

EVALUATION OF AVAILABLE DATA ON THE GEOHYDROLOGY, SOIL CHEMISTRY,
AND GROUND-WATER CHEMISTRY OF GAS WORKS PARK AND SURROUNDING REGION,
SEATTLE, WASHINGTON

By M. A. Sabol, G. L. Turney, and G. N. Ryals

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CONVERSION FACTORS AND ABBREVIATIONS

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

<u>Multiply inch-pound unit</u>	<u>By</u>	<u>To obtain metric unit</u>
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre	4,047	square meter (m ²)
square foot (ft ²)	0.09290	square meter (m ²)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
square foot per day (ft ² /d)	0.09290	square meter per day (m ² /d)
cubic foot per year (ft ³ /yr)	0.02832	cubic meter per year (m ³ /yr)
gallon per minute (gal/min)	0.06308	liter per second (L/s)

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 "Mean Sea Level of 1929."

To convert degrees Fahrenheit (°F) to degrees Celsius (°C), use the following equation: $^{\circ}\text{C} = 5/9 (^{\circ}\text{F} - 32)$

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ABSTRACT

Gas Works Park, in Seattle, Washington, is located on the site of an abandoned gasification plant. The accumulation of wastes deposited during 50 years of plant operations (1906-1956) has left soil underlying the park contaminated with a number of hazardous materials. These wastes were also deposited along the old shoreline of Lake Union, slowly extending the shoreline approximately 100 feet. Contaminants that have been identified in the park soils include polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pesticides, volatile organic compounds, cyanide, and metals. PAHs and metals have been detected in offshore Lake Union sediments.

Existing data were used to evaluate the soil chemistry, geohydrology, and potential for ground-water contamination of the park. Data sources include the U.S. Environmental Protection Agency, State of Washington Department of Ecology, University of Washington, several City of Seattle agencies, and Tetra Tech, Inc.

High total PAH concentrations, exceeding 100,000 $\mu\text{g}/\text{kg}$ (micrograms per kilogram), are common in both the soils of the park at 6-inch depths and sediments of the lake. The maximum total PAH concentration in the park soils was 106 million $\mu\text{g}/\text{kg}$ in a sample from a sandbox. The highest total PAH concentration in Lake Union sediments was 131 million $\mu\text{g}/\text{kg}$, and was in a sample collected 180 feet off the southwest shore of the park. Other contaminants are present in much lower concentrations.

The park is underlain by glacial drift from the Vashon glaciation. Waste materials from the gasification plant and clean fill overlie the glacial deposits, but exact thicknesses are unknown owing to regrading, rototilling and other disturbances to the park surface. Based on typical values for the region, ground-water hydraulic conductivities in the sands and gravels of the glacial deposits probably range between 2 and 860 feet per day. The gasification waste materials are a poorly sorted mixture of sand and gravels, with lampblack, oil, bricks, and other industrial waste material. They have a grain-size distribution of 16 to 36 percent gravel, 36 to 54 percent sand, and 21 to 45 percent silt and clay.

Ground water flowing under the park originates from the infiltration of precipitation and the influx of ground water from the upland on the north side of the park. Water levels measured in 1971 indicate that the ground water flows toward Lake Union. Vertical movement of ground water under the park has not been defined, but based on regional flow patterns it may be assumed that upward movement occurs into and near Lake Union.

Because of their low solubilities and high sorptive characteristics, concentrations of most soil contaminants are probably low in the ground water and in Lake Union. However, no data are available on the contaminant concentrations in the park ground water or the water of Lake Union to confirm this premise. Likewise, not enough data exist to determine the impact of contaminants from Gas Works Park on Lake Union. Data collected in conjunction with test holes drilled and a ground-water monitoring program could provide answers to many of these questions.

INTRODUCTION

In 1984 the U.S. Geological Survey began a cooperative program with the State of Washington Department of Ecology (WDOE) to use available data to describe the hydrologic setting, including water quality, of several hazardous waste sites within Washington and to identify data deficiencies. This report describes such a study of Gas Works Park, located on the northern shore of Lake Union in Seattle, Wash. (fig.1). The 20-acre park is the site of a former gasification plant. In the past 5 years, concerns have been raised regarding public safety at the park because of known contamination from former plant operations. Concerns have also been raised about water quality in Lake Union because limited appraisals have shown contaminants to be present in the lake.

Purpose and Scope

The purpose of this study was to describe to the extent existing data allowed 1) the regional geohydrologic setting of the Gas Works Park area, 2) the geohydrologic setting in the immediate vicinity of Gas Works Park, 3) the potential for ground-water contamination attributable to Gas Works Park, and 4) to determine what additional data, if any, are necessary to better define the foregoing characteristics. Data were collected and compiled from the various sources listed on page 5, and geologic data were obtained from various U.S. Geological Survey reports. This report presents discussion and compilation of these data, but not necessarily the individual data values.

Few site-specific data are available to describe the geohydrology and ground-water quality at the park. Therefore, data on geohydrology and ground-water quality gathered within the region around the park were used in this assessment and were extrapolated to the park itself. These data, in conjunction with a multitude of soil chemistry data from the park, provide enough information to satisfy the purposes of the study.

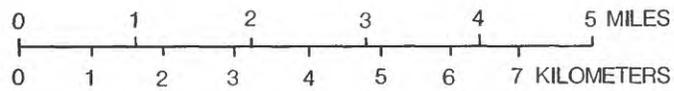
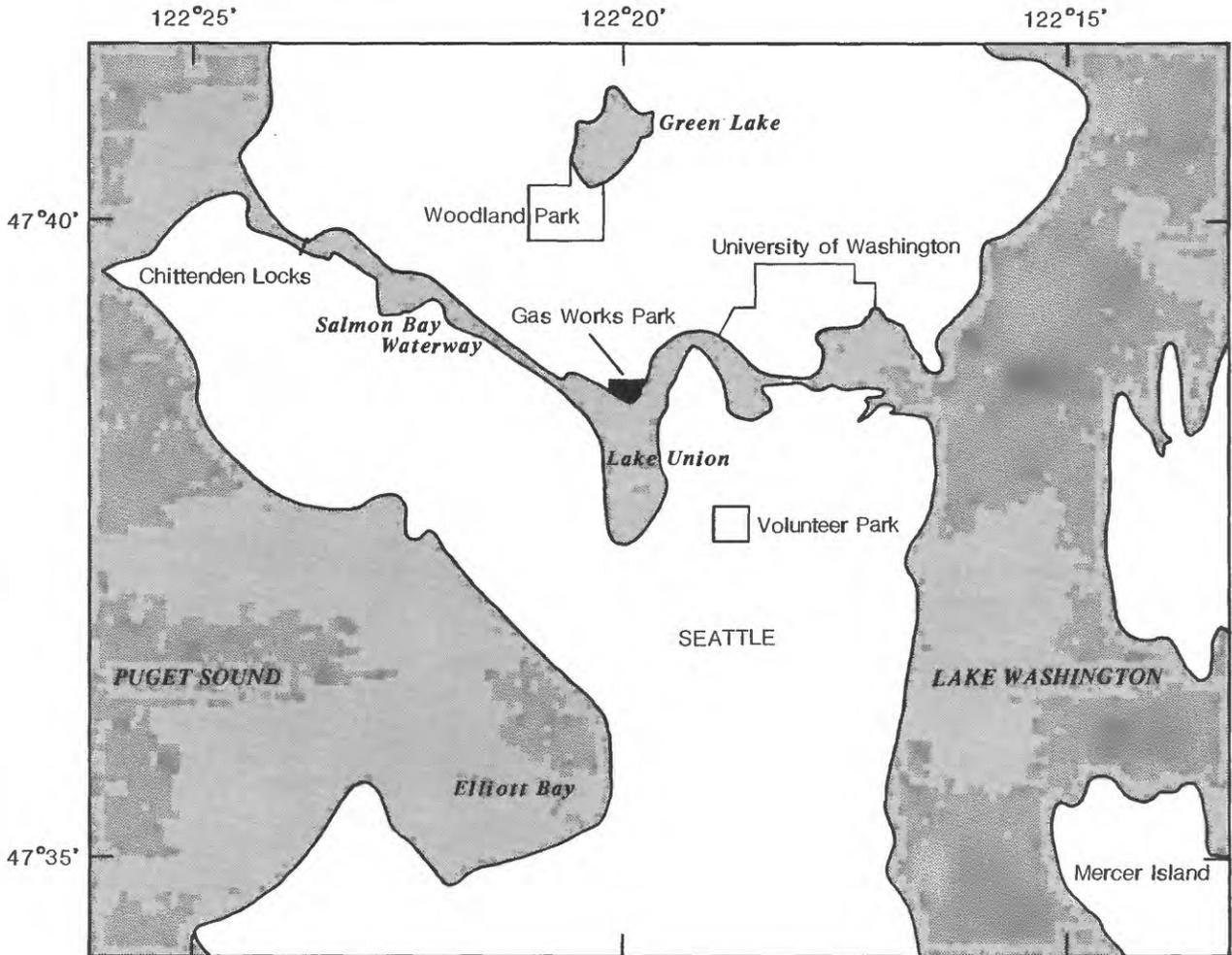
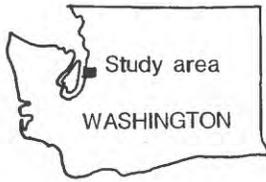


Figure 1.--Location of Gas Works Park.

Sources of Data

In addition to published reports of the U.S. Geological Survey, numerous contacts for data were made with other Federal, State, and local governmental agencies and organizations. These organizations provided both unpublished data and copies of reports that were written under contract for the agency by private consulting firms or by universities. The materials collected are stored in the Tacoma Office of the U.S. Geological Survey, Water Resources Division. Sources of data and reports included:

U.S. Environmental Protection Agency (EPA)
State of Washington Department of Ecology (WDOE)
State of Washington Department of Transportation (WDOT)
University of Washington (UW)
Municipality of Metropolitan Seattle (METRO) - Department of Water
Pollution Control
City of Seattle (COS) - Department of Parks and Recreation
Department of Engineering
Department of Water
U.S. Army Corps of Engineers (COE) - Washington Ship Canal
Lake Union Salinity Study
Foundation Studies
National Oceanic and Atmospheric Administration (NOAA)
Tetra Tech, Inc.

Data describing the geology and ground-water flow system came primarily from reports by Cole and Machno (1971) and Liesch, Price, and Walters (1963). The sources of sediment contamination and water-quality data for Lake Union and soil-contamination data for Gas Works Park were primarily published and unpublished data from the files of EPA, METRO, COE, COS and Tetra Tech.

The data used in this investigation that were not collected by the Survey were not subjected to the rigid verification procedures normally used by the Survey and, therefore, their use does not represent an endorsement by the Survey.

History of Gas Works Park

The land on which Gas Works Park is located was originally known as Browns Point. In 1906, the Seattle Gas Light Company built a gas works plant on the site. Illuminating, or "town" gas was produced at the plant from the gasification of coal from 1906 to 1937. In 1937, the plant was converted to oil gasification because it was more economical to produce gas from oil than from coal. Operations were discontinued in 1956 due to the importation of natural gas from the newly constructed Trans Mountain Pipeline. The abandoned plant was used mostly for storage from 1956 to 1962.

During 50 years of operation, air pollutants were emitted from the plant, and unknown quantities of solid and liquid waste byproducts were produced (Richard, 1983). These wastes were mostly deposited on-site and were used to extend the shoreline of Lake Union lakeward more than 100 feet in places beyond the 1907 shoreline (fig. 2). The wastes include slag, solvents, lamp-black carbon, coal byproducts, oil, tar, ashes, cinders and miscellaneous

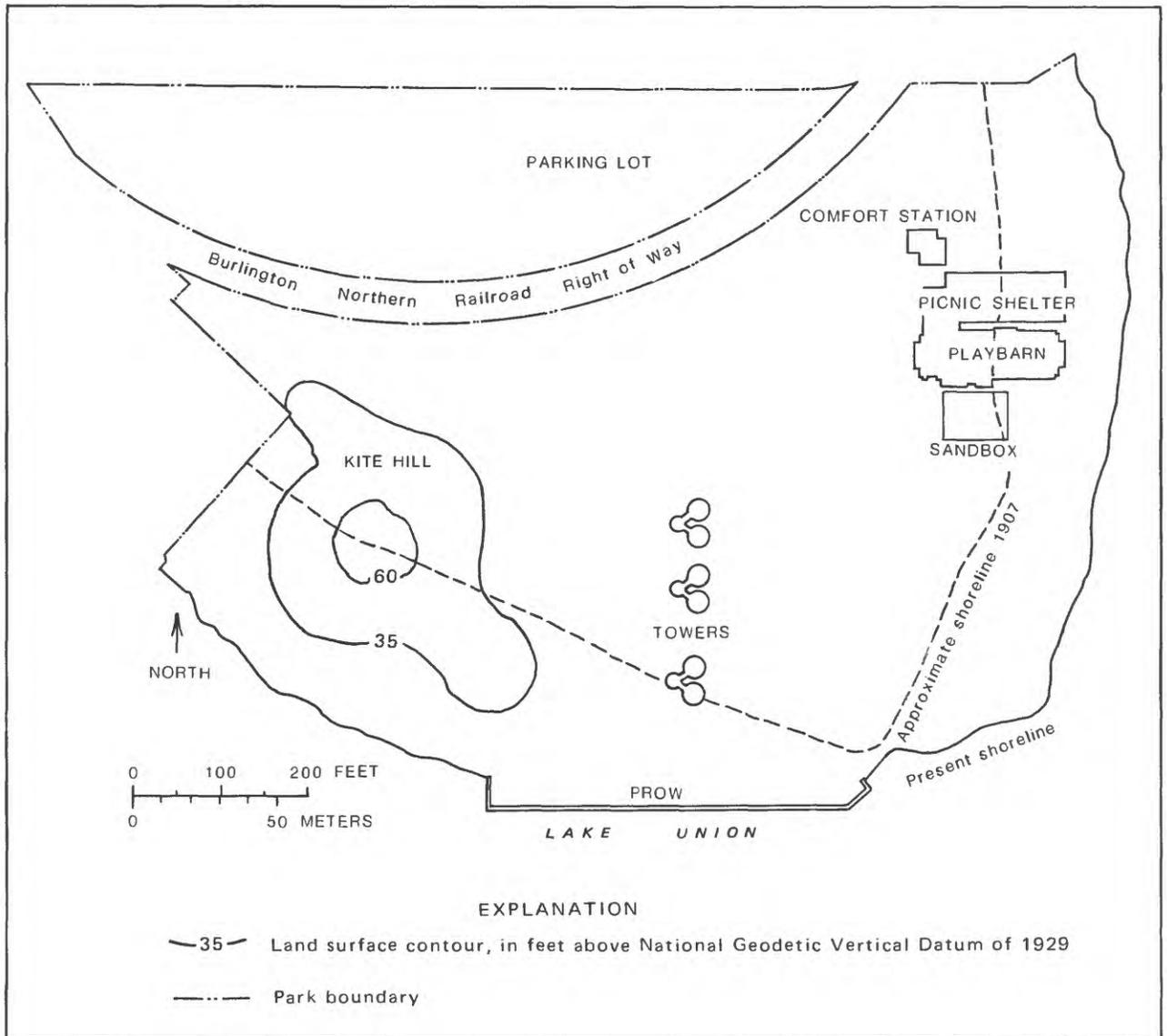


Figure 2.--Gas Works Park, with locations of 1907 and present shorelines.

materials such as wood, concrete, and bricks. Recent studies show that some of these wastes are highly toxic and include various types of organic compounds, trace metals, and other potentially toxic and carcinogenic compounds (Richard, 1983).

In 1962, the City of Seattle purchased the property and the abandoned plant. The property was established as a city park with the passage of a bond issue in 1968 and was developed into a park setting from 1970 to 1976. It officially opened in 1976. The park is unique in that it centers around the equipment and structures of the gas works plant, much of which was left intact (fig. 3). The land surface was recontoured and a large hill, "Kite Hill," was created from both the gasification waste material and fill obtained from the excavation of the Safeco Building in the University District. A large concrete bulkhead and sitting area, referred to as the "prow," was constructed on the southern shore. Presently, further architectural enhancements for the park are being formulated.

On April 20, 1984, the park was closed by the City of Seattle after it had obtained the results of analyses of soil samples collected by the U.S. Environmental Protection Agency (EPA). These soil analyses showed high levels of several known or suspected carcinogenic chemicals. A Health Advisory Committee was established to review EPA data and make recommendations concerning health risks associated with the park. On August 17, 1984, the park was reopened to the public after the Center for Disease Control concluded that risks to the public would be negligible upon closure of the children's playbarn and other contaminated areas. Subsequently, the playbarn was cleaned and painted, and the known contaminated areas were covered with fill material. Presently, most areas of the park are open to the public.

Climate

The climate of the Puget Sound lowland, in which Gas Works Park is located, is affected predominantly by the prevailing west winds from the Pacific Ocean, and thus, extreme temperatures are uncommon. The summers are dry, but the winters usually include moderate to heavy precipitation. The average annual temperature of the area is 53.2 °F, with July being the warmest month (average is 65.6 °F) and January the coolest (average is 40.7 °F). Precipitation averages 30 to 40 inches a year, with December being the wettest month and July or August being the driest (fig. 4, Washington State University, 1968). Seventy percent of the precipitation occurs from October through March. Local variations in temperature, rainfall, and wind direction are caused by the irregular relief of the area.

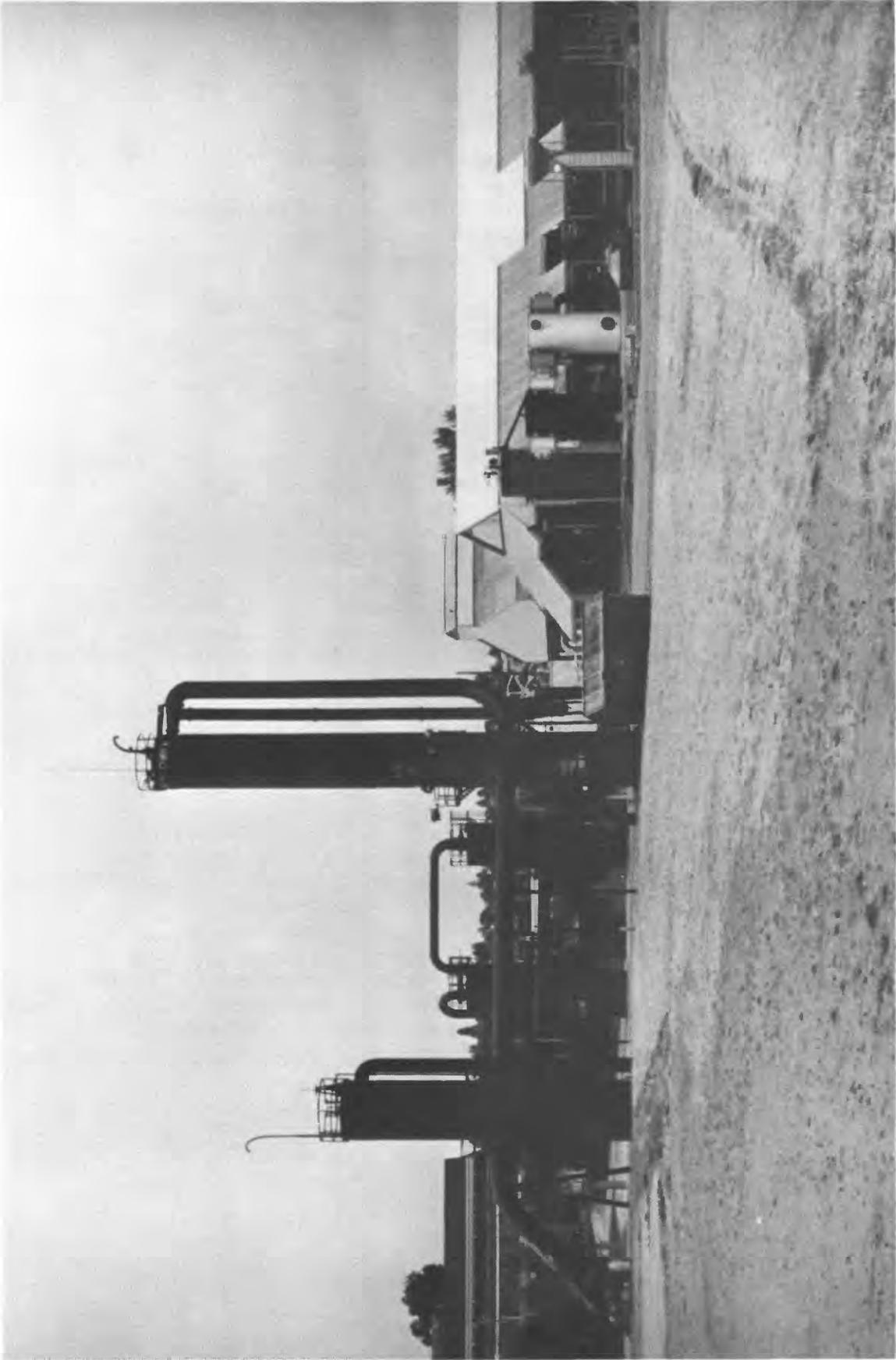


Figure 3.--Old gas works plant equipment still intact at the park.

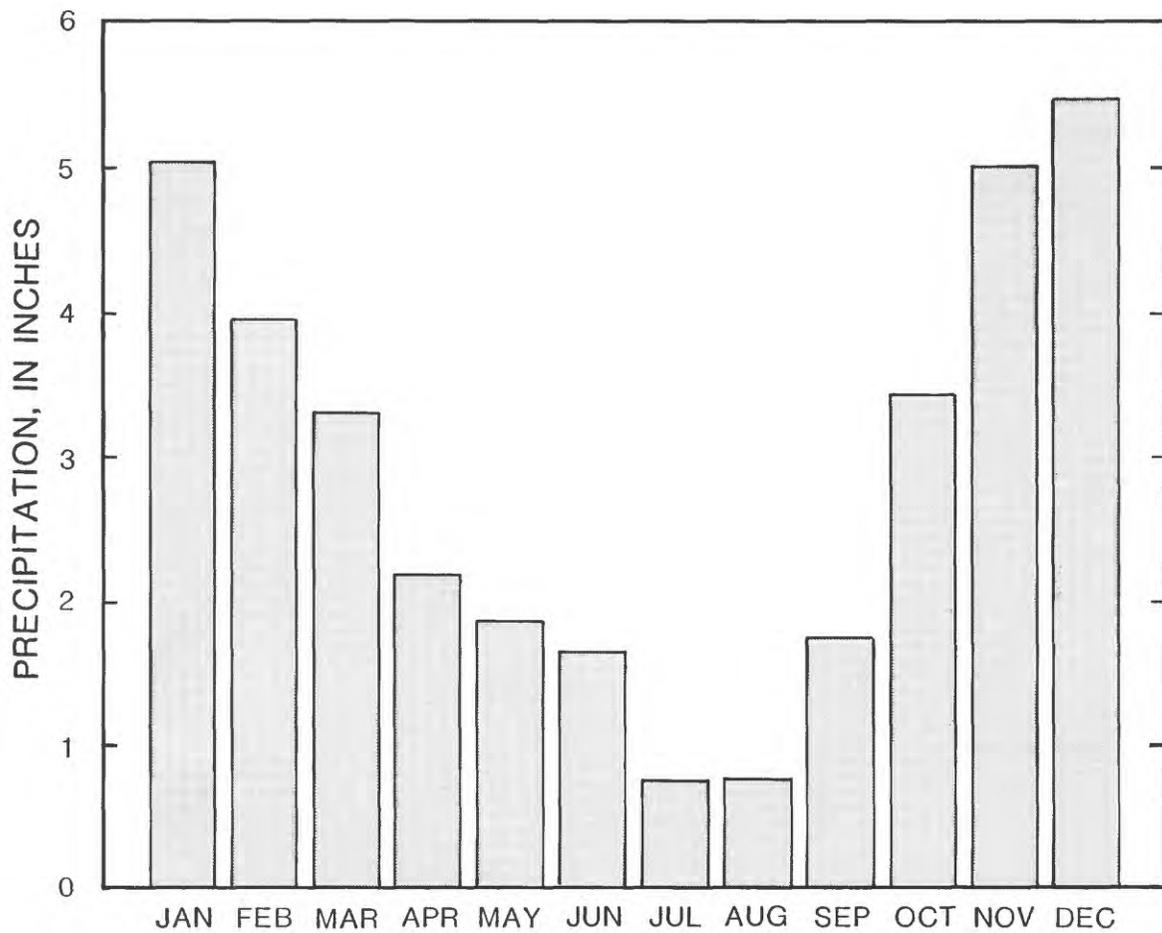
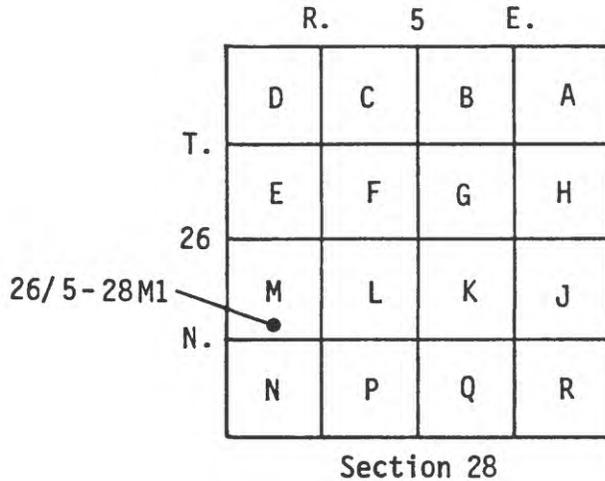


Figure 4.—Average monthly precipitation in the Seattle area.

Well-Numbering System

In this report, wells are designated by symbols that indicate their location according to the official rectangular public-land survey. For example, in the symbol 26/5-28M1, the part preceding the hyphen indicates, successively, the township and range (T.26 N., R.5 E.) north and east of the Willamette base line and meridian. The first number following the hyphen indicates the section (sec. 28), and the letter (M) indicates the 40-acre subdivision of the section as shown in the accompanying diagram.



The last number is the number of the well assigned in sequence as the data are gathered in the particular 40-acre tract. Thus, well 26/5-28M1 is in the NW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 28, T.26 N., R.5 E., and is the first well in the tract to be listed.

Acknowledgments

The cooperation and assistance of Mr. T. Rood, City of Seattle, Department of Parks and Recreation, and Mr. W. Hansen, Tetra Tech, Inc., are gratefully acknowledged. All Federal, State, and local agencies contacted were especially helpful by providing access to data and copies of reports.

GEOHYDROLOGY

Existing data on the thickness, grain size, and composition of deposits underlying Gas Works Park are insufficient to adequately define the geology. The only holes in the park were drilled in 1971, and none were deeper than 30 feet. Since then, the park surface has been tilled, and additional materials such as sewer sludge and clean fill have been deposited at various locations. However, regional geologic history and data-collection efforts provide a good indication of the types of natural deposits underlying Gas Works Park.

Regional Geology

Gas Works Park is located in a large structural basin called the Puget Sound trough. J. E. Sceva (1957), describes the depositional environment of the Puget Sound trough:

"...is a large structural basin in consolidated rocks of Tertiary and earlier age. It has been partly filled by unconsolidated deposits of clay, silt, sand, gravel, and glacial till. These unconsolidated sedimentary materials were deposited by water and ice during the Pleistocene glacial epoch (Ice Age), but in some low-lying areas Recent alluvial deposits underlie the surface. The upper materials of this fill, except the Recent deposits, were deposited by ice and glacial melt-water streams during the latest glaciation of the area (Vashon glaciation). During that glaciation, a large tongue of ice moved southward from British Columbia and Vancouver Island and partly filled the Puget Sound basin."

The geology of the regional area is summarized by Liesch, Price, and Walters (1963), and Luzier (1969). The bedrock consists predominantly of consolidated Tertiary rocks and is overlain by unconsolidated Quaternary sedimentary deposits of clays, sands, and gravels, and glacial drift from the Vashon glaciation. Surficial geology of the area is shown on plate 1 and three geologic sections in which some of the units of plate 1 are subdivided are shown in figure 5. The locations of the geologic sections are shown on plate 1. The surficial material consists mostly of Vashon Drift. Outcrops of Eocene volcanics and the Eocene and Oligocene Puget Group, a consolidated unit of sandstone, shale, coal, and some conglomerate, occur locally southeast of Lake Washington. There are also areas located along various waterways that have been extensively modified by man along with Recent and Pleistocene sedimentary deposits located in and around water bodies.

Consolidated Rocks

The Tertiary consolidated rocks within the area range in age from Eocene to Miocene. They consist mainly of folded and faulted shales, graywackes, sandstones, conglomerates, and andesites. Three consolidated units in ascending order are differentiated on plate 1: Eocene volcanic rocks, sedimentary rocks in the Puget Group, and Oligocene and Miocene marine sedimentary rocks. A fourth unit of older Eocene sedimentary rocks outcrops in a few small areas, but is not shown on plate 1. The Eocene volcanic rocks are as much as 7,000 feet thick and consist of tuffaceous andesitic sandstone and volcanic breccia. The Puget Group is 3,000 to 3,200 feet thick and is composed of interbedded sandstone, shale, and coal. The Oligocene and Miocene marine sedimentary rocks may be as much as 8,000 feet thick, and consist of beds of marine sandstone, shale, and minor amounts of conglomerate.

Unconsolidated Rocks

The Quaternary unconsolidated rocks consist mainly of gravel, sand, silt, and clay, and have a total known maximum thickness of 1,235 feet. Nine distinct subunits are listed in order from older to younger in figure 5.

The older unconsolidated deposits consist of a sequence of interbedded sand, silt, and clay, containing minor amounts of gravel, till, and volcanic ash. The maximum thickness of these deposits is more than 1,000 feet. They are moderately compacted with beds of silt, sand, tuff, and lapilli. The silt and sand is pale to dark yellowish gray, brown, or red, and has well-developed joints spaced less than 1 foot apart. The sand is well-sorted, medium grained, and composed of subrounded to angular fragments. Some beds contain pebbles up to half an inch in diameter. A white to light gray crystalline material is probably quartz and feldspar. The beds of tuff and lapilli are multicolored, with the grains ranging from subrounded to subangular.

The lower clay unit is composed of gray, blue, and brown clay and silt, and is approximately 50 feet thick. Some discontinuous beds of till that contain a large amount of clay and silt are present. Beds of peat up to 1 foot thick can be found bedded with clay, silt, and fine pumaceous sand.

The unnamed gravel consists of a sequence of cobble, pebble and gravel, and sand. It ranges in thickness from zero to 200 feet. Where encountered in drilling, the gravel is typically gray and appears fresh and unaltered.

The upper clay unit consists of beds of finely laminated to massive gray, brown, and blue-gray silt and clay, locally more than 200 feet thick. Deposits of silty peat are interbedded with the silt and clay of the upper clay unit, and beds of fossiliferous silt are exposed locally. Where the unnamed gravel is not present or recognized, no distinction is made between the upper and lower clay units, and the clay unit is referred to as undifferentiated clay.

The unnamed sand is as much as 220 feet thick. It consists of predominantly medium- to coarse-grained, slightly oxidized, stratified sand. The sand is well-sorted, mostly medium grained, and is composed of quartz, rock fragments, and lenses of gravel, silt, and clay. The sand is fine grained a few feet above the upper clay contact.

The Vashon Drift was deposited during the last glaciation of the Puget Sound lowland by northern ice. It is commonly more than 150 feet thick and consists of gravel, sand, silt, clay, and boulders. The rock fragments are subrounded to subangular in shape and were stream-worn before being incorporated into the glacier. Approximately 85 percent of the rocks are volcanics and white granite derived from the Central Cascades, with the other 15 percent being pink granite and metamorphic rocks derived from the North Cascades and Coast Range of British Columbia.

Liesch, Price, and Walters (1963) subdivide the Vashon Drift into three units, but only two appear in the geologic sections of figure 5. Unstratified drift is referred to as till. Drift that was deposited as the glacier advanced is referred to as advanced stratified drift, and that which was deposited as the glacier retreated is called recessional stratified drift. The till is a compact mixture of boulders, cobbles, pebbles, sand, silt, and clay, and is as much as 150 feet thick. This deposit surficially covers most of northwest King County and is similar to light-gray concrete. The till is commonly referred to as hardpan. The advance stratified drift ranges in grain size from silt to coarse gravel, and from well-sorted to unsorted. It is over 25 feet thick. The recessional stratified drift is a poorly sorted to well-sorted light-gray sand and gravel containing minor amounts of silt and clay. It is found on drift plains, New Castle-Grand Ridge Hills, and in major valleys. Thickness of this unit ranges from less than an inch to more than 100 feet.

The Vashon Drift is overlain by post-Vashon sedimentary deposits in many valleys and along bodies of water. These deposits are commonly as much as 50 feet thick, and in some places, are composed of manmade fill material used to modify the landscape. The natural deposits are predominantly sand, silt, and clay, and some gravel that were laid down by stream, lake, and marine processes. Interbeds of peat and pumicite are found throughout these deposits.

Geology of Gas Works Park

Gas Works Park is underlain by glacial deposits from the Vashon glaciation which are overlain by waste materials originating from the Gas Works plant, which in turn are overlain by fill material spread over the surface at various time periods. Although Liesch, Price, and Walters (1963) show that the surficial material that underlies Gas Works Park is the Vashon till, data from drilling in the park indicate that a sand-and-gravel deposit overlies the till. This sand-and-gravel deposit is assumed to be a locally occurring lens of recessional drift. The discrepancy between the deposit defined regionally and that found during drilling is probably due to the large-scale mapping at the regional level.

The stratigraphy and physical properties, such as grain size and material consistency, of deposits overlying the Vashon till at the park were estimated from data collected for the City of Seattle between 1971 and 1984, including well logs of drill holes, and results of sieve and standard penetration tests. Holes were drilled only to the top of the Vashon till, and therefore data are available for only the deposits above the till. However, it is assumed that the underlying deposits are similar to the regional deposits. The areal extent of the deposits under the park also is unknown.

Because man has altered the surface and subsurface deposits at the park to such a large extent, and because no drilling has occurred since this happened, it is necessary to know the sequence in which the alterations occurred in order to define the geology on the basis of the available data. The following is a chronology of the land alterations, drilling efforts, and soil excavations at the park, as compiled from several of the data sources listed on page 5:

1906-1956----Wastes from the gas plant operations were periodically deposited on the plant grounds and along the shoreline of Lake Union. The shoreline was gradually expanded to its present day configuration using these wastes and other fill material.

3/11/71-----Fourteen test borings up to 30 feet deep were made by the Seattle Engineering Department to determine thickness and subsurface soil properties for a foundation analysis of the park grounds. A hollow stem auger was used, and disturbed samples were obtained by standard penetration test using a 2-inch outside diameter split-spoon sampler. Well logs of the subsurface geology were compiled and water levels were noted on the logs. Observation wells consisting of slotted PVC pipe placed at the bottom of the hole and connected to 1/2-inch PVC riser pipe extending to ground surface were installed. The hole was backfilled with "pervious material" and sealed near ground surface.

Between 3/71 and 12/71--Seattle Engineering Department, with advice from the University of Washington, drilled six additional holes for soil testing. Depths of the holes ranged from 5 to 13 feet.

- 1972-----During initial park construction, thousands of cubic yards of fill material from the construction of the Safeco Building in Seattle's University District were deposited on the park grounds. The land was re-contoured by bulldozers.
- 1/73-----Thirty test holes were drilled and logged by the Seattle Engineering Department. The water table was noted if encountered. Holes range in depths from less than a foot to 14 feet. No maps are available showing the hole locations. Ash, oil, and cinders were found in the upper 10 feet at many sites.
- 12/73-----Five pits were dug by the Seattle Engineering Department along a proposed sewerline route at sites where manhole covers were to be constructed. Three additional pits were dug at the proposed restroom. Geologic logs, which show that the depth of the pits varied from 8 to 13 feet, were compiled. The depth of the water table was recorded if encountered.
- 6/74-----The Seattle Engineering Department applied 8 inches of sludge mixed with sawdust over the entire park grounds. The mixture was tilled into the first 18 inches of soil.
- 1977-----Fill was deposited in 1977 as the landscape was re-contoured.
- Between 4/20/84-8/17/84----The Seattle Engineering Department covered the areas considered to be the most highly contaminated with clean fill material (fig. 6).

Stratigraphy of the deposits underlying the park was interpreted from driller's logs of the first eight holes drilled by the Seattle Engineering Department in 1971. Figure 7 shows a schematic geologic section constructed from four of these logs. Inside the park, the top of the Vashon till occurs at an altitude between approximately 0 and 35 feet (NGVD of 1929). The overlying Vashon recessional drift ranges in thickness from 5 to 10 feet. The drift is overlain by the waste material, which was mixed together randomly with the fill (not shown) that was deposited in 1977 as the landscape was re-contoured.

It is impossible to determine the exact thickness of the fill on the basis of the available data. However, comparing the present park topographic contours with the Seattle Engineering Department well logs, the combined thickness of the gas works waste material and the fill material is estimated to be between 5 and 60 feet, with the thickest area under Kite Hill.

Grain-size distributions of the upper 9 feet of the gas plant waste deposits are estimated from sieve analyses conducted on eight samples taken during the drilling of the 14 test holes by the Seattle Engineering Department in March 1971. Grain sizes ranged from 16 to 36 percent gravel, 36 to 54 percent sand, and 21 to 45 percent silt and clay. Because the mixed composition of the soil material and gas plant wastes is unknown, it is impossible to correlate these grain sizes with hydraulic properties of any of the naturally occurring glacial deposits at the park. Reproduction of the 1971 grain-size analyses would be unlikely now because of the introduction of fill material and re-contouring of the land over the gas plant waste deposits.

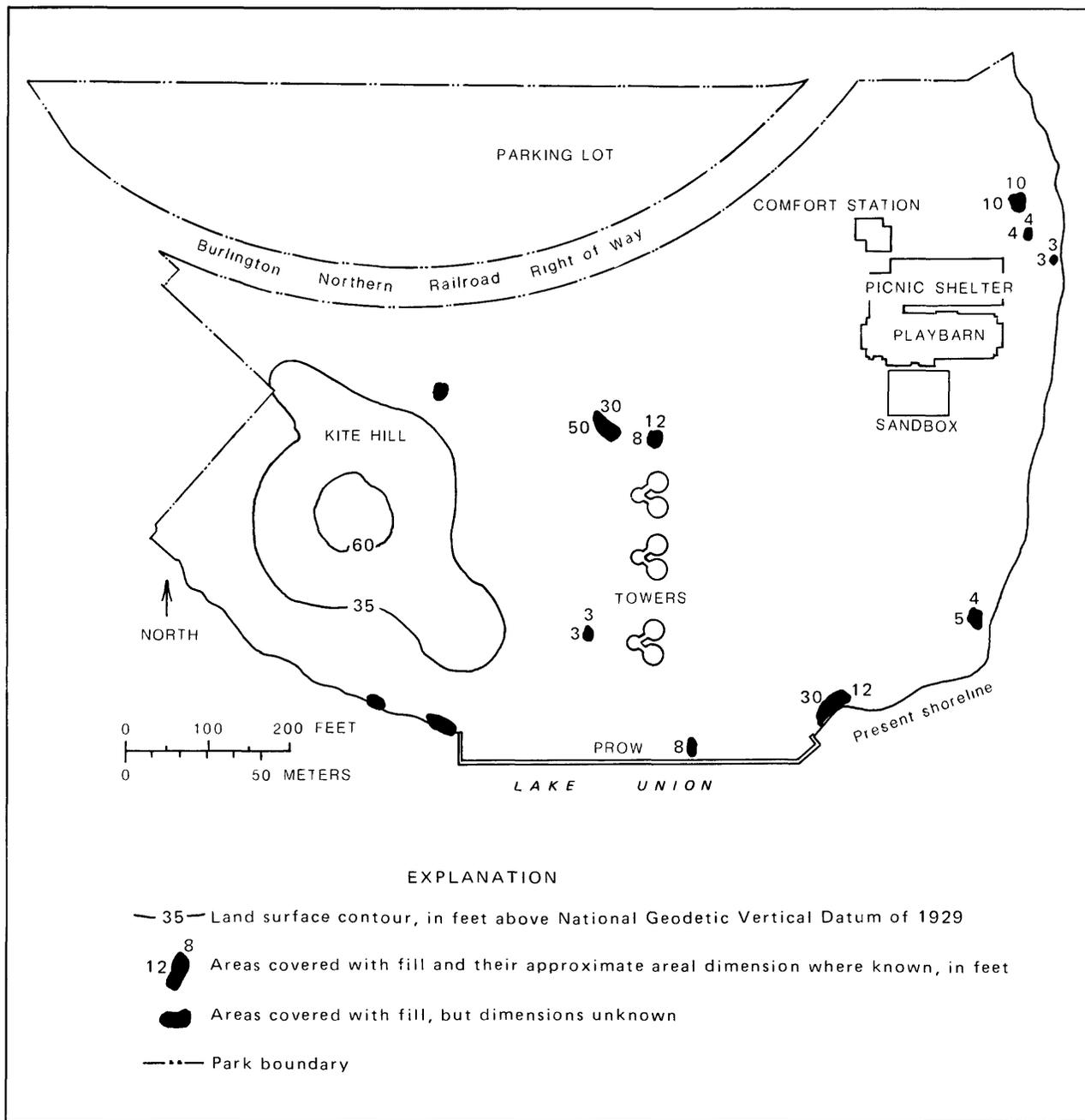


Figure 6.—Approximate locations and dimensions of areas covered with clean fill prior to re-opening of park, August 17, 1984.

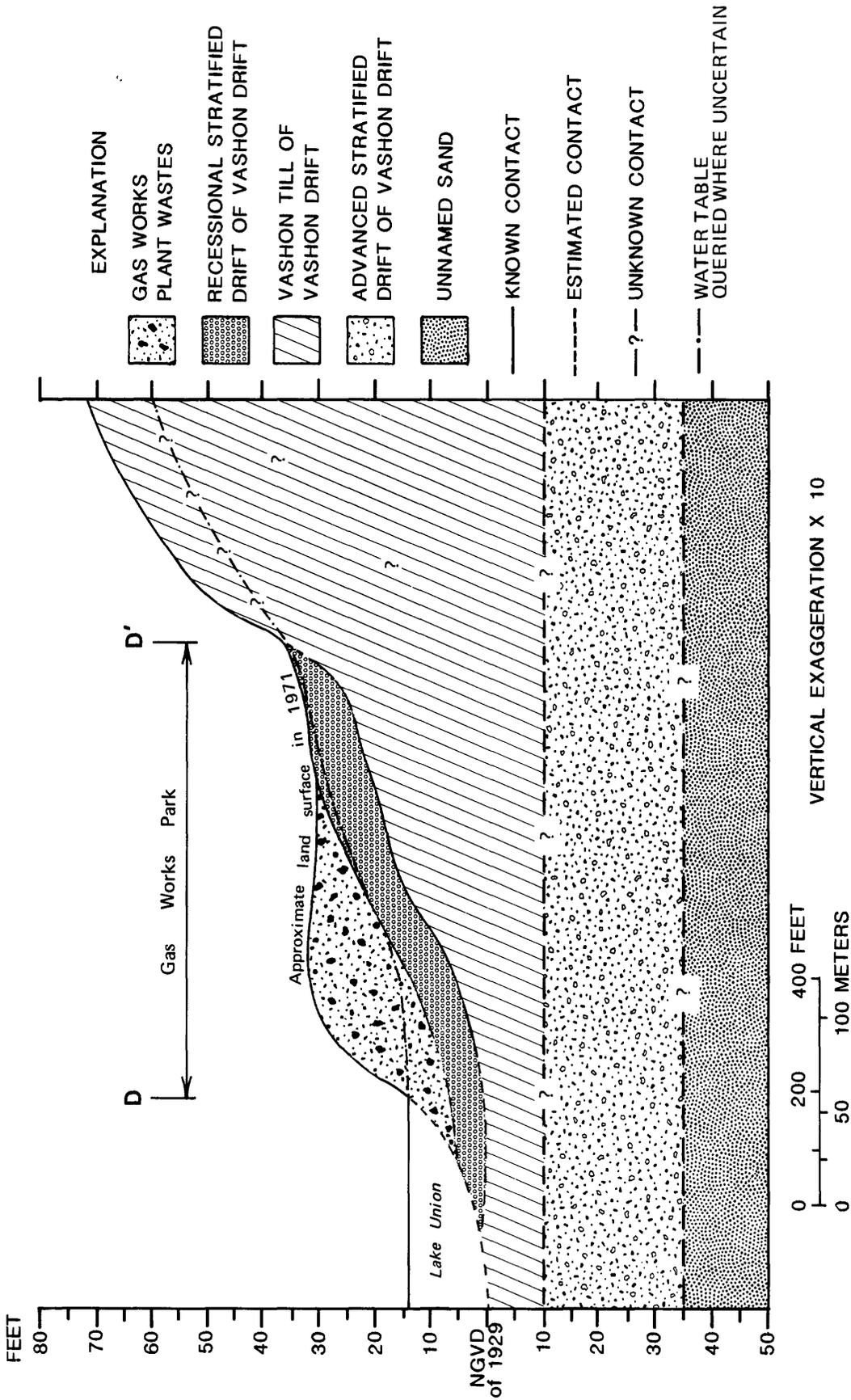


Figure 7.—Local geologic section DD' at Gas Works Park as of 1971.
(See figure 8 for location of section.)

Relative consistencies for the deposits present in the upper 15 to 30 feet of the park before fill material was brought in during 1977 were obtained from standard penetration tests conducted in 12 of the 14 original holes drilled in 1971 (Seattle Engineering Department, unpublished report, 1971). Classifications for the tests are shown in table 1. The consistencies, based on the number of blow counts per foot, range from loose to firm consistency at the 1971 surface, to a compact to very stiff consistency between 20 and 30 feet below that surface. According to the well logs, the loose consistency represents the gas plant wastes, the firm consistency represents the recessional drift, and the very compact and very stiff consistencies represent the Vashon till. Again, because the upper part of the gas plant waste deposits was mixed with fill material after the holes were drilled and standard penetration tests conducted, it would be unlikely that the results of the upper tests conducted in the gas plant waste deposits could be reproduced now exactly. However, these data still give a good indication of the consistencies of the recessional drift and till deposits under the park.

Table 1.--Standard penetration test classification

<u>Soil type</u>	<u>Standard penetration resistance</u> (blow counts, per foot of penetration)	<u>Consistency</u>
Granular:	10 or less	loose
	11 to 30	firm
	31 to 50	compact
	51 or more	very compact
Cohesive:	Push to 2	very soft
	3 to 5	soft
	6 to 15	medium
	16 to 25	stiff
	26 or more	very stiff

Hydraulic Conductivity

The available data are not sufficient to define the hydraulic conductivities of the deposits underlying the park. Estimates of hydraulic conductivities of glacially deposited sand, sand and gravel, and gravel under the park can be made only on the basis of values calculated regionally. Hydraulic conductivities of the unconsolidated deposits located within the regional area were estimated from specific-capacity data of 28 wells that have been entered into the U.S. Geological Survey's ground-water site inventory data base as of September 1985. Locations of the wells are shown on plate 1. The deposits in which the wells are completed range from coarse gravel to fine sands that are locally overlain by clay. These grain sizes were placed into categories of gravel, sand and gravel, and sand. Hydraulic conductivities were assigned to the appropriate category. Because of the discontinuous nature of these deposits, no attempt was made to correlate the hydraulic conductivities to geologic units.

The hydraulic conductivities of the deposits were estimated by the following equations from Bentall (1963):

$$T'(u) = Q/s[(-66 - 264\log_{10}(3.74r^2 \times 10^{-6})) - 264\log_{10} 5S + 264\log_{10} t]$$

$$T'(c) = Q/s[(-66 - 264\log_{10}(3.74r^2 \times 10^{-9})) - 264\log_{10}(5S \times 10^3) + 264\log_{10} t]$$

$$T = T' - 264(Q/s)\log_{10} (T \times 10^{-5})(.134)$$

$$K = T/i$$

where:

- $T'(u)$ = initial transmissivity for unconfined aquifer (ft^2/d)
- $T'(c)$ = initial transmissivity for confined aquifer (ft^2/d)
- Q = discharge (gal/min)
- s = drawdown (ft)
- r = radius of well casing (ft)
- S = storage coefficient
- t = pumping duration (days)
- T = final transmissivity (ft^2/d)
- K = hydraulic conductivity (ft/d)
- i = length of open interval of well (ft)

The equation chosen for computing T' is based on whether the deposit in which the well is completed is confined or unconfined. The confined equation was used at sites where the pumping water level was above the aquifer in which the well was screened. The storage coefficient (S) for confined deposits was assigned a value of 1×10^{-4} , and for unconfined deposits was assigned a value of 0.2. A value of 0.04 day was assigned as the pumping duration time for

well logs which lacked these data. This was the most common pumping duration for time used on the other wells chosen for this assessment. Because changes in this value produce only small changes in the final hydraulic conductivity value, 0.04 day is assumed to be sufficient for this calculation.

The computed hydraulic conductivities are shown in table 2. Values for gravels range from 37 to 860 ft/d and average 276 ft/d. Sands and gravels range from 2 to 523 ft/d and average 164 ft/d. Sands range from 25 to 230 ft/d and average 101 ft/d. These values are consistent with those obtained in similar deposits analyzed at Bainbridge Island and the Tulalip Indian Reservation (M. A. Jones and W. E. Lum, II, U.S. Geological Survey, written commun., 1985), and probably are representative of glacially deposited sands and gravels at Gas Works Park.

Although no data are available on hydraulic conductivity in the Vashon till at the park, regional geologic studies suggest that it is probably very low.

Hydraulic conductivities of the gas plant waste deposits, sewer sludge, and fill material are unknown. A wide variation in the grain-size data for the gas plant waste deposits exists, as discussed on page 16, suggesting that the hydraulic conductivity is also highly variable.

Table 2.--Hydraulic conductivities computed from specific-capacity data of wells located in the region

Well location	Grain-size category	Hydraulic conductivity (feet per day)
23N/05-03M01	Sand	25
23N/05-09E01	Gravel	37
23N/05E-17F04	Sand and gravel	523
24N/04E-12M01	Gravel	860
24N/05E-02D02	Sand	181
24N/05E-10A01	-do-	147
24N/05E-10J02	-do-	230
24N/05E-11B01	-do-	42
24N/05E-11N01	Sand and gravel	366
24N/05E-17D01	Sand	47
24N/05E-18G01	Sand and gravel	36
24N/05E-34Q	----do-----	138
25N/05E-15J01	----do-----	268
25N/05E-15P01	----do-----	18
25N/05E-17R01	Gravel	174
25N/05E-20C01	Sand and gravel	27
25N/05E-23E01	----do-----	15
25N/05E-23G01	----do-----	492
25N/05E-32N01	----do-----	2
25N/05E-34G01	----do-----	16
25N/05E-34R03	----do-----	123
26N/04E-16K01	Sand	73
26N/04E-23K01	Gravel	187
26N/04E-30J01	Sand	28
26N/05E-17H02	-do-	208
26N/05E-18E01	-do-	30
26N/05E-28M01	Sand and gravel	108
26N/05E-29L02	Gravel	124

Ground-Water Flow System

The volume and flow rates of contaminants moving through the deposits at Gas Works Park are affected by the configuration of the ground-water flow system and the chemical properties of the constituents in question. Leaching of contaminants to the ground-water system from deposits above the water table may occur from the infiltration of precipitation. Contaminants that reach the ground-water table in a dissolved state could be transported in the direction of flow.

No data are available on the present (1986) ground-water system under the park. Water levels obtained in observation wells in 1971 (fig. 8) give only a general flow pattern, as the ground-water flow system configuration may have changed after the surface of the park was re-contoured. Seasonal water-level fluctuations are unknown because water levels were measured only during a 1-month period. Vertical hydraulic gradients are also unknown. Although no data exist on the present (1986) ground-water system, regional flow patterns and the 1971 water levels (figs. 5, 8, and 9) give a probable estimate of the configuration of the present ground-water system.

The ground-water flow system in northwest King County involves the movement of both fresh and salt water. A freshwater-saltwater interface is present under inland areas along the Puget Sound coast. Major saltwater bodies in the area include the Salmon Bay Waterway and Puget Sound. Although Lake Union is considered a freshwater body, some saltwater infiltrates into the lake from Puget Sound at the Hiram M. Chittenden Locks. Major freshwater bodies include Lake Union, Lake Washington, Green Lake, Lake Sammamish, and the Duwamish River. Most fresh ground water occurs within the Vashon Drift and older unconsolidated deposits, although some wells penetrating the consolidated marine sedimentary deposits yield large quantities of freshwater. The consolidated Tertiary volcanics contain relatively small amounts of water, with most of it flowing along fractures of the upper sections (Williams, 1968). Figure 5 includes a schematic representation of the regional ground-water flow patterns along the three cross sections shown on plate 1. As indicated, water flows from major drainage divides into lakes, streams, and Puget Sound.

Recharge to the regional ground-water system occurs predominantly from the infiltration of precipitation. Irrigation water contributes only a minor amount of water to the system, if any, because farming is not a major use of water in this area. Recharge from lakes and streams is probably minimal, as most lakes and streams in the area are likely recharged by ground water.

Regionally, water naturally discharges from the ground-water system as evapotranspiration and seepage into the lakes, streams, springs, and Puget Sound. Springs are abundant in the region, and are mostly the result of the seepage of ground water through the Vashon Drift deposits and subsequent lateral movement atop the Vashon till, which has a low hydraulic conductivity relative to the other drift deposits. Mean-annual evapotranspiration in the Seattle area is calculated to be 19.8 inches. This value is the actual evapotranspiration for the 6-inch water-holding capacity soil at the University of Washington weather reporting station and is assumed to be representative of the soil type found in the vicinity of Gas Works Park.

The configuration of the water table at the park in March 1971 is shown in figure 8. The observed water levels were measured in the observation wells installed by the Seattle Engineering Department, and represent the only water-level data available at the park. Water-level data were not available for all wells. As indicated in the figure, water enters into the park ground-water system from the north side of the park and as vertical infiltration of precipitation, and eventually discharges into Lake Union. Re-contouring and tilling of the surface after 1971 may have created drains that may have locally changed the configuration of the ground-water flow system under the park. However, the general movement into Lake Union probably still occurs.

Two possible configurations of the vertical movement are shown in figure 9. In one case vertical movement is entirely upward from beneath the till. In the second case, water moves downward from the upland north of the park, then under the park and upward into Lake Union. In either case, water moves upward into Lake Union. However, it is unknown where the upward flow begins. The figure shows that probably part or all of the ground-water flow under the park is upward. The ground-water system is considered to be in equilibrium because there are no manmade stresses on the system.

The total amount of recharge from precipitation and influx from the area north of the park is unknown. A maximum amount of recharge from infiltration of precipitation falling directly on the park was estimated to be 1,045,000 ft³/yr (cubic feet per year), using the following equation:

$$R_{\max} = (P-E) \times A$$

where:

- R_{max} = maximum recharge from precipitation (ft³/yr)
- P = average annual precipitation (2.9 ft/yr)
- A = area of park (871,200 ft²)
- E = average annual evapotranspiration (1.7 ft/yr)

This value of R_{max} can be considered a conservative estimate because the calculation assumes that no runoff occurs. The actual recharge due to direct precipitation would be some value lower than the calculated R_{max} due to loss of recharge as runoff.

Water discharges from the ground-water system in the park into Lake Union, and some water may evapotranspire from the water table. It is unknown if the trees in the park are phreatophytes, which would be the major pathway of transpiration.

As indicated in figure 9, the water table in 1971 was in the contaminated deposits. Because the 1971 water table is considered to be a representation of the present water table, the possibility exists that contaminants could be entering the ground-water system and discharging into Lake Union. To date, no studies have been done to analyze if the contaminants are mobile in the system, and whether they actually occur in the ground water.

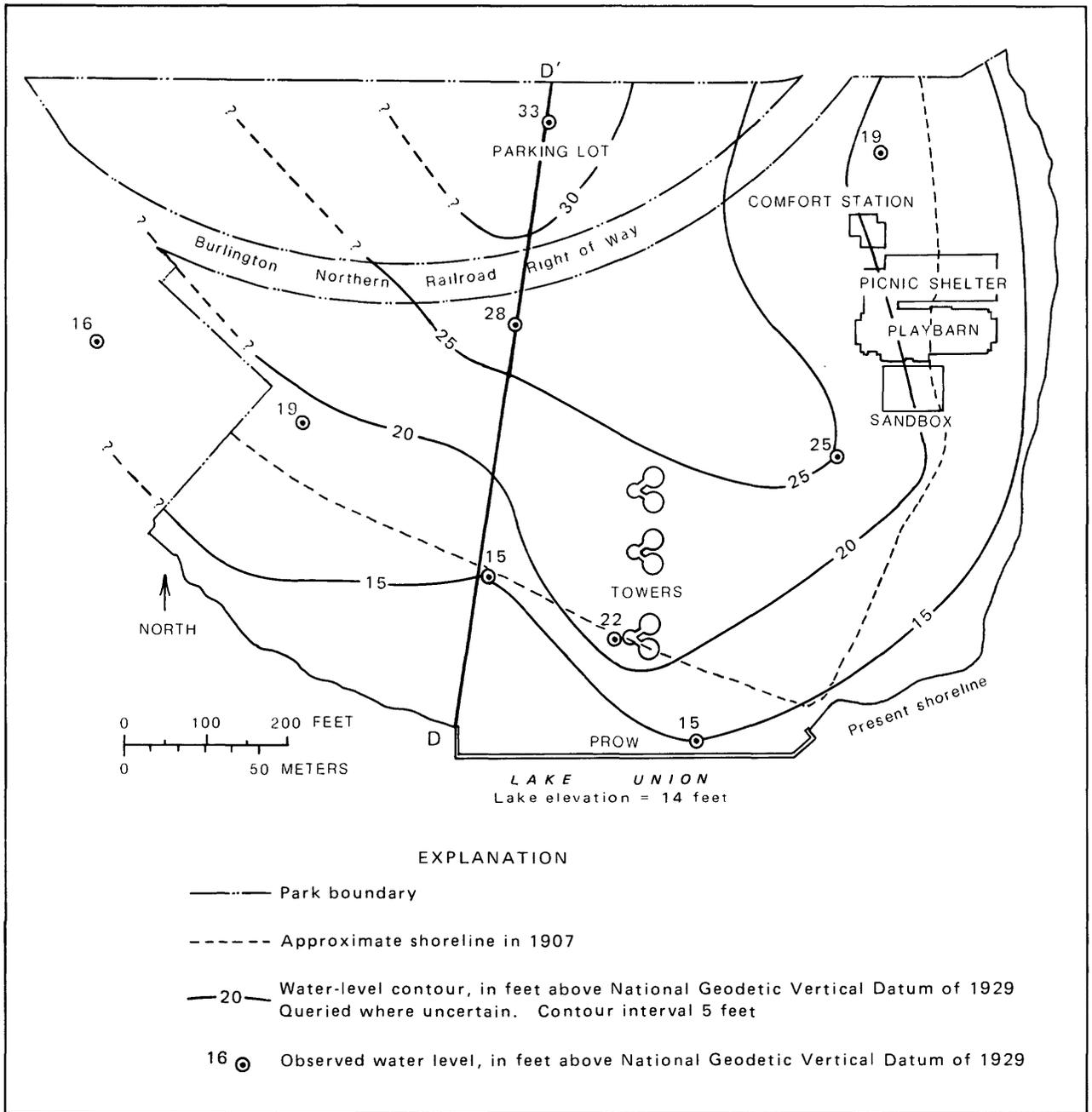


Figure 8.--Water-table configuration, March 1971, and location of geologic section D-D'.

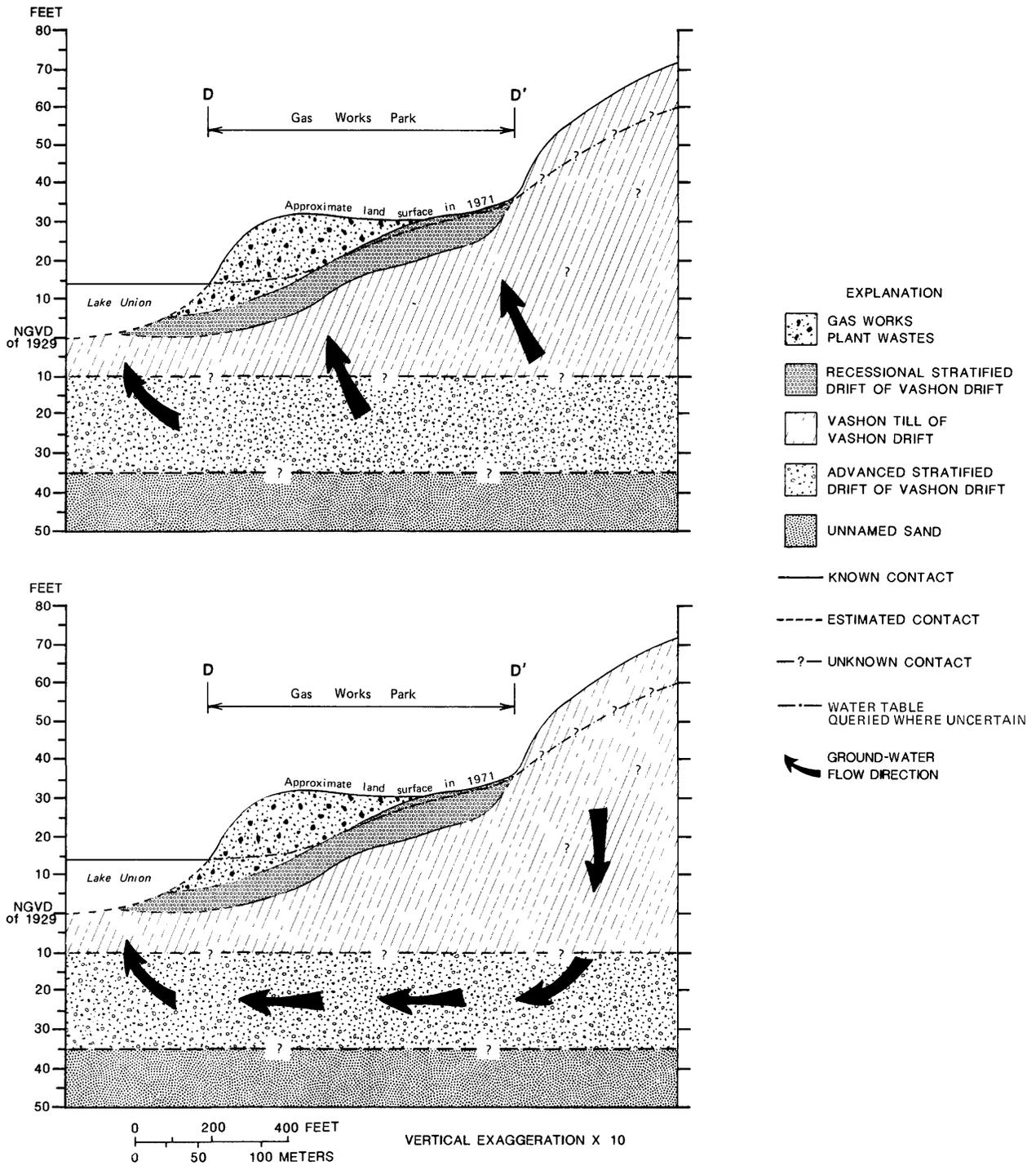


Figure 9.--Two scenarios for the vertical movement of ground water at Gas Works Park.

CHEMISTRY OF SOILS AND GROUND WATER

The ground water at Gas Works Park may contain a variety of organic compounds and metals originating from waste deposits. The soils and waste deposits of the park are known to contain these contaminants, and because the ground water is thought to occur in these soils and waste deposits, it is reasonable to assume that the ground water contains some of the same contaminants. The quality of the ground water is important because of the potential use of ground water as a water source, and the possibility that the ground water may be transporting contaminants to Lake Union.

No ground-water quality data are available for the park. However, using available soil and sediment chemistry data, and knowing the characteristics of the contaminants, some insight may be gained as to the types of contaminants that may be present in the ground water of the park.

Contaminants in the Soils of Gas Works Park and the Sediments of Lake Union

Numerous soil and sediment chemistry data have been collected from Gas Works Park and Lake Union, primarily because soil contamination has been of the greatest concern. Classes of compounds analyzed include polynuclear aromatic hydrocarbons, polychlorinated biphenyls, pesticides, volatile organic compounds, and metals.

The sampling efforts from which data are used are listed in table 3. The agency and type of data generated are shown also. All of these data were collected between March 1984 and March 1985. Much of the following discussion is based on the EPA soil samplings because they represent the most comprehensive analyses available. Data from some other studies do not directly concern soils but are pertinent to the subject and are also addressed.

Table 3.--Soil and sediment chemistry data-collection efforts

Date	Agency ¹	Sample types	Number of sites	Constituents analyzed
3/20-21/84	EPA	Lake Union sediment	33	priority pollutants ²
4/2/84	EPA	Park soil (surface)	7	Polynuclear aromatic hydrocarbons
4/17-19/84	EPA	Park soil (6 in. and 3 ft)	24	Priority pollutants
5/24/84	UW	Park soil (1 in.)	24	Polynuclear aromatic hydrocarbons
6/12-14/84	UW/PSAPCA	Air in park	9	Volatile
6/15/84	UW/PSAPCA	Air in park	9	Particle size
3/15-22/85	Seattle parks	Park soil (2 in.)	34	Polynuclear aromatic hydrocarbons

¹ EPA, U.S. Environmental Protection Agency
UW, University of Washington

² UW/PSAPCA, University of Washington/Puget Sound Air Pollution Control Agency.
Compounds from the following classes of priority pollutants were identified: Polynuclear aromatic hydrocarbons, polychlorinated biphenyls, pesticides, volatiles, metals, and cyanide.

A few qualifications regarding the interpretation of these data should be kept in mind. For most data, discrete samples only a few inches in diameter were collected. Due to the heterogeneity of the soil and the subsequent disturbance it underwent during park construction, samples collected 1 or 2 feet apart may have different soil and chemical compositions. In many instances, and particularly for the EPA soil samples, samples were collected from the areas thought to be the most contaminated. This may have resulted in a bias of the data towards higher concentrations.

Organic Compounds

Many types of organic compounds were found in the park soils, based on the EPA's analyses for priority pollutants. Polynuclear aromatic hydrocarbons were present in high concentrations. Polychlorinated biphenyls, pesticides, and some volatiles were also detected, but in lower concentrations.

Polynuclear aromatic hydrocarbons

Polynuclear aromatic hydrocarbons, or PAHs, have been detected in analyses of soils from Gas Works Park and sediments from Lake Union on many different occasions. The highest concentrations observed were in the Lake Union sediments sampled within 500 feet of the shore of the park by the EPA on March 20-21, 1984. Benzo(a)pyrene, a commonly occurring PAH, was present in concentrations up to 14,092,000 $\mu\text{g}/\text{kg}$ (micrograms per kilogram) or 1.4 percent (Hileman and others, 1985). Benzo(a)pyrene was detected in 21 of a total of 33 Lake Union sediment samples. The median concentration of benzo(a)pyrene in the 21 samples was 146,050 $\mu\text{g}/\text{kg}$. Other PAHs were present in similar concentrations in these sediments, and most of the samples from offshore sites had total PAH concentrations over 1 million $\mu\text{g}/\text{kg}$. One sample collected 180 feet off the southwest shore of Gas Works Park had a total PAH concentration of approximately 131 million $\mu\text{g}/\text{kg}$, or 13.1 percent.

Total PAH concentrations were less than 1 million $\mu\text{g}/\text{kg}$ in five of seven surface soil samples collected on April 2, 1984 (EPA, written commun., 1984). Although these concentrations are generally less than those observed in the lake sediment samples, they are still orders of magnitude above background concentrations, discussed later. Concentrations of many individual PAHs in the other two samples exceeded 1 million $\mu\text{g}/\text{kg}$. These two samples were collected from the sandbox and the prow, as shown in figure 10, and had total PAH concentrations of 106 million $\mu\text{g}/\text{kg}$ (10.6 percent) and 60 million $\mu\text{g}/\text{kg}$ (6 percent), respectively.

Soil samples were collected by the EPA from 24 sites in the park at 6-inch depths during April 17-19, 1984. The analyses of these samples indicated that PAHs are found throughout the park. Total PAH concentrations ranged from 23,000 to 2,400,000 $\mu\text{g}/\text{kg}$ with a median of 224,000 $\mu\text{g}/\text{kg}$ (EPA, written commun., 1984). Benzo(a)pyrene was found in all samples except one, and concentrations ranged from 880 to 190,000 $\mu\text{g}/\text{kg}$, with a median concentration of 23,000 $\mu\text{g}/\text{kg}$. Sample sites with total PAH concentrations exceeding 500,000 $\mu\text{g}/\text{kg}$ are shaded in figure 10. The sandbox, which had a total PAH

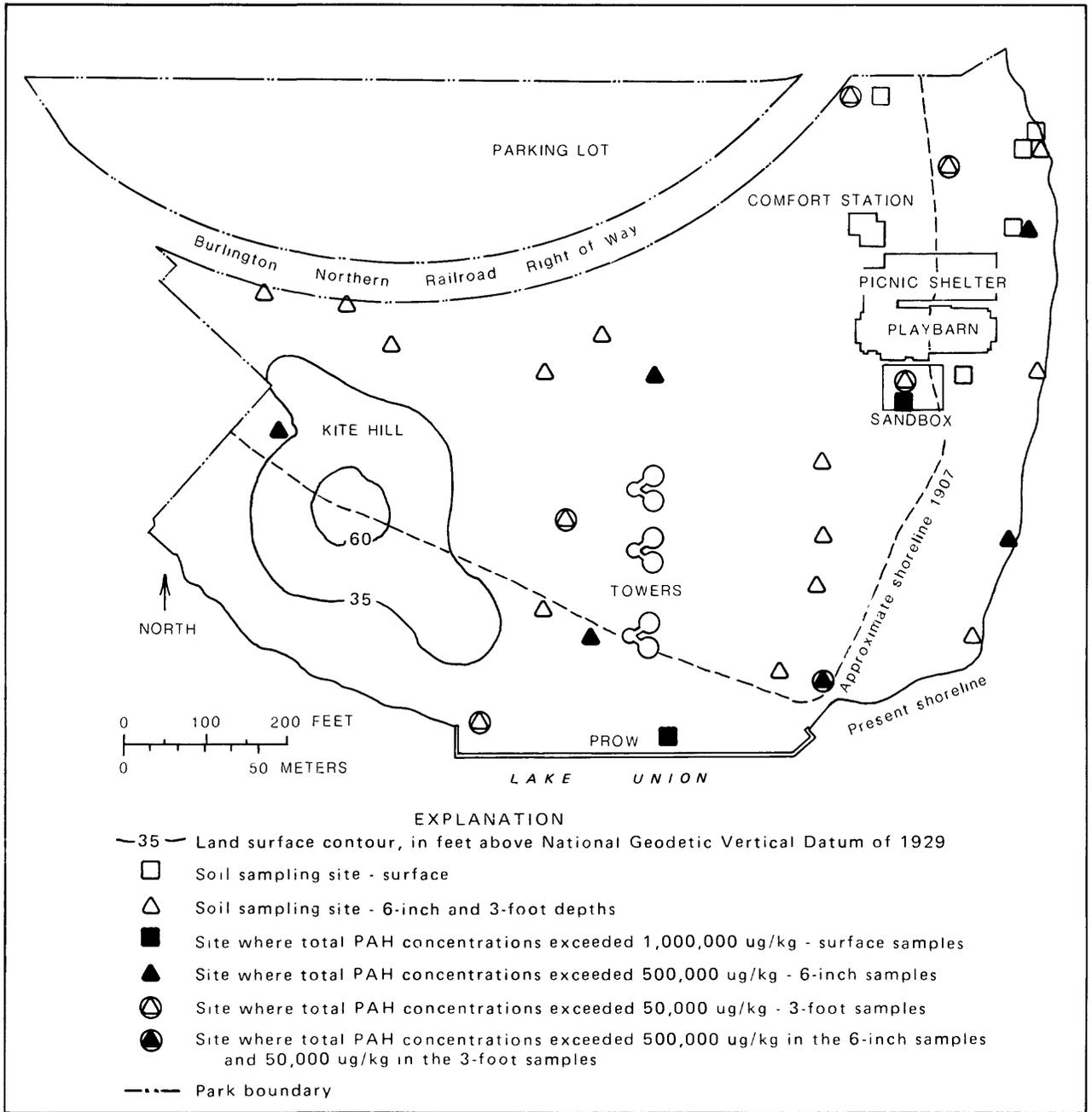


Figure 10.—Sites with highest polynuclear aromatic hydrocarbon (PAH) concentrations, in micrograms per kilogram (ug/kg): surface, 6-inch, and 3-foot depth samples.

concentration of 106 million $\mu\text{g}/\text{kg}$ in the initial surface-soil sampling, was resampled with this second set of samples collected at 6-inch depth. The second analysis indicated a total PAH concentration of 72,000 $\mu\text{g}/\text{kg}$, among the lowest in this set of data. The difference in PAH concentrations in samples from the sandbox probably is due to the introduction of clean fill to the sandbox between the two samplings.

Soil samples from 3-foot depths also were collected by the EPA during April 17-19, 1984. PAHs, although present in these soils, were found in concentrations about one order of magnitude lower than in those soils at 6-inch depths. Total PAHs ranged in concentration from less than 1,000 to 224,000 $\mu\text{g}/\text{kg}$, with a median concentration of 19,000 $\mu\text{g}/\text{kg}$ (EPA, written commun., 1984). Six samples with total PAH concentrations exceeding 50,000 $\mu\text{g}/\text{kg}$ are shown in figure 10. Five of these samples were from sites that have PAH concentrations less than 500,000 $\mu\text{g}/\text{kg}$ in the 6-inch depth samples. The sandbox sample has a total PAH concentration at 3-foot depth of 224,000 $\mu\text{g}/\text{kg}$. This concentration is several orders of magnitude less than that reported in the initial surface sample, but three times that of the 6-inch sample.

Samples of soil taken from 1-inch depths by the University of Washington (UW) on May 28, 1984, had a median concentration of benzo(a)pyrene of 5,680 $\mu\text{g}/\text{kg}$. The highest concentration, 63,500 $\mu\text{g}/\text{kg}$, was found in the playbarn as shown in figure 11. Areas where samples had concentrations exceeding 10,000 $\mu\text{g}/\text{kg}$ at 1-inch depth are also shown. These samples indicate that high concentrations of benzo(a)pyrene are present at sites on Kite Hill, but the UW sampling points were different from the EPA's and the EPA did not sample on Kite Hill. Total PAH concentrations were not determined in the UW study.

Tetra Tech collected 235 soil samples from 2-inch depths for the Seattle Department of Parks and Recreation during March 1985. Only 34 samples were analyzed, but of those 34, benzo(a)pyrene was present in all but one. The results are biased, however, because the 34 samples analyzed were selected from areas thought to have the highest PAH concentrations. Where detected, benzo(a)pyrene ranged in concentration from 40 to 35,000 $\mu\text{g}/\text{kg}$, with a median of 4,700 $\mu\text{g}/\text{kg}$ (Tetra Tech, Inc., written commun., 1985). Total PAHs ranged in concentration from less than 600 to 460,000 $\mu\text{g}/\text{kg}$ with a median of 100,000 $\mu\text{g}/\text{kg}$. Sites with total PAH concentrations exceeding 200,000 $\mu\text{g}/\text{kg}$ are shown in figure 12. These data, along with the UW data, indicate that surface benzo(a)pyrene concentrations in the park soil are generally less than those at 6-inch depths.

An attempt was made by the UW and the Puget Sound Air Pollution Control Agency (PSAPCA) in June 1984 to identify PAH concentrations in respirable airborne particulates. However, the percent of respirable airborne particulates was very low (10^{-2} to 10^{-4} percent) and insufficient material was collected to analyze for PAHs.

As part of the UW sampling from 1-inch depths, a series of reference samples were taken from Green Lake and Volunteer Parks. Concentrations of benzo(a)pyrene in these samples ranged from 5 to 36 $\mu\text{g}/\text{kg}$, substantially less than those detected at Gas Works Park.

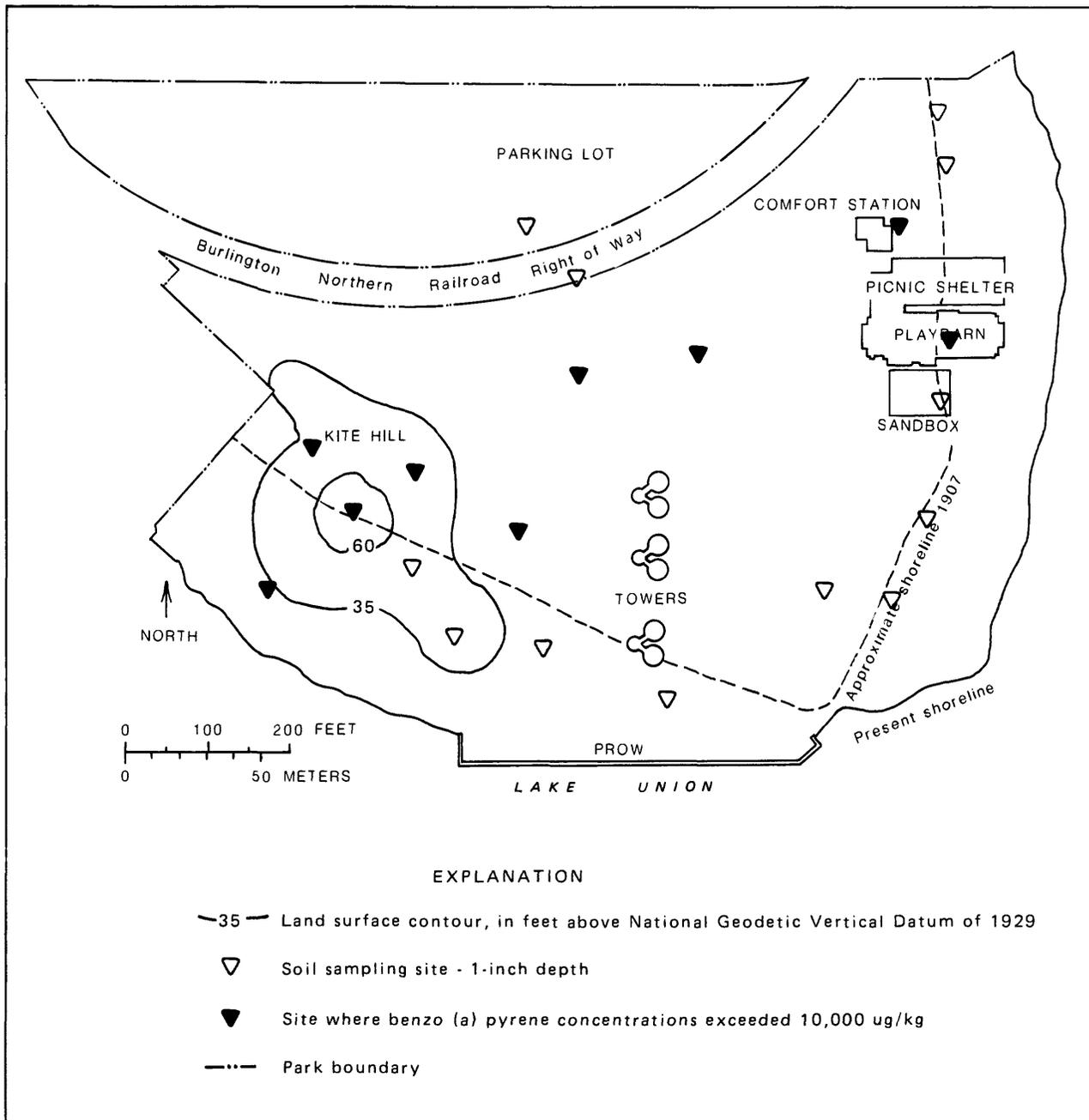


Figure 11.--Sites with highest benzo(a)pyrene concentrations, in micrograms per kilogram (ug/kg): 1-inch depth samples.

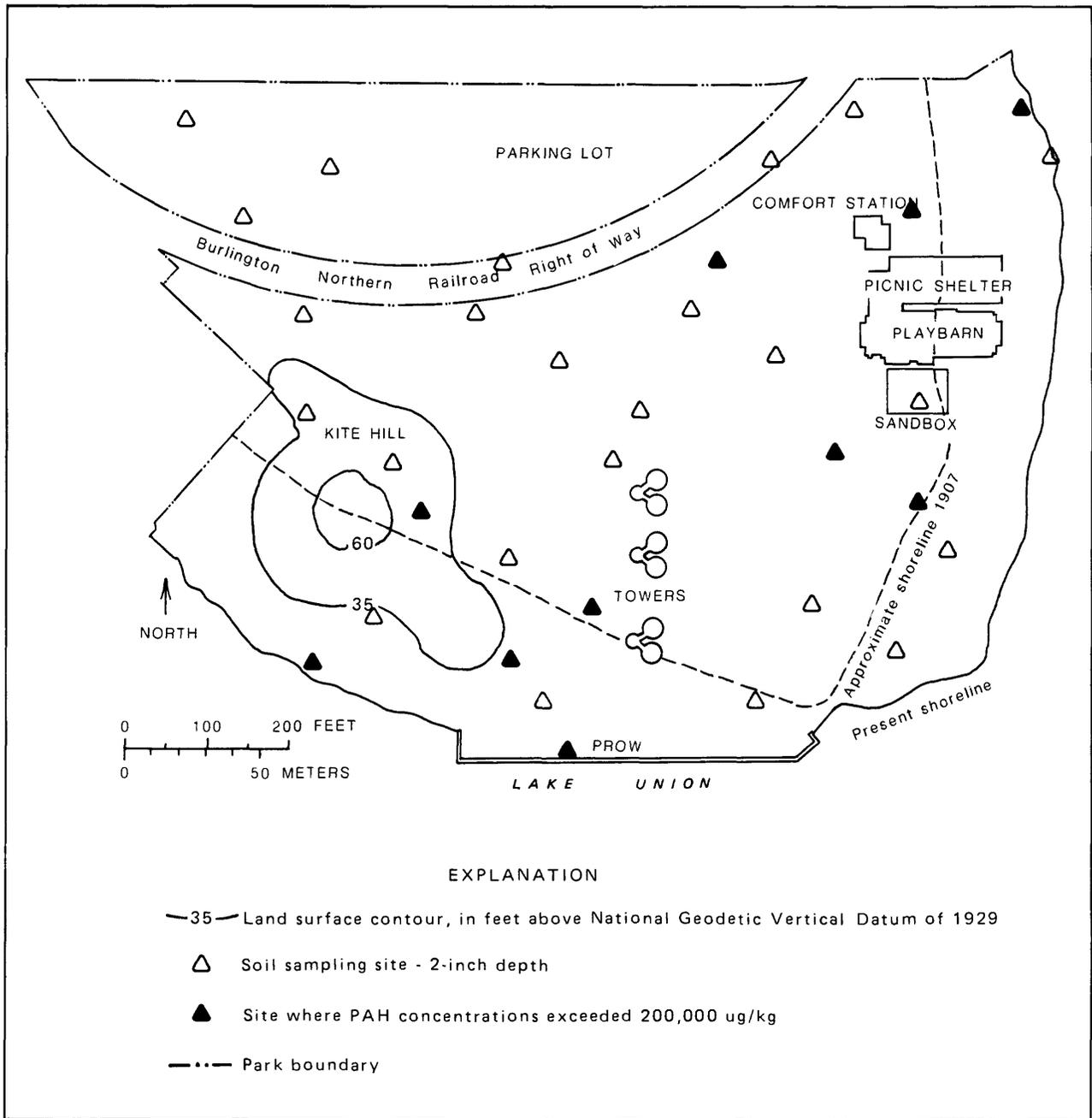


Figure 12.--Sites with highest polynuclear aromatic hydrocarbon (PAH) concentrations, in micrograms per kilogram (ug/kg): 2-inch depth samples.

Polychlorinated biphenyls

Polychlorinated biphenyls, or PCBs, were analyzed for in the EPA 6-inch and 3-foot soil samples, and in the Lake Union sediment samples. The PCBs Arochlor 1254 and 1260 were detected in almost all of the EPA's 6-inch depth samples. The observed concentrations ranged from 33 to 2,724 $\mu\text{g}/\text{kg}$. Ten sites with total PCB concentrations exceeding 1,000 $\mu\text{g}/\text{kg}$ are indicated in figure 13. All of these sites were also observed to have relatively high metals concentrations, which will be discussed later. PCBs were not detected in the samples from the 3-foot depths or the samples from Lake Union sediments offshore of Gas Works Park. However, five sediment samples from southern Lake Union and one from the northeast arm of the lake contained Arochlors 1254, 1248, and 1260 in concentrations as high as 11,500 $\mu\text{g}/\text{kg}$. This suggests that the PCBs in Lake Union sediments may have sources in addition to or instead of the park.

Pesticides

Pesticides were also analyzed for in the EPA 6-inch and 3-foot soil samples. Pesticides were detected in only one sample at the 6-inch depth. However, one or more types of pesticide were found in all but one of the samples from 3-foot depths. Samples from the southern and western part of the park contained DDT, in concentrations from 7.7 to 114 $\mu\text{g}/\text{kg}$ (fig. 14). DDD, endosulfan, endrin, heptachlor epoxide, (α)hexachlorocyclohexane and (β)hexachlorocyclohexane were also present in similar concentrations in these samples. Samples collected from the northeastern area of the park also contained these pesticides, but lindane(γ)hexachlorocyclohexane) was much more prevalent, ranging in concentrations from 55 to 731 $\mu\text{g}/\text{kg}$ in this area.

Volatiles

Volatile organic compounds were present in five of the EPA soil samples from 6-inch depths. Only benzene, ethylbenzene and toluene were detected, and the concentrations ranged from 2.3 to 43 $\mu\text{g}/\text{kg}$. As shown in figure 15, the samples were from just north of the towers and along the northeastern shore. Three samples from 3-foot depths had concentrations of these same volatiles up to 837 $\mu\text{g}/\text{kg}$; two of these were collected from the area north of the towers and the third from the eastern shore.

Air samples were collected by the PSAPCA and the UW in June 1984 to determine the presence of any volatile compounds that may be vaporizing from the park soil into the air. Samples were collected daily for 3 days in the park and at the park perimeter to determine the presence of volatiles in air blowing into the park. Some compounds were detected, including acetone, ethanol, hexane, pentane, 2-propanol, toluene, and xylene. However, they were at concentrations approaching the detection limit of the method, and were fairly consistent throughout the park. Because of the low concentrations and consistency, it is possible that the compounds detected in the samples were already in the air, and did not originate from within park boundaries, but this cannot be confirmed on the basis of the existing data.

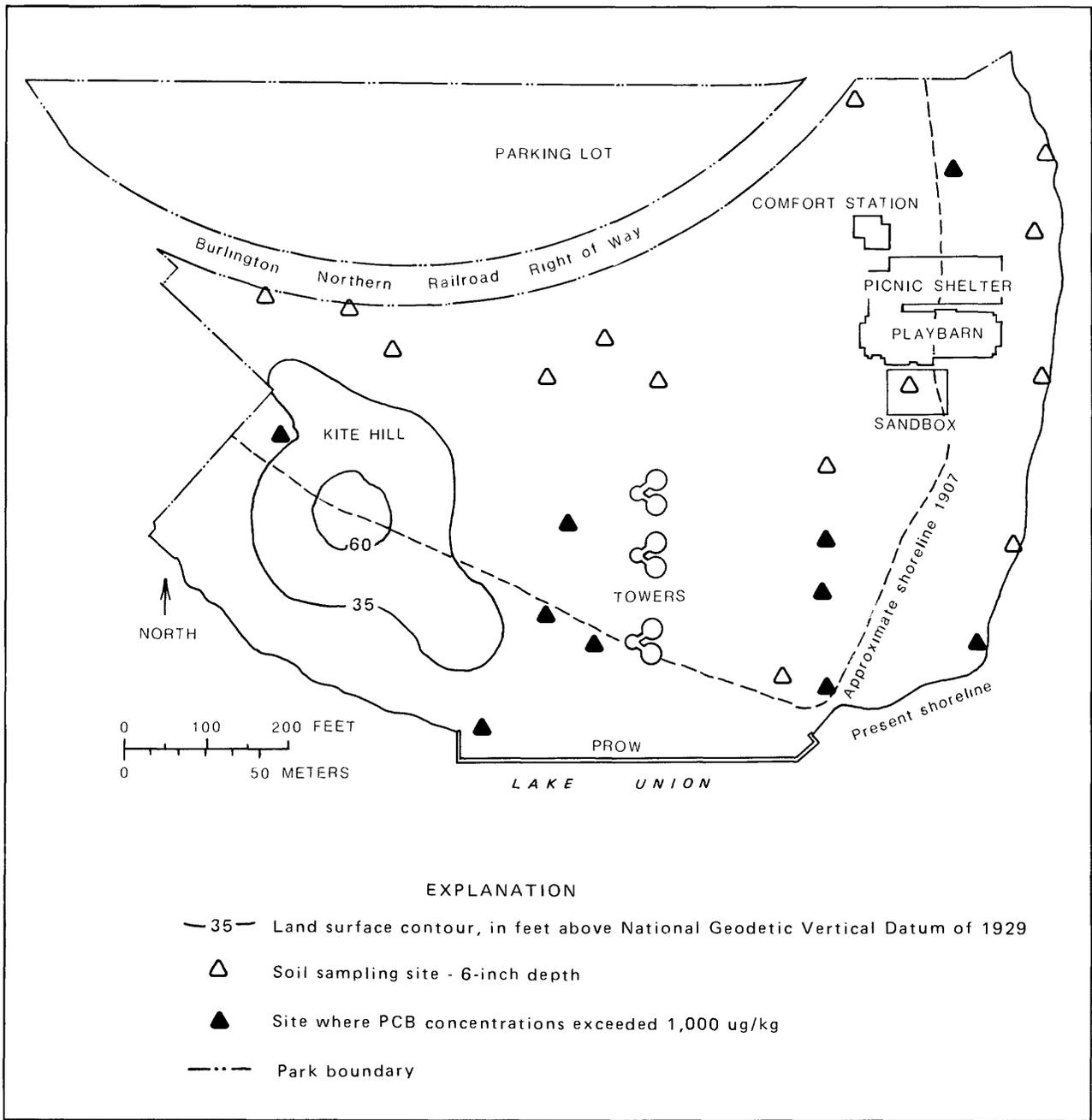


Figure 13.--Sites with highest polychlorinated biphenyl (PCB) concentrations, in micrograms per kilogram (ug/kg): 6-inch depth samples.

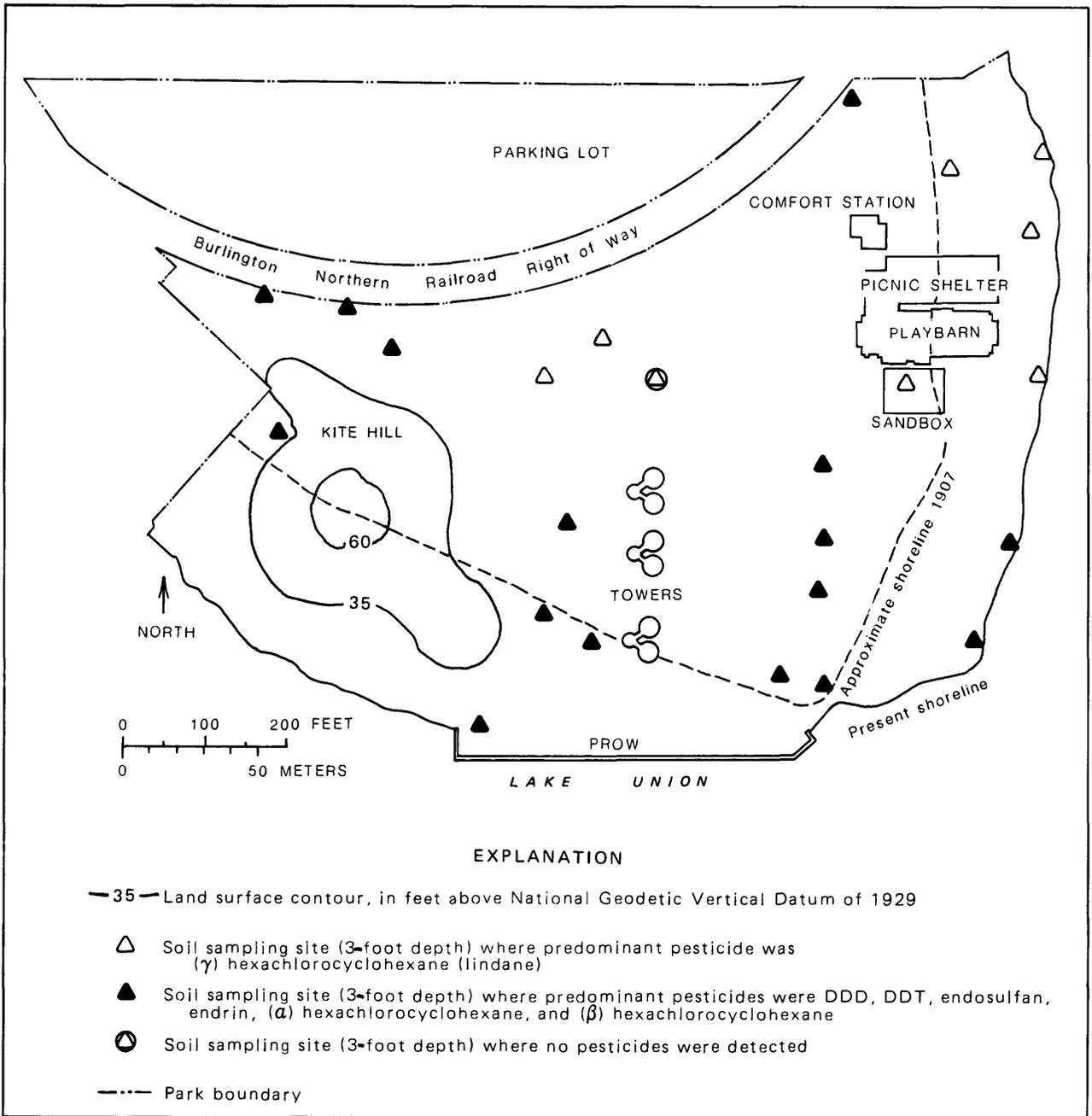


Figure 14.--Sites where pesticides were present: 3-foot depth samples.

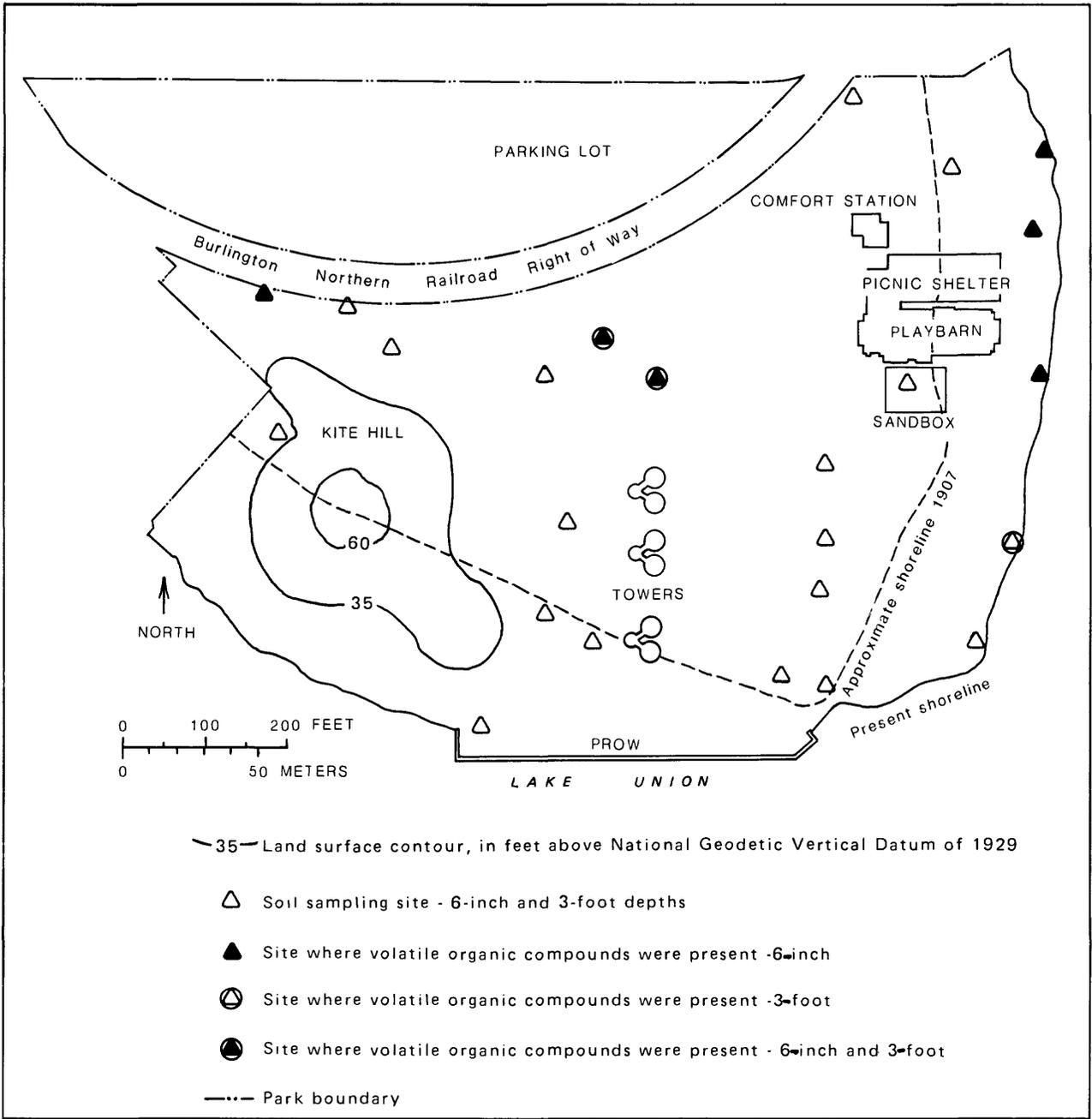


Figure 15.--Sites where volatile organic compounds were present: 6-inch and 3-foot depth samples.

Metals and Cyanide

Metals considered as priority pollutants, along with cyanide, were analyzed for in soil samples collected by the EPA from depths of 6 inches and 3 feet. The results were compared to typically occurring concentrations in uncontaminated soils, which are shown in table 4. For this report, concentrations exceeding five times the typical concentration were arbitrarily considered high enough to indicate contamination from anthropogenic sources and are referred to as "excessive" concentrations in this section. Concentrations of arsenic, cadmium, copper, cyanide, lead, mercury, silver and zinc exceeding five times the typical uncontaminated concentration were found in park soils in various locations.

In the 6-inch samples, excessive concentrations of cadmium, copper, mercury, silver and zinc were generally found in samples from the south-central part of the park (fig. 16). The distributions of excessive arsenic and cyanide concentrations were somewhat different, as shown in figure 17. Arsenic concentrations were as high as 47.5 mg/kg (milligrams per kilogram) and cyanide concentrations as high as 458 mg/kg. Additionally, excessive lead concentrations were found at almost all of the sites throughout the park (fig. 18). This widespread occurrence of lead may be due, in part, to atmospheric deposition from the surrounding urban environment. Excessive copper, lead, silver, and zinc concentrations were present in the sewage sludge that was spread throughout the park in June 1974 (City of Seattle, written commun., 1985), suggesting that the sludge may be one source of these metals. However, excessive concentrations of chromium and nickel were also present in the sewage sludge, but excessive concentrations of these metals were not found in the park soils.

Metal concentrations in samples from 3-foot depths were generally much lower than those at 6 inches. The highest concentrations generally were found in the same areas as those at 6 inches, but concentrations five times above the typical concentrations were observed in the 3-foot samples collected only from the southeastern part of the park and the railroad right-of-way (fig. 16). One exception was that excessive cyanide concentrations were observed as often at 3-foot depths as at 6-inch depths (fig. 17) and are in areas along the east shore and north of the towers in the center of the park. Cyanide concentrations in the 3-foot samples ranged from 28 to 340 mg/kg. As in the 6-inch samples, excessive concentrations of lead were found throughout the park, as indicated in figure 18.

Metals concentrations in the Lake Union sediments offshore of the park were somewhat higher than those in the park soil. The observed concentrations were fairly uniform except in the sediments off the eastern shore where arsenic and cyanide concentrations were as high as 284 and 2,680 mg/kg, respectively. A distinct concentration gradient for nickel, cyanide, and arsenic was also observed off the eastern shore, with higher concentrations near shore. Concentrations of other metals in the sediment samples taken offshore of Gas Works Park were similar to those in sediments from other areas of Lake Union indicating that there are possibly sources other than Gas Works Park for many of the metals in the Lake Union sediments.

Table 4.--Average concentrations of selected metals in regional soils

[Values are in milligrams per kilogram]

	Typical concentration in soil ^a	Concentration indicative of anthropogenic sources ^b
Arsenic	5	25
Beryllium	6	30
Cadmium	.5	2.5
Chromium	200	1,000
Copper	20	100
Cyanide	^c 5	25
Lead	10	50
Mercury	^d .09	.45
Nickel	40	200
Selenium	^e .1	.5
Silver	^f .9	4.5
Zinc	50	250

^aFrom Vinogradov (1959), unless otherwise noted.

^bThis concentration is five times the typical concentration.

^cNo value in Vinogradov. A concentration of 5 mg/kg was arbitrarily selected.

^dValue taken from an uncontaminated sample of Puget Sound glacial deposits (Jim Ebbert, U.S. Geological Survey, written commun., 1985) Vinogradov also gave a value of 0.01 mg/kg, which was thought to be low in this case.

^eValue arbitrarily chosen based on detection limit of analysis of 0.1 mg/kg. Vinogradov gave a value of 0.01 mg/kg for soils, which was thought to be low in this case. Vinogradov also gave a value of 0.6 mg/kg for sedimentary rocks.

^fValue selected from Vinogradov, but is for sedimentary rocks. Soils concentration in Vinogradov was 0.1 mg/kg, which was thought to be too low. Silver concentrations in an uncontaminated sample of Puget Sound till were <2 mg/kg (Jim Ebbert, U.S. Geological Survey, written commun., 1985).

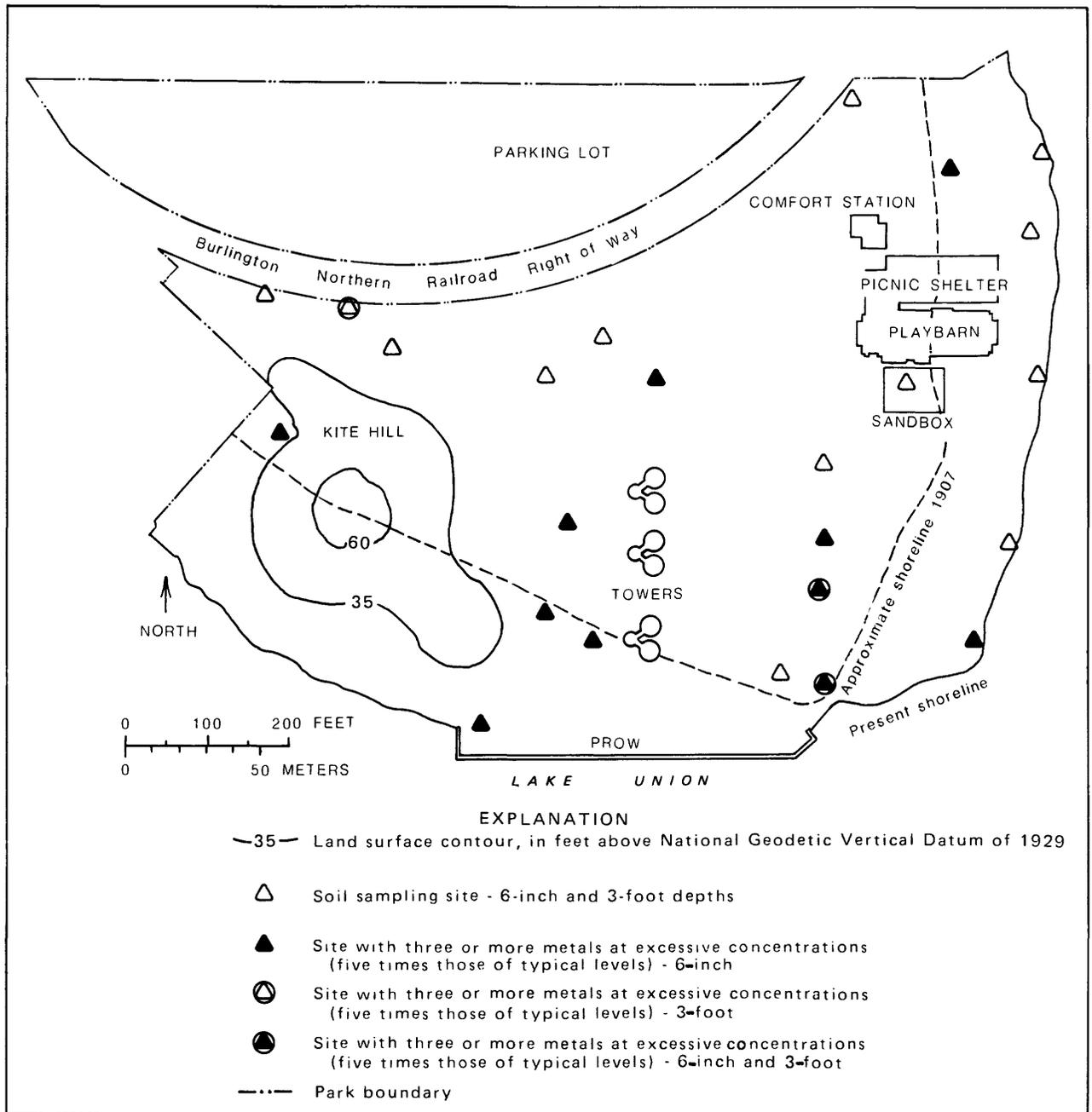


Figure 16.--Sites with three or more metals present at excessive concentrations: 6-inch and 3-foot depth samples.

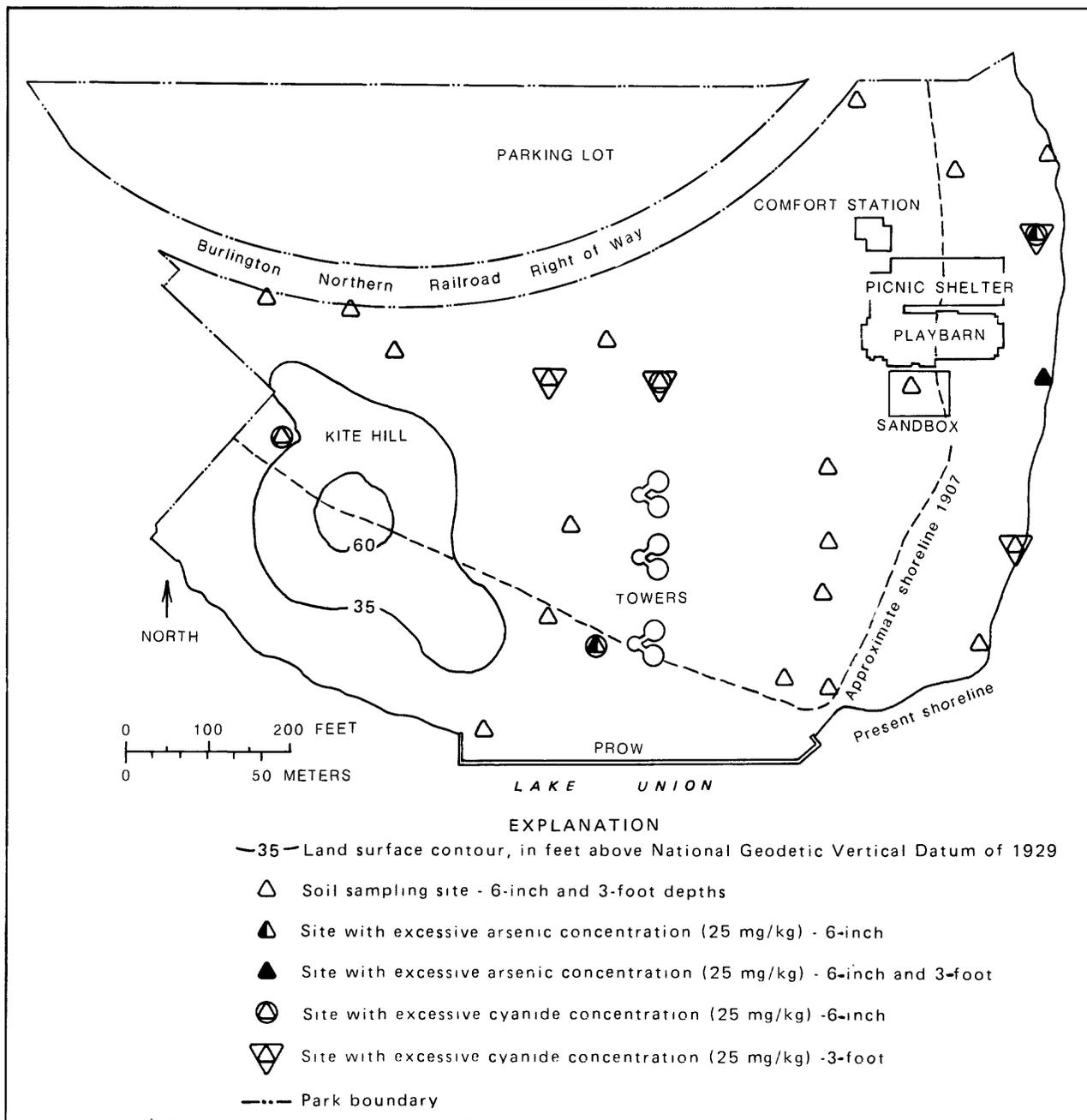


Figure 17.--Sites with excessive arsenic and cyanide concentrations, in milligrams per kilogram (mg/kg): 6-inch and 3-foot depth samples.

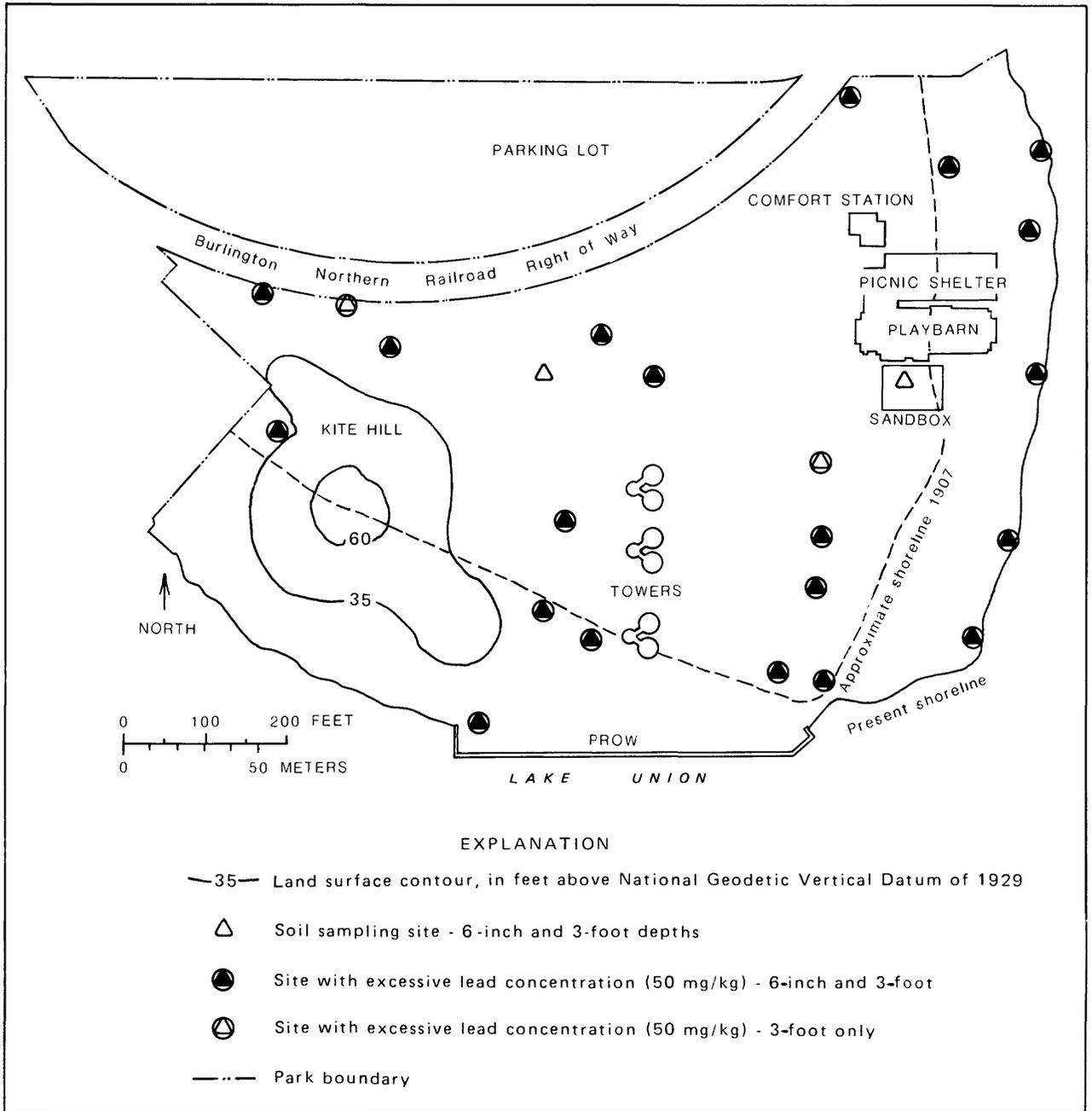


Figure 18.--Sites with excessive lead concentrations, in milligrams per kilogram (mg/kg): 6-inch and 3-foot depth samples.

Common Constituents in Ground Water at Gas Works Park

The common dissolved chemical constituents in the ground water at Gas Works Park help to characterize the type of water that the contaminants will be interacting with. Although no ground-water quality data exist to describe the common constituents, a reasonable assumption is that the common constituents are similar to those found in ground water throughout the Puget Sound region. It is possible, however, that the contaminants have affected the common constituents by increasing the mineralization of the ground water. Biodegradation of organics can lower the pH which will make the contaminated ground water dissolve aquifer material more readily than native ground water.

Ground water in the Puget Sound region is generally soft (hardness less than 75 mg/L; milligrams per liter) with low concentrations of dissolved constituents. Dissolved-solids concentrations are usually less than 150 mg/L and pH generally ranges from 6.5 to 8.0. Calcium and magnesium are the predominant cations in natural ground water, and the predominant anion is almost always bicarbonate (Turney, 1986). The primary exception is in areas where saltwater intrusion has occurred, introducing increased concentrations of sodium and chloride. Dissolved-solids concentrations can increase an order of magnitude or more when intrusion occurs.

Metals concentrations are generally less than 10 $\mu\text{g/L}$ (micrograms per liter). Iron and manganese are exceptions. Concentrations of these two metals commonly exceed 50 $\mu\text{g/L}$ (Turney, 1986). The higher iron and manganese concentrations are probably due mostly to natural causes (Van Denburgh and Santos, 1965).

The general chemical characteristics of the regional ground water suggest that the ground water at Gas Works Park probably is more conducive to dissolving contaminants, especially metals, than ground water in areas such as eastern Washington. Solubilities of most metals are higher in the soft, low pH waters typical of the region than in hard, high pH water. Most metal solubilities are also higher in reducing waters, which are indicated by high iron and manganese concentrations. Organic solubilities probably are higher in these waters also. For example, the solubility of anthracene, a PAH, is 1,290 $\mu\text{g/L}$ in distilled water and 600 $\mu\text{g/L}$ in saltwater (Brown and Weiss, 1978).

Potential for Contamination of Ground Water at Gas Works Park

Several potentially hazardous compounds exist in the soils of Gas Works Park and may also be present in the ground-water system. However, processes controlling the transport of the contaminants from the soil through the unsaturated zone to the ground-water table are such that the concentration of a specific contaminant in the water would generally be less than that in the soils. To understand this, one needs to consider the roles of these controlling processes in contaminant transport.

Contaminants may enter the ground water either by direct dissolution or by infiltration from the surface through the unsaturated zone. Direct dissolution may occur in areas of the park where the ground water is in contact with

waste deposits or contaminated soils. The amount of contaminants sorbed to soils that can dissolve into the ground water will vary depending largely on the contaminant's chemical characteristics. Likewise, surface water infiltrating through the unsaturated zone can dissolve contaminants with which it comes in contact, and then transport them to the ground water. Liquid contaminants may also infiltrate without dissolving in water, but this would be less likely at the present time than it would have been during plant operation.

Affinity for sorption and solubility are the two most important chemical characteristics in determining how much contaminant will be dissolved from the soils and the sediments. Sorption is the adherence of a chemical to a substance either on the substance's surface, known as adsorption, or within the substance's substrate, known as absorption. Sorption is not easily measured, but the octanol/water partition coefficient, which is the ratio of the amounts of a chemical dissolving in each fraction of an octanol-water mixture, is used for organic compounds as an indicator of relative sorption. The larger the coefficient, the greater the affinity for sorption. The solubility is the maximum amount of a chemical that will dissolve in a particular solvent, in this case water, under specified conditions. The sorption and solubility of a given chemical can vary under different water and soil conditions, but for the organic contaminants present, the variations probably are not significant enough to affect this general discussion. Solubilities and octanol/water partition coefficients (Callahan and others, 1979) for selected classes of organic contaminants present in soils are listed in table 5. Metals, however, have widely varying solubilities and sorptive characteristics and are not presented.

Table 5.--Solubilities and octanol/water partition coefficients of organic contaminants present in soils

Compound class	Solubility in water (micrograms per liter) ^a	Octanol/water partition coefficient
Polynuclear aromatic hydrocarbons	3.8 - ^b 1,290	10 ⁴ - 10 ⁷
Polychlorinated biphenyls	2.7 - 30	10 ⁶ - 10 ⁷
Pesticides	5.0 - 7,000	10 ⁴ - 10 ⁷
Volatiles	150,000 - 2,000,000	10 ² - 10 ³

^aRanges given for representative compounds.

^bSome compounds may have solubilities as high as 31,700 µg/L, but most are in the given range.

PAHs sorb strongly to soils as indicated by high octanol/water partition coefficients, commonly ranging from 10^4 to 10^7 . The solubilities of PAHs are low, and generally decrease with increasing number of benzene rings in the compound's structure. For example, naphthalene, phenanthrene, pyrene, and benzo(a)pyrene (which are 2-, 3-, 4-, and 5-ring structures, respectively) have solubilities in water of 31,700, 1,290, 135, and 3.8 $\mu\text{g/L}$, respectively. Most of the PAHs present in the soils in higher concentrations are 4- and 5-ring structures, and will not readily dissolve in water.

The PCBs present will sorb very strongly to sediments, having octanol/water partition coefficients of 10^6 to 10^7 . They also have low water solubilities, ranging from 2.7 to 30 $\mu\text{g/L}$. PCBs were analyzed as Arochlors, which are mixtures of individual PCBs chlorinated to varying degrees. Arochlors 1254 and 1260, which were detected in the 6-inch samples, consist primarily of PCBs with 5, 6, or 7 chlorine atoms each.

The pesticides present in the soils have solubilities somewhat higher than the PAHs and PCBs, ranging primarily from 5.0 to 300 $\mu\text{g/L}$ except for hexachlorocyclohexanes. Solubilities of the latter are around 1,000 $\mu\text{g/L}$ for the alpha and beta isomers, and around 7,000 $\mu\text{g/L}$ for the gamma isomer (lindane). All of these pesticides are strongly sorbed to soils, with octanol/water coefficients of 10^4 to 10^7 .

The volatile compounds benzene, ethylbenzene and toluene have octanol/water partition coefficients ranging from 10^2 to 10^3 . The solubilities range from 1.5×10^5 to 2×10^6 $\mu\text{g/L}$. These figures suggest that the solubility is higher and sorption lower for these compounds than for the PAHs, PCBs and pesticides.

Solubilities and sorptive characteristics of metals are complex. Solubilities in water are varied, even for individual elements, because of the effects of speciation and complexation. In a geohydrological system, sorption to the soils is usually more important than solubility in determining the amount of metal dissolving into the water, but sorption is also dependent upon speciation and complexation, as well as soil type and water chemistry.

As can be seen, the PAHs, PCBs, and pesticides present at the park have very high sorptive characteristics and low solubilities, suggesting a lower potential for higher concentrations in the ground water than in the soils. The volatile organic compounds have higher solubilities and lower octanol/water partition coefficients, suggesting that they may be present in the ground water in higher concentrations than the other organic compounds. The volatility of these volatiles, however, may have allowed much of the compounds originally deposited to be removed, either prior to or after entering the ground-water system. Concentrations of metals may or may not follow these patterns because of solubilities and sorptions that are more sensitive to other controls than those of the organic compounds.

The areal distribution of contaminants in the ground water is very difficult to predict. Although the occurrence of contaminants in the ground water might be expected to coincide generally with the occurrence of contaminants in the soils, the uncertainties of the details of the ground-water flow and of the mechanisms of contaminant transport are too great to allow any reasonable speculation.

Anomalies in the occurrence of PCBs and pesticides in park soils are unexplained by the existing data, and the effects on ground-water contaminant concentrations are unknown. As previously discussed, PCBs were present in all 6-inch soil samples, but not in any 3-foot soil samples. Likewise, pesticides were present primarily at the 3-foot depth, and not at 6 inches. Given the amount of disturbance of the soils in the park, this apparent stratification of contaminants seems unlikely. The reason for the higher concentrations of the pesticide lindane in the northeast section of the park was not readily apparent, either.

EFFECTS OF CONTAMINATION AT GAS WORKS PARK ON LAKE UNION

The impact on Lake Union of the contamination present at Gas Works Park is uncertain. The contaminants present in the lake sediments offshore of the park are similar to those in the park soils, and the gas works plant operations were probably the original source. The concentrations of PAHs and metals in those sediments are as high or higher than those in the park soils. However, the mechanism of transporting these contaminants to the lake sediments is not well understood. One possibility is that the contaminants were part of materials dumped offshore during the operation of the gas works plant. Probably this occurred to some degree, because the shore was expanded with waste materials. Some of these contaminants may have been transported from the park by hydrologic processes. One example would be desorption from park soils, movement through the ground-water system, and re-adsorption onto the lake sediments. Another possibility is the transport of shore and surface soils into the lake, as suspended material in the water.

Soils in the park that became suspended material in the lake are important because most of the contaminants are sorbed to these soils. Erosion, by both wind and surface water, and wave action are mechanisms that suspend these soils in the lake. These suspended soils can then deposit as lake sediment anywhere the water carries them, spreading the contaminants. The suspended materials also raise the total concentration of the contaminant in the water, often beyond the concentration that would be expected by considering the solubilities only. Possible evidence that this has occurred may be seen in the concentrations of benzo(a)pyrene in Lake Union. Two whole water samples collected off the southeast shore of the park had concentrations of 5.6 and 270 $\mu\text{g/L}$, but the solubility of benzo(a)pyrene in water is only 3.8 $\mu\text{g/L}$. The difference most likely is due to benzo(a)pyrene sorbed onto suspended material in the lake sample.

It cannot be concluded, based on the available data, that all contamination in the sediments and water of Lake Union is from Gas Works Park. Some contaminant concentrations in sediments, especially PCBs and metals, are as high in other parts of the lake as they are near the park. Potential sources of many of these contaminants are located along the lakeshore. All sources must be evaluated, and flow patterns of the lake considered to determine a true picture of the relation of the contamination of Gas Works Park to that observed in Lake Union.

ADDITIONAL DATA NEEDS

To adequately define the geology, ground-water flow system, and ground-water quality under Gas Works Park, additional data need to be collected and analyzed. Needed data-collection activities include:

1) Test-hole drilling and piezometer installation.

A series of holes need to be drilled to provide information on stratigraphy, horizontal and vertical hydraulic gradients, and water chemistry. The holes should be logged and samples taken of the drill cuttings to determine thicknesses of the deposits. Piezometers should be installed in the holes, with a few of the sites containing two piezometers, each at different depths, to define the vertical hydraulic gradients. Piezometers should be left in place, in case ground-water contamination is found and long-term water quality and water-level monitoring becomes necessary.

2) Water-quality sampling.

Water samples need to be collected from the piezometers. All of the samples need to be analyzed for polynuclear aromatic hydrocarbons and volatile compounds. A complete priority pollutants scan, or at minimum an expanded analysis including polychlorinated biphenyls, pesticides, and metals should be conducted on a representative number of samples.

3) Seismic refraction survey.

A seismic refraction survey needs to be conducted to determine the thickness and depth of geologic units and to locate the water table. A sledge hammer or drop weight probably would provide sufficient energy at this site.

4) Soil-gas survey.

A soil-gas survey needs to be conducted to determine if volatilization is occurring and, if so, to locate and define the plumes. At least two methodologies exist for doing this. One involves pumping air from the unsaturated zone, through a sorptive column. The column is then heated in the lab to desorb any volatiles, which are then analyzed using a gas chromatograph. Another utilizes a wire coated with activated charcoal which is placed in the soil for a week or so, and retrieved. Any volatiles are desorbed and analyzed.

5) Survey of Lake Union.

To determine the effects of Gas Works Park on Lake Union, a comprehensive study of Lake Union and its contaminant sources is necessary. Design of such a study is beyond the scope of this report.

SUMMARY

Gas Works Park is located on the site of the Seattle Gas Light Company gasification plant, which operated from 1906 to 1956. During this period, toxic wastes from the operations were deposited on the ground surface and along the shoreline of Lake Union, and the shoreline was extended 100 feet lakeward. In 1956, the plant closed. The City of Seattle purchased the property and established it as a park in 1968. The park is constructed around much of the gas works plant equipment, which was left on the site.

Gas Works Park is underlain by glacial deposits from the Vashon glaciation which are overlain by waste materials originating from the gas works plant. Since 1971, the ground surface has been tilled, recontoured, and various fill materials have been deposited on the park ground. Based on regional values, the hydraulic conductivities of the sands and gravels of the glacial deposits probably range from 2 to 860 feet per day. Grain-size distribution of the upper 9 feet of the waste deposits range from 16 to 36 percent gravel, 36 to 54 percent sand, and 21 to 45 percent silt and clay. Relative consistencies of the upper 15 to 30 feet of deposits underlying the fill material, as determined from standard penetration tests, range from loose to firm at the top to very stiff between 20 and 30 feet. The thickness and exact contents of the upper deposits are unknown.

Water levels measured in 1971 indicate that ground water flowing under the park eventually discharges into Lake Union. It is assumed that upward movement occurs under Lake Union, but the vertical flow pattern under the park is unknown.

Numerous data are available describing the concentrations of contaminants in the soils of Gas Works Park and in the surrounding sediments of Lake Union. Analyses of soil and sediment samples show high concentrations of many toxic substances including polynuclear aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), pesticides, volatile organic compounds, metals, and cyanide. Of these contaminants, PAHs have been detected in the highest concentrations. The highest total PAH concentration detected was 131 million $\mu\text{g}/\text{kg}$, or 13.1 percent, in the Lake Union sediments. Total concentrations of PAHs exceeding 100,000 $\mu\text{g}/\text{kg}$ are common in park soil samples from 6-inch depths.

Contaminants may be present in the ground water, but generally in concentrations lower than those seen in the soils. Although the organic compounds sorb strongly to the soils and most have low solubilities in water, some dissolution may occur. The metals and cyanide are less predictable, because of varying solubilities and sorptive characteristics.

Although the contaminants in Gas Works Park soils potentially may enter Lake Union, this cannot be verified on the basis of the available data. Possible methods of transport need to be determined, along with an assessment of other potential contributors of contaminants to Lake Union.

Assessments of the geology, hydrology, and ground-water chemistry of Gas Works Park can be accomplished through the establishment of a monitoring well system. The stratigraphy and geologic composition of the deposits can be determined during well drilling. Water levels could then be measured to establish ground-water flow patterns and hydraulic characteristics. Water samples could be collected and analyzed, not only for polynuclear aromatic hydrocarbons, but for a complete scan of priority pollutants. A comprehensive study of Lake Union could be done to assess the effects of Gas Works Park on the lake.

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