

GROUND-WATER CONTAMINATION AT AN INACTIVE  
COAL AND OIL GASIFICATION PLANT SITE,  
GAS WORKS PARK, SEATTLE, WASHINGTON

By G.L. Turney and D.F. Goerlitz

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## CONVERSION FACTORS

For the convenience of readers who may prefer to use metric units rather than the inch-pound units used in this report, values may be converted by using the following factors:

<u>Multiply inch-pound units</u>	<u>by</u>	<u>to obtain metric units</u>
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)

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**Sea Level:** In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929."

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ABSTRACT

Gas Works Park, in Seattle, Washington, is located on the site of a coal and oil gasification plant that ceased operation in 1956. During operation, many types of wastes, including coal, tar, and oil, accumulated on site. The park soil is presently (1986) contaminated with compounds such as polynuclear aromatic hydrocarbons, volatile organic compounds, trace metals, and cyanide. Analyses of water samples from a network of observation wells in the park indicate that these compounds are also present in the ground water.

Polynuclear aromatic hydrocarbons and volatile organic compounds were identified in ground-water samples in concentrations as large as 200 milligrams per liter. Concentrations of organic compounds were largest where ground water was in contact with a nonaqueous phase liquid in the soil. Concentrations in ground water were much smaller where no nonaqueous phase liquid was present, even if the ground water was in contact with contaminated soils. This condition is attributed to weathering processes at the site, such as dissolution, volatilization, and biodegradation. Soluble, volatile, low-molecular-weight organic compounds are preferentially dissolved from the nonaqueous phase liquid into the ground water. Where no nonaqueous phase liquid is present, only stained soils containing relatively insoluble, high-molecular-weight compounds remain; therefore, contaminant concentrations in the ground water are much smaller. Concentrations of organic contaminants in the soils may still remain large.

Values of specific conductance were as large as 5,280 microsiemens per centimeter, well above a background of 242 microsiemens per centimeter, suggesting large concentrations of minerals in the ground water. Trace metals concentrations, however, were generally less than 0.010 milligrams per liter, and below limits of U.S. Environmental Protection Agency drinking-water standards. Cyanide was present in ground water samples from throughout the park, ranging in concentration from 0.01 to 8.6 milligrams per liter.

## INTRODUCTION

Gas Works Park is located in Seattle, Washington, on the north shore of Lake Union (fig. 1). The park occupies a point of land that was the site of a coal gasification plant from 1906 to 1937 and an oil gasification plant from 1937 to 1956. Operations at the plant ceased in 1956 because of the importation of natural gas. The City of Seattle purchased the property in 1962, and from 1970 to 1976 developed it into a park. The park opened in 1976, with several of the gas plant structures left intact as centerpieces and reminders of the site's past.

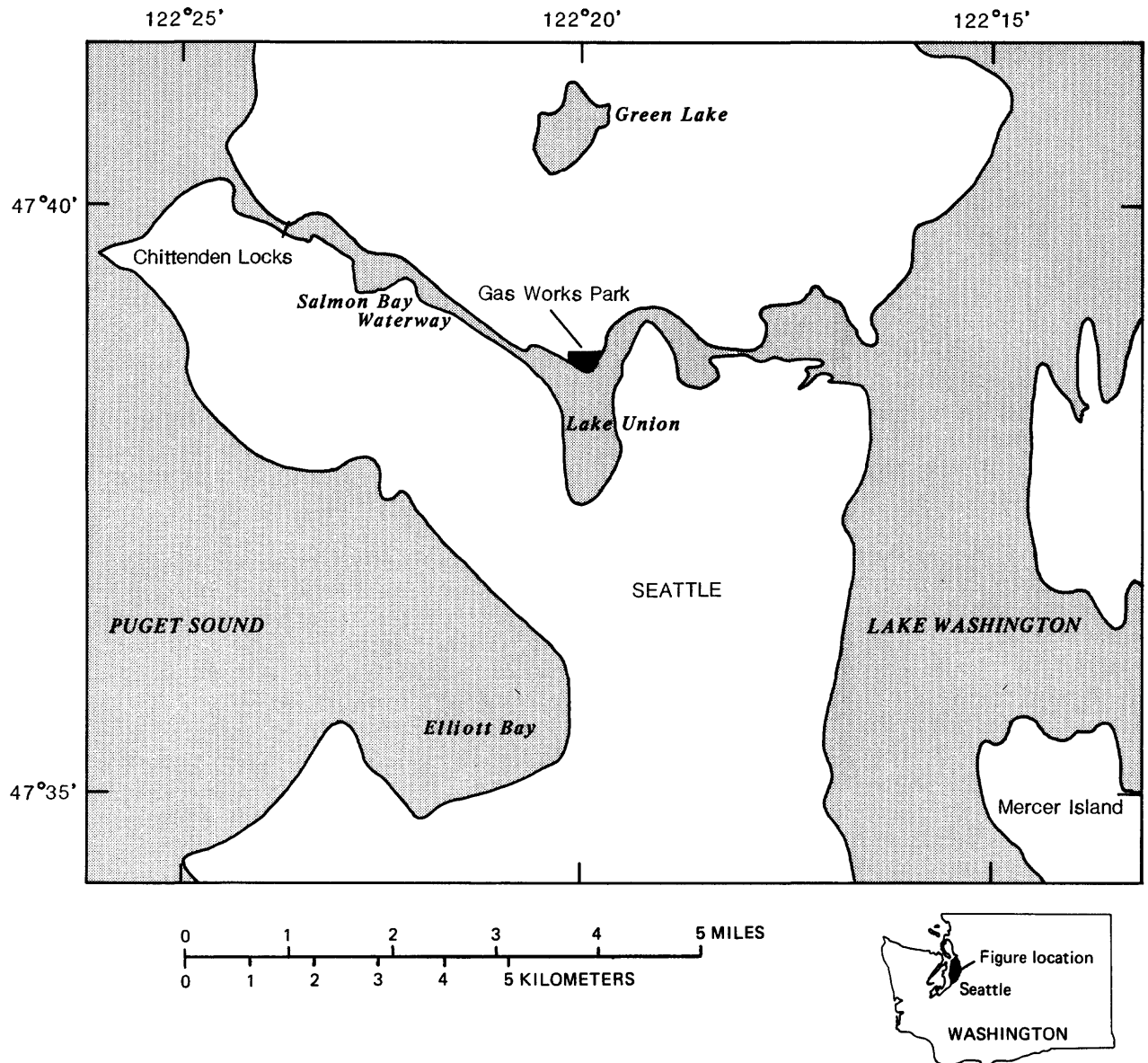


Figure 1.--Location of Gas Works Park, Seattle, Washington.

## Background

During the 50 years of plant operation, unknown quantities of solid and liquid wastes were generated. These wastes included slag, solvents, lampblack carbon, coal gasification by-products, oils, tars, ashes, cinders, wood, concrete, and bricks (Sabol and others, 1988). Many of these wastes were deposited on site and some were used to extend the shoreline 100 feet or more into the lake (fig. 2). In the 1970's, fill materials, including the wastes and imported material, were used to recontour the site (fig. 2) when the park was developed.

Several investigations conducted at the park have dealt primarily with the soils or geology. Cole and Machno (1971) reported on the geology and water table at the site as it existed before park construction. In 1984, the U.S. Environmental Protection Agency (USEPA) and the University of Washington collected separate sets of soil samples and analyzed them for concentrations of various organic compounds and(or) trace metals (Tim Rood, City of Seattle, written commun., 1986). The City of Seattle also employed Tetra Tech, Inc.<sup>1</sup>, a consulting firm, to collect soil samples to be analyzed for organic compounds (Tetra Tech, Inc., 1985). The University of Washington studied contamination of air by dust and by volatile organic compounds escaping from park soils (Tim Rood, City of Seattle, written commun., 1986). Sabol and others (1988) described the regional geohydrology and summarized the data from these previous studies. All of these previous data indicate that the shallow soil of Gas Works Park is contaminated with many compounds, including polynuclear aromatic hydrocarbons (PAH), pesticides, polychlorinated biphenyls (PCB), volatile organic compounds, trace metals, and cyanide (Sabol and others, 1988).

On the basis of previous work at other similar sites, it was thought that some of these soil contaminants are also present in the ground water at the park. Ground-water samples from a coal gasification site in Stroudsburg, Pennsylvania, contained PAH, volatile aromatic compounds, trace metals, and cyanide as the major contaminants (Villaume, 1984). Hult and Schoenberg (1984) found various PAH and phenols in the ground water near a coal-tar distillation and wood-preserving plant in St. Louis Park, Minnesota. Coal-tar is a by-product of coal-gasification processes. Pereira and others (1983) also identified a number of nitrogenous organic bases, many of them aromatic compounds, in the ground water at the St. Louis Park site. In a study of ground-water pollution resulting from underground coal gasification operations in Texas (Humenick and Mattox, 1978), the major organic contaminants were PAH and the major inorganic contaminants were calcium, sodium, ammonia, and sulfate. Reports of coal-tar composition indicate that as much as 30 percent may be PAH (Villaume, 1984) and that all aromatics may make up as much as 58 percent (Novotny and others, 1981).

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<sup>1</sup>Use of firm and brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

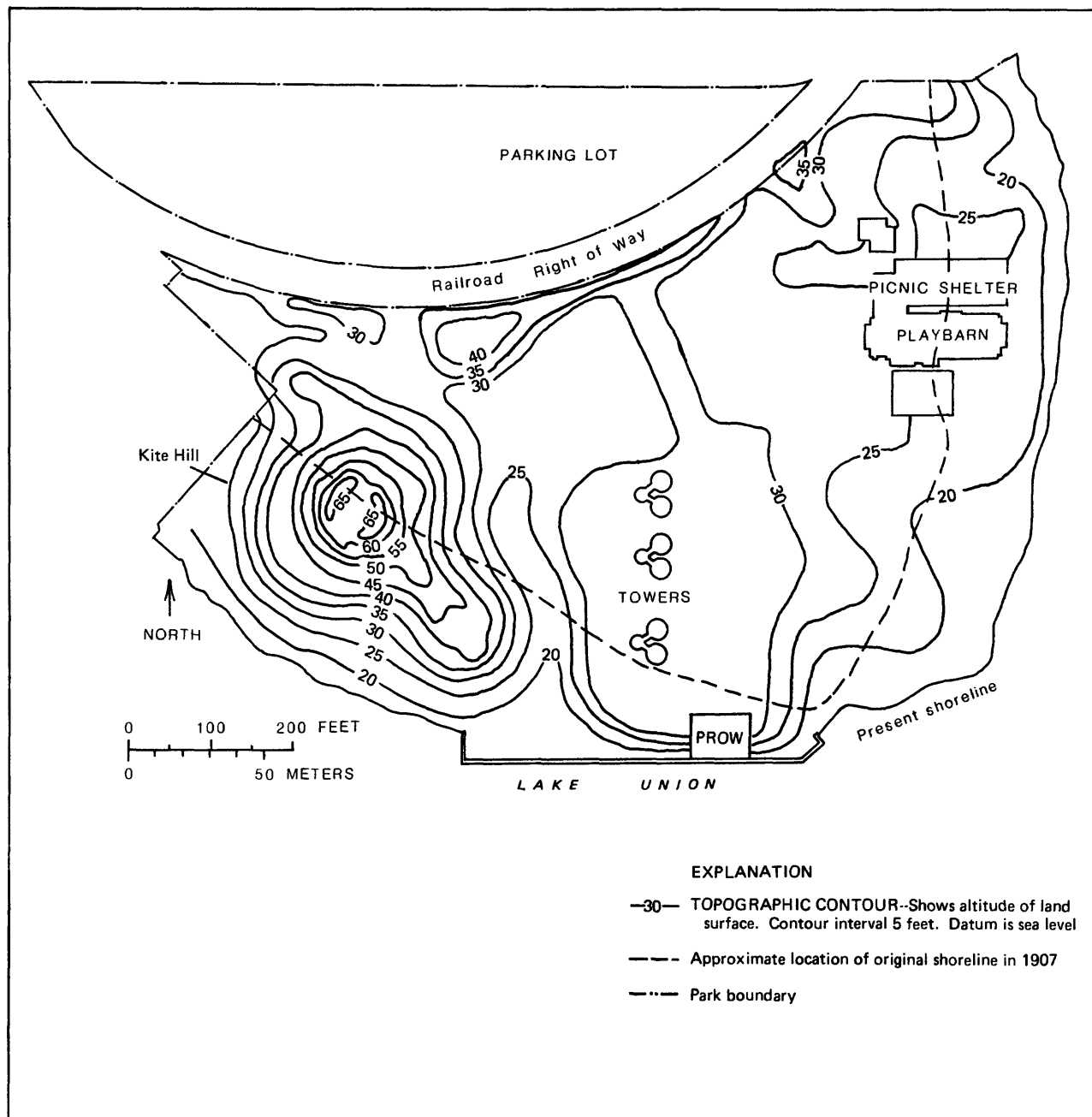


Figure 2.--Present (1986) topography at Gas Works Park.



### Purpose and Scope

In order to address the concern about ground-water contamination, the U.S. Geological Survey conducted a study of the Gas Works Park site in 1986, in cooperation with the City of Seattle Department of Parks and Recreation. The primary purpose of this study was to determine if any of the organic compounds and trace metals identified in the shallow soils are present in the underlying ground water. The relation between concentrations in ground water and concentrations in soil was also examined. Ground water near the water table was of specific interest because of large contaminant concentrations in the unsaturated soils (Tim Rood, City of Seattle, written commun., 1986) and reports of oil "pools" on the water table. This report describes the results of the study.

To meet the study objectives, the Geological Survey installed a network of observation wells and collected water samples from them to be analyzed for selected organic compounds and trace metals. Water levels were also measured to help define the flow patterns of the ground water. Selected soil samples were preserved during well drilling and later analyzed for organic compounds. This work was performed with the assistance of Tetra Tech, Inc., under contract with the City of Seattle. To aid in the placement of wells, the U.S. Geological Survey also contracted for a seismic survey of the park with G.B. Mohl, an independent exploration geologist, and for the collection and analysis of subsurface soil gas samples with J.F. Pankow of the Oregon Graduate Center.

## DATA COLLECTION AND LABORATORY PROCEDURES

### Well Installation

During October 1986, 16 observation wells were installed, 15 shallow and 1 deep. Fourteen of the shallow wells were placed inside the park and range in depth from 9.5 to 29.9 feet. A shallow control well 34.8 feet deep was placed about 600 feet north of the park boundary to sample ground water upgradient from the site. The shallow wells are numbered 1 through 16 on the basis of preselected drilling sites, and the locations of all except the control well (well 1) are shown in figure 3. Because of problems with access, well 4 was never installed, and that number is not used. All of the shallow holes except for the control well were drilled with a hollow-stem auger. The control well was drilled using air-rotary drilling techniques. Down-hole tools were steam-cleaned between each use. The wells were constructed of 2-inch polyvinyl-chloride pipe, with 7- to 10-foot lengths of 0.010-inch slotted screen at the bottoms. Screens were set so that the middle was close to the water table at the time of drilling. The annulus of each well was packed around the screen with sand, then sealed to the surface with bentonite or a bentonite and concrete mix.

The deep control well (3D) was installed next to shallow well 3 (fig. 3) for the purpose of sampling the deeper ground water and determining the vertical ground-water flow direction. Air-rotary drilling techniques were used. This well is 57.6 feet deep and was constructed similarly to the shallow wells except that the length of the screen at the bottom is 3 feet. The annulus of this well was sand-packed around the screen, filled with bentonite for a 6-foot section, then backfilled with clean cuttings. The surface was sealed with a bentonite and concrete mix.

### Sample Collection

Continuous soil cores, from land surface down to the water table, were collected ahead of the auger using a splitspoon-core barrel sampler during drilling. Sections of the cores were saved and chilled, and chemical analyses were later performed on selected sections.

Water samples were collected from all wells during December 1986. The wells, which had been developed previously by intensive pumping, were pumped to purge three to five casing volumes. Water samples for organic analysis were collected with a bottom-filling glass bailer immediately after purging. The bailer was rinsed with acetone and organic-free water after each sampling. These samples were packed in ice and shipped at the end of each day to the appropriate laboratory by overnight delivery service.

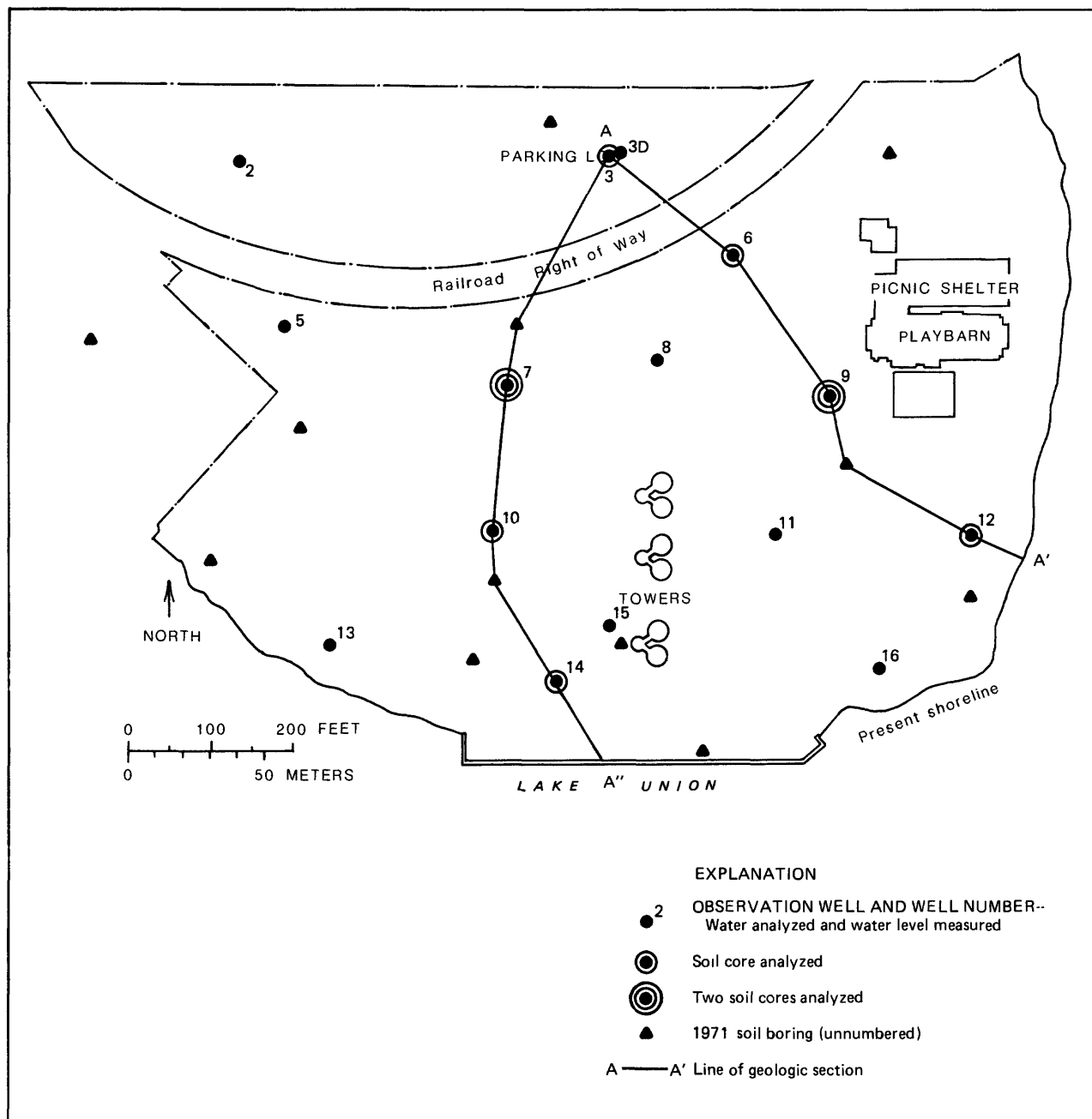


Figure 3.--Location of observation wells, soil borings, and geologic sections at Gas Works Park. Well 1, a control well, is located outside the park, 681 feet north and 15 feet west of well 3, and is not shown; there is no well 4.

Water samples for trace metals and cyanide analysis were collected by inserting clean tubing down the well and pumping the water with a peristaltic pump directly through a 0.1-micron ( $\mu\text{m}$ ) filter. The pump and filtration system were flushed between wells with a 3-percent hydrochloric acid solution, followed with a distilled water rinse. The outside surfaces of pump tubing were cleaned with acetone and organic-free water. The trace metal samples were acidified with nitric acid, and the cyanide samples treated with sodium hydroxide, then shipped at the end of the week to the laboratory by First-Class mail.

Soil gas samples collected by the Oregon Graduate Center (OGC) before drilling were obtained from the 3-foot depth at all well sites, and from the 6-foot depth at well sites 2, 5, 7, 8, and 15. A stainless steel tube was driven the appropriate depth into the soil and evacuated using a peristaltic pump. The sample was collected in a syringe from a port on top of the tube. The samples were analyzed on site using a gas chromatograph with a flame-ionization detector and a photo-ionization detector. At well sites 2 and 5 additional samples were collected in sorptive cartridges. These cartridges were thermally desorbed and analyzed using gas chromatography-mass spectrometry by the OGC at their laboratory facility.

#### Laboratory Analyses

Water samples from all wells were analyzed for semivolatile organic compounds at the U.S. Geological Survey's research facility in Menlo Park, California. The samples were allowed to stand in the refrigerator for a minimum of 4 hours, and usually overnight, to permit particulate and nonaqueous liquid separation. Appropriate subsamples were then carefully removed from beneath the liquid surface by pipet to avoid inclusion of any surface film in the analysis.

The subsamples first were directly analyzed by high-performance liquid chromatography (HPLC). If organic compounds were found, the sample was extracted with dichloromethane and analyzed by computer-controlled gas chromatography-mass spectrometry (GC-MS). The GC-MS analysis was supplemented by flame-ionization gas chromatography (GC-FID) where appropriate. Any discrepancies among results of the three techniques were resolved by conventional GC-MS or by direct probe insertion of collected chromatographic fractions.

High-performance liquid chromatography was done using a gradient elution liquid chromatograph, a data and gradient control station, and a scanning ultraviolet (UV) detector. From 0.010 to 10.00 mL (milliliters) of filtered sample was loaded onto a reverse phase column and eluted with a solution grading from 100-percent aqueous to 100-percent acetonitrile in 15.0 minutes. Spectral scans of the column effluent from 190 to 400 nanometers wavelength were recorded at 1-second intervals. Compounds were identified by comparing the chromatographic retention data and UV spectra with authentic standards. Also, quantitative determinations were made by comparing responses of samples to responses of standards at favorable wavelengths. Because quinolinone and isoquinolinone are difficult to extract from water and decompose at the high temperatures of gas chromatography, they were quantitatively determined by HPLC only.

The subsamples for gas chromatographic analysis were acidified to pH 1.5, and extracted using dichloromethane. The neutral aromatic compounds and phenolic compounds were extracted in the solvent and the basic nitrogen heterocycles (NH) remained in the acidified water. The phenolic compounds were separated from the neutral aromatic compounds by back-extracting the phenolic compounds from the solvent layer into 5-molar potassium hydroxide. The basic solution then was brought back to pH 5-7 and the phenolic compounds were reextracted into dichloromethane. The initially acidified water from the first extraction was brought to pH 10, and the basic organic compounds were isolated by extraction into dichloromethane. The three resulting extracts, containing the neutral aromatic compounds, the phenolic compounds, and the basic NH, were dried using anhydrous sodium sulfate. When necessary, the volumes of the extracts were reduced by evaporation under a stream of nitrogen gas.

After extraction, the three isolated fractions were qualitatively and quantitatively analyzed using a quadrupole mass spectrometer interfaced to a gas chromatograph. Two separate gas chromatographic analyses on two different types of fused silica columns, one polar and the other nonpolar, were required to resolve the complex mixtures. The polar column, designated DB-WAX, was 98 feet (30 meters) long with a bonded polyethylene glycol liquid phase. The non-polar column, designated DB-5, consisted of a bonded silicone phase, with 95-percent methyl and 5-percent phenyl substitution. The compounds were first identified by comparison with the National Bureau of Standards mass spectral library, then positively identified and quantitatively measured using authentic compounds as standards. Two columns were also used in the GC-FID system that supplemented the GC-MS analysis.

Blanks were analyzed for each determination at each analytical step to test for interferences contributed by reagents, reference standards, and glassware. A control blank and a recovery test mixture were carried through each analytical procedure. Individual stock solutions [1.00 milligrams per milliliter (mg/mL)] of selected compounds found in the samples were prepared in either dichloromethane or acetonitrile as appropriate, and standard reference mixtures were prepared from the stock solutions. Only selected compounds were included in recovery test mixtures, and they were individually weighed into a volumetric flask and dispensed as needed.

The methods were tested using matrices of reagent water and ground water. Average percent recoveries determined by gas chromatographic analysis of selected compounds extracted from 18 water samples fortified at 1.0 mg/L (milligrams per liter) were as follows: naphthalene, 96; benzo(a)pyrene, 96; fluorene, 97; phenanthrene, 95; pyrene, 101; 3,5-dimethylphenol, 98; 3-methylphenol, 93; 1-naphthol, 95; phenol, 79; pyridine, 79; and quinoline, 92. Quantitative determinations by HPLC of naphthalene, 2-quinolinone and 1-isoquinolinone averaged recoveries of 97, 99, and 102 percent, respectively, from 12 water samples fortified at 1.0 mg/L.

Water samples from all wells were also analyzed for concentrations of trace metals and cyanide at the U.S. Geological Survey's National Water Quality Laboratory (NWQL), using standard methods described by Fishman and Friedman (1985). Water samples from wells 1, 2, 3, 6, 7, 9, 12, and 14 were analyzed at the NWQL for concentrations of volatile organic compounds, organochlorine and organophosphorus pesticides, and PCB, using standard procedures described by Wershaw and others (1987).

Ten soil samples were analyzed for concentrations of organic compounds by a contract laboratory using USEPA methods 3550 and 8270 (U.S. Environmental Protection Agency, 1986). These methods call for extraction of the compounds in dichloromethane, using a horn-type sonicator to agitate the sample. The extract was then analyzed using GC-MS methodology.

## HYDROGEOLOGIC SETTING

The study site lies in the Puget Sound trough, where the recent geology is largely the result of glaciation. At the park, four stratigraphic units are of interest. The deepest and oldest of these is the till in the Vashon Drift of Pleistocene age, which is a compacted conglomerate of clay, sand, gravel, cobbles, and boulders. The till is approximately 33 feet thick at well 3D (fig. 3), but the variation in thickness within the park is unknown. The till probably underlies the entire park. Above the till is a layer of sand with some clay and gravel, identified as recessional stratified drift in the Vashon Drift. That layer is not present everywhere in the park, but is more than 10 feet thick at some locations. Overlying the recessional drift is a layer of the previously described wastes of the gas works mixed with soil. This unit, referred to as the "Gas Works deposit" in this report, usually appeared as a dark gray or black-stained natural material, interspersed with cinders, brick fragments, and wood chips. In some areas tar and oily residues were also present. This deposit occurs throughout most, but not all, of the park and is as much as 9 feet thick. The uppermost and youngest unit is artificial fill that was emplaced when the park was constructed. It consists mostly of soil and is 1 to 5 feet thick in most places, except under Kite Hill (fig. 2), where 50 feet or more of fill may be present.

Knowing the vertical position of the Gas Works deposit is important in understanding the mechanisms by which the ground water becomes contaminated. Figure 4 shows the altitude of the bottom of the Gas Works deposit, which lies on top of the Vashon till, or recessional drift where present. The contours are based on data from the well logs of this study and from soil borings made in 1971 and described by Cole and Machno (1971). The shape of this surface is similar to the present day surface topography (fig. 2), except for the landscaped Kite Hill. The bottom of the Gas Works deposit was sharply distinguishable in most soil cores, but in some cores it was diffuse because of staining of the natural material by downward-migrating liquid contaminants and mixing of contaminants with natural material.

Figure 5 shows the water table configuration in December 1986. Ground-water flow is radially southward from the north-central part of the park to the lake shore. A comparison of the water-table altitudes with the altitude of the bottom of the Gas Works deposit indicates that the deposit lies below the water table in some areas, generally near the shore. The occurrence of ground water in the Gas Works deposit may be variable and complex; for example, in figure 6, the water table is above or within the Gas Works deposit in two places along section A-A'. The flow of the ground water through the Gas Works deposits is suspected to be a mechanism for contamination of ground water.

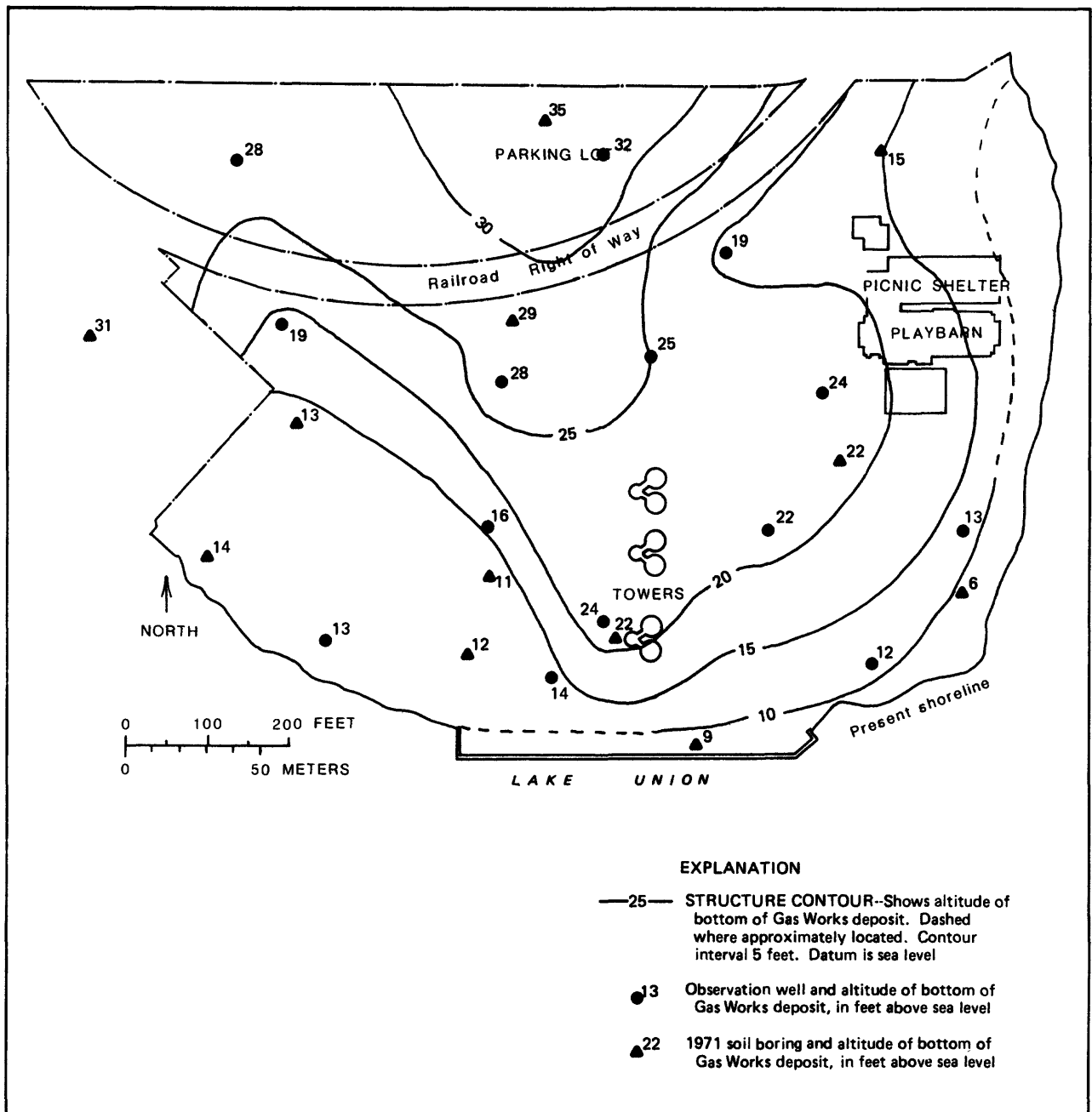


Figure 4.--Structure contours of bottom of Gas Works deposit.



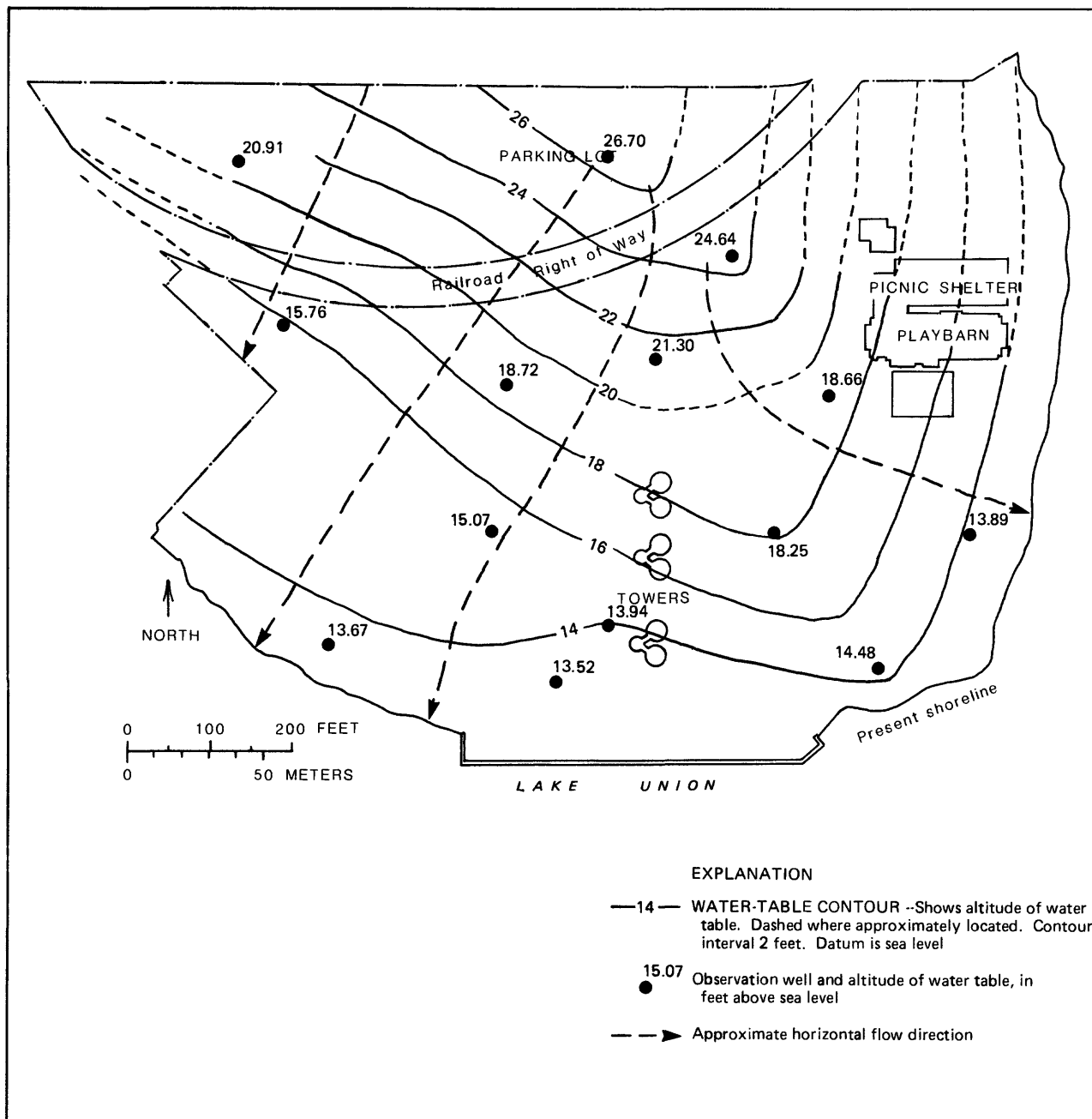


Figure 5.--Generalized configuration of water table at Gas Works Park on December 18, 1986.

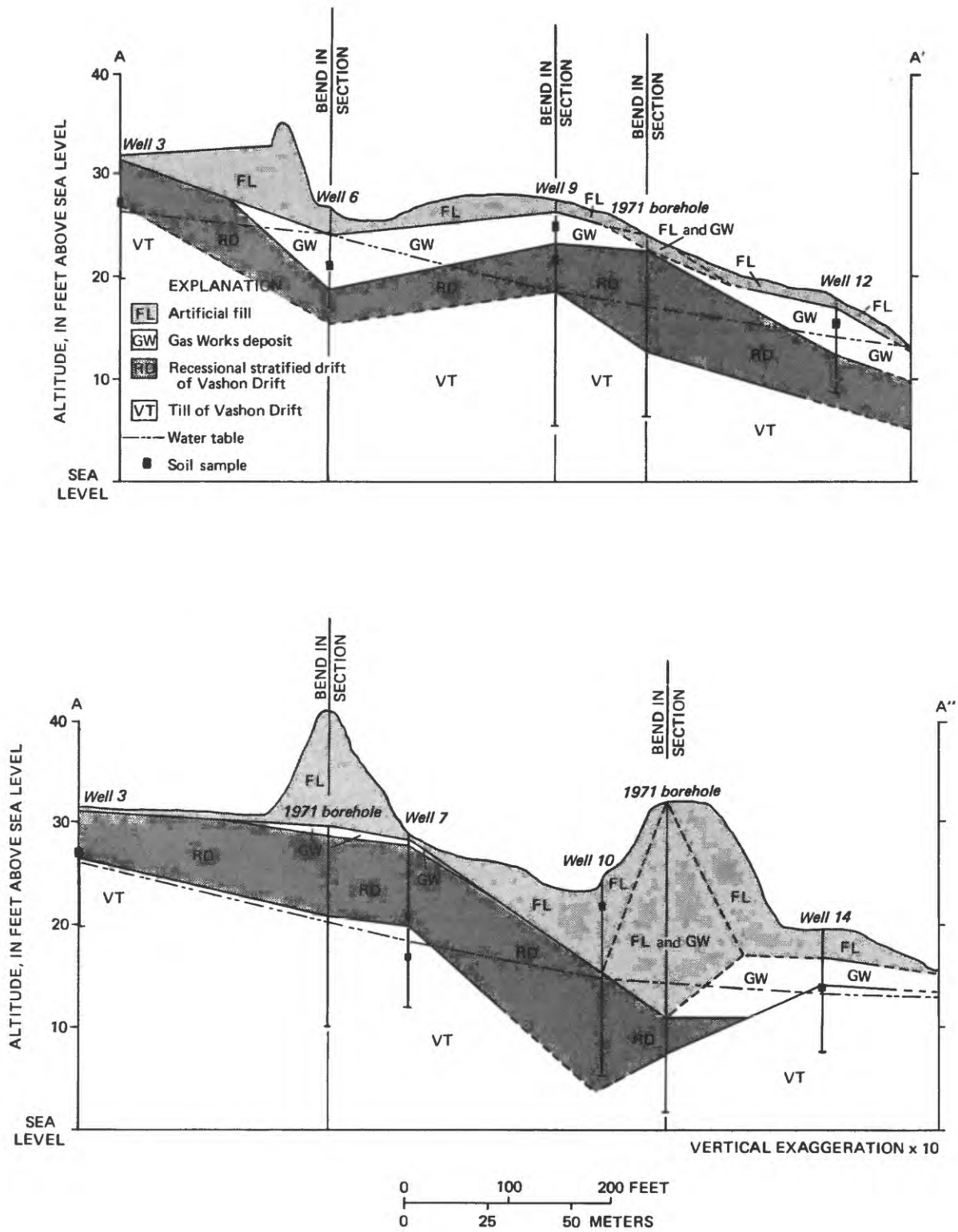


Figure 6.--Geologic sections A-A' and A-A'' showing the location of soil-sample collection sites and the water table. Location of sections shown on figure 3.

Because of its relatively low hydraulic conductivity, the till probably strongly affects the position of the water table. The shape of the water-table surface (fig. 5) is similar to that of the top of the till (fig. 7), suggesting some control by the till, especially in the southwest part of the park where the shoreline has been extended the farthest (see fig. 2 for location of the original shoreline). The surface of the till appears to be the foundation for the general site topography. The altitude of the top of the till as determined from well logs and core samples is consistent with seismic data reported by Mohl (independent exploration geologist, written commun., 1986).

The data used to determine the vertical direction of saturated ground-water flow were obtained only at the site of wells 3 and 3D. The water level in well 3D (57.6 feet deep) was 10.87 feet lower than in well 3 (10.6 feet deep), indicating a downward component of flow at this site. However, because all water levels in the park are higher than the lake level, ground water flows into Lake Union and upward flow near the shore is expected.

Ground-water recharge to the park is primarily from ground-water influx from off site and direct infiltration of precipitation. In the northern and northeastern parts of the park, water also infiltrates from a lawn sprinkler system that uses a municipal water supply. The vertical flow of precipitation and irrigation water through unsaturated sections of the Gas Works deposits is a mechanism of transporting contaminants to the ground water. Ground-water discharge is into Lake Union. There are no streams at the park, but storm drains in the parking lot and near the picnic shelter also discharge to the lake.

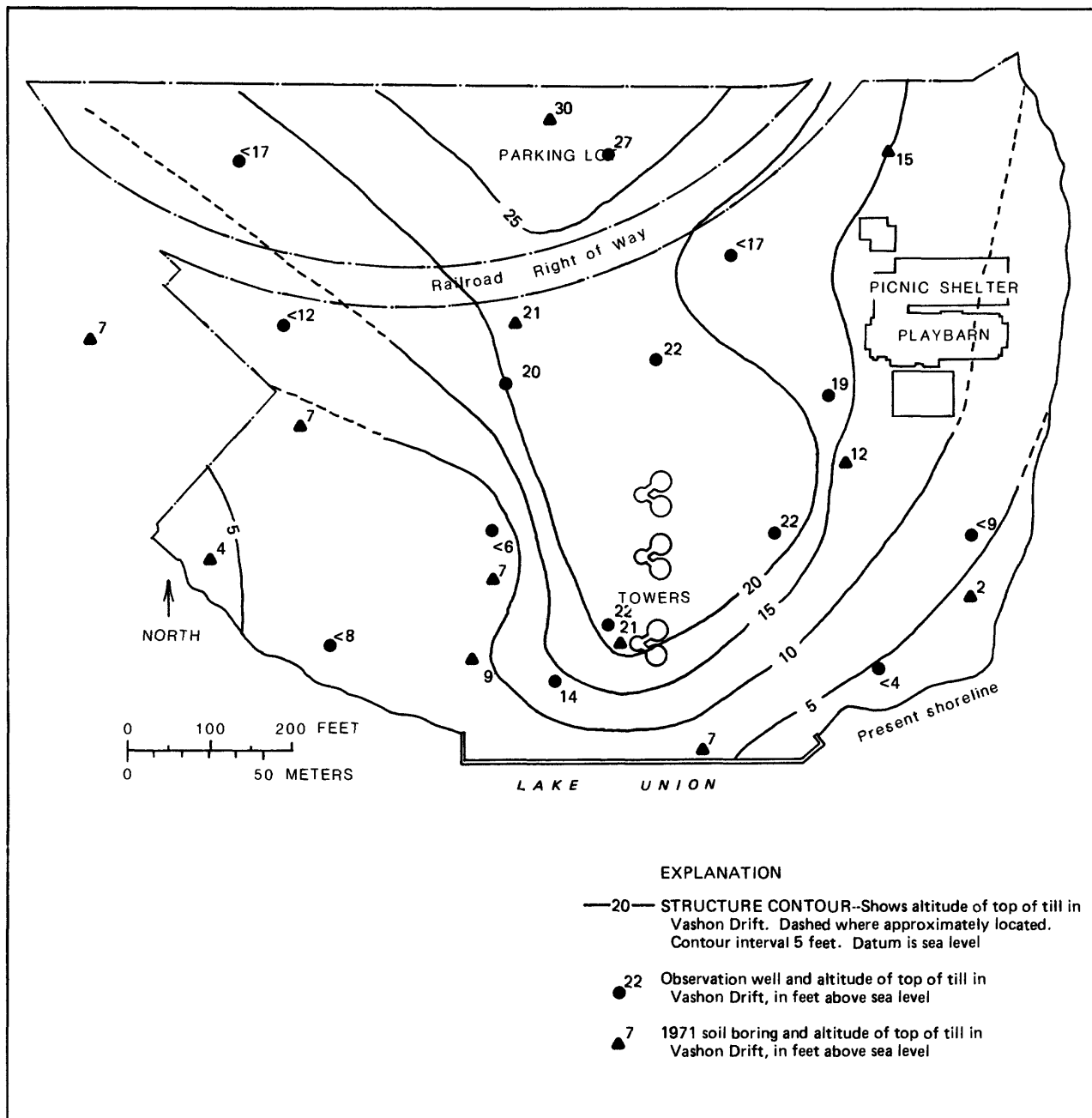


Figure 7.--Structure contours of top of till in Vashon Drift at Gas Works Park.

## CONTAMINANT CONCENTRATIONS AND MECHANISMS AFFECTING THEIR DISTRIBUTION

### Organic Compounds in Ground Water and Soils

Many of the organic compounds detected in ground water and soils were those that would be expected in wastes from a coal or oil gasification plant (tables 1-3). The largest number and largest concentrations of organic compounds were in water samples from wells 2, 5, 9, and 12. Water samples from wells 1, 3, 3D, 11, 13, and 16 contained no organic compounds above the detection level of 0.005 mg/L. Soil samples with the largest concentrations of compounds were from the sites of wells 6, 9, 12, and 14.

The neutral compounds detected in the water (table 1) were primarily mononuclear and polynuclear aromatic hydrocarbons (PAH) and heterocyclic compounds. Naphthalene and alkyl naphthalenes were present in more than half the samples, and naphthalene concentrations exceeded 1.0 mg/L in samples from wells 2, 5, 9, 12, and 15. Benzene and toluene concentrations exceeded 1.0 mg/L only in samples from wells 9 and 12, and were as large as 200 and 150 mg/L, respectively, in well 12. Several other alkylbenzenes were present in concentrations exceeding 0.50 mg/L, but only in samples from wells 5, 9, and 12. Some 3- and 4-ring compounds, such as phenanthrene and pyrene, were present in several samples, but at concentrations of 0.20 mg/L or less.

Phenolic compounds were detected in water samples from well 5, where individual compound concentrations were as large as 2.5 mg/L. Water samples from well 9 contained a few phenolic compounds in small concentrations. Nitrogen heterocycles were also found in samples from well 5. Pyridines, quinolines, and quinolinones were present in concentrations ranging from 0.04 to 5.7 mg/L. Carbazole was the only NH compound found in water samples from wells other than well 5, and was present in those samples at concentrations of 0.06 mg/L or less.

Concentrations of pesticides and PCB in water were generally at or below detection limits in the samples analyzed for these compounds (from wells 1, 2, 3, 6, 7, 9, 12, and 14), and are not presented. The largest concentration observed was 0.0012 mg/L of heptachlor in a water sample from well 12, which is small in comparison to other contaminant concentrations.

The locations of 9 of the 10 wells from which soil samples were analyzed are shown in figures 3 and 6 (the tenth sample was from well 1, the control well). Organic contaminants were found only in samples from the Gas Works deposit and in samples from the recessional stratified drift in the Vashon Drift at well 9 (table 2). The compounds identified in soils were predominantly 2- to 6-ring PAH and closely resemble those found in coal tars (table 3). Concentrations of lower-molecular-weight PAH were largest in soils from well 12, where naphthalene and C2 naphthalene concentrations were 46 and 39 mg/kg (milligrams per kilogram), respectively. Concentrations of higher-molecular-weight PAH were largest at wells 6 and 9, where concentrations of benzo(b)fluoranthene, benzo(a)pyrene, and benzo(g,h,i)perylene ranged from 13 to 19 mg/kg.

TABLE 1.--Concentrations of organic compounds in ground water at Gas Works Park

[All concentrations in milligrams per liter. Samples from wells 1, 3, 3D, 11, 13, and 16 contained no organic compounds at the 0.005 milligram-per-liter detection limit. Unless identified, the semivolatile methodology described in the text was used.]

Compounds	Well number									
	2	5	6	7	8	9	10	12	14	15
Neutral aromatic compounds										
Benzene <sup>1</sup>	0.35	---	n <sup>3</sup>	0.007	---	22	---	200	0.48	---
Toluene <sup>1</sup>	.044	---	n	n	---	17	---	150	n	---
Ethylbenzene <sup>1</sup>	.013	---	n	.061	---	n	---	3.0	.013	---
Xylene <sup>4</sup>	.080	.92	n	n	n	2.0	n	3.2	n	n
Styrene <sup>1</sup>	n	---	n	n	---	2.5	---	3.8	n	---
o-Xylene	.15	.59	n	n	.01	1.1	n	2.0	n	n
1-Ethyl-2-methylbenzene	.12	.22	n	n	n	.18	n	1.2	n	n
Trimethylbenzene <sup>4</sup>	.39	.38	n	n	n	.76	n	.52	n	n
2-Propenylbenzene	.14	.55	n	.10	.11	.37	n	n	n	n
2,3-Dihydro-(1H)-indene <sup>5</sup>	n	n	.01	n	n	n	.03	n	.04	.01
Indene	.87	3.2	.01	n	.03	13	n	3.0	n	.06
1-Phenylethanone	n	n	n	n	n	n	n	.52	n	n
3-Methylindene	.25	.27	n	n	.10	1.6	n	n	n	n
1,1a,6,6a-Tetrahydro-cycloprop(a)indene	.25	.23	n	.05	n	n	n	n	n	n
Naphthalene	12	7.2	.16	n	.18	11	.02	1.7	.04	1.2
Benzothiophene	.57	.59	.01	n	.04	.38	.10	.08	.03	.14
Methylbenzofuran	n	n	n	n	n	.14	n	n	n	n
3-Phenyl-2-propanal	n	.22	n	n	n	n	n	n	n	n
2,3-Dihydro-(1H)-indene-1-one <sup>5</sup>	n	.61	n	n	n	.14	n	.22	n	n
2-Methylnaphthalene	.10	1.3	.03	n	.07	1.4	n	.07	n	.04
1-Methylnaphthalene	.16	1.1	.03	.19	.94	1.1	.09	.05	.02	.11
1,1'-Biphenyl	n	n	.01	n	.06	.07	n	n	n	.04
1-Ethynaphthalene	n	n	.01	n	n	n	n	n	n	n
Dimethylnaphthalene <sup>4</sup>	n	n	n	n	.40	.26	n	n	n	.08
1,3-Dimethylnaphthalene	n	n	n	.02	n	n	.06	n	n	n
1,4-Dimethylnaphthalene	n	n	.01	n	n	n	n	n	n	n
2,3-Dimethylnaphthalene	n	n	.01	.03	.10	.07	.03	n	n	.02
Acenaphthylene	n	n	.01	n	n	.25	n	n	.02	.11
Acenaphthene	n	.15	.04	.04	.18	.03	.15	n	.05	.06
Fluorene	n	.14	n	.02	.02	.07	.06	n	.03	.07
Dibenzofuran	n	n	n	n	n	n	n	n	n	.06
Dibenzothiophene	n	n	.01	n	n	n	n	n	n	n
Phenanthrene	n	.13	.06	n	.03	.06	n	n	.05	.20
1H,3H-Naphtho(1,8-cd)-pyran-1,3-dione <sup>5</sup>	n	.15	n	n	n	n	n	n	n	n
Fluoranthene	n	n	.05	n	n	n	n	n	.02	.02

TABLE 1.--Concentrations of organic compounds in ground water at Gas Works Park--continued

Compounds	Well number									
	2	5	6	7	8	9	10	12	14	15
Pyrene	n	n	0.08	n	n	n	n	n	0.02	0.03
Chrysene	n	n	.01	n	n	n	n	n	n	n
Phenolic compounds										
Phenol	n	0.56	n	n	n	0.34	n	n	n	n
2-Methylphenol	n	2.2	n	n	n	.55	n	n	n	n
3-Methylphenol	n	1.5	n	n	n	n	n	n	n	n
4-Methylphenol	n	1.5	n	n	n	.06	n	n	n	n
2,6-Dimethylphenol	n	.41	n	n	n	n	n	n	n	n
2-Ethylphenol	n	.15	n	n	n	.10	n	n	n	n
2,4-Dimethylphenol	n	1.0	n	n	n	n	n	n	n	n
2,5-Dimethylphenol	n	1.5	n	n	n	n	n	n	n	n
3,5-Dimethylphenol	n	2.5	n	n	n	n	n	n	n	n
2,3-Dimethylphenol	n	.34	n	n	n	n	n	n	n	n
3,4-Dimethylphenol	n	.50	n	n	n	n	n	n	n	n
2,4,6-Trimethylphenol	n	.18	n	n	n	n	n	n	n	n
3-(1-Methylethyl)phenol	n	.12	n	n	n	n	n	n	n	n
2-Ethyl-4-methylphenol	n	.47	n	n	n	n	n	n	n	n
2,3,5-Trimethylphenol	n	.25	n	n	n	n	n	n	n	n
Nitrogen heterocycles										
Pyridine	n	1.6	n	n	n	n	n	n	n	n
2-Methylpyridine	n	2.1	n	n	n	n	n	n	n	n
4-Methylpyridine	n	1.9	n	n	n	n	n	n	n	n
2,4-Dimethylpyridine	n	.93	n	n	n	n	n	n	n	n
2,3-Dimethylpyridine	n	.22	n	n	n	n	n	n	n	n
2-Ethyl-6-methylpyridine	n	.13	n	n	n	n	n	n	n	n
2,4,6-Trimethylpyridine	n	.16	n	n	n	n	n	n	n	n
2,3,6-Trimethylpyridine	n	.08	n	n	n	n	n	n	n	n
4-Methylbenzamine	n	.11	n	n	n	n	n	n	n	n
Isoquinolin	n	.08	n	n	n	n	n	n	n	n
2-Methylquinolin	n	.80	n	n	n	n	n	n	n	n
2,6-Dimethylquinolin	n	.04	n	n	n	n	n	n	n	n
4-Methylquinolin	n	.07	n	n	n	n	n	n	n	n
2,4-Dimethylquinolin	n	.05	n	n	n	n	n	n	n	n
Carbazole <sup>6</sup>	n	.59	n	n	n	.03	n	n	.03	.06
Quinolinone <sup>6</sup>	n	5.5	n	n	n	n	n	n	n	n
Isoquinolinone	n	5.7	n	n	n	n	n	n	n	n

<sup>1</sup> Concentration obtained using volatile analysis methodology.

<sup>2</sup> -- = Compound was not analyzed for.

<sup>3</sup> n = Compound was undetected in this sample.

<sup>4</sup> Concentrations for this compound may represent more than one isomer.

<sup>5</sup> "H" designates the position of an "indicated hydrogen" in order to uniquely identify the compound.

<sup>6</sup> Quinolinone and isoquinolinone may also be classified as neutral aromatic compounds.

TABLE 2.--Concentrations of organic compounds in selected soil samples at Gas Works Park

[All concentrations are in milligrams per kilogram.]

	Well number									
	1	3	6	7	7	9	9	10	12	14
Depth (feet)	58	4.3	5.8	8.0	12.0	2.5	5.7	3.4	3.3	6.0
Stratigraphic Unit <sup>1</sup>	VT	RD	GW	RD	VT	FL+GW	RD	FL+GW	GW	GW
<u>Compounds</u>										
C3 Benzene <sup>2</sup>	n <sup>3</sup>	n	n	n	n	n	n	n	9.6 e <sup>4</sup>	n
Nitrobenzene	n	n	n	n	n	n	n	n	.79	n
Benzoic acid	n	n	n	n	n	n	n	n	n	0.29 e
Naphthalene	n	n	9.0	n	n	6.0	0.66	0.037	46	1.5
2-Methylnaphthalene	n	n	2.6	n	n	1.3 e	.31 e	n	6.3	n
2,4,5-Trichlorophenol <sup>2</sup>	n	n	n	n	n	n	n	n	.96 e	n
C2 Naphthalene	n	n	8.3 e	n	n	n	n	n	39 e	n
Acenaphthylene	n	n	1.9 e	n	n	3.0 e	.50	n	1.6 e	.065 e
Acenaphthene	n	n	1.8 e	n	n	.33 e	.22 e	n	1.1 e	1.9
Dibenzofuran	n	n	n	n	n	.39 e	.13 e	n	.98 e	.046 e
C3 Naphthalene <sup>2</sup>	n	n	4.2 e	n	n	n	1.2 e	n	8.7 e	n
Fluorene	n	n	2.1 e	n	n	1.3 e	.39 e	n	6.5	.34 e
Dibenzothiophene	n	n	4.1 e	n	n	n	n	n	n	.22 e
Pentachlorophenol	n	n	.46 e <sup>5</sup>	n	n	n	n	n	n	.052
Phenanthrene	n	n	18 b	n	n	26 b	3.3 b	.053 b	19 b	.23 b
Anthracene	n	n	3.1	n	n	2.4 e	.54	n	1.0 e	.28
C1 Phenanthrene and/or C1 Anthracene <sup>2</sup>	n	n	5.4 e	n	n	6.2 e	7.4 e	n	16 e	n
4H-Cyclopenta-(d,e,f)phenanthrene <sup>2</sup>	n	n	6.6 e	n	n	11 e	n	n	n	.16 e
C2 Phenanthrene/ <sup>2</sup>	n	n	n	n	n	8.5 e	n	n	n	n
C2 Anthracene	n	n	n	n	n	n	n	n	n	n
Fluoranthene	n	n	26 b	n	n	26 b	4.3 b	.054 b	11 b	.74 b
Pyrene	n	n	33 b	n	n	43 b	5.9 b	.11 b	19 b	1.1 b
C1 Fluoranthene and/or C1 Pyrene <sup>2</sup>	n	n	n	n	n	5.9 e	6.2 e	n	n	n
Benzo(a)anthracene	n	n	8.5	n	n	8.6	3.4	n	6.6	.037
bis(2-Ethylhexyl)-phthalate	0.059 b	n	.27 e	0.18 e	n	n	.15 e	n	n	.038
Chrysene	n	n	9.4	n	n	12	2.5	.033 e	6.2	.051
C1 Benzo(a)anthracene and/or C1 Chrysene <sup>2</sup>	n	n	n	n	n	7.9 e	3.7 e	n	n	n
Benzo(b)fluoranthene <sup>6</sup>	n	n	16 d	n	n	19 d	4.1 d	0.040 d	11 d	0.037 d
Benzo(k)fluoranthene <sup>6</sup>	n	n	16 d	n	n	19 d	4.1 d	.040 d	11 d	.037 d
Benzo(j)fluoranthene	n	n	n	n	n	n	1.2 e	n	n	n
Benzo(e)pyrene	n	n	8.7 e	n	n	12 e	3.5 e	n	n	n



TABLE 2.--Concentrations of organic compounds in selected soil samples at Gas Works Park--continued

[All concentrations are in milligrams per kilogram.]

	Well number									
	1	3	6	7	7	9	9	10	12	14
Depth (feet) <sup>1</sup>	58	4.3	5.8	8.0	12.0	2.5	5.7	3.4	3.3	6.0
Geologic Unit	VT	RD	GW	RD	VT	FL+GW	RD	FL+GW	GW	GW
<b>Compounds</b>										
Benzo(a)pyrene	n	n	13	n	n	15	2.9	n	5.5	n
Indeno(1,2,3-cd)pyrene	n	n	12	n	n	13	1.8	n	5.3	n
Dibenz(a,h)anthracene	n	n	1.8 e	n	n	2.0 e	.57	n	1.6 e	n
Benzo(g,h,i)perylene	n	n	14	n	n	16	1.9	n	6.1	n

<sup>1</sup> VT - Till in Vashon Drift, RD - recessional stratified drift in Vashon Drift, GW - Gas Works deposit, FL - artificial fill.

<sup>2</sup> C1, C2, and C3 indicate a given number of carbon atoms attached to a compound. There is usually more than one compound represented by this type of nomenclature, and the compounds cannot be distinguished from one another using the given methodology. C3 benzene, for example, represents one or more compounds that could be trimethyl benzene, ethylmethyl benzene, or propyl benzene. When two compounds are given, such as C2 phenanthrene/C2 anthracene, the base compound may be either one, in this case phenanthrene or anthracene.

<sup>3</sup> n = compound was undetected in this sample.

<sup>4</sup> e = estimated concentration.

<sup>5</sup> b = Compound was also detected in blank, but at a concentration judged to be insignificant.

<sup>6</sup> d = Benzo(b)fluoranthene and benzo(j)fluoranthene co-elute.

TABLE 3.--Concentrations and aqueous solubilities of principal organic compounds in a representative coal tar (Adapted from Villaume, 1984)

Compound	Concentration in coal tar (milligrams per liter)	Aqueous solubility <sup>1</sup> (milligrams per liter)
Benzene	---	<sup>2</sup> 1,780
Toluene	---	<sup>2</sup> 515
o-Xylene	---	<sup>2</sup> 175
Trimethylbenzene	13,000	---
Naphthalene	36,000	31.7
1-Methylnaphthalene	---	28.5
2-Methylnaphthalene	---	25.4
Dimethylnaphthalenes	21,500	---
1,3-Dimethylnaphthalene	---	8.0
2,3-Dimethylnaphthalene	---	3.0
Acenaphthylene	7,400	---
Acenaphthene	7,200	3.93
Trimethylnaphthalenes	17,800	---
1,4,5-Trimethylnaphthalene	---	2.1
Fluorene	9,800	1.98
Phenanthrene	23,000	1.29
Anthracene	23,000	.073
2-Methylanthracene	---	<sup>3</sup> .0213
Methylphenanthrenes	15,000	---
Fluoranthene	32,000	.26
Pyrene	5,600	.135
Chrysene	3,100	.0020
Benzo(a)anthracene	3,100	.014
Benzo(j)fluoranthene	370	---
Benzo(a)pyrene	1,000	.0038
Indeno(1,2,3-cd)pyrene	<250	---
Benzo(g,h,i)perylene	<250	.00026
Phenol	.99	<sup>4</sup> 93,000
Methylphenol	.33	---
2-Methylphenol	---	<sup>4</sup> 25,000

<sup>1</sup>From MacKay and Shiu (1977), unless otherwise noted.

<sup>2</sup>From MacKay and Wolkoff (1973).

<sup>3</sup>From May, Wasik, and Freeman (1978).

<sup>4</sup>From Morrison and Boyd (1973).

A nonaqueous phase liquid (NAPL), thought to be primarily a liquid hydrocarbon mixture, was present in the soils at wells 5, 9, and 12. This NAPL was observed as an oily film in samples of the saturated recessional drift below the Gas Works deposit at wells 5 and 12. No such film was noted in the soils at well 9, but oil droplets in the ground-water sample combined to form a surface oil film in the sample. Ground water from these three wells had the largest total contaminant concentrations, and the presence of the NAPL was thought to be a major source of the contaminants.

## Volatile Organic Compounds in Soil Gas

Concentrations of volatile organic compounds in soil gas are shown in table 4 (from J. F. Pankow, Oregon Graduate Center, written commun., 1987). Benzene, several alkylbenzenes, and naphthalene were identified; some at several well sites. Concentrations were largest at well sites 2 and 5, but excessive soil moisture may have interfered with sample collection at other well sites, especially those near Lake Union. The sorptive cartridges collected at well sites 2 and 5 were analyzed qualitatively, and indene, trimethylbenzenes, and alkylated cyclohexanes were identified in addition to the compounds shown in table 4. Methane was detected semiquantitatively in most soil gas samples, and was largest at well site 9. Methane and other volatile compounds were also detected semiquantitatively in the airspace of almost all of the wells by portable monitoring equipment used during and after drilling. Concentrations of volatile compounds in the well airspace were largest in wells 9 and 12.

TABLE 4.--Concentrations of volatile organic compounds in soil gas at Gas Works Park

[All concentrations in milligrams per liter. det = detected, but below detection limit; n = not detected.]

	3-foot depth														
Site number	2	3	5	6	7	8	9	10	11	12	13	14	15	16	
Benzene	0.12	det	0.56	det	det	0.028	n	det	0.022	det	det	det	det	0.021	
Toluene	.027	n	.11	n	n	.026	n	n	n	n	n	n	n	n	
Ethylbenzene	.21	n	.55	n	n	n	n	n	n	n	n	n	n	n	
m- and p-Xylene	.077	n	.60	n	n	n	n	n	n	n	n	n	n	n	
o-Xylene	.14	n	.29	n	n	n	n	n	n	n	n	n	n	n	
Naphthalene	.29	.001	.49	det	det	.028	n	det	n	det	.009	.004	0.0005	n	
	6-foot depth														
Site number	2		5		7	8								15	
Benzene	0.023		1.3		det	det								det	
Toluene	.004		2.3		n	n								n	
Ethylbenzene	.055		1.0		n	n								n	
m- and p-Xylene	.019		1.3		n	n								n	
o-Xylene	.038		.53		n	n								0.001	
Naphthalene	.122		1.1		0.035	0.005								.383	

### Weathering of Organic Compounds in Soils

When the gasification plant was operating at Gas Works Park, the soils probably contained more NAPL than at present (1986). However, during the past 30 years, the hydrocarbons in the NAPL have weathered, leaving behind in many places primarily high-molecular-weight compounds that stain the soils. This may be expected because during the processes of hydrocarbon weathering, the lighter compounds generally enter the ground water and soil gas preferentially over heavier compounds.

The weathering mechanism involves several processes, some of which are evident at the park. The simplest is dissolution, which, in a flowing ground-water system, flushes away the more water-soluble components (table 3). This process appears to be occurring upgradient of wells 2, 5, 9, and 12, where various highly water-soluble compounds are present. Once dissolved, sorption of these compounds to clean soil is probably not an important attenuation process. Goerlitz and others (1985) demonstrated that sorption was insignificant in the transport of phenol, 3-methylphenol, 2,5-dimethylphenol, and naphthalene in sand-and-gravel aquifers. Also, the partition of nonionic organic compounds into soil organic matter decreases with increasing solute solubility in water (Chiou and others, 1979; and Smith and others, 1988). In general, once dissolved, the compounds tend to remain in solution.

Volatilization is a mechanism by which compounds move from the NAPL, the contaminated ground water, and the contaminated soils to the soil gas, and ultimately to the atmosphere. The volatilization rate is generally higher for lighter-molecular-weight compounds than for heavier ones, and is an important process when hydrocarbons are in ground water (Hult and Grabbe, 1987). The presence of volatile compounds in the soil gas at many locations indicates that this is an active process at the park. The degree and rate of volatilization from a given location depends upon such variables as temperature, atmospheric pressure, porosity, water saturation, and the presence of other inorganic and organic compounds.

Ultimately, many of the compounds present in the park soils may be biodegraded. Anaerobic degradation of phenols, methylphenols, and quinoline has been documented under similar circumstances (Ehrlich and others, 1982; Godsy and Goerlitz, 1986; Godsy and others, 1987; Smith and Novak, 1987). The presence of these compounds in ground water at wells 5 and 9, along with the semiquantitative detection of methane in the unsaturated zone at well 9 (J. F. Pankow, Oregon Graduate Center, written commun., 1987), indicates this process may be occurring. Godsy and others (1983) showed that methane is an end product of the anaerobic degradation of phenols in ground water.

As weathering proceeds, the amount of NAPL decreases and the remaining hydrocarbons in the soils consist of compounds that are not easily biodegradable, have low volatilities, and are relatively insoluble in water. These are characteristics of the more persistent 3- to 6-ring PAH that were found in the soils of the Gas Works deposit. This weathering concept, in conjunction with the soil-chemistry data presented in table 2, indicates that the hydrocarbons in the Gas Works deposit at wells 6 and 9 are more weathered than those in the Gas Works deposit at well 12. The concentrations of hydrocarbons in the soils at wells 10 and 14 appear to be much smaller in general, and little may be concluded about weathering at these two wells.

### Mechanisms Affecting Organic Compounds in Ground Water

It is hypothesized that ground water entering the park becomes contaminated with organic compounds upon contacting the Gas Works deposit. The degree of contamination of the ground water depends on the composition of the hydrocarbons in the soils with which the water comes in contact. Where the hydrocarbons are weathered, few highly water-soluble compounds remain and ground-water contamination is relatively small. Where the hydrocarbon is not weathered--especially where a NAPL exists--more water-soluble compounds are present in large concentrations and significant ground-water contamination occurs. To examine this hypothesis, the interaction of the ground-water flow path, soil chemistry, and ground-water chemistry was considered. The geologic sections in figure 6 demonstrate these relations.

Geologic section A-A' (fig. 6) is approximately along a ground-water flow path. No organic compounds were detected in the soils or ground water at well 3. Because no gasification-related organic compounds were found in samples from the control wells (1 and 3D, not shown), ground water entering the park was considered to be uncontaminated by these compounds. At well 6 the ground water was in contact with the contaminated Gas Works deposit, but only a few organic compounds were found in the water. Because the hydrocarbon in the soil at well 6 appeared relatively weathered, this is to be expected. At well 9 the water table was below the Gas Works deposit and the water contained large concentrations of organic compounds. Although the soil-chemistry analysis shows that the hydrocarbon in the unsaturated deposits was weathered, the soil chemistry of the saturated natural deposits is unknown. Given the presence of a NAPL in contact with the ground water, as suggested by the oil droplets in the water samples, large concentrations of organic compounds in the ground water may be expected. At well 12 the ground water was highly contaminated because the ground water is in contact with a NAPL in an unweathered Gas Works deposit. In general, the contamination of ground water along this section is associated with the presence of a NAPL.

Geologic section A-A" is also approximately along a ground-water flow path. At well 7 the water table was almost 10 feet below a thin Gas Works deposit, and the ground water contained relatively small concentrations of organic compounds. The natural soils immediately above and below the water table contained no organic compounds. This indicates either horizontal migration of small amounts of organic compounds with the ground water from upgradient sources or vertical migration with the recharge through the unsaturated zone. The absence of a NAPL in the Gas Works deposit at this well indicates a weathered hydrocarbon, therefore large concentrations of organic compounds in the ground water would not be expected in any case. The situation at well 10 was similar, and the same conclusions may be drawn. Well 14 was the only location along section A-A" where the Gas Works deposit was below the water table. The ground water contained only moderate concentrations of organic compounds at that point, but this is expected because the concentrations of organic compounds in the Gas Works deposit soils at this well were small in comparison to concentrations in the Gas Works deposit at other wells in the park. Overall, the ground-water contamination along A-A" was much less than that along section A-A', largely because the Gas Works deposit was thinner there, a NAPL was not present, and the water table was generally below the Gas Works deposit.

The dependence of ground-water contamination on the presence of a NAPL, and, to a lesser extent, on contact between the ground water and the Gas Works deposit, is apparent in table 5, which summarizes these data for all of the wells. Ground water at wells 5, 9, and 12, which has the greatest concentrations of organic compounds, also is in contact with a NAPL. At wells 6, 13, 14, and 16, ground water was in contact with or within 1 foot of the Gas Works deposit, but no NAPL was present and concentrations of organic compounds are much smaller. Relatively small concentrations in ground water at wells 7, 8, 10, and 15 are attributed to horizontal or vertical migration from a contaminated area. Only well 2 is an exception to the hypothesis, and the naphthalene concentration there was the largest observed. Possible explanations for this exception include an undetected NAPL, a seasonal rise of the water table into the Gas Works deposit, or migration from an upgradient source.

TABLE 5.--Occurrence of ground water in relation to the Gas Works deposit

Well Number	Well depth (in feet)	Altitude of land surface (in feet)	Depth to water from land surface on 12/18/86 (in feet)	Depth to top of Gas Works deposit (in feet)	Depth to bottom of Gas Works deposit (in feet)	Location of water table relative to the Gas Works deposit	Nonaqueous phase liquid (NAPL) present	Concentration <sup>1</sup> of organic compounds
1	34.8	78.12	22.03	Absent	Absent	NA <sup>2</sup>	no	0
2	13.9	31.99	11.08	1.1	4.4	below	no	2
3	10.6	32.12	5.42	Absent	Absent	NA	no	0
3D	57.6	32.21	16.29	Absent	Absent	NA	no	0
5	18.3	29.21	13.45	2.0	10	below	yes	3
6	9.9	27.16	2.52	3.0	8.5	in	no	1
7	17.1	29.32	10.60	0.5	1.0	below	no	1
8	19.5	29.88	8.58	.5	5.0	below	no	1
9	20.8	27.62	8.96	1.0	4.0	below	yes	3
10	15.3	25.57	10.50	Absent	Absent	NA	no	1
11	29.9	31.51	13.26	6.0	10	below	no	0
12	9.6	18.73	4.84	1.1	6.0	in	yes	3
13	17.3	25.81	12.14	2.0	13.2	in	no	0
14	9.5	20.20	6.68	3.0	6.0	below	no	1
15	19.5	31.05	17.11	1.0	7.0	below	no	1
16	10.6	16.56	2.08	1.0	4.4	in	no	0

<sup>1</sup> Subjective scale based on concentrations of organic compounds in table 1, 0=none, 1=low, 2=moderate, 3=high.

<sup>2</sup> Not applicable.

## Physical Characteristics and Trace Metals in Ground Water

Mineral content of the shallow ground water in the park is exceptionally high in some areas, on the basis of specific-conductance values of water samples (table 6). Conductance values of all samples exceeded 242  $\mu\text{S}/\text{cm}$  (microsiemens per centimeter), the value at the off site control well (well 1). Specific conductance values of samples from wells 7, 8, and 16 ranged from 3,280 to 5,280  $\mu\text{S}/\text{cm}$ , indicating a potentially large amount of inorganic contamination. Common ions were not analyzed as part of this study, and thus it is impossible to determine which dissolved minerals are responsible for the large specific conductances. Values of pH ranged from 6.4 to 6.8 except for unexplained low values of 5.5 and 5.8 in samples from wells 7 and 15 and a high value of 8.2 in the sample from well 3D. Dissolved-oxygen concentrations were low, with a median value of 1.0 mg/L, but only at well 9 was the ground water anaerobic. The presence of small amounts of dissolved oxygen do not necessarily preclude the occurrence of anaerobic conditions at other wells, because some oxygen may remain from other sampling or drilling activities. Little correlation between pH, specific conductance, dissolved oxygen, and the concentrations of organic compounds was apparent.

Concentrations of trace metals and cyanide in ground water are also shown in table 6. Most metal concentrations were generally less than 0.010 mg/L and rarely exceeded EPA drinking-water standards (U.S. Environmental Protection Agency, 1976). Only arsenic, boron, nickel, and zinc were present above trace concentrations (0.005 mg/L) at more than one well. Arsenic, nickel, and zinc are all present in coal tar (Villaume, 1984), and their presence may indicate ground-water contamination. Cyanide was present in all samples and ranged in concentration from 0.01 to 8.6 mg/L. No correlations were apparent among concentrations of the inorganic compounds, or among concentrations of inorganic constituents, concentrations of organic compounds, and specific conductance.

TABLE 6.--Field measurements and concentrations of trace metals and cyanide in ground water at Gas Works Park

Well number	pH (Standard Units)	Specific conductance, (micro-siemens per centimeter)	(milligrams per liter)																
			Oxygen dissolved	Cyanide dissolved	Arsenic dissolved	Beryllium dissolved	Boron dissolved	Cadmium dissolved	Chromium dissolved	Copper dissolved	Lead dissolved	Mercury dissolved	Nickel dissolved	Selenium dissolved	Silver dissolved	Zinc dissolved			
1	6.4	242	3.8	<0.01	0.002	<0.0005	0.06	0.001	0.002	0.002	<0.005	0.0011	<0.001	<0.001	<0.001	0.006			
2	6.6	600	1.8	0.74	.018	<0.0005	.19	<0.001	<0.001	<0.001	<0.005	<.0001	.005	<.001	<.001	.015			
3	6.7	352	1.5	0.12	.006	<0.0005	.11	<0.001	<0.001	<0.001	<0.005	<.0001	.005	<.001	<.001	.005			
3d	8.2	242	0.3	0.01	.002	<0.0005	.03	<0.001	<0.001	<0.001	<0.005	.0003	<.001	<.001	<.001	.009			
5	6.7	855	--	0.10	.004	<0.0005	.32	.001	<0.001	<0.001	<0.005	.0001	.004	<.001	<.001	.049			
6	6.4	432	2.3	0.26	.011	<0.0005	.08	.002	.002	.001	<0.005	<.0001	.020	<.001	<.001	.013			
7	5.8	5,280	1.4	0.40	.003	<.01	.48	<0.001	<0.001	<0.001	.070	.0001	.028	.001	<.001	.150			
8	6.4	3,280	0.8	1.1	.060	<.01	.20	<0.001	<0.001	<0.001	<0.005	.0001	.005	<.001	<.001	.057			
9	6.8	1,370	0	1.1	.022	<0.0005	.39	.001	<0.001	<0.001	<0.005	.0002	.019	<.001	<.001	.028			
10	6.6	945	1.6	0.16	.003	<0.0005	.13	.001	<0.001	<0.001	<0.005	.0001	<.001	<.001	<.001	.028			
11	6.8	865	0.8	1.1	.006	<0.0005	.17	.001	<0.001	<0.001	<0.005	.0001	.030	<.001	<.001	.014			
12	6.5	848	2.6	1.5	.011	<0.0005	.14	.004	<0.001	<0.001	<0.005	.0001	<.001	<.001	<.001	.015			
13	6.7	1,280	1.0	0.03	.007	<0.0005	.45	.002	<0.001	<0.001	<0.005	.0001	.011	<.001	<.001	.028			
14	6.5	988	0.4	0.24	.002	<0.0005	.20	.001	<0.001	<0.001	<0.005	.0001	<.001	<.001	<.001	.010			
15	5.5	670	1.0	0.16	<.001	<0.0005	.19	.002	<0.001	<0.001	<0.005	.0001	.070	<.001	<.001	.061			
16	6.8	4,950	1.0	8.6	.004	<.01	.38	<0.001	<0.001	<0.001	<0.005	.0004	.006	<.001	<.001	.016			
DWS	6.5-8.5	n	n	n	.050	n	n	.010	.050	1.0	.050	.002	n	.010	.050	5.0			

<sup>1</sup> --- = Compound was not analyzed for.

<sup>2</sup> Environmental Protection Agency drinking water standard.

<sup>3</sup> n = no Environmental Protection Agency drinking water standard is available.



## SUMMARY AND CONCLUSIONS

The soils and associated nonaqueous phase liquids (NAPL) of Gas Works Park are a source of contaminants in ground water at the park, even though it has been more than 30 years since gasification operations were discontinued. The contaminants were present in the soils as a layer of gray- or black-stained natural material, interspersed with cinders, bricks, fragments, woodchips, and in some instances tar and oil. These contaminated soils, called the "Gas Works deposit" in this study, occur throughout most of the park and are as much as 9 feet thick in some places. The organic compounds identified in the ground water and soil are similar to those found in coal tar.

Concentrations of organic compounds in the ground water were largest at wells where the ground water was in contact with a NAPL such as oil. At these wells, mononuclear and polynuclear aromatic hydrocarbons (PAH), especially benzene, alkylbenzenes, naphthalene, and alkyl naphthalenes, were present in the ground water at concentrations ranging from 1.0 to 200 mg/L. Concentrations of less soluble 3- and 4-ring PAH were below 0.20 mg/L in the ground water. The soils at these wells were stained and contained 2- to 6-ring PAH in concentrations as large as 46 mg/kg.

Where the NAPL was not present, the ground water contained much smaller concentrations of benzene and alkylbenzenes, even if in contact with the Gas Works deposits. Concentrations of naphthalene, alkyl naphthalene, and 3- to 4-ring PAH in ground water were similar to those at wells where a NAPL was present. Generally, the Gas Works deposit was stained and contained 2- to 6-ring PAH, but had much smaller concentrations of 2- and 3-ring PAH, such as naphthalene and phenanthrene than at wells with a NAPL.

The degree of ground-water contamination is thought to depend on the weathering of the hydrocarbons in the soils and in the NAPL, if present. Weathering processes such as dissolution, volatilization, and biodegradation are evident at the park. These processes release water-soluble, lower-molecular-weight organic compounds into the ground water, leaving behind the characteristic stained soil that contains relatively insoluble, higher-molecular-weight compounds.

Horizontal or vertical migration of organic compounds in the ground water was indicated by the presence of these compounds in ground water that was not in contact with the Gas Works deposit. Where a NAPL was present, vertical migration of liquid contaminants from the Gas Works deposit to underlying uncontaminated natural material was also apparent, but the data are insufficient to describe migration processes beyond this qualitative assessment.

Inorganic contamination by minerals appears high in some places, based on specific conductance of water samples. Specific conductance values in the park ground water were as large as 5,280  $\mu\text{S}/\text{cm}$ , compared to 242  $\mu\text{S}/\text{cm}$  upgradient from the park. Cyanide was present in ground water throughout the park, but concentrations of most trace metals were smaller than EPA drinking-water standards. On the basis of the limited inorganic data collected in this study, it appears that there is little correlation between the organic and inorganic contaminants in the ground water.

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