW-50	143.00	30.20	116.3	5	123.85
MW-51	157.00	70.30	90.2	5	149.58
VIW-52	157.00	34.00	126.5	5	139.48
MW-53	159.30	77.90	84.9	5	141.09
VIW-54	145.80	52.00	97.3	5	120.18
MW-55	145.90	35.00	114.4	5	121.63
MW-56	133.60	20.30	116.8	5	119.84
MW-57	141.30				
Screen Reference Points					
SRP-1				114.41	
SRP-2				114.92	
JRP-3				116.05	
SRP-4				115.86	
SRP-S				NA	
SRP-6				128.81	
SRP-7				137.28	
SRP-8				134.11	

*Not installed.

[1] Assume screens are installed one foot above the bottom of the well.

reflected in hydraulicconductivities throughout the outwash deposits at the facility. There is some suggestion of such a trend in the head data from the site.

The map of hydraulic head values and screen midpoint elevations were evaluated considering both the possible hydrogeologic phenomena expected for the geology of the area and the depositional processes creating the aquifer. Several working hypotheses were developed to explain the apparent ground-water flow patterns and the identified vertical gradients.

- Hypothesis 1: Vertical gradients can be explained by classifying areas where the vertical gradients were reflective of discharge and recharge areas. (See Figure 15-41.)
- Hypothesis 2: The top surface of the till forms a trough with a saddle. (See Figure 15-40.) The vertical gradients showing higher head with depth reflect the movement of water as it flows upward over the saddle.
- Hypothesis 3: The vertical gradient may correlate with locations of buildings and parking lots at the site. Recharge occurs primarily where the ground is not paved. The downward gradient near the river may be caused by runoff flowing downhill and recharging the ground water at the edge of the pavement.
- Hypothesis 4: Most of the ground-water flow is horizontal. The vertical gradients reflect, phenomena whose scale is. smaller than the resolution of available data, and an accurate interpretation cannot be made. Geologic systems exhibit heterogeneity on different scales, causing fluctuations in head on different scales. The small-scale fluctuations detected at the site are due to undefined causes and may represent:

    1. details of stratigraphy (such as till beds in parts of the outwash deposit),
    2. artificial recharge and discharge (such as leaky sewer pipes), or
    3. errors in the data.

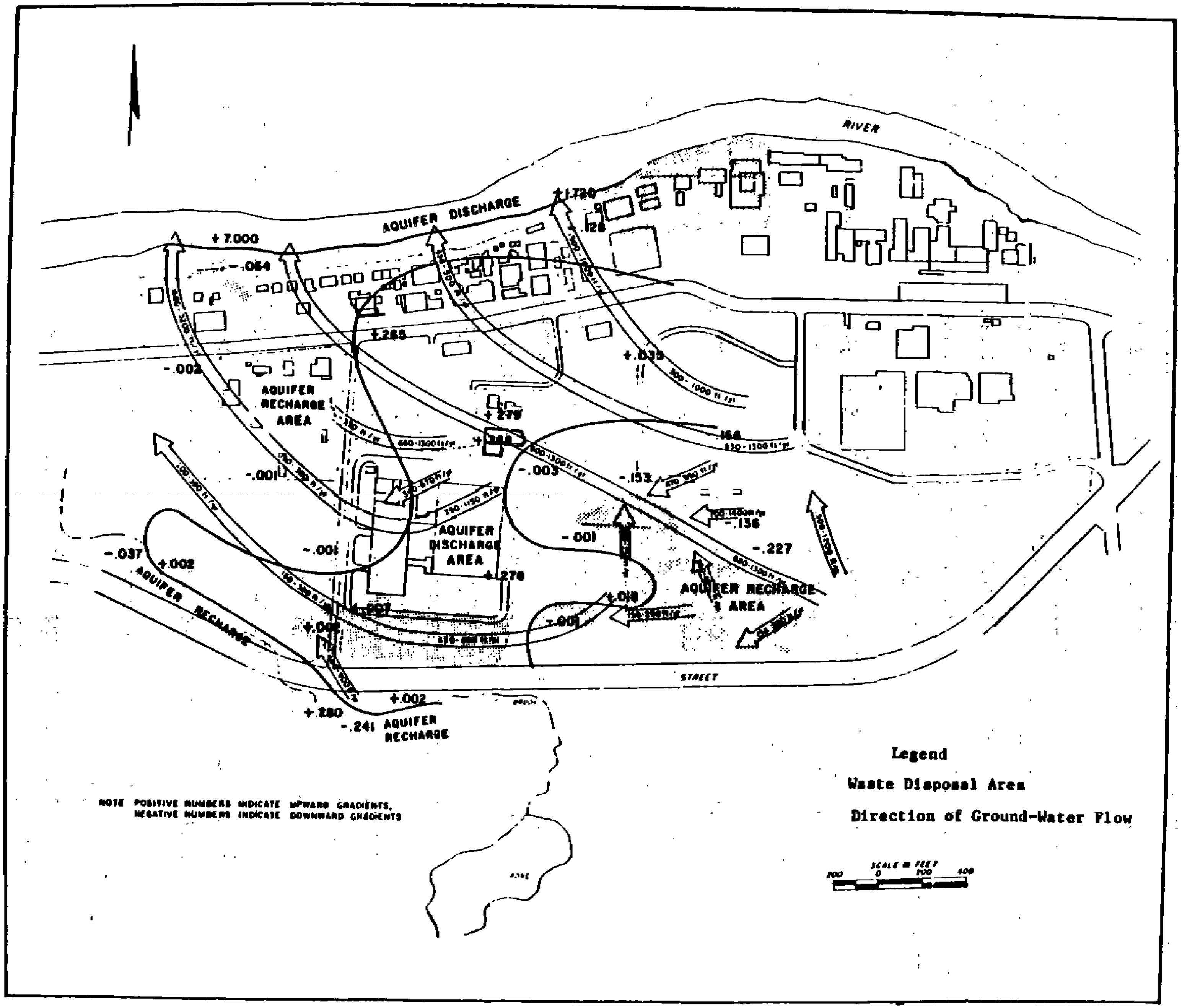


Figure 15-41. Recharge/Discharge Areas and Flow Directions

To characterize flow at the site and to support the design of corrective measures (if needed), a working (conceptual) model of flow at the site should be developed. This model, in this case a vetical flow net, can be used to identify data gaps and to prioritize gathering of the necessary additional information. Considering the hypotheses developed, an area for characterizing the vertical flow regime was selected. Determination of this area, where a geologic cross-section and flow net will be constructed, was based on:

- Assumptions and requirements necessary to construct flow nets, as identified in the Criteria for Identifying Areas of Vulnerable Hydrogeology, Appendix B: Ground-Water Flow Net/Flow Line Construction and Analysis (Vulnerable Hydrogeology, Appendix B). For example, ground-water flow should be roughly parallel to the direction of the cross-section and vertical flow net.

- Flow being representative of the hydrogeologyof the facility.

- Flow representing the major paths of ground-water movement. For example, the aquifer is shaped like a trough and a major portion of the ground-water flow occurs in the middleof this trough; therefore, a cross-section and flow net should be constructed along the axis of the trough.

A geologic cross-section was constructed for the area of interest and is identified as T-T' in Figure 15-40. A flow net was then constructed following the methodology described in Vulnerable Hydrogeology, Appendix B; see Figure 15-42. Construction of a vertical flow net requires a graphical solution of Darcy's Law. Data that do not fit the solution become evident in Figure 15-42 as shown, for example, by the head value for MW 52.

Construction of a vertical flow net allowed for a systematic evaluation of the various hypotheses. Hypothesis 1, where vertical gradients are-labeled recharge and discharge, is rejected because the gradients vary significantly in a very irregular pattern (compare well clusters MW 14-18 and MW 12, and 53); there is no apparent reason that natural recharge would vary so irregularly. Hypothesis 2 seemed reasonable initially but, after closer inspection, is rejected because upward

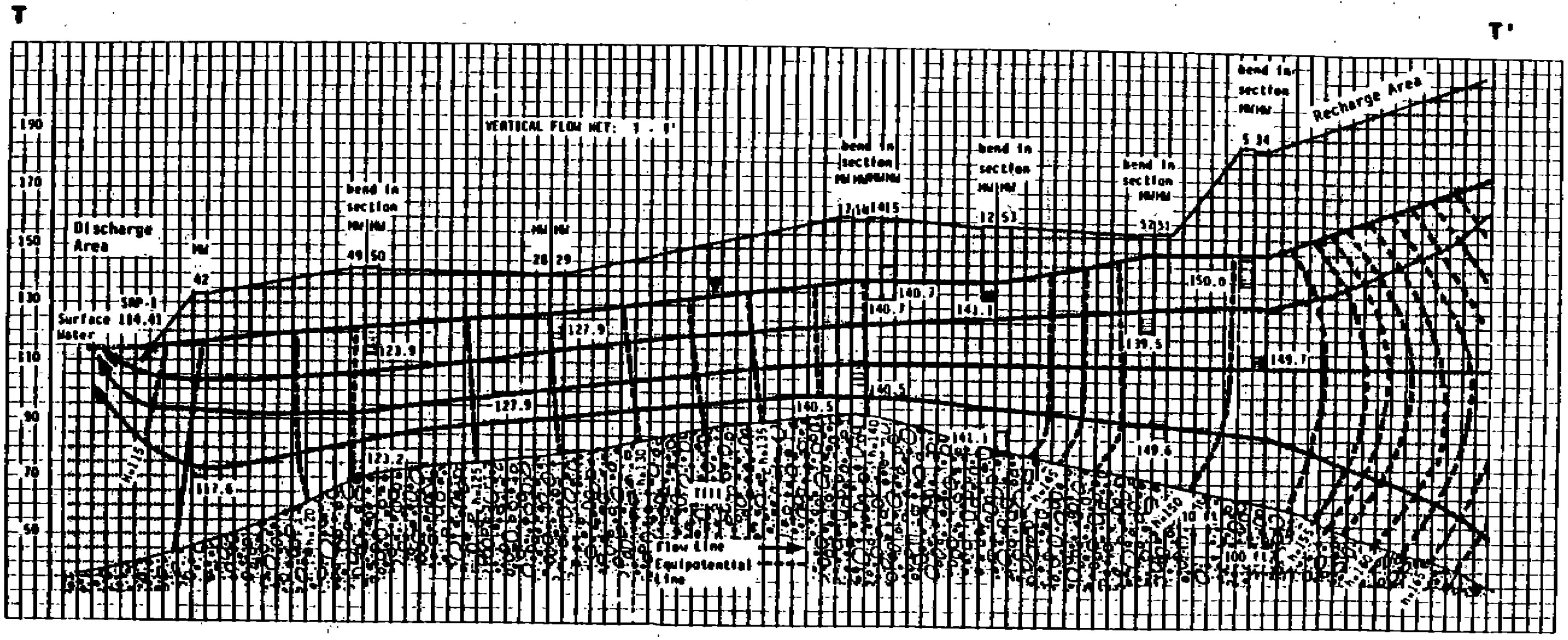


Figure 15-42. Vertical Flow Net T-T'

gradients are not consistently found near the saddle. Hypothesis 3 is feasible and deserves further study. Aerial photographs were examined to identify paved and unpaved areas, but the available ground-water data are insufficient for detailed correlation to these distinct areas. Additional data are needed to construct a more-detailed flow net to further evaluate this hypothesis. Hypothesis 4, which asserts that most of the flow is horizontal addresses the area of the site where the major portion of ground-water flow occurs. Although it relies on undefined causes to explain fluctuations, it reflects the most logical explanation of the data.

Results

During construction of the flow net and testing of the hypotheses several issues were identified. One of the most important gaps in the study to date is how localized flow at the site fits into the regional ground-water flow regime. Regional flow issues would need to be resolved prior to determining the extent and type of corrective measures, if necessary. The following regional flow issues were identified:

- Geologic information beyond the facility property boundary is necessary to explain the suspected bedrock in the middle of the river directly beside the site to characterize the regional ground-water flow (i.e., to determine the possibility for contamination of regional ground water). The difference in elevation of the top of the bedrock in the river and the top of the bedrock throughout the facility is approximately 120 feet. How can this be explained? Is the bedrock surface irregular or is this rock a glacially-transported boulder exposed in the river? How does this affect regional ground-water flow?

- Data consistently show a downward gradient (i.e., recharge conditions) near the river. This is difficult to explain because rivers in this region are not expected to be losing streams (Heath, 1984). The expected flow direction near a ground-water discharge area, in this case a gaining stream, is upward. Data points showing downward flow near the river are not included in flow net T-T'. (Further investigation of vertical gradients near the river is recommended). If this downward gradient near the river is confirmed, near-water-table contamination could move downward and contaminate deeper ground water. If deeper, regional contamination must be addressed, corrective measures maybe significantly more difficult and extensive.

Other issues deal with localized flow patterns that may affect design of corrective measures. Resolution of these issues will probably not change the overall scope of corrective measures, but would need to be considered in the detailed design.

These localized flow pattern issues are as follows:

- The hydraulic head in the brook is higher than the head in the closest wells in the aquifer, but the water slopes toward the stream. This is inconsistent. If ground water from the site is not discharging into this stream, fewer interceptor wells may be needed.

- Anisotropy must be taken into account in determining the region of flow captured by interceptor wells, drains, etc.

- Till identified as lenses in outwash deposits may actually be continuous with upgradient till, causing the aquifer to flow-under confined conditions. Are the till beds isolated lenses or are they continuous? If the till beds in the outwash aquifer are continuous and isolate adjacent zones within the aquifer, they will have the potential of blocking flow to interceptor wells that may be included in the corrective measures plan.

- Vertical gradients of 0.25 and 0.002 in the same geologic unit are presented. Are these gradients accurate and how can they be explained? There could be artificial discharge (pumping) or recharge (possibly from a leaking sewer) near the wells showing a high vertical gradient. The areas labeled discharge areas show no signs at surface water or other surficial evidence of discharge. Artificial recharge and discharge may create areas of relatively constant head, such as where ground water contacts leaky sewers; these areas could limit the growth of cones of influence of any interceptor wells or drains. Also, any contaminated water that may be discharging from pipes should be identified and corrected.

Case Discussion

Further investigation is necessary to resolve the above issues. Regional flow issues should be resolved first. This information would be used to better understand localized flow patterns which would affect the design of corrective measures. The following options for further investigation are suggested:

1. Study the regional geology and hydrogeology. Techniques that could be employed using existing data include review of geologic maps, analysis of well logs, and interpretation of existing surface geophysical data (e.g., gravity and magnetic surveys). Measurement of water level elevations in wells outside the site would also be useful.

2. Conduct a detailed study of the depositional, environment of the glacial deposits on the site. This should provide a better understanding of flow patterns.

3. Collect a full-year series of head data at existing wells to differentiate transient from steady-state (e.g., artificial from natural) effects in the measured heads.

4. Conduct multiple well pumping tests to determine the degree of connectivity of geologic formations using wells at different depth and locations. [Note: this should be done with careful attention to details of well construction so that it is understood exactly what is being measured.]

5. Collect detailed chemical data (including major ions and contaminants) at the existing wells and interpret them to aid in characterizing the flow regime.

6. Drill one or more wells into the bedrock near the river to determine the vertical component of ground-water flow at this location.

Options 1 through 5 above are recommended prior to drilling additional wells in the outwash deposits, unless more wells are needed to delineate the release.

Further single-well hydraulic conductivity tests in the glacial deposits are not recommended at this time. The large-scale flow in the outwash aquifer should be determined by the location and relative degree of continuity of the till versus the sand because the permeability contracts between the till and sand is so much greater than the variability among the different sands. (See paper by Graham Fogg in Water Resources Research, 22, 679.) Single-well tests would be useful for determing localized hydraulic conductivities of the sand bodies, not their connectivity.

Gathering existing data and constructing an initial vertical flow net proved useful in identifying data gaps in defining ground-water flow, and identified problems due to differing interpretations of the existing data. Determining options for gathering additional data necessary to resolve these issues was based on a qualitative understanding of the ground-water flow regime gleaned from construction of the vertical flow net.

References

Fogg, Graham. Water Resources Research. 22, 679.

Heath. 1984. Ground Water Regions of the U.S. USGS Water Supply Paper No. 2242.

U.S. EPA. 1986. Criteria for Identifying Areas of Vulnerable Hydrogeology, Appendix B: Ground-Water Flow Net/Flow Line Construction and Analysis. Office of Solid Waste. Washington, D.C. 20460.

CASE STUDY 23: PERFORMING A SUBSURFACE GAS INVESTIGATION

Points Illustrated

- Design of a phased monitoring program to adequately characterize the extent and nature of a subsurface gas release.
- The use of ambient air and basement monitoring to supplement monitoring well data.
- The importance of subsurface characterization prior to design of a monitoring network.

Introduction

Gases produced in a landfill will migrate via the path of least resistance. Subsurface, lateral migration of landfill gas can occur due to natural and man-made barriers to vertical gas migration, such as impermeable overlying soil layers, frozen soil, or surface water. Installation of a gas-monitoring well network, in conjunction with sampling in buildings in the area, can be used to determine the need for corrective measures.

Facility Description

The unit in question is a landfill covering approximately 140 acres and bordered by a river on one side and a floodwall on the other. Beyond the floodwall lies a residential area (Figure 15-43). Several factors contribute to the subsurface gas migration problem at this landfill. The site reportedly received large quantities of organic wastes which, when decomposed in the absence of air, produce methane and carbon dioxide gases. The presence of “tight”, low permeability soils at the ground surface (12 feet of clayey silt at the surface grading to coarse sand and gravel at a depth of 55 feet) in the residential area, combined with a rapidly rising water table below the landfill due to increased infiltration, restrict the vertical area available for gas migration and encourage lateral movement.

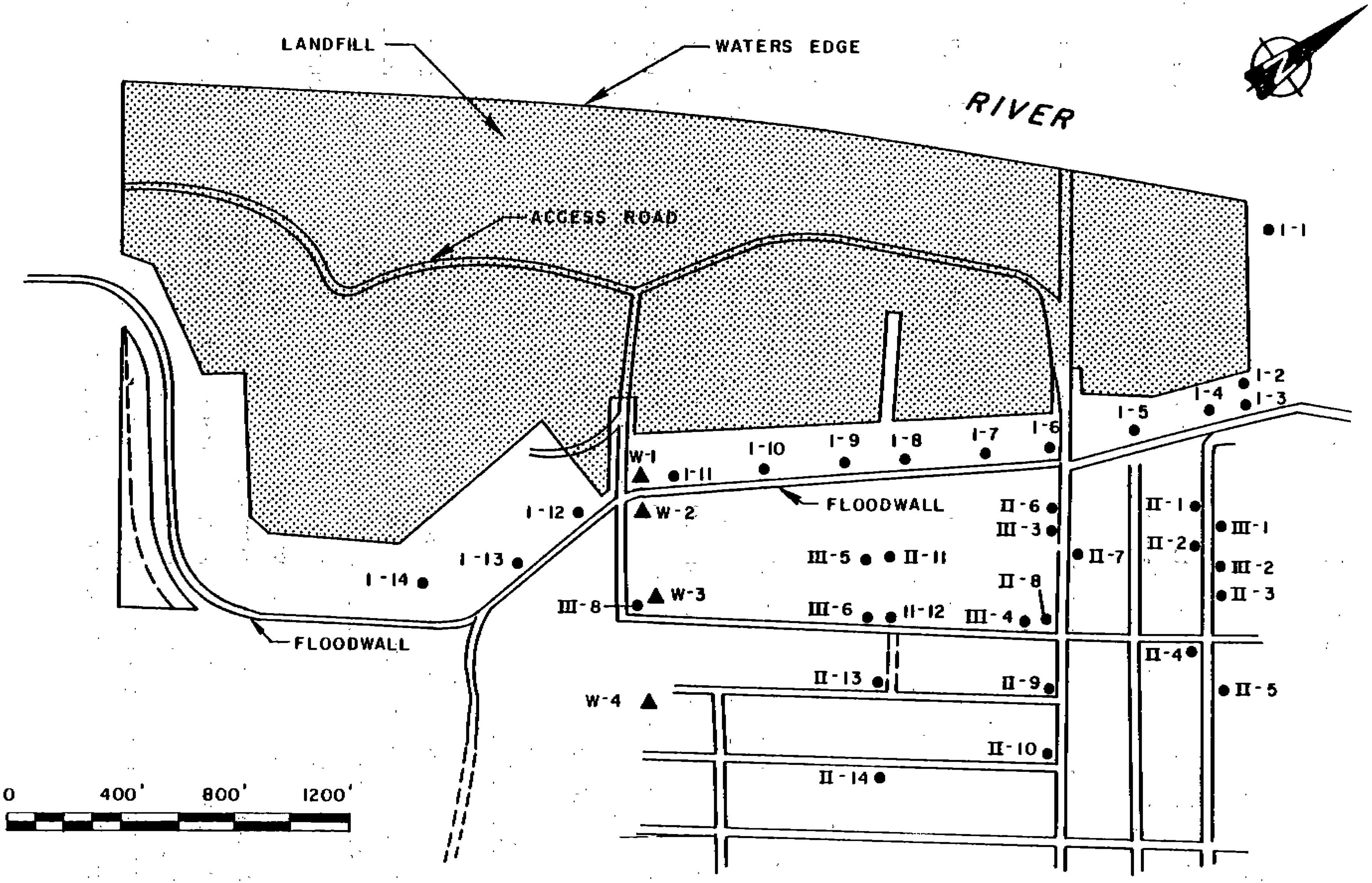


Figure 15-43. Site Plan

Investigation of the gas migration began when foul odors and explosive levels of methane (5 to 15 percent by volume in air) were discovered in the basement of a home approximately 200 feet from the landfill. Residents in the area were evacuated a sampling network was installed, and monitoring was conducted.

Sampling Program

The sampling was conducted in four phases, an initial screening phase and a more detailed three-phase sampling program. The monitoring network for the initial screening phase consisted of four wells (W1 through W4) aligned perpendicular to the long axis of the landfill, in the direction of (and extending beyond) the house where the gas was initially detected (Figure 15-43). The wells were drilled to an approximate depth of 30 feet below the land surface with the farthest well located about 1000 feet from the landfill boundary. These wells were sampled twice a day for a month. Samples were analyzed for methane and combustible hydrocarbons. The results of this initial monitoring showed average methane levels to be highest at the monitoring well closest to the landfill (30 percent by volume), and roughly grading to below the detection limit at the well farthest from the landfill.

Grab and composite ambient air samples were also taken at the landfill and around houses in the neighborhood where gas was detected during the initial monitoring phase. These samples were analyzed for methane and other combustible, hydrocarbons. No gases were detected above normal background levels in any of these above ground samples.

The next phase of monitoring (Phase I of the detailed sampling) involved the installation of 14 new gas monitoring wells (I-1 through I-14 in Figure 15-43). Most of these were placed in a line 250 feet from and parallel to the longitudinal axis of the landfill. Seven of these wells were drilled to an average depth of 55 feet, at least 5 feet below the water table so that ground-water levels could be monitored. The other seven wells averaged 30 feet and did not intercept ground water. As shown in Figure 15-44, each well consists of three separate gas monitoring probes at evenly spaced depth intervals. Each probe was packed in gravel to allow gas to collect in its vicinity. Clay plugs were installed between each probe interval and

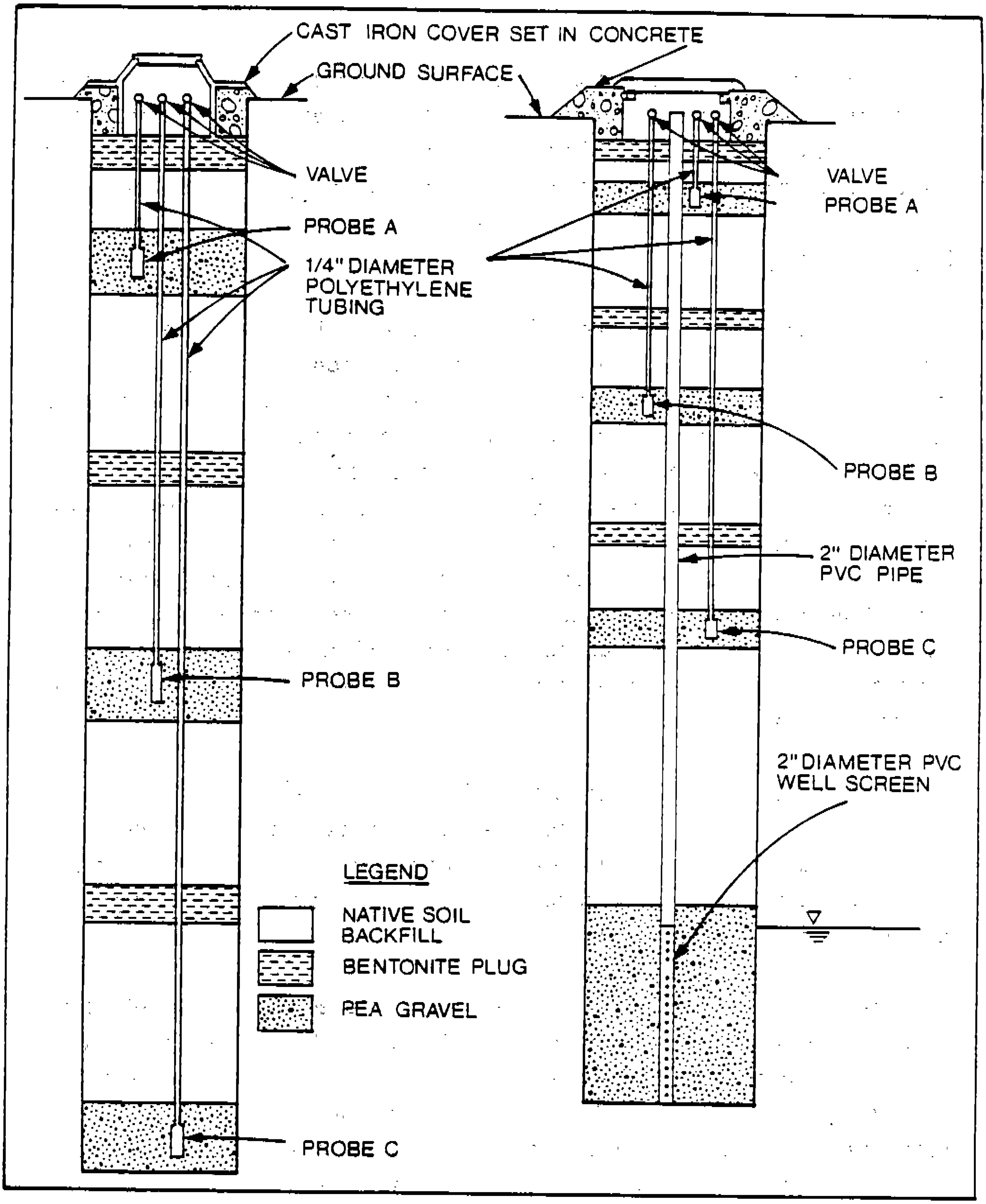


Figure 15-44. Gas Monitoring Well

between the top probe and the surface to minimize vertical movement of gas in the well. After two months of monitoring the well headspace twice monthly, concern over the high levels of methane that were being measured prompted an expansion of the monitoring well system.

The Phase II monitoring network involved another 14 wells (II-1 through II-14) installed to a depth of 6 feet along, three radial lines from the landfill. These wells were monitored twice monthly with the. Phase I wells. Methane was not detected at these wells because they were not deep enough to penetrate the clayey silt layer which in this area extended to a depth of 12 feet. Had adequate boring logs been compiled prior to the placement of these wells, the time and money involved in their installation and sampling could have been saved.

Detailed soil boring logs were compiled during the installation of the Phase III wells (III-1 through III-8 in. Figure 15-43). These wells were drilled to ground water, averaging 55 feet in depth, were located in the vicinity of the Phase II wells, and were constructed in the same manner as the Phase I wells, with three gas probes placed in each well. The Phase III, wells were located from 510 to 900 feet from the landfill. These wells were monitored twice a month for two months concurrently with the Phase I wells. Methane levels at all but two Phase III wells (which are located along the same radial line) exhibited explosive concentrations, ranging up to 67 percent by volume in air. These high concentrations of gas prompted another round of sampling of homes in the vicinity of wells exhibiting high methane concentrations.

Methane and combustible hydrocarbons were measured in basements, crawl spaces, and living areas of 28 homes adjacent to the landfill. All proved to be well below the lower explosive limit of methane.

Wells were then selected based upon proximity to houses exhibiting the highest levels of combustible gases, and sampled to determine gas composition and concentration. The proportion of constituents in the collected gas was similar in, all samples analyzed, and concentrations decreased with increasing distance from the landfill.

Ambient air sampling for organic gases at the landfill and in the residential area was also performed at this time and showed low levels of several organic compounds. Air samples collected in houses near the landfill showed the presence of two of the gas components measured in the test wells (methane and ethane).

The gas migration hazard had been sufficiently characterized so that a plan for corrective measures could be developed. This involved the installation of 31 gas extraction wells which were located along a line between the landfill and the residential areas, and a blower system to "pump" the gas out of these extraction wells.

Results

The monitoring program implemented for this case was, for the most part, effective in characterizing the extent and concentrations of subsurface gas contamination. The four initial monitoring wells verified that the landfill was the source of contamination. Phase I monitoring confirmed that the high levels of methane were present at all depths monitored and along the entire length of the landfill. The horizontal location of the Phase II wells, in lines radiating from the landfill, was appropriate, although the lack of subsurface characterization rendered them useless. Phase III sampling established the vertical and lateral extent of subsurface contamination into the residential area.

Throughout the study, ambient air sampling as well as monitoring of homes in the area of concern provided adequate safety control, as well as an additional indication of potential migration of landfill-generated gases.

Case Discussion

Subsurface gas migration can occur when atmospheric ventilation of gases generated in a landfill is insufficient. The gas produced migrates along the paths of least resistance. Conditions restricting release to the atmosphere, such as saturated or tight surficial soils, may force the gas to move laterally over considerable distances.

This case was selected as an illustration of a phased approach to monitoring a subsurface gas release. The results of one phase of monitoring were incorporated into the design of the next phase throughout the study. Monitoring was performed at discrete vertical levels below the surface and at distances from the landfill that were adequate to confirm the extent of the contaminant plume.

The study also illustrates the importance of characterizing subsurface conditions prior to installing monitoring wells. Fourteen unusable wells were installed and then monitored for two months because of insufficient preliminary soil (stratigraphic) characterization.

The use of ambient and basement monitoring for gas to supplement monitoring well data is also noted in this case study. The location of new wells can be based in part on readings from these sources.

CASE STUDY 24: USE OF A SUBSURFACE GAS MODEL IN ESTIMATING GAS MIGRATION AND DEVELOPING MONITORING PROGRAMS

Point Illustrated

- Predictive models can be used to estimate the extent of gas migration from a suspected subsurface source. This information can be used to estimate human exposure and to determine appropriate locations for monitoring wells and gas collection systems.

Introduction

Methane is a common landfill gas and is often used as an indicator of landfill gas migration. The subsurface methane predictive model, described in Volume II, Appendix D of this document, will yield a methane concentration contour map and predict the distance that methane will migrate. The model consists of a series of charts developed by imposing a set of simplifying assumptions on a general methane migration computer model.

A methane migration distance prediction chart is used to find a preliminary migration distance based on the age of the site and the soil type. The remaining chart are used to find correction factors which are in turn used to adjust the migration distance. These factors are based upon site characteristics (e.g., depth of the waste).

Facility Description

The unit is located on a 583-acre site in a suburb of a major metropolitan area. Figure 15-45 shows the site layout. The landfill itself occupies 290 acres. 140 acres of the landfill were used for the disposal of hazardous wastes. Both hazardous and nonhazardous wastes were disposed at the site from 1968 to 1984. Hazardous waste disposal ended in 1984. The disposal of sewage treatment sludges and municipal refuse continues. As seen in Figure 15-45, residential development has taken place with houses now bordering the facility to the south. A population of 30,000 to 40,000 people reside within a mile radius of the landfill center.

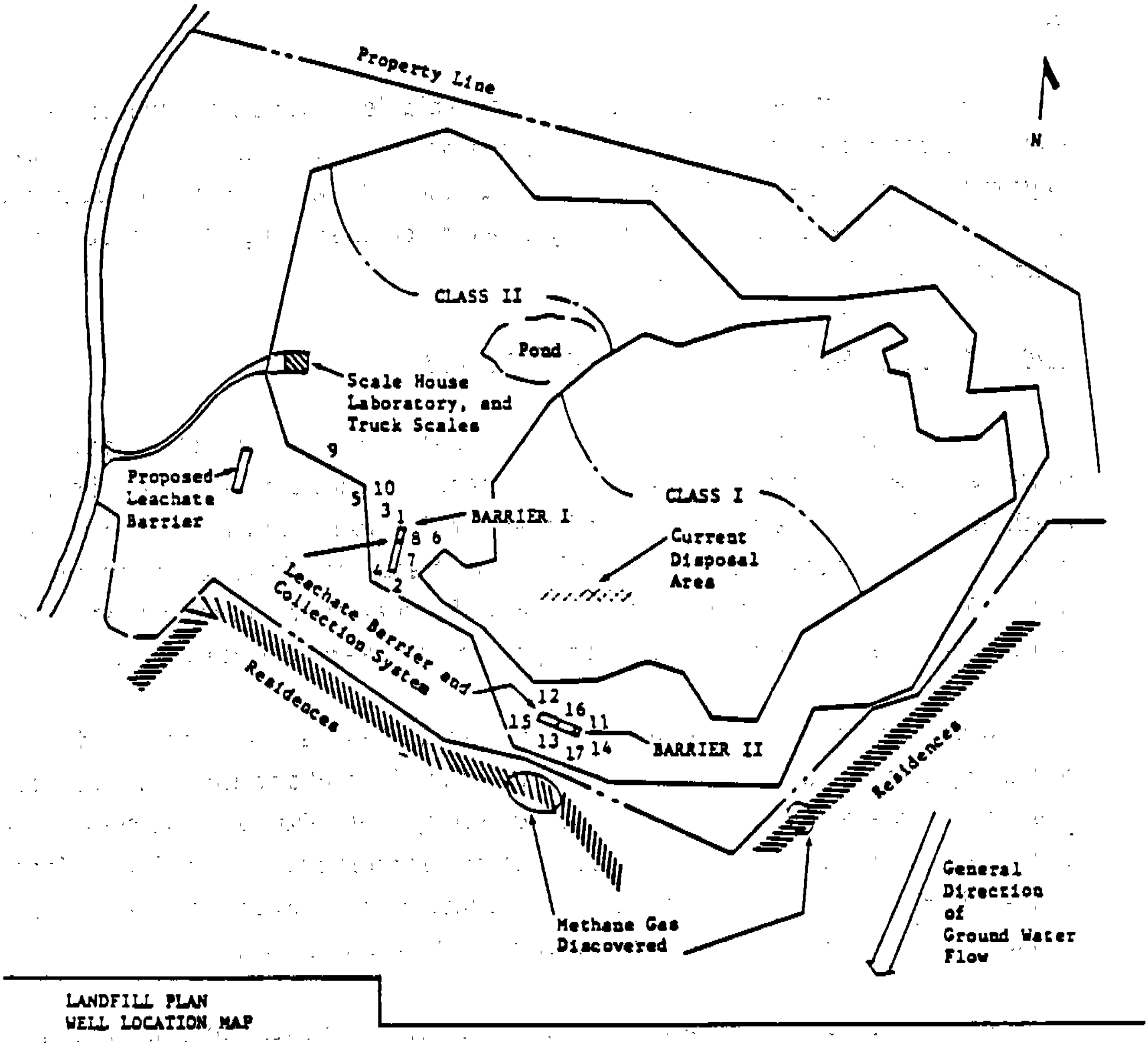


Figure 15-45. Facility Map

The unit is a V-shaped fill overlying sediment and bedrock. The rock type is a poorly consolidated, fractured sandy silt offering no lithologic barrier to gas migration. The shape of the water table has not been established. Also unknown are the possible effects of local, permeable formations such as sand lenses, faults, etc.

The warm climate at the site encourages rapid degradation of organic wastes and therefore rapid gas production. Site characteristics suggest that vertical gas migration is not hindered. However, the compaction of the fill cover by truck traffic combined with the rapid production of gas has forced lateral migration through the fractured sandy silt.

Applying the Subsurface Methane Predictive Model

The subsurface methane predictive model-allows the development of a subsurface methane concentration contour map. The model predicts. the distance methane will migrate from a unit based on its age, depth, soil type, and environmental factors. A contour map for two different methane concentrations, 5 and 1.25 percent, is predicted. The likelihood of human exposure can be estimated from the location of the contours with respect to on-site and off-site structures.

Application of the model involves three steps. The first step is the prediction of gas migration distances, based on the age of the landfill and the local soil type. The unit of interest is 18 years old and has sandy soils. Figure 15-46 shows the uncorrected methane migration distances for various soils over time. From Figure 15-46, the uncorrected migration distances for the subject site are 165 feet and 255 feet for 5 and 1.25 percent methane concentrations, respectively.

The second step in applying the model involves the application of a correction factor to the migration distances based on waste depth. The deeper the waste, the greater the opportunity for subsurface migration. Figure 15-47 is used to find the correction factors for depth. For the subject waste unit the depth is 25 feet, which corresponds to a correction factor of 1.0 for both concentrations.

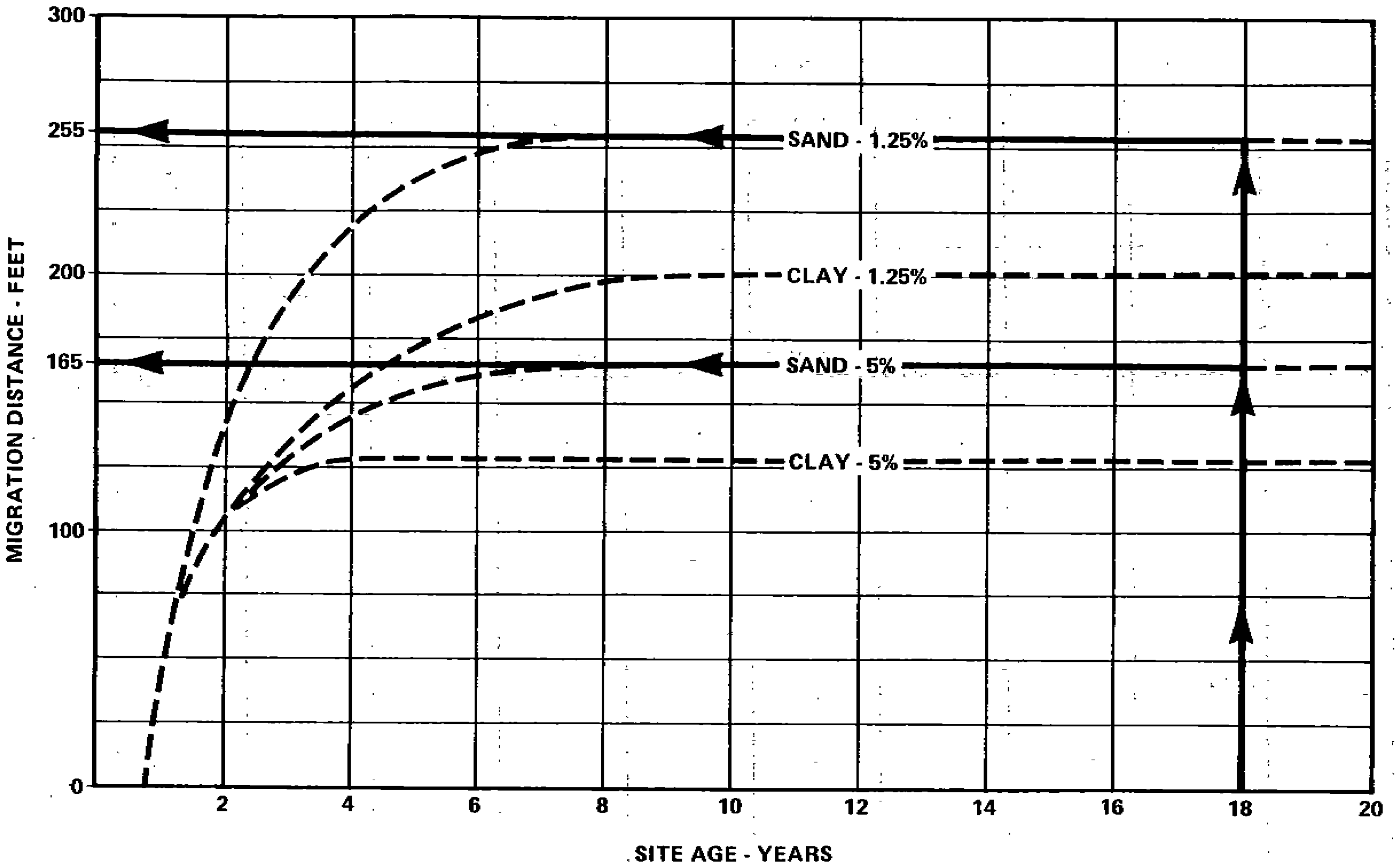


Figure 15-46. Uncorrected Migration Distances for 5 and 1.25% Methane Concentrations

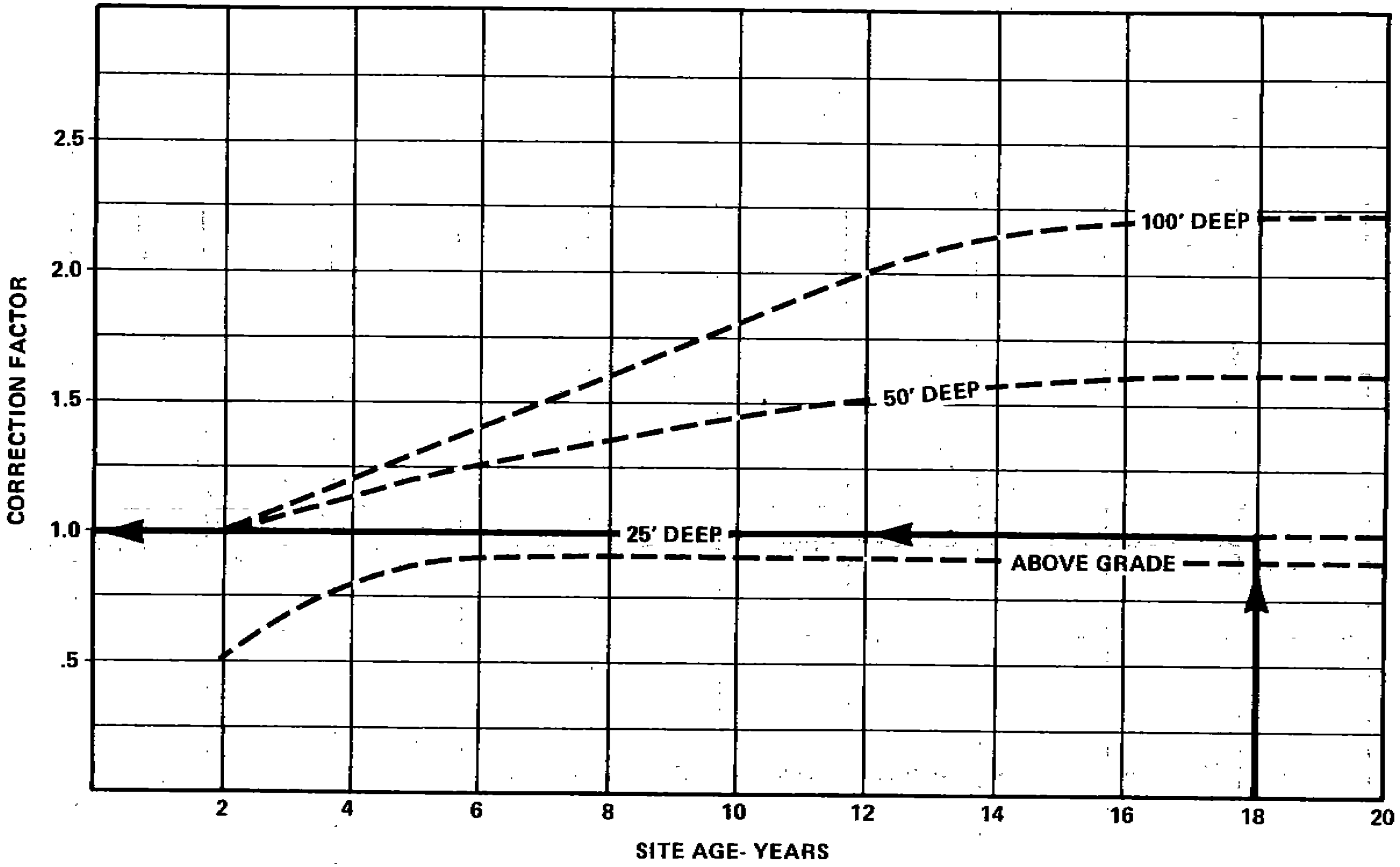


Figure 15-47. Correction Factors for Landfill Depth Below Grade

The final step in applying the model is the correction of migration distances based on surface venting conditions. The following equation is used to calculate the adjusted correction factor, ACF:

ACF = [(ICF-1)(fraction of site which is impermeable)] + 1

The impervious correction factor, ICF, is obtained from Figure 15-48. In the above equation, ICF is adjusted to account for the fraction of time the solid is saturated or frozen and the fraction of the land area that is impermeable due to natural or man-made barriers. If corrections for both time and area are required, the fractions are additive. From Figure 15-48, the ICF for a unit 18 years old arid 25 feet deep is 2.4. Site characteristics together with weather conditions indicate a value of 0.4 for the fraction of impermeable area. Substituting these values into the above equation yields an adjusted correction factor of:

ACF = [(2.4-1)(0.4)] + 1 = 1.56.

Results

Table 15-14 summarizes the results from steps one through three of the model application. The predicted migration distances for methane are found by multiplying the uncorrected distance from step one by the correction factors from steps two and three. The predicted distances of travel for methane are 255 feet and 395 feet for 5 and 1.25 percent concentrations, respectively.

TABLE 15-14

MODEL RESULTS

Methane Concentration (percent)	Uncorrected Distance (ft)	Correction for Depth	Correction for Venting	Corrected Distance (ft)
5	165	1.0	1.56	255
1.25	255	1.0	1.56	395

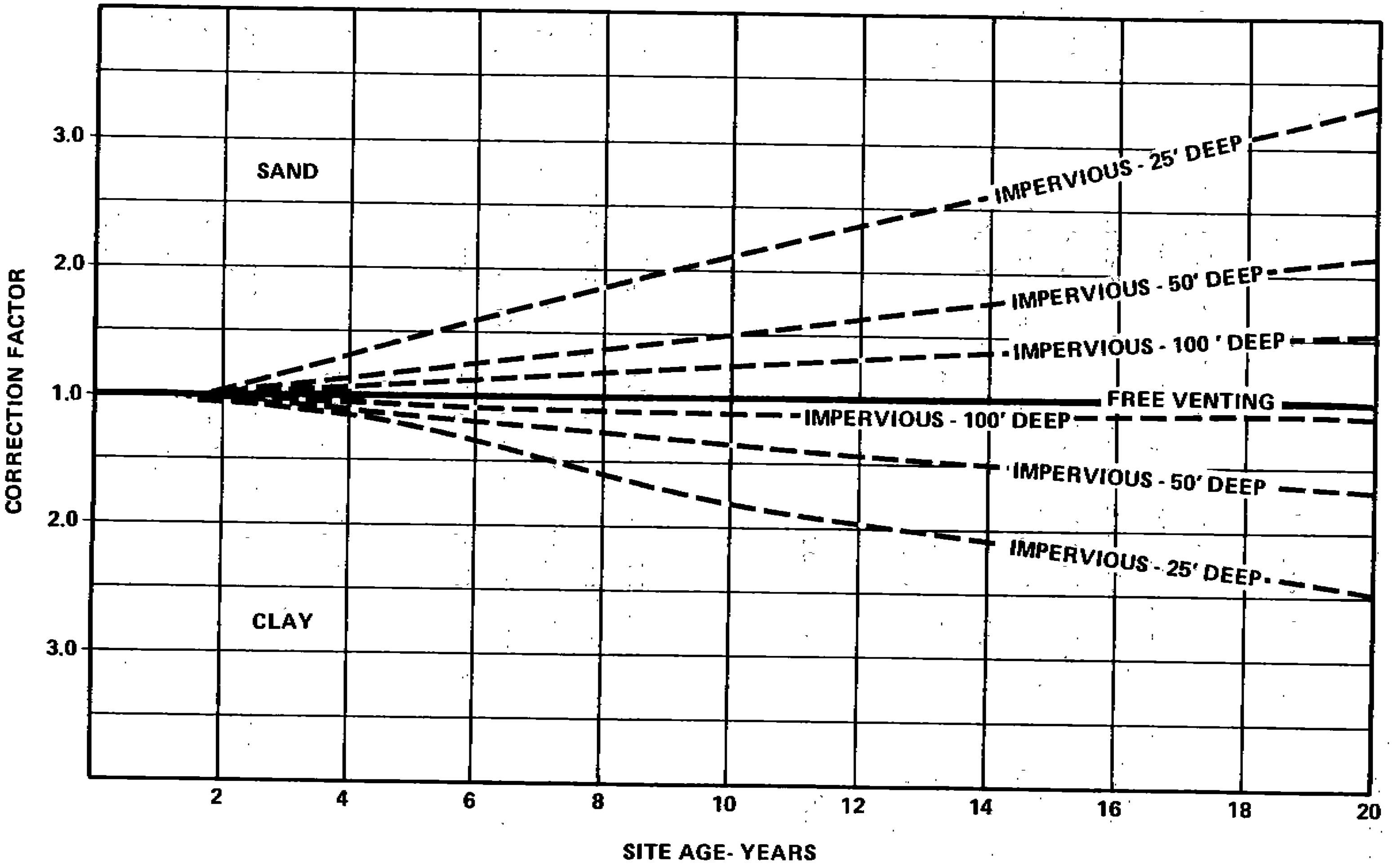


Figure 15-48. Impervious Correction Factors (ICF) for Soil Surface Venting Condition Around Landfill

Case Discussion

Figure 15-49 is a methane concentration contour map developed from the predicted travel distances. The map indicates that the possibility of human exposure to landfill gas is high. Landfill gas is known to be present and well drilling operations at the landfill have caused minor explosions. The monitoring wells along the facility perimeter and testing in nearby homes indicate that gas has migrated off site. Both the 5 percent and 1.25 percent methane contours enclose homes evacuated because of gas accumulation. Measures have been taken to mitigate the immediate problems and the landfill operators have installed additional gas collection wells and extended the monitoring system.

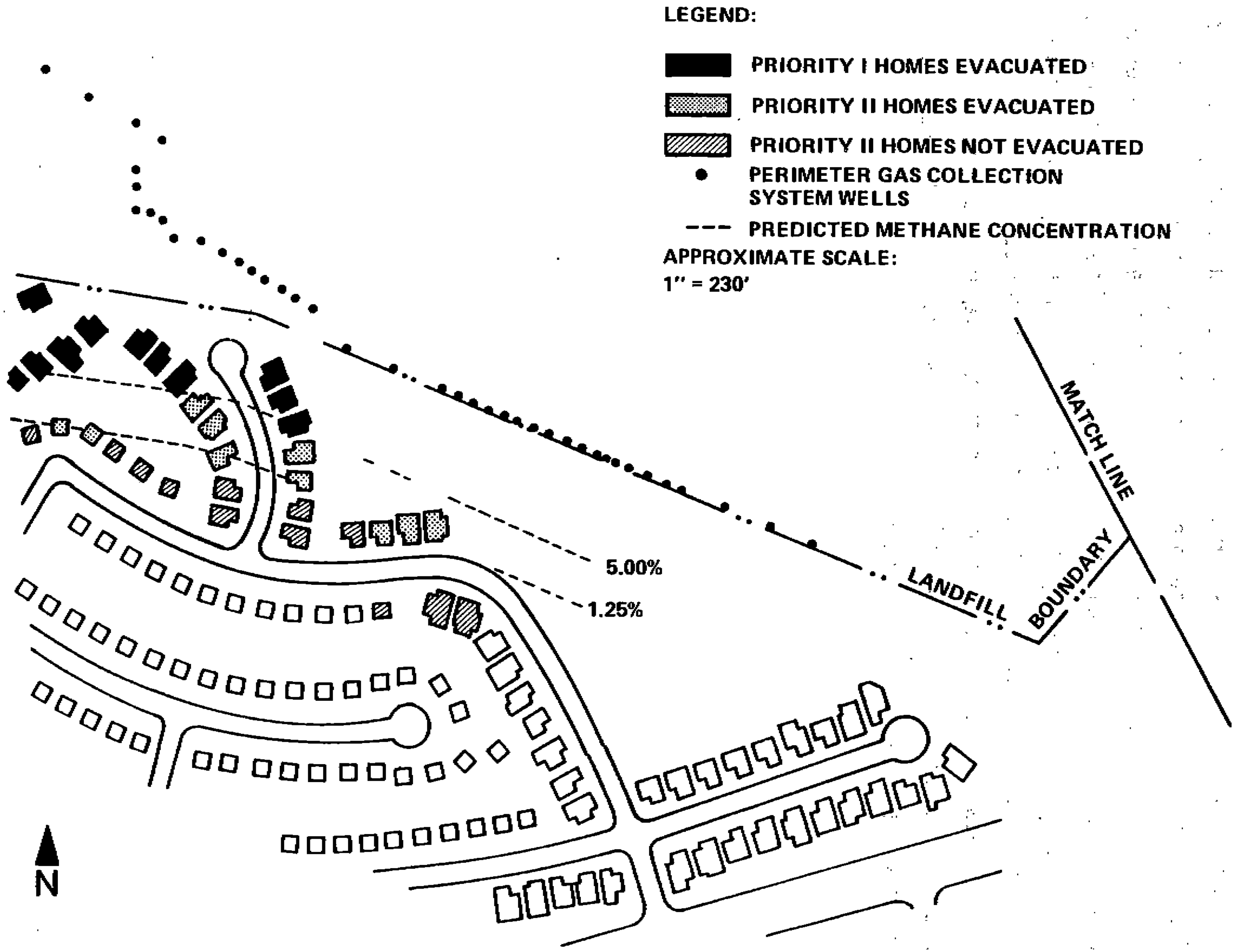


Figure 15-49. Landfill Perimeter Gas Collection System Wells

CASE STUDY 25: USE OF METEROROLOGICAL/EMISSION MONITORING DATA AND DISPERSION MODELING TO DETERMINE CONTAMINANT CONCENTRATIONS DOWNWIND OF A LAND DISPOSAL FACILITY

Point Illustrated

- How to use meteorological/emission monitoring data and dispersion modeling to estimate contaminant concentrations.

Introduction

Concern over possible vinyl chloride transport into residential areas adjacent to a land disposal facility prompted initiation of this study. As a followup to a screening assessment (involving emission modeling) a survey and emission monitoring program with the application of an air dispersion model were used to assess potential health hazards.

Facility Description

The facility is a landfill which has been in operation since 1963. The facility occupies an area of 583. acres, of which 228 acres contain hazardous and municipal waste. The facility and surrounding terrain is hilly with elevations ranging from 600 to 1150 feet above mean sea level. Residential areas are located immediately adjacent to the south and southeast facility boundaries, as shown in Figure 15-50.

The facility previously received waste solutions from the synthesis of polyvinyl chloride which included the vinyl chloride monomer. Gas is generated by municipal waste decomposition and chemical waste volatilization. The primary air release from the particular unit is vinyl chloride. A gas collection system has not been installed for this unit.

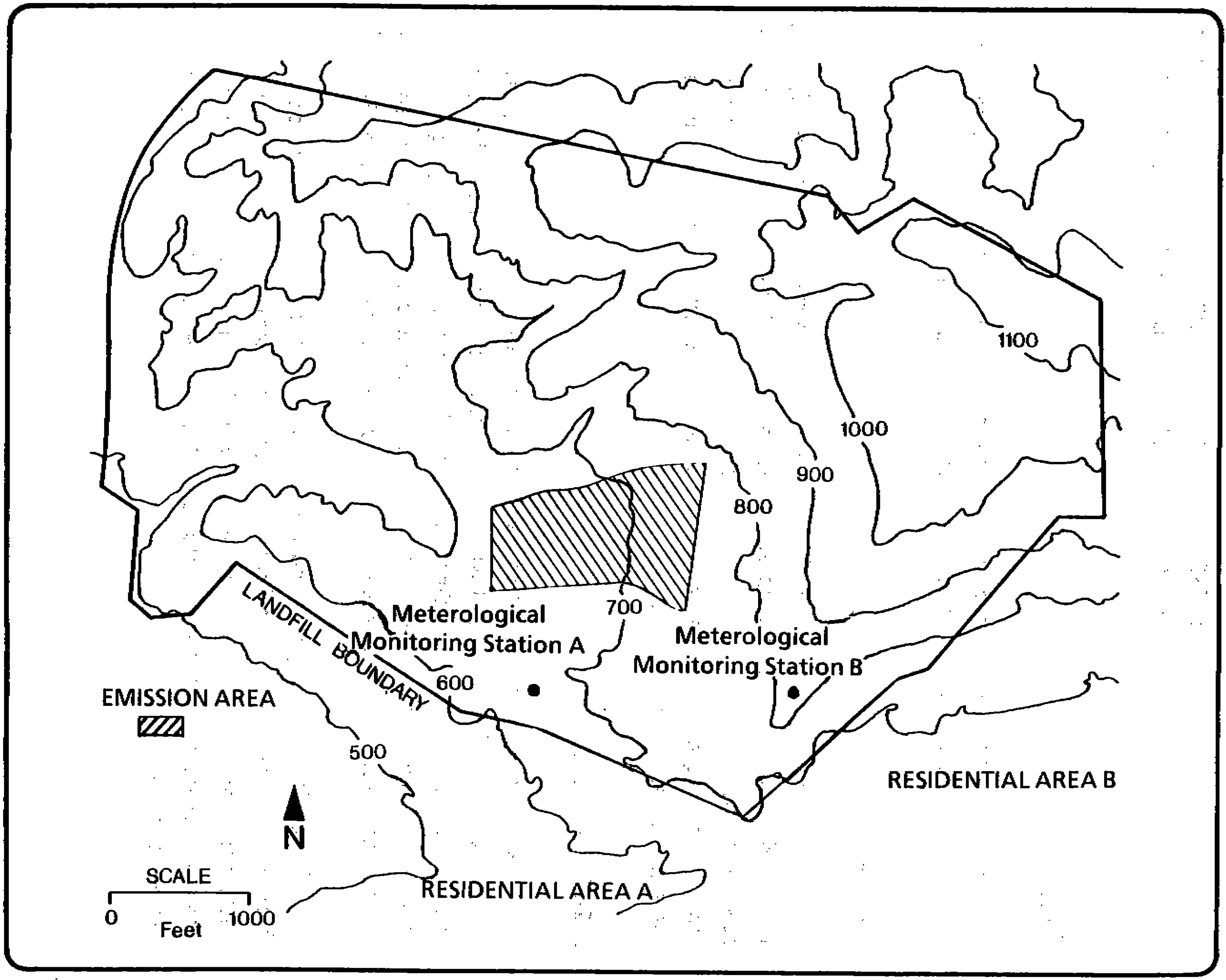


Figure 15-50. Site Map Showing Location of Meteorological Sites A and B (Adapted from Baker and Mackay, 1985)

Program Design/Data Collection

A screening assessment (based on emission/dispersion modeling) was conducted to evaluate vinyl chloride emissions from the landfill. Evaluation of these results indicated that emission monitoring should be conducted to more accurately quantify the release. An isolation flux chamber was used to measure vinyl chloride emissions during a three-day period in August. This sampling period was selected based on the screening assessment results to represent worst case emission and dispersion conditions.

An on-site meteorological survey program was also conducted to characterize wind flows at this complex terrain site. Two meteorological stations were deployed to evaluate wind flows, as influenced by complex terrain, which may impact the two adjacent residential areas (see Figure 15-50.) A one-month data collection period during August was conducted to characterize on-site wind and stability patterns during worst-case, long-term emission/dispersion conditions. Although the facilty is located in complex terrain, the diurnal wind pattern during the meteorological survey was very consistent from day to day. Therefore, the one-month meteorological monitoring period was adequate for this RFI application.

Program Results/Data Analysis

The emission monitoring and meteorological monitoring data were used as input for dispersion modeling. The wind patterns were different for each of the on-site meteorological stations (see Table 15-15). Therefore, two sets of modeling runs were conducted (meteorological station A data were used to estimate concentrations at residential area A and meteorological station B data were used to estimate concentrations at residential area B).

The dispersion modeling results indicated that estimated concentrations at both residential areas were significantly below the RFI health criteria. Therefore, followup air release characterizations were not necessary and information was sufficient for RFI decision making.

TABLE 15-15

SUMMARY OF ON-SITE METEOROLOGICAL SURVEY RESULTS

	Station A	Station B
Prevailing daytime wind direction.	S	SW
Prevailing nighttime wind direction	NNE	ENE

Case Discussion

Emission sampling was appropriate for this application because of the uncertainties associated with emission rate modeling for landfills (including uncertainties in emission modeling inputs such as the waste composition and spatial distribution). The isolation flux chamber technique provided a basis for direct measurement of vinyl chloride emission rates for dispersion modeling input.

The conduct of an on-site meteorological monitoring survey provided the required wind and stability input for dispersion modeling. The use of multiple meteorological towers for this application was necessary to characterize wind flow patterns in complex terrain and to account for off-site exposure at two residential areas subject to different wind conditions. The combination of emission monitoring, meteorological monitoring and dispersion modeling provided an effective air release characterization strategy for this RFI application.

References

Baker, L.W. and K.P. MacKay. 1985. Screening Models for Estimating Toxic Air Pollution Near a Hazardous Waste Landfill. Journal of Air Pollution Control Association, 35:11.

CASE STUDY 26: USE OF, METEOROLOGICAL DATA TO DESIGN AN AIR MONITORING NETWORK

Points Illustrated

- How to design an air monitoring program
- How to conduct an upwind/downwind monitoring program when multiple sources are involved.

Introduction

A screening assessment (based on emission/dispersion modeling) commensurate with RFI guidance was concluded to characterize hazardous air constituents being released from a wood treatment facility. Evaluation of these screening results indicated that it was necessary to conduct a monitoring program to more accurately quantify air emissions from units at the facility. Meteorological data were first collected to determine the wind patterns in the area. The wind direction data with the locations of the potential emission sources were then used to select upwind/downwind air sampling locations.

Facility Description

The site is a 12-acre wood treatment facility located in a flat inland area of the southeast. Creosote and pentachlorophenol are used as wood preservatives; heavy metal salts have been used in the past. Creosote and pentachlorophenol are currently disposed in an aerated surface impoundment. Past waste disposal practices included treatment and disposal of the metal salts in a surface impoundment, and disposal of contaminated wood shavings in waste piles. The constituents of concern in the facility's waste stream include phenols, cresols, and polycyclic aromatic hydrocarbons (PAH) in the creosote; dibenzodioxins and dibenzofurans as contaminants in pentchlorophenol; and particulate heavy metals. The potential emission sources (Figure 15-51) include the container storage facility for creosote and pentachlorophenol, the wood treatment and product storage areas, the aerated surface impoundment for the creosote and pentachlorophenol wastes, and the contaminated soil area which previously contained both the surface

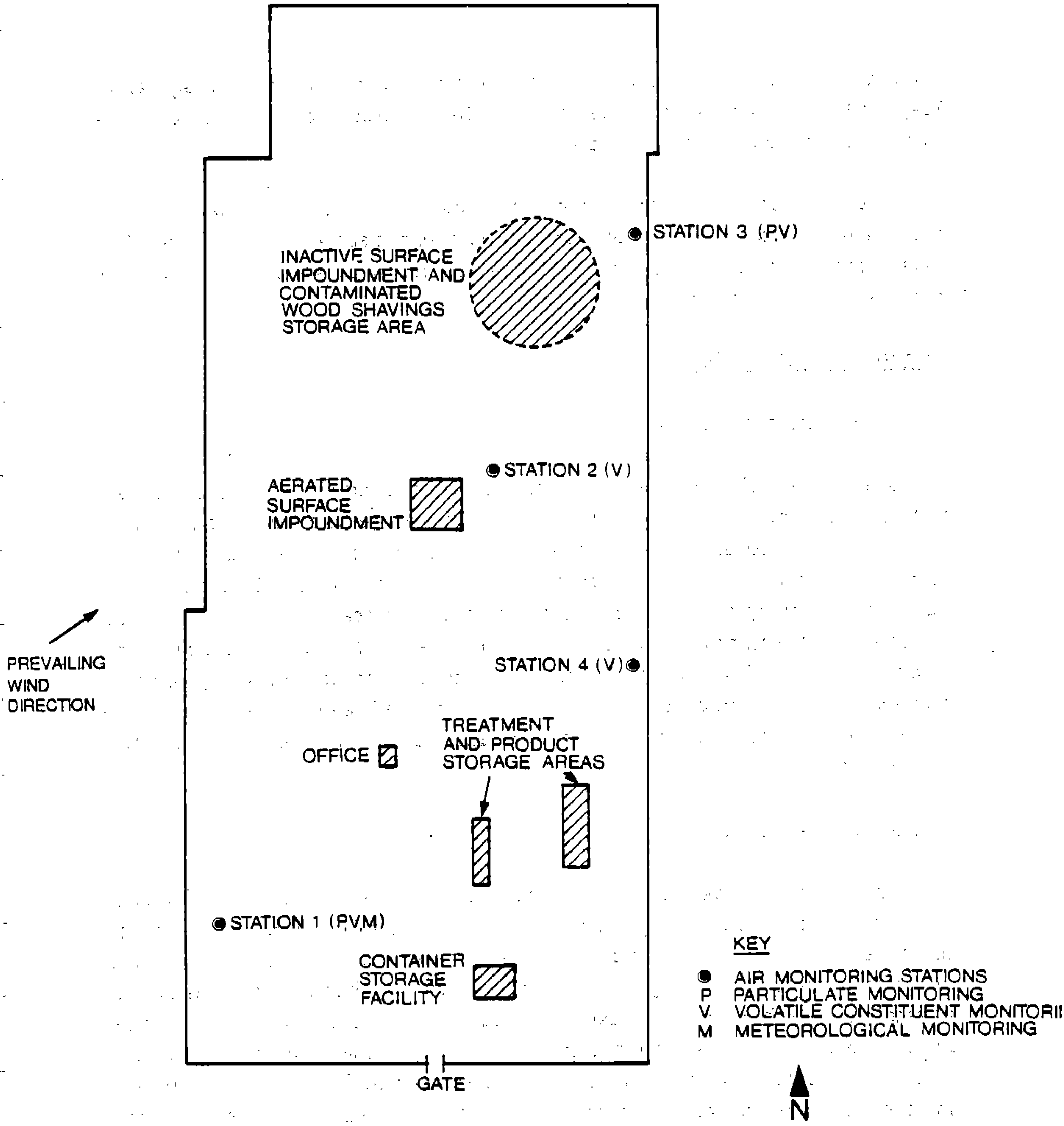


Figure 15-51. Site Plan and Locations of Air Monitoring Stations

impoundment for treating the metal salts and the wood shavings storage area. Seepage from these waste management units has resulted in documented ground-water and surface water contamination.

The area surrounding the facility has experienced substantial development over the years. A shopping center is now adjacent to the. eastern site perimeter. This development has significantly increased the number of potential receptors of air releases of hazardous constituents.

Program Design/Data Collection

Preliminary Screening Survey--

A limited-on-site air screening survey was first conducted to document air releases of potentially hazardous constituents, to prioritize air emission sources, and to verify screening assessment modeling results and the need to conduct a monitoring program. Total hydrocarbon (THC) levels were measured with a portable THC analyzer downwind of the aerated surface impoundment, wood treatment area, and product storage area. Measurements were also made upwind of all units to provide background concentrations. Because THC levels detected downwind were significantly higher than background levels, a comprehensive monitoring program to characterize releases to the air was designed and implemented.

Waste Characterization--

To develop an adequate monitoring program, the composition of wastes handled in each waste management unit was first determined to identify which constituents were likely to be present in the air releases. Existing water quality data indicated contamination of ground water with cresols, phenol, and PAHs and of surface water with phenols, benzene, chlorobenzene, and ethyl benzene. A field sampling program was developed to characterize further the facility’s waste stream. Wastewater samples were collected from the aerated surface impoundment and soil samples were collected from the heavy metal salt waste treatment/disposal area. Analytical data from this sampling effort confirmed the presence of the constituents previously identified. Additional, constituents detected included toluene and xylenes in surface impoundment wastes, and arsenic, copper, chromium, and zinc in the treatment/disposal area.

Based on their individual emissior potentials and potentials for presenting health and environmental hazards, the following constituents were selected for measurement in the air monitoring program:

Volatile/semi-volatile constituents:	toluene, benzene, total phenols, pentachlorophenol, PAHs, cresols
Particulateconitituents:	arsenic, copper, chromium, zinc.

Meteorological Data Collection--

Meteorological information is critical for designing an air monitoring program because stations must be located both upwind and downwind of the contaminant sources. Therefore, a one-month meteorological monitoring survey was conducted at this flat terrain site. The survey was conducted under conditions considered to be representative of the summer months during which air samples would be collected. Summer represented worst-case conditions of light steady winds and warm temperatures. The collected meteorological data showed that the local wind direction was from the southeast. No well-defined secondary wind flows were identified.

Initial Monitoring--

Alternative methods were considered for monitoring emissions from the aerated surface impoundment and contaminated storage area. Direct emission measurements (such as use of isolation flux chambers) would not be practical for aerated ponds or for monitoring particulate emissions from area sources. Therefore, an air monitoring program with samplers located in proximity to the other units of concern was selected for this application.

The on-site meteorological survey data were used with the EPA atmospheric dispersion model, ISC (Industrial Source Complex Model), to estimate-worst-case air emission concentrations and to help determine the locations for the air sampling stations. The ISC model was used because it is capable of simulating conditions of point and non-point source air emissions. Using the established southeast wind direction, maximum downwind concentration were predicted for different meteorological conditions (e.g., wind speed). Upwind background stations and downwind monitoring stations were selected based on the predicted dispersion pathways. Because the releases from the individual waste management areas overlapped, the model also provided a means for separating the incremental contamination due to each source.

Figure 15-51 shows the locations of the selected sampling stations. Station 1 is the upwind background station. Here background volatile concentrations, particulate concentrations, and meteorological conditions were monitored. Stations 2 and 4 were located to identify volatile emissions from the aerated surface impoundment and wood treatment/product storage areas, respectively. Station 3 was located downwind of the inactive surface impoundment/wood shavings disposal area. This station was sited to document releases from these waste management units and to document worst-case concentrations of volatiles and particulate at the facility property boundary. For this application the locations of Stations 2, 3 and 4 were adequate to characterize. air concentrations at both the unit boundary as well as the facility property boundary (due to the proximity of these two boundaries in the area downwind, based on the prevailing wind direction, of the units of concern). A trailer-mounted air monitoring station was used, to supplement the permanent stations and to account for any variability in wind direction.

Sample Collection--

The air quality monitoring was conducted over a three month period during the summer. Meteorological variables were measured continuously on site throughout the study. Air samples were taken over a 24-hour period approximately even six days. The sampling dates were flexible to insure that worst-case conditions were documented.

Volatile and semi-volatile constituents were sampled by drawing ambient air through a sampling cartridge containing sorbent media. A modified. high. volume sampler consisting of a glass fiber filter with a polyurethane foam backup sorbent (EPA Method TO4) was used to sample for total phenols, pentachlorophenol, and PAHs. Benzene and toluene were collected on Tenax sampling cartridges (EPA

Method TO1) and cresol was collected on silicagel cartridges (NIOSH Method Z001). Particulate were collected on filter cassettes using high-volume samplers.

In addition to the constituents previously discussed, Appendix VIII metals were analyzed on the first few sets of samples. These analyses were conducted to identify air releases of constituents other than those known to be present. The results indicated that no additional constituents were present in significant concentrations, so the additional analyses were dropped for the remainder of the study.

Program Results/Data Analysis

Standard sampling/analytical methods were available for all the target monitoring constituents. Analytical detection limits were below specific health and environmental criteria for all constituents except cresol. The high analytical detection limit for cresol which exceeded reference health criteria complicated data analysis. This difficulty was handled by the routine collection and analysis of waste water samples during the air monitoring program. These data were used to estimate cresol levels in the air by comparing its emission potential to the other air monitoring constituents which have relatively low detection levels.

Analytical results obtained during this sampling program established that fugitive air emissions significantly exceeded reference health criteria. Source control measures were implemented to reduce emission concentrations below health criteria levels. Subsequent air monitoring was conducted at the same stations used previously on a weekly basis immediately after implementation of the remedial measures, and on a quarterly basis thereafter.

Case Discussion

This case illustrates a sequence of tasks which were taken to design an air monitoring program at a site with multiple air emission sources. An initial field survey was conducted to identify decal prevailing wind patterns and to identify potential downwind receptors of fugitive air emissions. The meteorological survey results were used to design an effective monitoring network. Monitoring station locations were selected to obtain background conditions and to document air releases downwind of each emission source. Also, the monitoring strategy included use of a portable sampling station to provide flexibility in sampling locations to account for variation in wind direction. Spatial variability in air concentration was assessed with the aid of an air dispersion model to assist in data interpretation.

Air, emissions data showed an air release of hazardous constituents significantly above health criteria levels. Remedial measures were implemented, and periodic subsequent monitoring was conducted to insure compliance with the health criteria.

References

Methods T01 and T04, Compendium of Methods for Determination of Toxic Organic Compounds in Ambient Air, 1984, EPA-600/4-84-041.

Method Z001, NISOH Manual of Analytical 1984, National Institute of Occupational Safety and Health.

CASE STUDY 27: DESIGN OF A SURFACE WATER MONITORING PROGRAM

Point Illustrated

- When designing a surface water monitoring program, site-specific sediment and suspended solids information should be considered.

Introduction

Designing a surface water monitoring program to determine the extent of contamination involves identifying the potential waste sources, the contaminants likely to be present in each waste stream, and the flow paths by which the contaminants could reach surface waters. The fate of the contaminants once they reach the surface water must also be considered when selecting sampling stations and parameters to be measured. The example described here illustrates-the design of a monitoring program for a river system.

Facility Description

A facility which processed zinc, copper and precious metals from ores operated along a river for five years. The plant was closed after being cited for repeated fish kills which were reportedly due to failures of a tailings pond dike. At present, the site is covered with tailings containing high concentrations of copper, zinc, cadmium, arsenic and lead. There is no longer a tailings pond.

Site Setting

The site is located on coarse colluvium (hill-slope deposits of weathered bedrock) and fine-grained alluvium. These deposits, are, typically 50 feet thick. Metamorphic rock (phyllite) underlies the unconsolidated materials. Ground water moves laterally in the gravel formations from the steep valley walls towards the river.

The site is about 400 feet from the river. Two drainage ditches cross the lower portion of the site and merge prior to leaving the site. The ditch carries the combined flow and discharges directly into the river (Figure 15-52). No other tributaries enter the river within two miles of the location.

Sampling Program

A surface water monitoring program was designed as part of the Phase I remedial investigation to determine the extent of contamination in the river. Existing data from a reconnaissance visit had shown high concentrations of metals in the drainage ditch sediments (e.g., 5,170 mg/kg Cu and 11,500 mg/kg Zn). Ground water data from the plant's well showed concentrations of Cu (7 µg/l) and Zn (54 µg/l). The contribution of metals to the river by ground-water discharge at the site was considered to be relatively small.

Based on a review of the plant history and the available water quality and sediment data, a monitoring program, was designed. The potential pathways by which metals could reach the river appeared to be direct discharge from the drainage ditch, seepage of contaminated ground water, and storm water runoff. Plant records indicated that typical flows in the drainage ditch at its confluence with the river varied from 1 to 3 cubic feet per second (cfs) in the spring. During extreme flood conditions, the flow in the ditch exceeded 20 cfs. In the summer, flows in the drainage ditches at all locations were less than 0.5 cfs. Resuspension of contaminated sediments in the ditches during storm runoff appeared to be the most likely pathway for metals to reach the river. The specific metals of concern were identified as As, Cd, Cu, Pb and Zn based on the processes used at the plant and the composition of the ores which contained some arsenopyrites (As, Cu), galena (Pb), and sphalerite (Zn, Cd).

The available soil and water quality data, from the reconnaissance visit were reviewed to determine the likely fate of the metals. Soils in the area were circumneutral (pH = 6.5) and contained about 0.5 percent organic matter by weight. Thus the metals, particularly Pb, would, be, expected to adsorb onto the soil particles. In the on-site tailings piles, the pH of core samples ranged between 3.3 and 4.9. Low soil pH values had been measured in sediments in the drainage ditch just downgradient of the tailings pile. The pH of the river during the reconnaissance was 6.9. The suspended solids concentration was 10 mg/l.

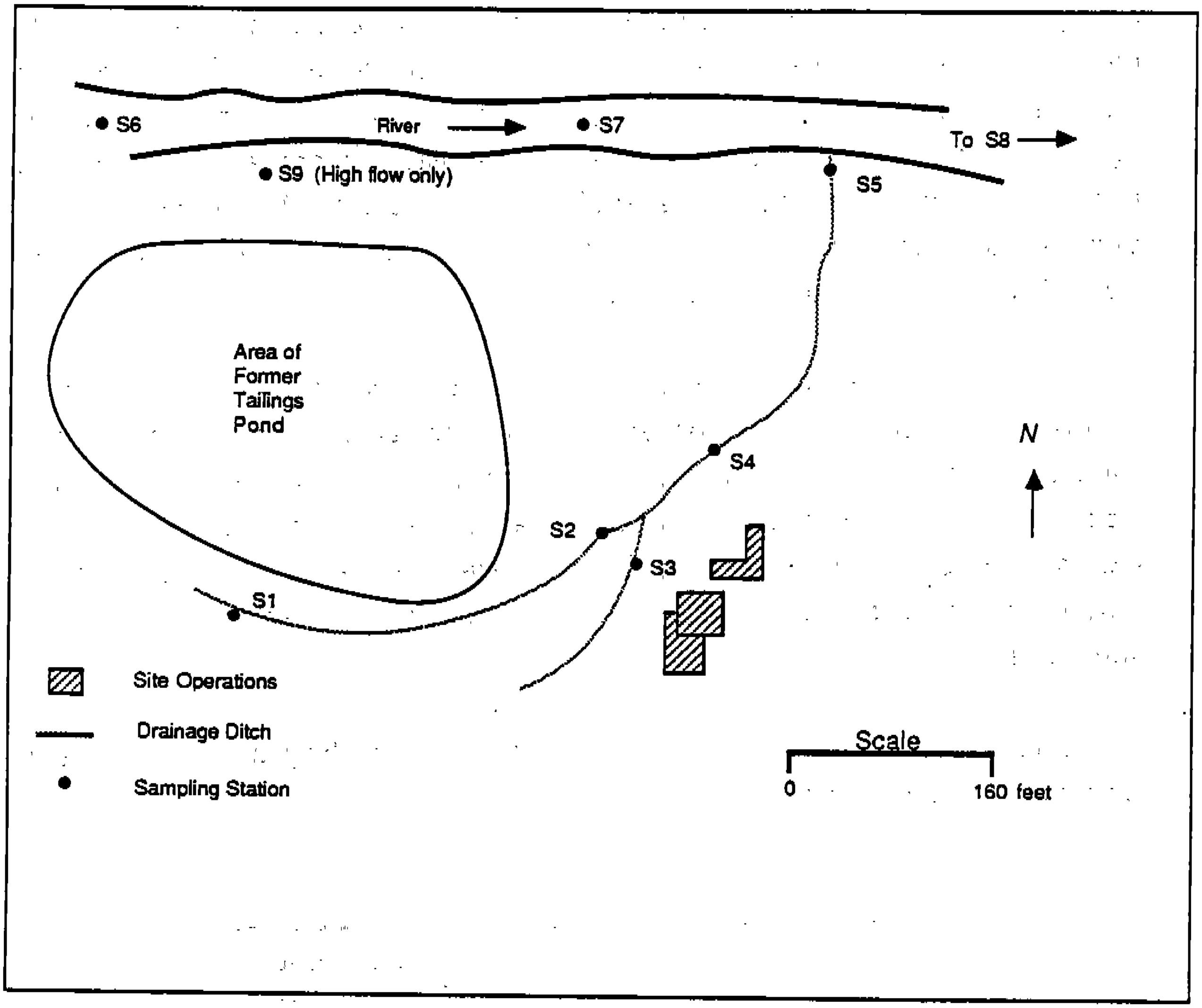
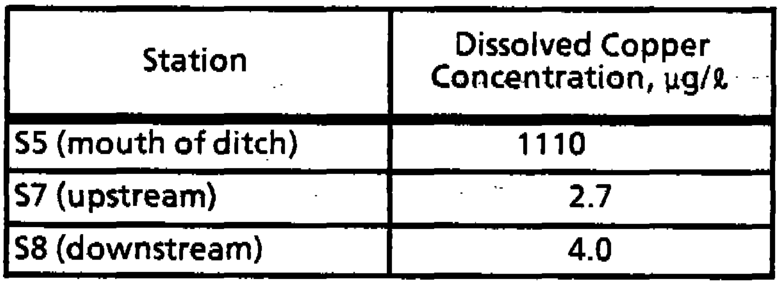


Figure 15-52. Sampling Station Locations for Surface Water Monitoring

Estimates of the distribution of metals between the dissolved and adsorbed phases for a range of partition coefficients (K_P) are shown in Table 15-16. For example, if $K_P = 10^4$ the suspended solids concentration was 10 mg/l, 90 percent of the metal present would be in the dissolved phase. This information indicated that even though a metal (e.g., lead), was known to sorb strongly, a significant amount could be transported in the dissolved phase. Thus, both water and suspended solids should be analyzed for metals. The complete list of parameters selected for measurement in the Phase I investigation and the rationale for their selection are outlined in Table 15-17.

The sampling stations were selected to determine river quality up- and downstream of the site and to determine whether particulates with sorbed metals were deposited on the river banks or streambed. The sampling stations and the rationale for their selection are listed in Table 15-18. The station locations are shown in Figure 15-52. Because floods were considered to be one cause of contamination incidents, samples were to be collected under both high and low flow conditions.

Selected results of the surface water quality sampling program for spring conditions are given below:



Station	Dissolved Copper Concentration, µg/ℓ
S5 (mouth of ditch)	1110
S7 (upstream)	2.7
S8 (downstream)	4.0

TABLE 15-16

RELATIONSHIP OF DISSOLVED AND SORBED PHASE POLLUTANT CONCENTRATIONS TO PARTITION COEFFICIENT AND SEDIMENT CONCENTRATION

K_P	SS (ppm)	C_W/C_T[a]	If C_T = 100 ppb		
			C_W =	x =	C_S =
10^0	1	1.0	100.	100.	0.0
	10	1.0	100.	100.	0.0
	100	1.0	100.	100.	0.0
	1000	1.0	100.	100.	0.0
	10,000	1.0		99.	1.0
10^1	1	1.0	100.	$1x10^3$	0.0
	10	1.0	100.	$1x10^3$	0.0
	100	1.0	99.9	999.	0.1
	1000	1.0	99.0	990.	1.0
	10,000	0.9	~ 90.9	909.	9.1
10^2	1	1.0	100.	$1 x 10^4$	0.0
	10	1.0	99.9	$1x10^4$	0.1
	1OO	1.0	99.0	$9.9 x 10^3$	1.0
	1000	0.9	90.9	$9.1x10^3$	9.1
	10000	0.5	50.	$5 x 10^3$	50.
10^3	1	1.O	99.9	$1x10^5$	0.1
	10	1.0	99.0	$9.9 x 10^4$	1.0
	100	0.9	90.9	$9.1x10^4$	9.1
	1000	0.5	50.	$5x10^4$	50.
	10000	0.1	9.1	$9x10^3$	90.9
10^4	1	1.0	99.0	$9.9x10^5$	1.0
	10	0.9	90.9	$9.1x10^5$	9.1
	100	0.5	50.	$5x10^5$	50.
	1000	0.1	9.1	$9.1x10^4$	90.9
	10,000	0.0	1.0	$9.9x10^3$	99.0

After Mills et al., 1985.

[a] The fraction dissolved (C_W/C_T) is calculated as follows:

$$\frac{C_W}{C_T} = \frac{1}{1 + K_P x 5x10^{-6}}$$

here K_P = partition coefficient,l/kg
SS = suspended solids concentration, mg/l

TABLE 15-17

PARAMETERS SELECTED FOR SURFACE WATER MONITORING PROGRAM

Parameters	Rationale
Metals - As, Cd, Cu, Pb, Zn	Determine extent of contamination
pH	Predict sorption behavior, metal solubility, and speciation
Dissolved Oxygen, Sulfide, Fe(II), Fe(III)	Determine redox conditions which influence behavior of metals, particularly the leaching of tailings
Alkalinity	A measure of how well buffered a water is; allows consideration of the likelihood of pH change
Total Dissolved Solids	Used as a water quality indicator and for QA/QC checks
Major Cations (Ca^{2+}, Mg^{2+}, Na^+, K^+, NH^+_4) Major Anions ($C1^-$, SO_4^{2-}, NO_3^-)	May identify other waste sources; can influence fate of trace metals
Suspended Solids	Predict the fraction of metal in water which is sorbed
Streamflow	Compute mass balances and assist in identifying sources of observed contamination

TABLE 15-18

SELECTED SURFACE WATER MONITORING STATIONS AND RATIONALE

Station	Media	Rationale
Drainage ditch west of site (S1)	Water and sediments	Determine whether off-site drainage is significant source of contamination
Drainage ditches on site (S2 and S3)	Water and sediments	Identify on-site sources
Downstream of confluence of 2 ditches (S4)	Water and sediments	Provide information for checking mass balances from the two drainage ditches
Mouth of drainage ditch (S5)	Water, suspended sediment, bedload	Determine upstream water quality
River (S6, S7, and S9)	Water, suspended sediment, bedload	Determine upstream water quality
River (S8)	Water, suspended sediment, bedload	Determine quality downstream of site and provide data for mass balance

A mass balance was computed to determine how much of the apparent decrease from the ditch (S5) to the downstream river sampling point (S8) was due to dilution and how much could be attributed to other processes (e.g., sorption, precipitation). The concentration in the river considering dilution alone was predicted using the following mass balance equation:

$$C_R = \frac{C_U Q_U + C_W Q_W}{Q_U + Q_W}$$

where

CR = downstream concentration of pollutant in river following mixing with ditch waters (S8), µg/l

C_W = concentration in ditch water (S5), µg/l

C_u = concentration in river above ditch (S7) µg/l

Q_W = discharge rate of ditch, ft^3/sec

Q_U = flow rate of river above ditch, ft^3/sec.

At the time of sampling, the flow in the ditch at station S5 was 1 cfs and the river flow at station S7 was 155 cfs. Using the above equation, the predicted river concentration for Cu was approximately 10 µg/l. (The observed concentration was 4 µg/l.) The observed decrease in concentration was primarily due to dilution, although other attenuation processes (e.g., sorption) were probably occurring. The expected sorbed concentration was estimated as follows:

$$X = K_P C$$

where

x = sorbed concentration, µg/kg
K_p = partition coefficient, l/kg
c = concentration of dissolved phase, µg/l.

Here, the sorbed concentration of Cu was estimated as 8×10^5 µg/kg (800 mg/kg).

Case Discussion

This case illustrates the use of site-specific data and the use of information on the environmental fate of contaminants in the design of a surface water monitoring program. Site data are needed to locate waste sources and to determine the likely flow paths by which contaminants reach rivers. An understanding of the general behavior of the contaminants of interest. and of the factors which influence their fate is helpful in determining where samples should be collected and what parameters, particularly master variables, should be measured. Collecting data on such parameters (e.g., pH, suspended solids) ensures that the necessary information is available to interpret the data.

CASE STUDY 28: USE OF BIOASSAY5 AND BIOACCUMULATION TO ASSESS POTENTIAL BIOLOGICAL EFFECTS OF HAZARDOUS WASTE ON AQUATIC ECOSYSTEMS

Point Illustrated

- Measurements of toxicity (i.e., bioassays) and bioaccumulation can be used to assess the nature and extent of potential biological impacts in off-site areas.

Introduction

A study was conducted to determine whether leachate discharged into surface waters had adversely affected biota in a stream adjacent to a waste site and in a nearby lake. The components of the study included chemical analyses of the leachate, surface waters, sediments, and tissue samples; toxicity testing of the surface waters; and surveys of the structure and composition of the biological communities. Tissue analyses are important for determining contaminant bio-accumulation and assessing potential human exposure through consumption of aquatic organisms. Toxicity testing is important for determining potential lethal and sublethal effects of contaminant exposure on aquatic biota. Although ecological analysis of community structure and composition is also an important component of biomonitoring, it will not be discussed here since the focus is on the relationships between the leachate source, the distributions of contaminants near the waste site, and the toxic effects and bioaccumulation of the contaminants in the tissues of local fauna.

Site Description

The 5-acre facility is an industrial waste processing site which accepts wastes from nearby plastic manufacturing and electroplating industries. Liquid wastes are dewatered on site prior to removal to an off-site disposal area. The principal wastes processed at the faclity include several organic compounds and metals.

The site contains a wastewater impoundment with numerous seeps and drainage channels that transport leachate into an adjacent river (Figure 15-53). The river flows from northeast to southwest, and is joined by a tributary stream before entering a nearby lake. The RFA indicated an oily sheen associated with a strong chemical odor on the surface of the stream below the treatment pond, and further reported numerous violations of the NPDES permit. Subsequent analyses of samples taken from the drainage channels and seeps flowing into the river showed high concentrations of organic and trace metal contaminants, principally bis(2-ethylhexyl). phthalate, ethylbenzene, phenol, copper, cadmium, and zinc.

Sampling Program

Six stations were sampled to assess possible toxicity and bioaccumulation of released substances (Figure 15-53). Station 6, located upstream of the release, was selected as a reference location for the stream. Station 17 was selected as a reference location for the lake because it is distant from the river mouth and because prevailing winds from the northwest direct the river discharge along the southeast shore of the lake away from the station. Stations 7, 15, and 18 were selected to determine the extent of toxic impacts on river and lake biota.

Water, sediments, and tissues of bottom-dwelling fishes (brown bullhead catfish, *Ictalurus nebulosus*) were collected at each station. Concentrations of bis(2-ethylhexyl) phthalate, ethylbenzene, phenol, copper, cadmium, and zinc were measured in each matrix. Analyses were conducted according to U.S. EPA guidelines for sediments, water, and tissues. Water quality variables (dissolved oxygen, temperature profiles, and alkalinity), total organic carbon in sediments, and lipid content of tissues were also measured.

Three independent bioassays were conducted on each water sample. The test species and endpoints used in the bioassays were those recommended in the U.S. EPA protocol for bioassessment of hazardous waste sites (Tetra Tech, 1983). Growth inhibition in the alga *Selanastrum capricornutum,* and mortality in the crustacean *Daphnia magna* were determined using U.S. EPA (1985) short-term methods for chronic toxicity testing. Inhibition of enzyme-mediated" luminescence in the bacterium *Photobacterium phosphoreum* (i.e., the Microtox procedure) was measured according to the methods established by Bulich *et al.* (1981).

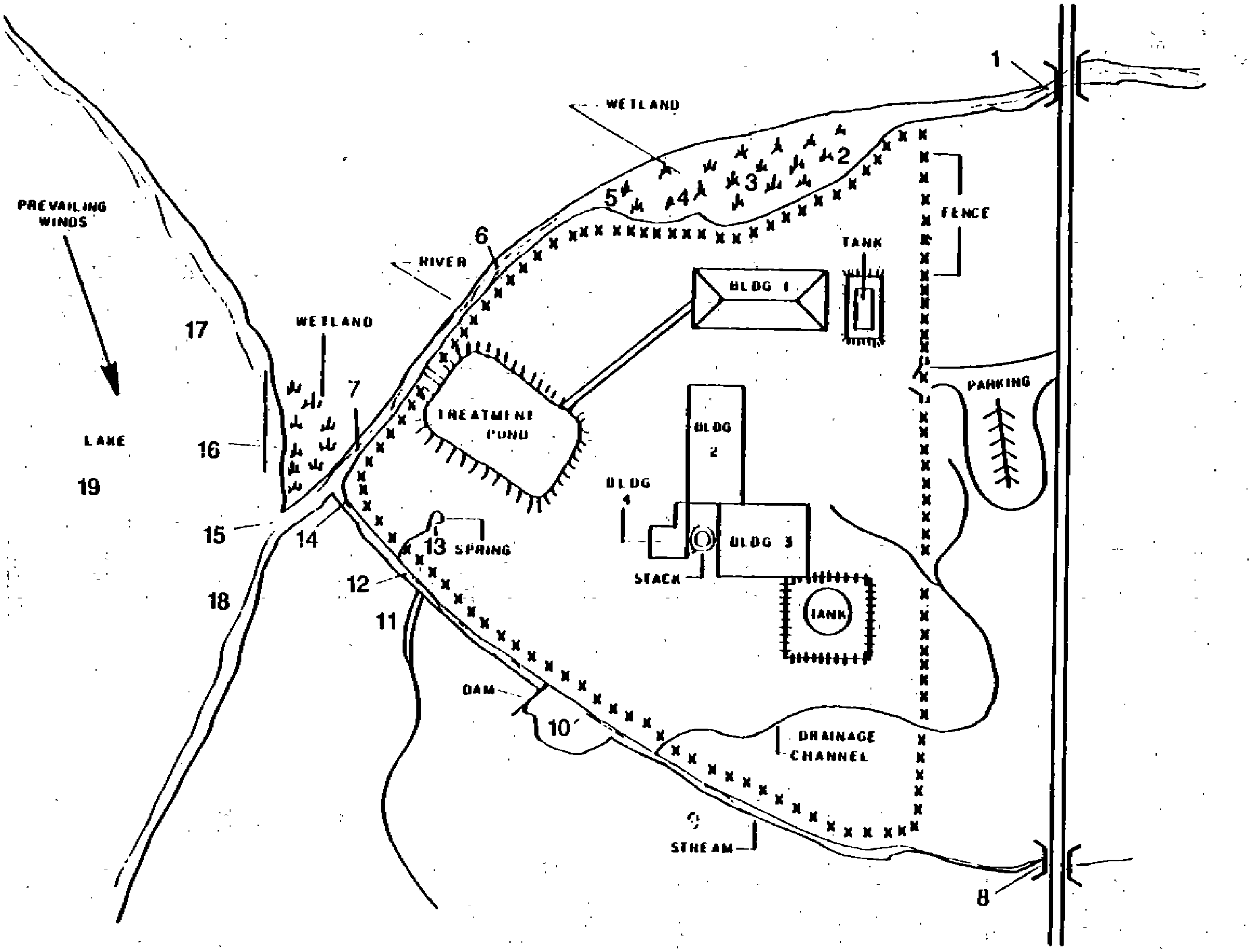


Figure 15-53. Site Plan and Water Sampling Locations

Results

Results of the survey indicated that concentrations of organic contaminants in the surface waters were generally less than U.S. EPA water quality criteria, but that concentrations of inorganic contaminants generally exceeded water quality criteria at Stations 7, 15, and 18 (Table 15-19). In comparison with the reference stations, significant sediment contamination was evident at Stations 7, 15, and 18 for the three trace metals (Table 15-20). Tissue concentrations of organic substances exceeded detection limits for bis(2-ethylhexyl) phthalate at Stations 7 and 15, and for ethylbenzene at Station 7(Table 15-21). However, trace metal concentration in tissues were highly elevated at Stations 7 and 15, but only slightly elevated at

The bioassay data showed a considerable range in sensitivity, with the algal bioassay being the most sensitive (Table 15-22). Consequently, the bioassay results were normalized to the least toxic of the reference stations (i.e., Station 6) to compensate for the wide range of sensitivity among, the test species (Table 15-23). Overall, the bioassay results showed a high degree of agreement with contaminant concentrations in water and sediments (Figure 15-54, Table 15-19 and 15-20). Stations 7 and 15 showed highly toxic results, and Station 18 indicated moderate toxicity. Only the algal bioassay indicated significant, but low, toxicity at Station 17 (the lake reference station).

In summary, the results indicated that the organic contaminants were less of a problem than the trace metals in terms of bioaccumulation and potential toxicity. Most of the observed toxicity was attributed to trace metal contamination, which is consistent with the elevated concentrations of trace metals measured in the water, sediments, and tissues.

Case Discussion

This case study provides an example of a biomonitoring program designed to characterize the relationship between a contaminant source, contaminant concentrations in sediments and water, bioaccumulation in tissues, and receiving-water toxicity. It should be recognized that in many instances, the relationship

TABLE 15-19

MEAN CONCENTRATIONS (μg/ℓ) OF ORGANIC SUBSTANCES AND TRACE METALS IN LEACHATE AND SURFACE WATERS[a]

Chemical Class	Chemical	Station						Water Quality Criteria[b]	
		Seep L1	River 6	River 7	Lake 15	Lake 18	Lake 17	Acute	Chronic
Base Neutral	Bis (2-ethylhexyl) phthalate	600	2	11	10	1	2	940	3
Volatile	Ethylbenzene	100	1	1	<1	1	2	32,000	NA[c]
Acid Extractable	Phenol	1500	<1	18.37	<1	<1	<1	10,200	2560
Metals	Copper	4300	<1	489	56	26	2	18	12
	Zinc	35,000	17	4290	1100	37	35	320	47
	Cadmium	4800	<1	146	49	<1	<1	3.9	1.1

[a] River and lake alkalinity = 100 mg $CaCO_3$/L

[b] Trace metal criteria adjusted for alkalinity

[c] Not available for this substance

TABLE 15-20

MEAN SEDIMENT CONCENTRATIONS (μg/kg DRY WT) OF ORGANIC SUBSTANCES AND TRACE METALS

Chemical Class	Chemical	Station					
		Seep L1	River 6	River 7	Lake 15	Lake 18	Lake 17
Base Neutral	Bis (2-ethylhexyl) phthalate	NA[a]	216	1188	1080	108	216
Volatile	Ethylbenzene	NA	10	34	20	14	8
Acid Extractable	Phenol	NA	<30	<30	<30	<30	<30
Metals	Copper	NA	3	1663	190	88	7
	Zinc	NA	11	28,314	7260	24	23
	Cadmium	NA	<0.1	19	6	<0.1	<0.1

[a] Not applicable (NA).

TABLE 15-21

MEAN LIVER TISSUE CONCENTRATIONS (μg/kg WET WT) OF ORGANIC SUBSTANCES AND TRACE METALS

Chemical Class	Chemical	Station					
		Seep L1	River 6	River 7	Lake 15	Lake 18	Lake 17
Base Neutral	Bis (2-ethylhexyl) phthalate	NA[a]	<25	95	86	<25	<25
Volatile	Ethylbenzene	NA	<5	9	<5	<5	<5
Acid Extractable	Phenol	NA	<30	<30	<30	<30	<30
Metals	Copper	NA	118	1600	750	237	180
	Zinc	NA	983	28,400	8500	2139	1420
	Cadmium	NA	115	1600	639	190	125

[a] Not applicable (NA).

TABLE 15-22

MEAN LC_{50} AND EC_{50} VALUES (PERCENT DILUTION) FOR SURFACE-WATER BIOASSAYS[a]

Bioassay	Endpoint	Station					
		Seep L1	River 6	River 7	Lake 15	Lake 18	Lake 17
Algae	Growth inhibition (EC_{50}%)[a]	NA[b]	>100[c]	0.4	10.0	24.9	75.0
Daphnia	Mortality (LC_{50}%)[d]	NA	>100	3.3	18.5	100.0	90.0
Microtox	Decreased luminescence (EC_{50}%)[a]	NA	>100	5.6	15.0	43.4	>100

[a] Percent dilution required corresponding to a 50 percent response
[b] Not applicable (NA) because leachate toxicity was not tested
[c] Response of >100 indicates that samples were not toxic at all dilutions tested
[d] Percent dilution corresponding to 50 percent mortality

TABLE 15-23

RELATIVE TOXICITY OF SURFACE-WATER SAMPLES[a]

Bioassay	Endpoint	Station					
		Seep L1	River 6	River 7	Lake 15	Lake 18	Lake 17
Algae	Growth inhibition (EC_{50}%)	NA[b]	0.0	99.6	90.0	75.1	25.0
Daphnia	Mortality (LC_{50}%)	NA	0.0	96.7	81.5	0.0	10.0
Microtox	Decreased luminescence (EC_{50}%)[a]	NA	0.0	94.4	85.0	56.6	0.0

[a] Relative toxicity = 100 x [(Reference Station - Impacted Station)/Reference Station]
[b] Not applicable (NA) because leachate toxicity was not tested

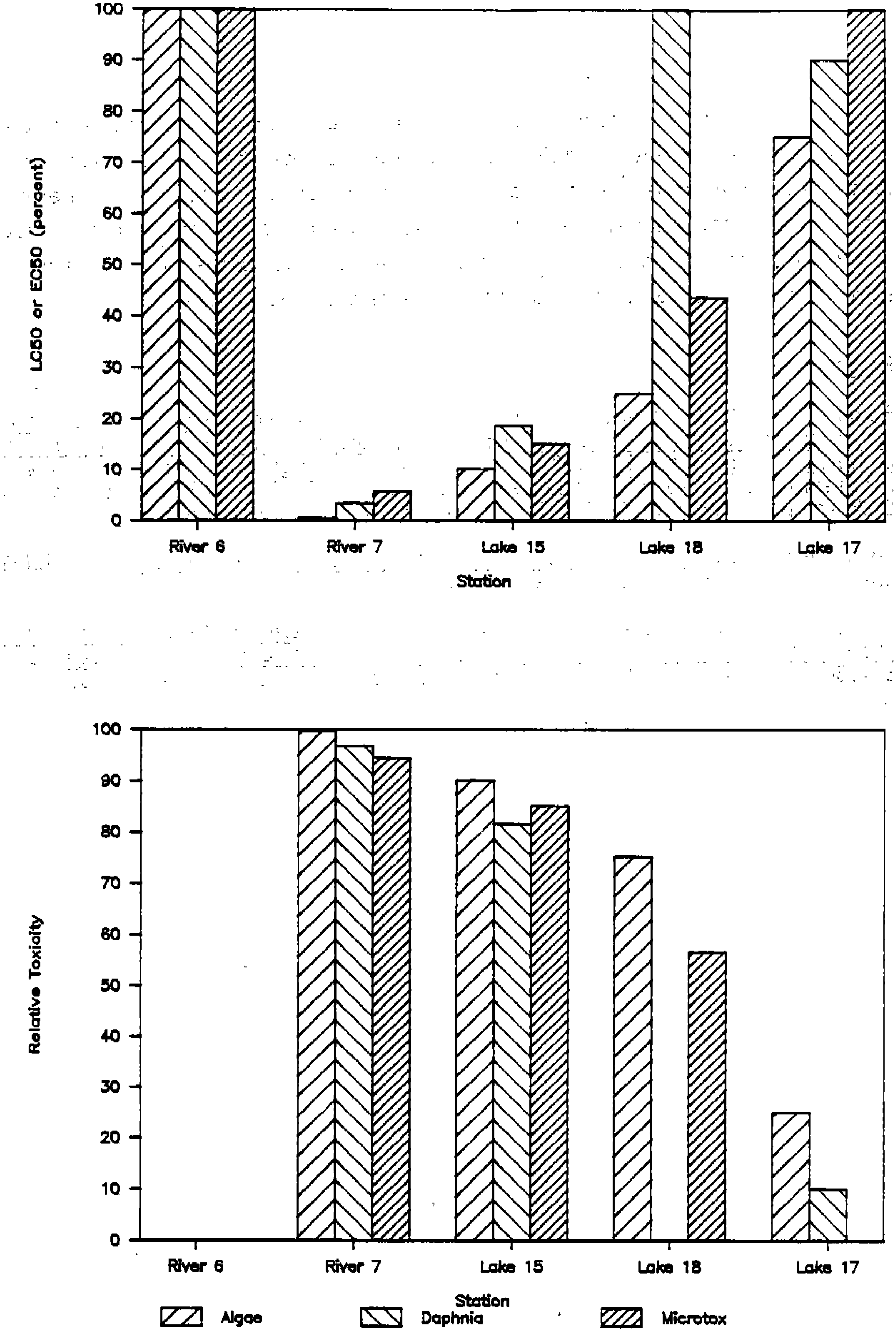


Figure 15-54. Bioassay Responses to Surface Water Samples

between contaminant concentrations in the water and toxicity till not be as clear-cut as described in this example. Consideration of the chemical composition in leachate samples, mass balance calculations, and transport and fate mechanisms may indicate that sediments are the primary repository of contaminants. In such instances; sediment bioassays rather than receiving-water bioassays may be better suited for characterization of potential toxic effects on local fauna.

References

Bulich, A.A., M.W. Greene, and D.L. Isenberg. 1981. Reliabilty of the bacterial luminescence assay for determination of the toxicity of pure compounds and complex effluent, pp. 338-347. In: Aquatic toxicology and hazard assessment: Proceedings of the fourth annual symposium. ASTM STP 737. D.R. Branson and K.L. Dickson (eds)., American Society for Testing and Materials, Philadelphia, PA.

Tetra Tech. 1983. Protocol for bioassessment of hazardous waste sites. EPA- 600/2-83-054. Lafayette, CA. 42 pp. + appendices.

U.S. Environmental Protection Agency. 1985. Short-term methods for estimating the chronic toxicity of effluents and receiving waters to freshwater organisms. EPA/600/4-85/014. U.S. EPA, Environmental Monitoring and Support Laboratory, Cincinnati, OH. 162 pp.

CASE STUDY 29: SAMPLING OF SEDIMENTS ASSOCIATED WITH SURFACE RUNOFF

Point Illustrated

- Contaminated sediments associated with surface runoff pathways (rivulets or channels) are indicati.ve of the migration of chemicals via overland flow.

Introduction

This facility is a secondary lead smelting plant which began operation in 1976. The plant reclaims lead from materials such as waste automotive batteries, byproducts of lead weight manufacture, and wastewater sludges. Lead grid plates from alvaged batteries are temporarily stored on site in an open pile prior to being re-melted. It is therefore appropriate to conduct some form of-runoff sampling to monitor migration of contaminants from the site via this route.

Facility Description

The facility covers approximately 2,000 ft^2 and is situated in an area primarily used for farming. A creek flows adjacent to the plant and drains into a major river 6 miles west of the site. Population is sparse with the nearest town 4 miles to the south. In the past, there have been four on-site impoundments in operation and two landfills. In addition, blast furnace slag, lead grid plates, and rubber chips from the recycled batteries have been stored in two on-site waste piles.

Sediment Sampling

Four sediment samples (020, 022, 025, and 027) were collected from surface runoff pathways and a creek which receives runoff from the site. Figure 15-55 shows the locations of the runoff pathways relative to the facility and the four sampling points. Additional sediment samples were collected from the creek at various points upstream and downstream of known overland leachate seeps and surface water runoff routes. The program design enabled comparison between

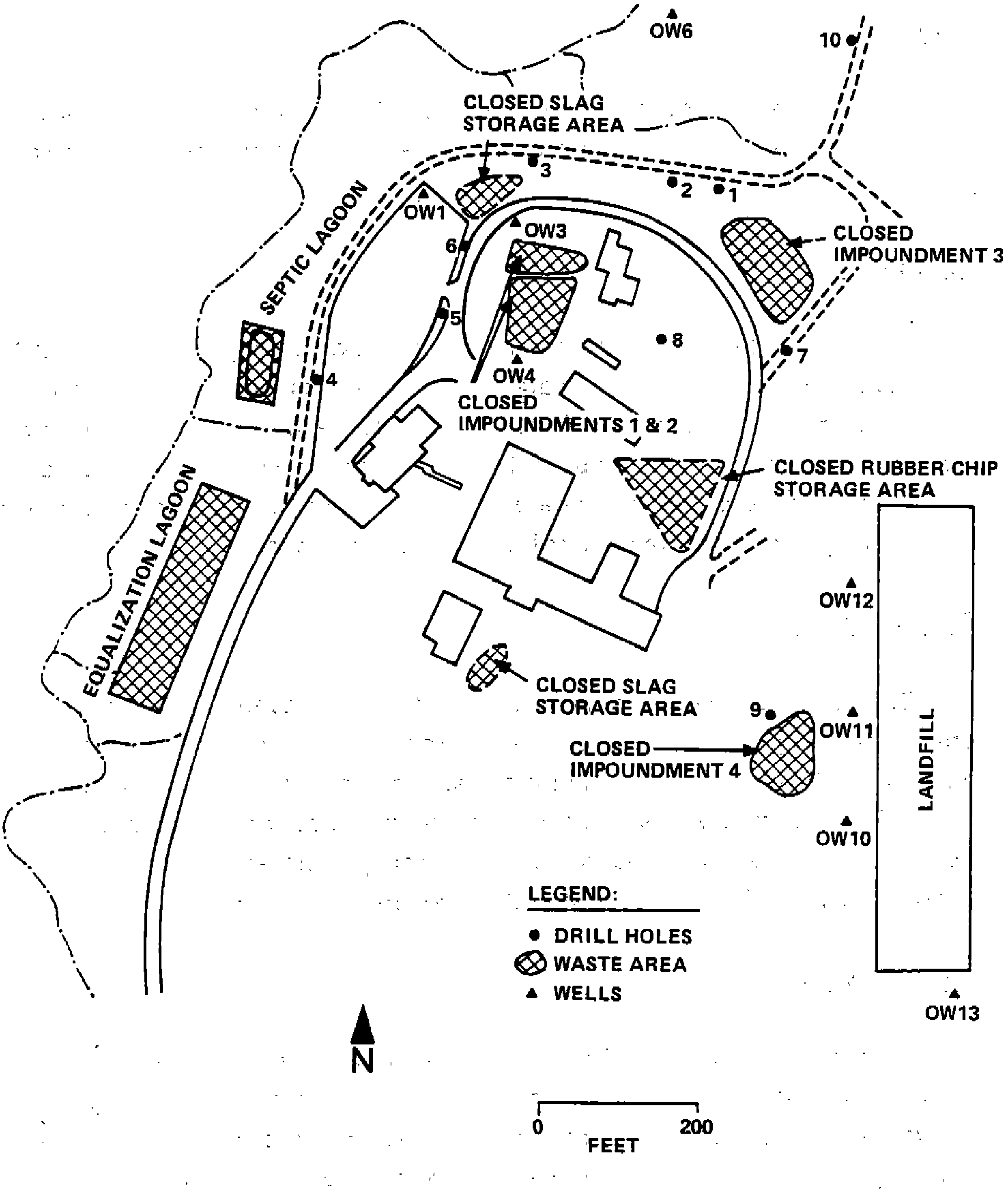


Figure 15-55. Surface Water and Sediment Sample Locations

concentrations at different sections of the creek and background locations in relation to the runoff pathways.

Results

Table 15-24 presents,the concentrations of lead and arsenic measured on the four surface runoff pathways and at location 029, which represents an upstream background concentration (Figure 15-55). It is clear that highly elevated levels of lead, were detected in all four of the runoff pathway samples. The highest concentration of lead, 1,900 ppm, was detected in the western-most portion of the site. Runoff pathway sediment at the northern end of the facility, adjacent to the slag storage area, recorded 1,600 ppm of lead. Concentrations of this order represent a substantial source of sediment contamination.

TABLE 15-24

ARSENIC AND LEAD CONCENTRATIONS (PPM) IN RUNOFF SEDIMENT SAMPLES

	Sampling Location				
Contaminant	# 020	# 022	# 025	# 027	Background # 029
Arsenic	11.0	9.6	2.0	8.9	<0.1
Lead	1300	1900	1600	1700	11.0

Case Discussion

This case illustrates the importance of monitoring surface runoff pathways, because they can represent a major route of contaminant migration from a site, particularly for contaminants likely to be sorbed on or exist as fine particles. This type of monitoring is especially useful for units capable of generating overland flows. Such monitoring can establish the need for corrective measures (e.g., surface runon/runoff controls and/or some form of waste leachate collection system).

CASE STUDY 30: SAMPLING PROGRAM DESIGN FOR CHARACTERIZATION OF A WASTEWATER HOLDING IMPOUNDMENT

Points Illustrated

- Sampling programs should consider three-dimensional variation in contaminant distribution in an impoundment.
- Sampling programs should encompass active areas near inflows and outflows, arid potentially stagnant areas in the corner of an impoundment.

introduction

This study was conducted to assess whether an act impoundment could be assumed to be of homogeneous composition for the purpose of determining air emissions. This case shows the design of an appropriate sampling grid to establish the three-dimensional-composition of the impoundment.

Facility Description

The unit being investigated in this study is a wastewater impoundment at a chemical manufacturing plant. The plant primarily produces nitrated aromatics and aromatic amines. Raw materials include benzene, toluene, nitric acid, and sulphuric acid. Wastewater from the chemical processing is discharged into the impoundment prior to being treated for release into a nearby water body. The impoundment has an approximate surface area of 3,750 m^2 and a depth of 3 m.

Sampling Program

For the most part sampling involved the collection of grab samples using an extended reach man-lift-vehicle. The program was designed to collect samples at different locations and depths in the impoundment.

Sampling Locations and Procedures

Sampling Grid - The wastewater impoundment was divided into 15 segments of equal area. Within this grid, eight sampling locations were selected which included all pertinent areas of the impoundment, such as active portions near the inflows and outflows, potential stagnant areas in the corners, and offshore points near the center line of the impoundment.

It was decided to take samples from four depths in the liquid layer and one from the bottom sediments at each of the eight locations. Figure 15-56 shows the impoundment schematic and sampling locations.

Liquid Sampling - A total of 32 liquid grab samples were taken. These were analyzed for the following parameters: all identifiable volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs) using gas chromatograph/mass spectroscopy; and selected VOCs and SVOCs by gas chromatography using a flame ionization detector.

Sediment/Sludge Sampling -The bottom layer was sampled using a Ponar grab sampler. The same analyses were performed on the eight sediment/sludge samples as on the liquid samples.

Meteorological Monitoring - The ambient meteorological conditions were monitored throughout the sampling period, including wind speed, wind direction, and air temperature. A video camera was also used to record the movement of surface scum on the impoundment.

Table 15-25 summarizes the sampling locations and analyses, including locations where QC data were collected.

Results

From the sampling program, it was discovered that approximately 99 percent of the organic compounds (by weight) were contained in the bottom sludge layer.

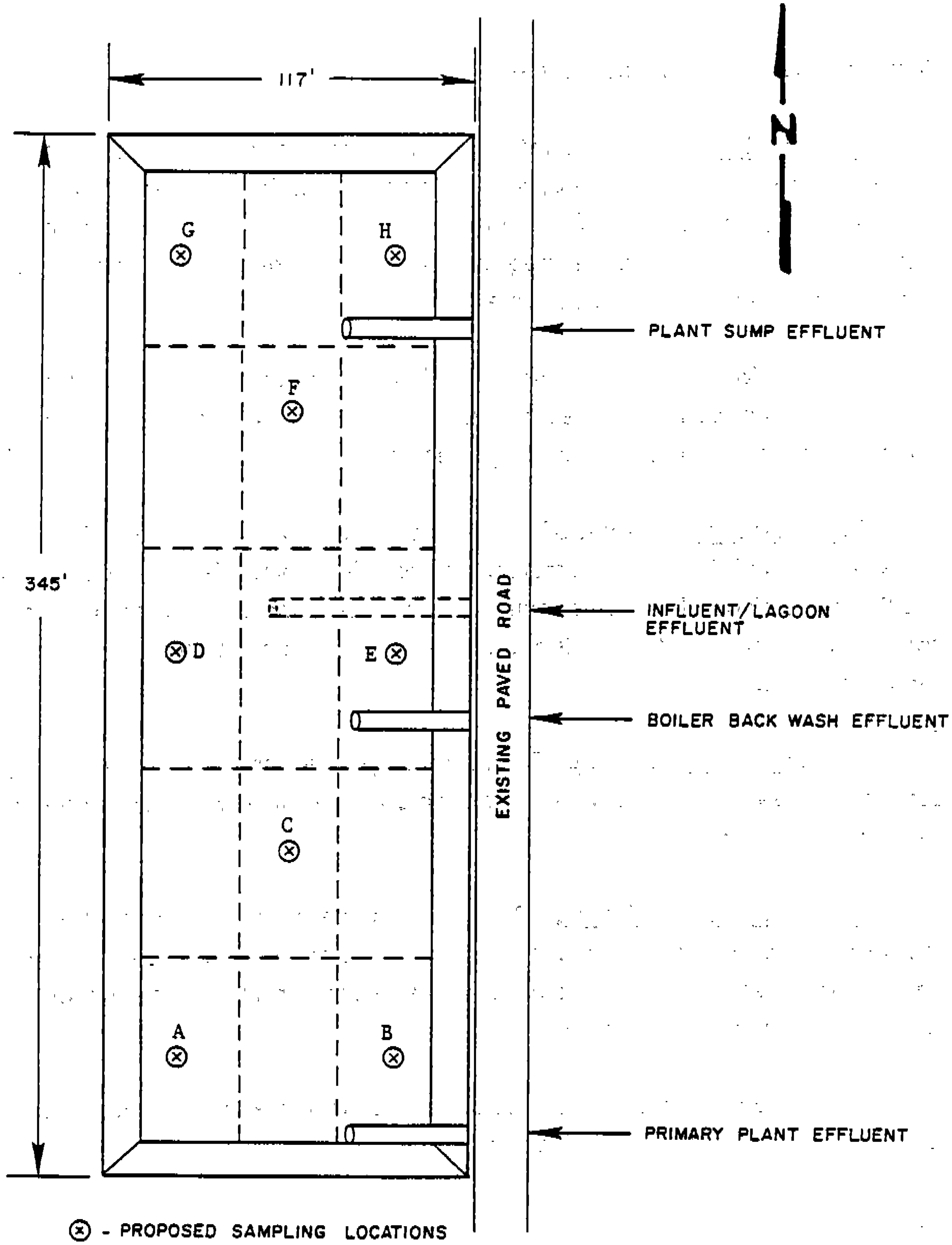


Figure 15-56. Schematic of Wastewater Holding Impoundment Showing Sampling Locations

TABLE 15-25

SUMMARY OF SAMPLING AND ANALYSIS PROGRAM FOR WASTEWATER IMPOUNDMENT

Location	Depth (Feet)	Sample Analyses						
		GC/FID VOA	GC/MS VOA	TOC	POC	Onsite Parameters[a]	GC/FID SVOC	GC/MS SVOC
A-1	0-1	X	X	X	X	X	X	X
A-2	2	X				X	X	
A-3	4	X				X	X	
A-4	6	X				X	X	
A-5	Bottom Sediment	X	X	X		X	X	X
B-1	0-1	X	X	X	X	X	X	X
B-2	2	X				X	X	
B-3	4	X				X	X	
B-4	6	X				X	X	
B-5	Bottom Sediment	X	X	X		X	X	X
C-1	0-1	X	X	X	X	X	X	X
C-2	2	X				X	X	
C-3	4	X				X	X	
C-4	Bottom Sediment	X	X	X		X	X	X
D-1	0-1	X	X	X	X	X	X	X
D-2	2	X				X	X	
D-3	4	X				X	X	
D-4	6	X				X	X	
D-5	Bottom Sediment	X	X	X		X	X	X

a Includes pH, turbidity, specific conductance, and dissolved oxygen measurements.
X Indicates locations where QC samples were collected.

TABLE 15-25 (continued)

Location	Depth (Feet)	Sample Analyses						
		GC/FID VOA	GC/MS VOA	TOC	POC	Onsite Parameters[a]	GC/FID SVOC	GC/MS SVOC
E-1	0-1	X	X	X	X	X	X	X
E-2	2	X				X	X	
E-3	4	X				X	X	
E-4	6	X				X	X	
E-5	Bottom Sediment	X	X	X		X	X	X
F-1	0-1	X	X	X	X	X	X	X
F-2	2	X				X	X	
F-3	4	X				X	X	
F-4	6	X				X	X	
F-5	Bottom Sediment	X	X	X		X	X	X
G-1	0-1	X	X	X	X	X	X	X
G-2	2	X				X	X	
G-3	4	X				X	X	
G-4	6	X				X	X	
G-5	Bottom Sediment	X	X	X		X	X	X
H-1	0-1	X	X	X	X	X	X	X
H-2	2	X				X	X	
H-3	4	X				X	X	
H-4	6	X				X	X	
H-5	Bottom Sediment	X	X	X		X	X	X

a Includes pH, turbidity, specific conductance, and dissolved oxygen measurements.
X Indicates locations where QC samples were collected.

Vertical and horizontal variation in the composition of the lagoon was apparent. The degree of horizontal variation was relatively small, but sample point “A” showed considerably higher concentrations of 2,4-dinitrophenol than the other locations. This could have resulted from a recent discharge from the outflow at the southern end of the impoundment. Vertical variation in composition showed a general trend of increasing concentration with depth, but certain chemicals tended to have higher concentrations at mid-depth in the impoundment.

Case Discussion

This case provides an example of a sampling program at an areal source designed to yield accurate information for characterizing air emissions from the unit. The study illustrated the importance of characterizing the organic composition of the lagoon in three dimensions and considering variations resulting from inflow and outflow areas.

It should be mentioned that this study did not consider variation in the chemical composition of the impoundment with time. T obtain this information, it would be necessary to conduct subsequent sampling programs at different times. From this study, it is apparent that chemical composition varies both horizontally and vertically, and is likely to change depending on inflows and outflows of wastes. This sampling program is therefore limited to effectively characterizing competition at a single point in time.

CASE STUDY 31: USE OF DISPERSION ZONE CONCEPTS IN THE DESIGN OF A SURFACE WATER MONITORING PROGRAM

Point Illustrated

- Estimation of the dispersion zone of contaminants downstream of a release point can be used to help design a surface water monitoring program.

Introduction

When a contaminant is initially released to a body of water, the concentration of the contaminant will vary spatially until fully dispersed. In streams, the contaminant will disperse with the surrounding ambient water as the water moves downstream and will eventually become fully dispersed within the stream. Downstream of this point, the contaminant concentration will remain constant throughout the stream cross-section, assuming that streamflow is constant and that the contaminant is conservative (e.g., nondegradable). The area in which a contaminant's concentration will vary until fully dispersed, referred to here as the dispersion zone, should reconsidered when determining the number and location of sampling stations downstream of the release point.

Facility Description

A facility that processed zinc, copper and precious metals from ores operated along a stream for five years. The plant was closed after being cited for repeated fish kills, reportedly due to failures of a tailings pond dike. At present, the site is covered with tailings containing high concentrations of copper, zinc, cadmium, arsenic, and lead. There is no longer a tailings pond. This is the same facility described in Case Study 27.

Site Setting

The site is located on coarse colluvium (hill-slope deposits of weathered bedrock) and fine-grained alluvium. These deposits are typically 50 feet thick. Metamorphic rock (phyllite) underlies the unconsolidated materials. Ground water moves laterally in the gravel formations from the steep valley walls toward the stream.

The site is located about 400 feet from the stream. Two drainage ditches cross the lower portion of the site and merge prior to leaving the site. The ditch carries the combined flow and discharges directly into the stream (Figure 15-57). No other tributaries enter the stream within 2 miles of this location. Downstream of the release point, streak width and depth remain fairly constant at 45 and 3 feet, respectively. Mean stream velocity is 0.5 feet per second and channel slope is 0.0005 feet per foot.

Sampling Program

A surface water monitoring program was designed as part of a Phase I investigation to determine the extent of contamination in the stream. Existing data from previous sampling had shown high concentrations of metals in the drainage ditch sediments (e.g., 5,170 mg/kg Cu and 11,500 mg/kg Zn). Ground-water data from the plant's well showed {concentrations of Cu (7 µg/l) and Zn (54 µg/l). The contribution of metals to the stream by ground-water discharge was considered to be relatively minor.

Based on a review of the plant history and the available water quality and sediment data, a monitoring program was designed. The potential pathways by which metals could reach the stream appeared to be direct discharge from the drainage ditch, discharge of contaminated ground water, and storm water runoff over the general facility area. Plant records indicated that typical flows in the drainage ditch at its confluence with the stream varied from 1 to 3 cubic feet per second (cfs) in the spring. During extreme flood conditions, the flow in the ditch exceeded 20 cfs. In the summer, flows in the drainage ditches at all locations were less than 0.5 cfs. Resuspension of contaminated sediments in the ditches during storm runoff appeared to be the most likely pathway for metals to reach the stream. The specific metals of concern were identified as As, Cd, Cu, Pb and Zn, based on the processes used at the plant and the composition of the ores which contained some arsenopyrites (with As, Cu), galena (Pb), and sphalerite (with Zn, Cd).

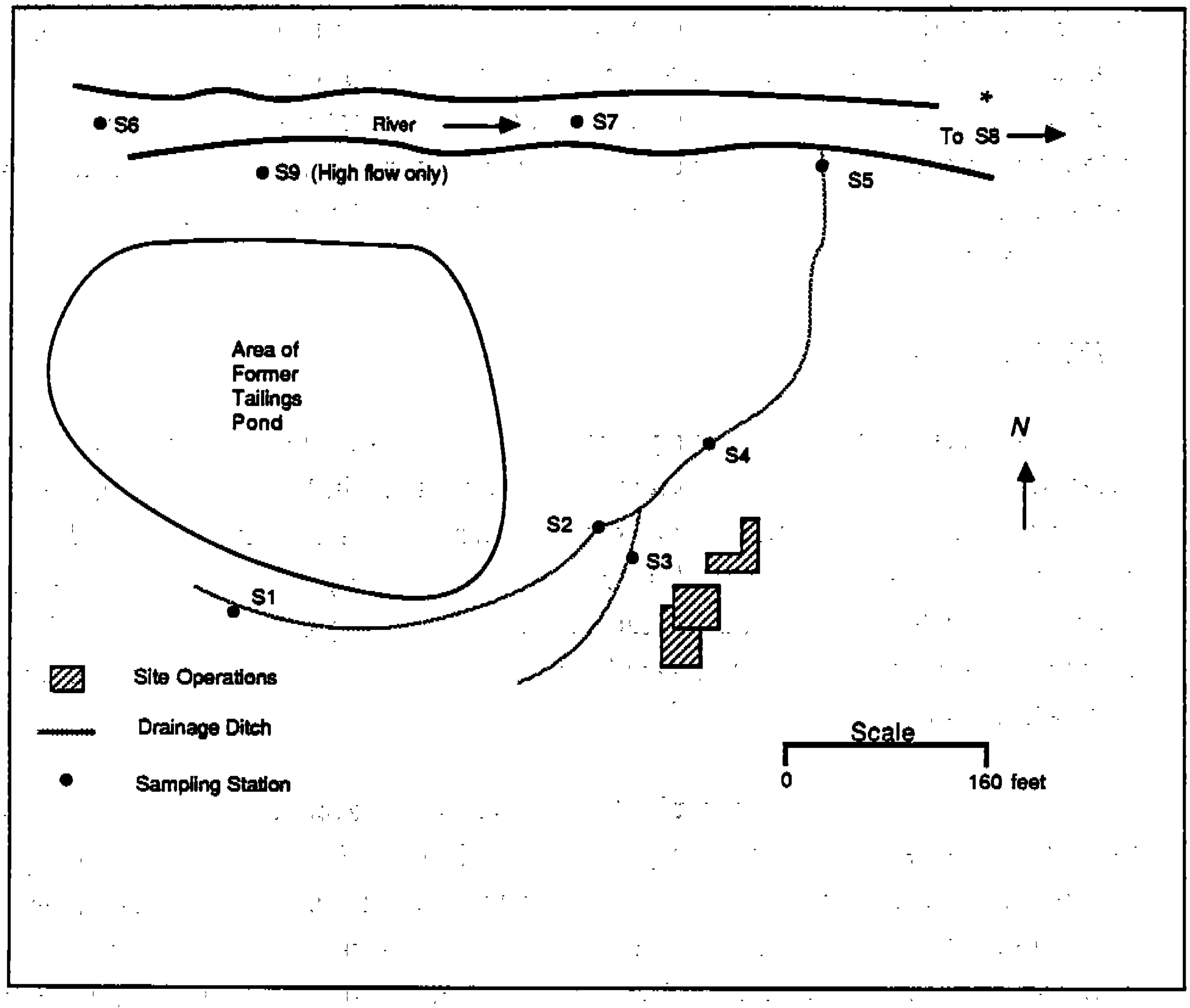


Figure 15-57. Sampling Station Locations for Surface Water Monitoring

* Located approximately 1030 feet downstream of the confluence of the ditch with the stream.

The available soil and water quality data from previous sampling were reviewed to help determine the likely fate of the metals. The pH of soils in the area is about 6.5 and they contain about 0.5 percent organic matter by weight. Under such conditions,the metals, particularly Pb, would be expected to adsorb onto the soil particles. In the on-site tailings piles, the pH of core samples ranged between 3.3 and 4.9. Low soil pH values had been measured in sediments in the drainage ditch just downgradient of the tailings pile. The pH of the stream during the previous sampling was 6.9. The suspended solids concentration was 10 mg/l.

Estimates of the distribution of metals between the dissolved and adsorbed phases for a range of partition coefficients (K_P) are shown in Table 15-26. For example, if $K_p = 10^4$ and the suspended solids concentration was 10 mg/l, 90 percent (0.9) of the metal present would be in the dissolved phase. This information indicated that even though a metal (e.g., lead) was known to strongly sorb, a significant amount could still be transported in the dissolved phase. Thus, both water and suspended solids should be analyzed for metals. The complete list of parameters selected for measurement in the Phase I investigation and the rationale for their selection are outlined in Table 15-27.

The sampling stations were, selected to determine stream water quality up- and downstream of the site and to determine whether particulate with sorbed metals were deposited on the stream banks or streambed. The sampling stations and the rationale for their selection are listed in Table 15-28. The station locations are shown in Figure 15-57. Because floods were considered a cause of contamination incidents, samples were to be collected under both high and low flow conditions.

The location of the downstream station (S8) was determined after estimating the stream length that may be required for complete dispersion of the contaminants. The following equation was used for this estimation:

$$DZ = \frac{0.4\ w2u}{.6d\sqrt{gds}}$$

TABLE 15-26

RELATIONSHIP OF DISSOLVED AND SORBED PHASE CONTAMINANT CONCENTRATIONS TO PARTITION COEFFICIENT AND SEDIMENT CONCENTRATION

K_p	S_p	C_w/C_T[a]
10^0	1	1.0
	10	1.0
	100	1.0
	1000	1.0
	10,000	1.0
10^1	1	1.0
	10	1.0
	100	1.0
	1000	1.0
	10,000	0.9
10^2	1	1.0
	10	1.0
	100	1.0
	1000	0.9
	10,000	0.5
10^3	1	1.0
	10	1.0
	100	0.9
	1000	0.5
	10,000	0.1
10^4	1	1.0
	10	0.9
	100	0.5
	1000	0.1
	10,000	0.0

After Mills *et al* 1985.

[a] The fraction dissolved (C_w/C_T) is calculated as follows:

$$\frac{C_W}{C_T} = \frac{1}{1 + K_p \times 5 \times 10^{-6}}$$

where K_p = partition coefficient, ℓ/kg
SS = suspended solids concentration, mg/ℓ
C_w = Dissolved concentration
C_T = Total concentration

TABLE 15-27

PARAMETERS SELECTED FOR SURFACE WATER MONITORING PROGRAM

Parameters	Rationale
Metals - As,Cd, Cu, Pb, Zn	Determine extent of contamination
pH	Predict sorption behavior, metal volubility, and speciation
Dissolved Oxygen Sulfide, Fe(II), Fe(lll)	Determine redox conditions which influence behavior of metals, particularly the leaching of tailings
Alkalinity	A measure of how well buffered a water is, allows consideration of the likelihood of pH change
Total Dissolved Solids	Used as a water quality indicator and for QA/QC checks
Major Cations (Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}, NH^{4+}) and Major Anions (Cl-, SO_4^{2-}, NO_{-3})	May identify other waste sources, can influence fate of trace metals
Suspended Solids:	Predict the fraction of metal in water which is sorbed
Streamflow	Compute mass balances and assist in identifying sources of observed contamination

TABLE 15-28

SELECTED SURFACE WATER MONITORING STATIONS AND SELECTION RATIONALE

Station	Media	Rationale
Drainage ditch west of site (S1)	Water and sediments	Determine whether off-site drainage is significant source of contamination
Drainage ditches on site (S2 and S3)	Water and sediments	Identify on-site sources
Downstream of confluence of two ditches (S4)	Water and sediments	Provide information for checking mass balances from the two drainage ditches
Mouth of drainage ditch (S5)	Water, suspended sediment, bedload	Determine quality of direct discharge to stream
Stream (S6, S7 and S9)	Water, suspended sediment, bedload	Determine upstream water quality
Stream (S8)	Water, suspended sediment, bedload	Determine quality downstream of site following complete dispersion and provide data for mass balance

where:

DZ = dispersion zone length, ft
w = width of the water body, ft (45 ft)
u = stream velocity, ft/sec (0.5 ft/sec)
d = stream depth, ft (3 ft)
s = slope (gradient) of stream channel, ft/ft (0.0005)
g = acceleration due to gravity (32 ft/sec^2).

Using the above equation, the estimated stream length required for complete contaminant dispersion is 1030 feet. This can serve as an approximate distance downstream of the release point at which a sampling station should be located.

Case Discussion

This case illustrates the use of contaminant dispersion zones in the design of a surface water monitoring program. In this example, the data indicate that approximately 1030 feet of flow within the described stream channel is required before a contaminant will become fully dispersed. A downstream station should therefore be located at or below this dispersion zone to fully characterize the extent of the release. An adequate number of sampling stations should also be located upstream of this point.