GROUND WATER RESOURCE ASSESSMENT STUDY FOR THE DISTRICT OF COLUMBIA

FINAL REPORT

A Report Submitted to the

WATER QUALITY CONTROL BRANCH

of the

D.C. Department of Consumer and Regulatory Affairs
Environmental Regulation Administration Water
Resources Management Division

Grant No. 89g-89-WHBOI Amendment *No.*
89g-89-WHB01-91-01 Amendment *No.*
89g-89-WHBOI-92-01

Prepared by the

D.C. WATER RESOURCES RESEARCH CENTER
University of the District of Columbia 4200
Connecticut Ave, NW Building 50, MB 5004
Washington, DC 20008

October 1993
Washington, DC

ABSTRACT

TITLE: Ground Water Resource Assessment Final Report

DATE: October 1993

AUTHOR(S): Jutta Schneider, Hamé M. Watt, James V. O'Connor, Fred M. Chang and Clarence W. Wade

CONTENT: Describes regional hydrogeologic setting, aquifer occurrence, ground water flow systems, and ground water quality. Provides information on potential pollution sources. Recommends future data and research needs as well as a strategy for designing and implementing a ground water protection strategy for the District of Columbia.

PROJECT STAFF

GROUND WATER RESOURCE ASSESSMENT STUDY
FOR THE DISTRICT OF COLUMBIA

Hamé M. Watt, Jutta Schneider - UDC/DC Water Resources Research Center
James V. O'Connor - UDC Dept. of Env. Science
Fred M. Chang - UDC Dept. of Civil Engineering
Clarence W. Wade - UDC Dept. of Chemistry
H. P. Pao - CUA Dept. of Civil Engineering
Akbar Montaser - GWU Dept. of Chemistry
James Johnson - HU Dept. of Civil Engineering
Kobina Atobrah - Geomatrix, Inc.
Gascoyne Laboratories, Inc

PREFACE

Ground water is a resource of immense value that is heavily used by people in the United States. The protection of ground water from contamination, however, has long been neglected. In recent years, the need for ground water protection and management has been recognized. Particularly for rural areas, where up to 97 % of the people may use ground water for a number of purposes, ground water protection strategies have been investigated and implemented. On the other hand, little attention has been paid to ground water protection in urban settings.

Pollutants due to urban land use activities create immense problems for cities such as Washington, DC. These pollutants originate from such diverse activities as soils disturbance by construction, leaking underground storage tanks, and chemical application to golf courses, gardens and landscapes. There is an increasing recognition that urban land use activities may produce highly toxic substances. The understanding of the toxic pollutant transport and fate under the city poses a great challenge to researchers and city planners.

To provide city managers with the data needed to design and implement a ground water protection strategy in the District of Columbia, the DC Water Resources Research Center (DC WRRC) was tasked by the Department of Consumer and Regulatory Affairs/Environmental Regulation Administration to conduct a "Ground Water Resource Assessment Study (GWRAS)" for the District of Columbia. The DC WRRC arranged for a consortium of universities, consisting of the University of the District of Columbia, Howard University, the George Washington University and the Catholic University of America to conduct the study. The GWRAS included a background investigation of land use and hydrogeologic conditions, and the installation and sampling of ground water monitoring wells in various locations in the District of Columbia.

This final report presents the findings of the background and field investigations as a comprehensive ground water resource assessment. A chapter with recommendations for the implementation of a Comprehensive State Ground Water Protection Program applies the study results to finding a practical approach to ground water protection in an urban setting. Results of this study should be used not only as a basis for a ground water management and protection program, but also for informing citizens about the urban ground water resource.

We would like to express our gratitude to the many firms and individuals who offered us their assistance and support. First to be mentioned are the sub-contractors and university professors who worked closely on various aspects of the project: Dr. Kobina Atobrah of Geomatrix, Inc., Mr. Michael Arbaugh of the Gascoyne Laboratories Field Team, Dr. Akbar Montaser of the George Washington University, Dr. H.P. Pao of the Catholic University, and Dr. Clarence Wade, Dr. Fred Chang and Prof. James V. O'Connor, all of the University of the District of Columbia. Many employees of the National Park Service proved very helpful and cooperative during the site selection and well installation process. Among them are Mr. Robert Ford, Mr. Stephen Syphax, Mr. T. Buxton and Mr. William Shields. We also wish to express our gratitude to Dr. Mohsin Siddique, Dr. Hamid Karimi, Mr. Timothy Karikari, Ms. Jerusalem Bekele, Mr. V. Sreenivas, all of the Department of Consumer and Regulatory Affairs, and Dr. Gordon M. Matheson, of Schnabel Engineering Associates, for their assistance during the course of the project. Finally, we are grateful to Dr. David Kargbo, formerly of the Department of Consumer and Regulatory Affairs, now with EPA Region III, for initiating the funding of this study.

Dr. Hamd M. Watt
Director

GROUND WATER RESOURCE ASSESSMENT STUDY FOR THE DISTRICT OF COLUMBIA

EXECUTIVE SUMMARY

Protecting the Nation's ground water has become a major goal of the U.S. Environmental Protection Agency (EPA). Under the Federal Clean Water Act and its subsequent amendments, the States are required to undertake an assessment of the quality and quantity of their ground water resources. States are also encouraged to develop strategies for ground water protection and to establish programs for the implementation of these strategies. Presently, efforts are underway to implement EPA's Ground Water Protection Strategy for the 1990's by providing the States with guidance on developing a Comprehensive State Ground Water Protection Program (CSGWPP).

In 1989, DCRA tasked the University of Columbia's Water Resources Research Center with assessing the ground water resources of the District of Columbia. A consortium of universities was formed to address the various tasks of the ground water resource assessment. The purpose of the ground water resource assessment (GWRAS) for the District of Columbia was defined as follows:

- Assess the quantity and quality of ground water in the District
- Predict the impact of the District's ground water on surrounding areas and vice versa
- Evaluate the hydrologic connection between ground waters and surface waters in the District
- Identify sensitive areas within the District with respect to ground water pollution

For the purpose of this study, an aquifer is defined in general as a hydrostratigraphic unit that is saturated, permeable, and capable of yielding water to a well or spring. A hydrostratigraphic unit is a geological formation, group of formations, or part of a formation with similar hydrologic characteristics. Based on these definitions, four aquifer types exist in the District of Columbia: 1) the crystalline rock aquifer in the Piedmont, 2) the perched aquifers in the Coastal Plain, 3) the surficial aquifer in the Coastal Plain, and 4) the Potomac Group Aquifer in the Coastal Plain. The table below shows the relationship between geologic series, stratigraphic unit and the local aquifers.

Geologic Time	Stratigraphic Unit	Local Aquifer
Holocene to Pliocene Epoch	Fill Alluvium River Terrace Deposits Upland Gravel and Sand	Surficial Coastal Plain Aquifer
Miocene Epoch	Calvert Formation (Chesapeake Group)	Perched Aquifer
Paleocene Epoch	Aquia Formation (Pamunkey Group)	Perched Aquifer
Upper Cretaceaous Period	Monmouth Formation	Perched Aquifer
Lower Cretaceaous Period	Potomac Pataosco/Arundel Group Patuxent	Potomac Group Aquifer
Precambrian Era Lower Paleozoic Era or both	Kensington Gneiss Georgetown Mafic Complex Wissahickon Formation	Crystalline Rock Aquifer

To complement the already available ground water information, thirteen wells were installed during the Ground Water Resource Assessment Study (GWRAS). The well installation method .varied by depth and aquifer material. Five wells were installed to reflect the major hydrogeologic provinces in the District of Columbia, namely the Potomac Group (MW-1, 2), the crystalline rock (MW 3), and the surficial terrace and alluvial deposits (MW-4, 5). To assess the impact of nonpoint source pollution, the remaining eight wells were installed in shallow ground water in community gardens (MW-A1,2,3 and MW-B1,2,3) and a golf course (NM-C1,2). MW A1,2,3 and MW B1,2,3 are located in the surficial terrace and alluvial deposits, while MW C1,2 tap ground water in the weathered crystalline rock. Information from all thirteen wells has been included in the aquifer characterization. The well numbering system is alphanumeric, with numerals to indicate well locations and letters to indicate site locations. Thus, each Group A well was assigned a number, since only one well was installed at each site. Each Group B well was assigned a character to indicate the site, and a number to indicate the well.

Well	Depth (ft)	Aquifer Media	Method
MW-1	250	Unconsolidated clay, sand	Hydraulic (Mud) Rotary
MW-2	50	Unconsolidated fill, sand, gravel, clay	Hollow-Stem Auger
MW-3	100	Massive/ fractured rock	Air-Percussion Rotary
MW-4	30	Unconsolidated fill, sand, gravel, clay	Hollow-Stem Auger
MW-5	22	Unconsolidated fill, sand, gravel, clay	Hollow-Stem Auger
MW-A1,2,3	22	Unconsolidated fill, sand, clay	Hollow-Stem Auger
MW-B1,2,3	19	Unconsolidated fill, sand, gravel	Hollow-Stem Auger
MW-C1,2	18	Unconsolidated saprolite	Hollow-Stem Auger

The physical and hydraulic characteristics vary widely among the four aquifer types and within each aquifer. Highest transmissivities were found for the Potomac Group Aquifer and localized areas within the surficial aquifer. Both local and regional flow patterns exist in the District of Columbia. The local flow systems correspond to the surface water drainage basins of the Potomac River, the Anacostia River, Rock Creek and Oxon Run. Some differences can be expected in the downtown area, where the sewering of Tiber Creek has resulting in a rerouting of surface water runoff from the Potomac River to the Anacostia River. Ground water, however, may still follow the natural topographic gradient and discharge directly to the Potomac River.

An additional factor in Washington, DC is the urban character of the watersheds. In the surficial aquifer in downtown Washington particularly, pipelines and METRO tunnels serve as effective barriers to ground water flow, raising the water table on the up gradient side and lowering it on the down gradient side. Additionally, anthropogenic recharge and discharge areas cause ground water sources and sinks that can significantly alter the water table contours: water from discharge into the structures. Well readings during the sewer system evaluation in 1981 and 1982 brought evidence of the impact of these urban structures on the ground water table: water levels in one well dropped 20 feet after a nearby water main break was repaired. Detailed measurements of ground water elevations are necessary to obtain water table contours of some accuracy. Additionally, the shape of the water table may change temporarily with construction dewatering. The underground utility system of sewers, water pipes and sump pumps may have created micro flow systems around these artificial recharge and discharge areas. Steeper than natural gradients around artificial discharge areas likely result in increased velocities. Decreased water table elevations in the vicinity of streams may also resuls in a reversed hydraulic gradient, causing streams to lose water to the ground water instead of gaining water. Additionally, the presence of coarser-grained materials around pipelines, originating from old stream channels, may result in preferred flow paths along the pipelines.

Ambient water quality analyses showed the presence of distinct hydrochemical facies (based on major anion/cation analysis) as well as high concentrations in iron and, in some cases, nitrate. Effects of urbanization were detected mostly in shallow wells tapping the surficial aquifer, which exhibited high Total Dissolved Solids, chloride and sulfate concentrations. Chloroform and Chlordane were detected in two shallow wells in downtown Washington, DC. No other pesticides/herbicides and volatiles/semi-volatiles were found.

Potential pollution sources are located in the recharge areas of all aquifers. Consequently, all ground water in the District of Columbia is threatened with water quality degradation by human activities. Based on the characteristics, values and uses of ground water in the different aquifers, protection priorities were ranked from the Potomac Group aquifer and the surficial aquifer to the crystalline rock aquifer and the perched aquifers. Ground water should be protected "to prevent the degradation of all ground waters from human activities to the extent possible, and to restore degraded ground waters to a level of quality that will sustain the perceived uses and values of ground water in the District of Columbia."

A Comprehensive Ground Water Protection Program should be implemented as soon as possible and include the following steps:

- Finalize ground water protection goal and ground water protection activities Define detailed ground water protection program
- Conduct organizational resource assessment and create organizational structure
- Develop/ implement comprehensive data collection and management program
- Expand monitoring network and conduct additional research
- Develop/ implement public education program

GROUND WATER RESOURCE ASSESSMENT STUDY FOR THE DISTRICT OF COLUMBIA

TABLE OF CONTENTS

GROUND WATER RESOURCE ASSESSMENT STUDY - FINAL REPORT

LIST OF FIGURES, CONT.

LIST OF TABLES

GROUND WATER RESOURCE ASSESSMENT STUDY
FOR THE DISTRICT OF COLUMBIA

1. INTRODUCTION

Protecting the Nation's ground water has become a major goal of the U.S. Environmental Protection Agency (EPA). Under the Federal Clean Water Act and its subsequent amendments, the States are required to undertake an assessment of the quality and quantity of their ground water resources. States are also encouraged to develop strategies for ground water protection and to establish programs for the implementation of these strategies. Presently, efforts are underway to implement EPA's Ground Water Protection Strategy for the 1990's by providing the States with guidance on developing a Comprehensive State Ground Water Protection Program (CSGWPP).

The potential uses and impacts of local ground water sytems in the District of Columbia, such as use as an emergency drinking water supply and impact on the quality of surface water, have been increasingly recognized during the last decade. The District of Columbia Water Pollution Control Act of 1984 required the restoration of local waters, including ground water, in the District of Columbia. The mandate was subsequently delegated to the DC Department of Consumer and Regulatory Affairs (DCRA). The Department has since created a Ground Water Protection Office as part of its Water Resources Management Division. In order to meet the need for management and protection of the District's ground water, and since information on the quality and quantity of the District's ground water is limited, a ground water resource assessment became necessary.

In 1989, DCRA tasked the University of Columbia's Water Resources Research Center with assessing the ground water resources of the District of Columbia. A consortium of universities was formed to address the various tasks of the ground water resource assessment. A series of 10 interim reports, relating to each task, have been provided to DCRA over the course of this project. These reports are:

- Background Study of the Ground Water in the District of Columbia, DC WRRC Report No. 103 (with Howard University)
- Group A Wells Combined Quality Assurance/ Project Plan - Phase II, DC WRRC Report No. 124
- Group A Wells Combined Quality Assurance/ Project Plan - Phase III, DC WRRC Report No. 129
- Group B Wells Combined Quality Assurance/ Project Plan, DC WRRC Report No. 123

- Well Drilling and Field Operations Report - Group A Wells, DC WRRC Report No. 126 (with Geomatrix, Inc.)
- Well Drilling and Field Operations Report - Group B Wells, DC WRRC Report No. 127 (with Geomatrix, Inc.)
- Modeling Report, DC WRRC Report No. 135 (with The Catholic University of America)
- Sampling and Analysis Report Phase II - Group A Wells, DC WRRC Report No. 136 (with The George Washington University)
- Sampling and Analysis Report Phase III - Group A Wells, DC WRRC Report No. 137 (with The George Washington University)
- Sampling and Analysis Report - Group B Wells, DC WRRC Report No. 138 (with The George Washington University)

This report comprises the final report for the Ground Water Resource Assessment Study for the District of Columbia. It follows the requirements outlined in the project agreement and subsequent amendments, and adheres as closely as possible to the Technical Assistance Document for Ground Water Resource Assessments by the EPA Office of Ground Water (1992). The report consists of two parts: 1) a resource characterization describing the local aquifers and their physical and chemical characteristics, and 2) recommendations for the development of a Comprehensive State Ground Water Protection Program (CSGWPP).

2. PURPOSE AND SCOPE

The purpose of the ground water resource assessment (GWRAS) for the District of Columbia was defined as follows:

- Assess the quantity and quality of ground water in the District
- Predict the impact of the District's ground water on surrounding areas and vice versa
- Evaluate the hydrologic connection between ground waters and surface waters in the District
- Identify sensitive areas within the District with respect to ground water pollution

The scope of the ground water resource assessment was defined as follows:

- Conduct a background survey of ground water data in the District, including geology, soils, and land use (Task 1)
- Install five ground water monitoring wells in the major geologic formations within the District, and install nine shallow wells to determine the impact of nonpoint source pollution on the ground water (Task 2)
- Evaluate ground water flow and transport models for application in the District of Columbia and determine available data and future data needs (Task 3)
- Conduct sampling and analysis program on all thirteen wells for a variety of parameters to determine ambient ground water quality as well as the extent of contamination, if any (Task 4)

In addition to aiding in the design of a ground water protection strategy, the information and data gathered during the course of this study can be used in conjunction with related federal and State pollution control programs, such as the non-point source pollution control program, the Leaking Underground Storage Tank Program, the Pesticide Program and the Hazardous Waste Program. It will also allow environmental managers to determine the potential use of DC's ground water as an emergency water supply and to determine areas of potential health hazards to residents from ground water contamination.

3. CHARACTERIZ.ATION OF THE GROUND WATER RESOURCE

The characterization of the ground water resource includes information on the regional hydrogeologic setting, on the occurrence and physical characteristics of local aquifers, and on ground water flow patterns. Ambient ground water quality and existing and potential contamination sources are discussed in a separate chapter.

3.1. REGIONAL HYDROGEOLOGIC SETTING

3.1.1. Location and Physiography

The District of Columbia covers an area of about 65 square miles on the northeast side of the Potomac River, adjacent to the mouth of the Anacostia River (Figure 1). The District has two physiographic provinces, the Mid-Atlantic Coastal Plain and the Piedmont Province.

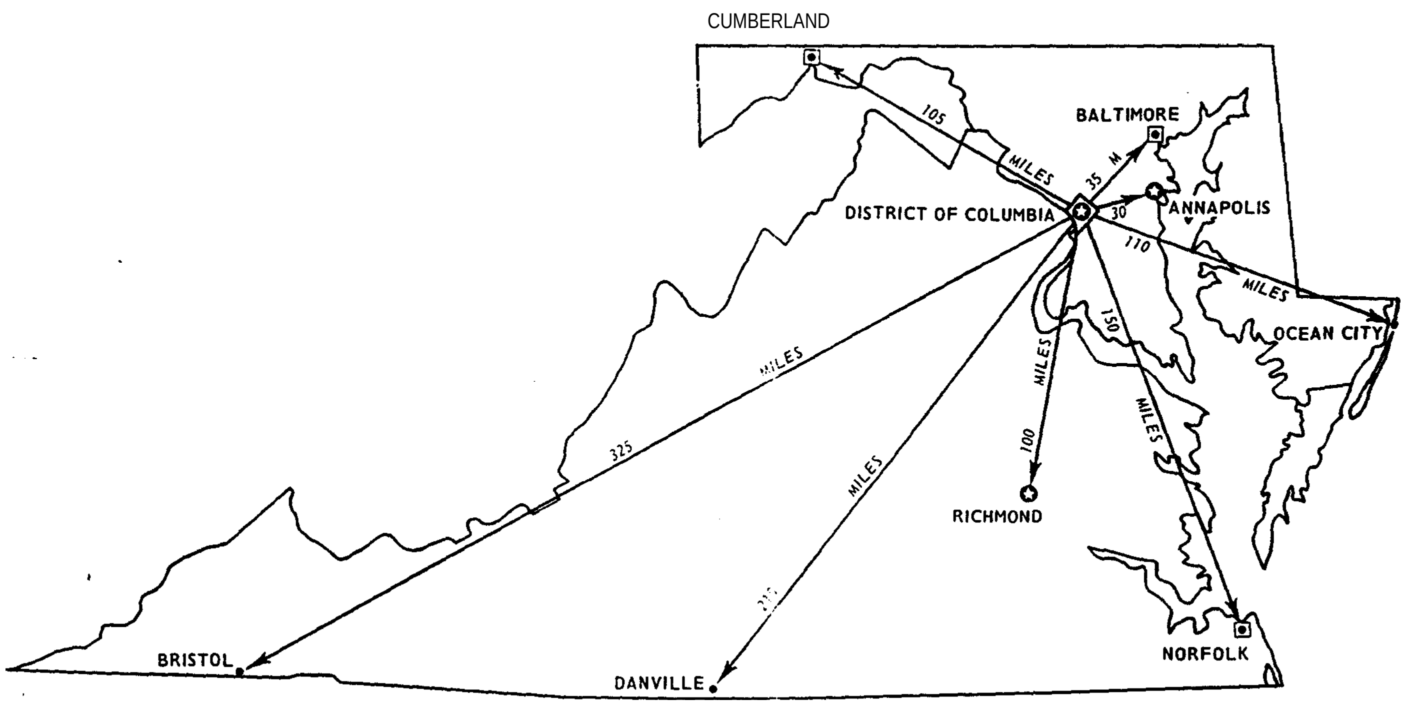


Figure 1. Location of the District of Columbia (from USDA, 1976).

The Fall line, which separates the Piedmont Province in the west from the Coastal Plain Province in the east, bisects the area diagonally from northeast to southwest (Figure 2a). Much of the District is dissected by erosion and is characterized by nearly level to gently rolling uplands, steep valley walls, widely separated interstream divides and narrow valley bottoms. In the downtown area, most public buildings and memorials are on nearly level lowlands formed on river terrace deposits, alluvium and artificial fill. Elevation ranges from sea level in the southern part of Washington, where Anacostia and Potomac are tidal estuaries, to 420 feet in Tenleytown in the west of the city. Interstream ridges are highest in the Piedmont section of the city, and grade gradually to the south and east, where elevation are generally below 230 feet (Figure 2b).

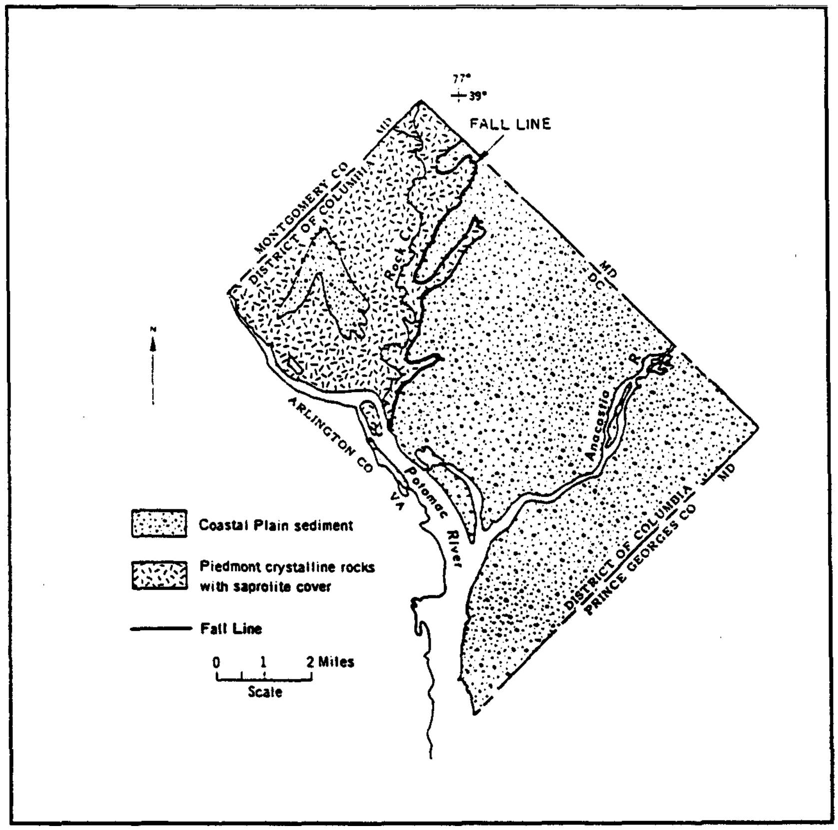


Figure 2a. Physiographic provinces in the District of Columbia (from: USDA, 1976)

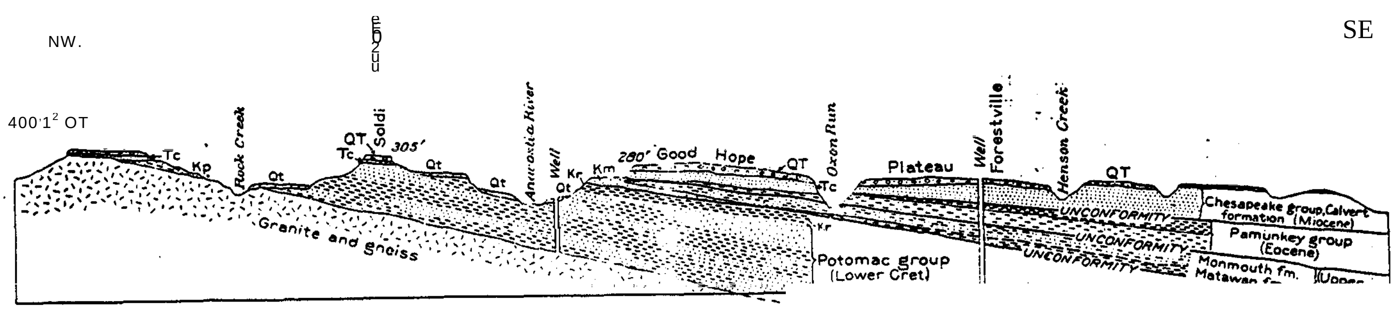
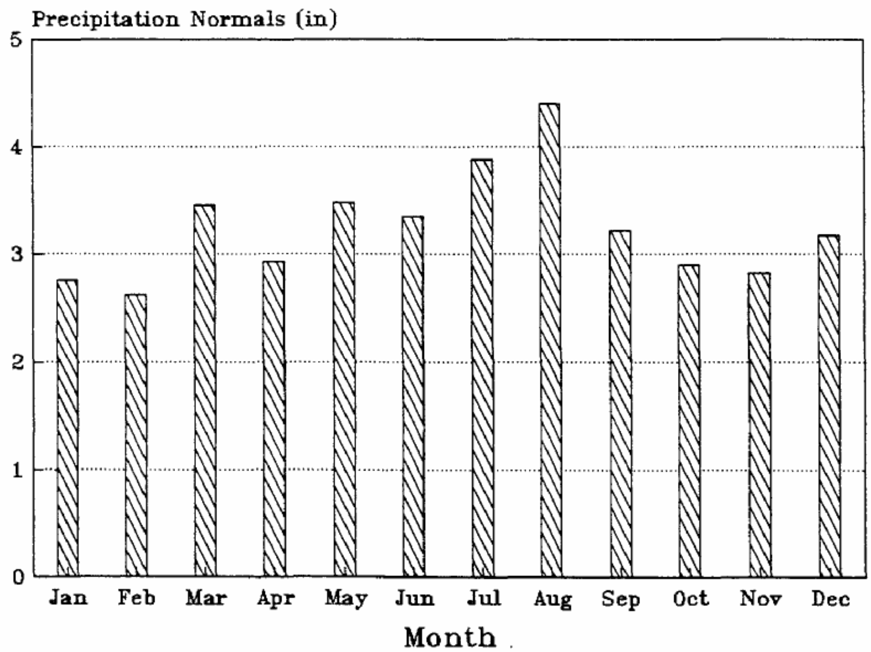


Figure 2b. Elevation profile of the District of Columbia from northwest to southeast (from

3.1.2. Climate and Drainage

The climate in the District of Columbia is humid. Annual precipitation ranges from 30 to 50 inches and is distributed fairly evenly throughout the year, with the highest rates occurring in the summer. The amount of ground water recharge is estimated conservatively at 10 % of the average annual rainfall as 4 inches per year (Johnston, 1964). Figure 3 shows annual average temperatures and precipitation.

In the Coastal Plain portion of the District of Columbia, the topography and drainage pattern have been significantly affected by urbanization. At the time of the earliest settlement, the topography of the downtown Washington area was marked by the drainage systems of Tiber Creek, which discharged into the Potomac River, and St. James Creek, which discharged into the Anacostia. These streams circled the southwestern portion of Washington on the lines of the Mall, Canal Street and Delaware Avenue. Small tributaries to this system cut across near Judiciary Square and along the line of 10th Street, and a larger tributary flowed southwest from Union Station. Another creek called Slash Run flowed south from the vicinity of Wyoming Avenue and 18th Street NW where it turned west, crossing Connecticut Avenue and then turned north again to discharge into Rock Creek. All these stream channels were subsequently filled and the principal drainage channel of Tiber Creek was replaced by a trunk sewer. Additionally, extensive fills raised grades in low-lying areas adjacent to the Potomac and Anacostia Rivers (Figure 4). As a consequence of these human activities, the downtown drainage originally affected by Tiber Creek was no longer directly to the Potomac River, but to the Anacostia River. The remaining streams and their tributaries are south flowing and form a dendritiic drainage network. The District of _Columbia is part of the Potomac River Basin. All of the drainage is into the Potomac River; with Rock Creek and Anacostia as the major tributaries. Figure 5 shows the sub-basins of Rock Creek and the Anacostia River within the District of Columbia. Rock Creek is incised in a narrow valley that drains the Piedmont portion of the District. The Anacostia River meanders in the flood plain of a broad gently sloping valley across the Coastal Plain. The odd shape of the Anacostia basin is due to the alteration of the original Tiber Creek drainage basin to a sewershed draining to the Anacostia.



Recorded at National Airport

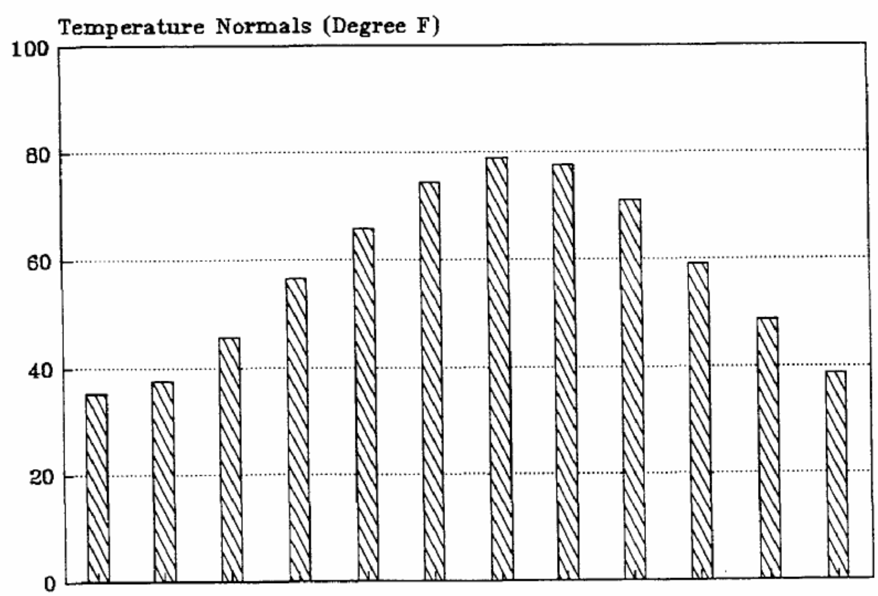


Figure 3. Climatic data for the District of Columbia. A. Precipitation normals. B. Temperature normals

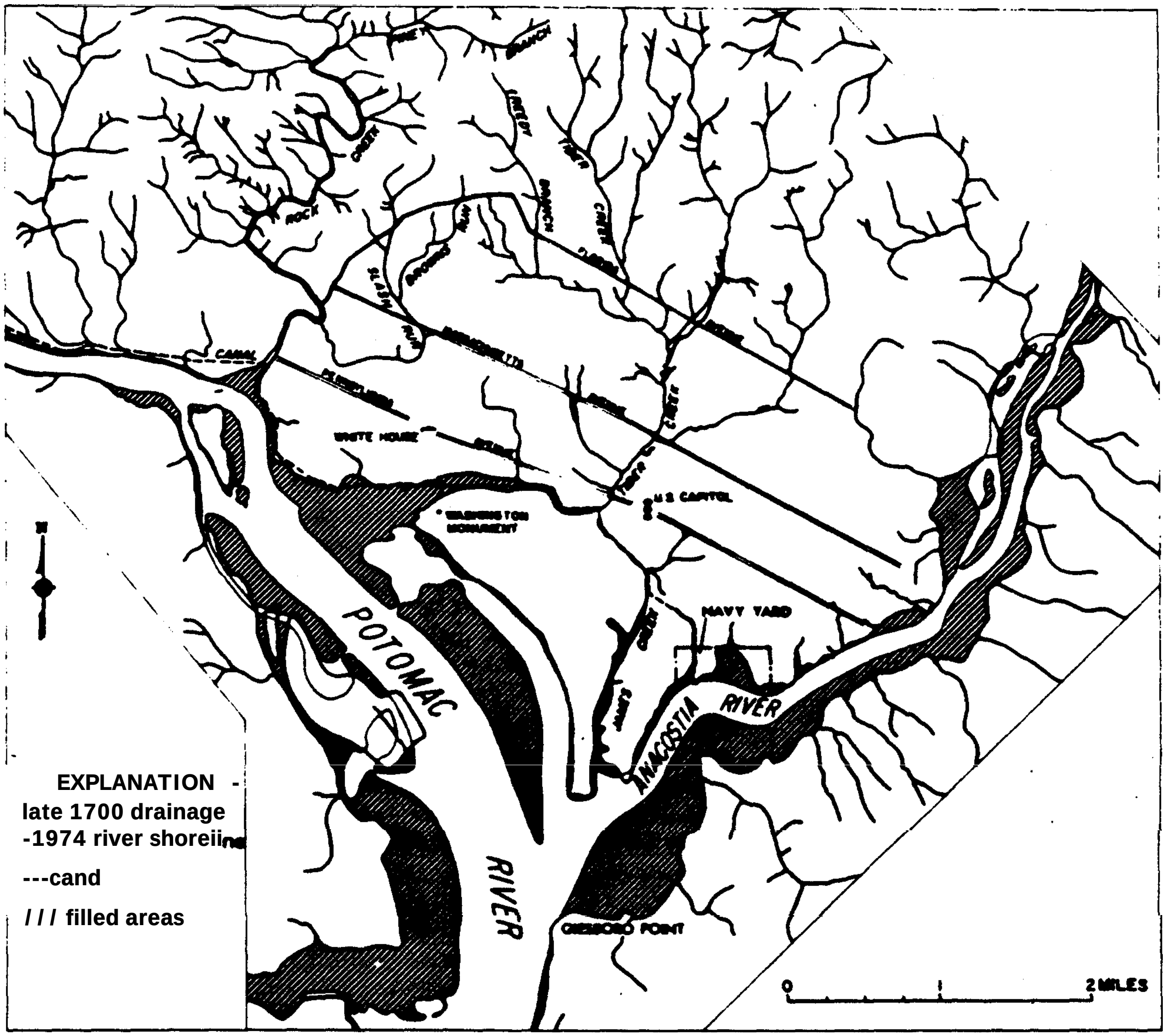


Figure 4. Original drainage pattern in downtown Washington, DC (from: Williams, 1977)

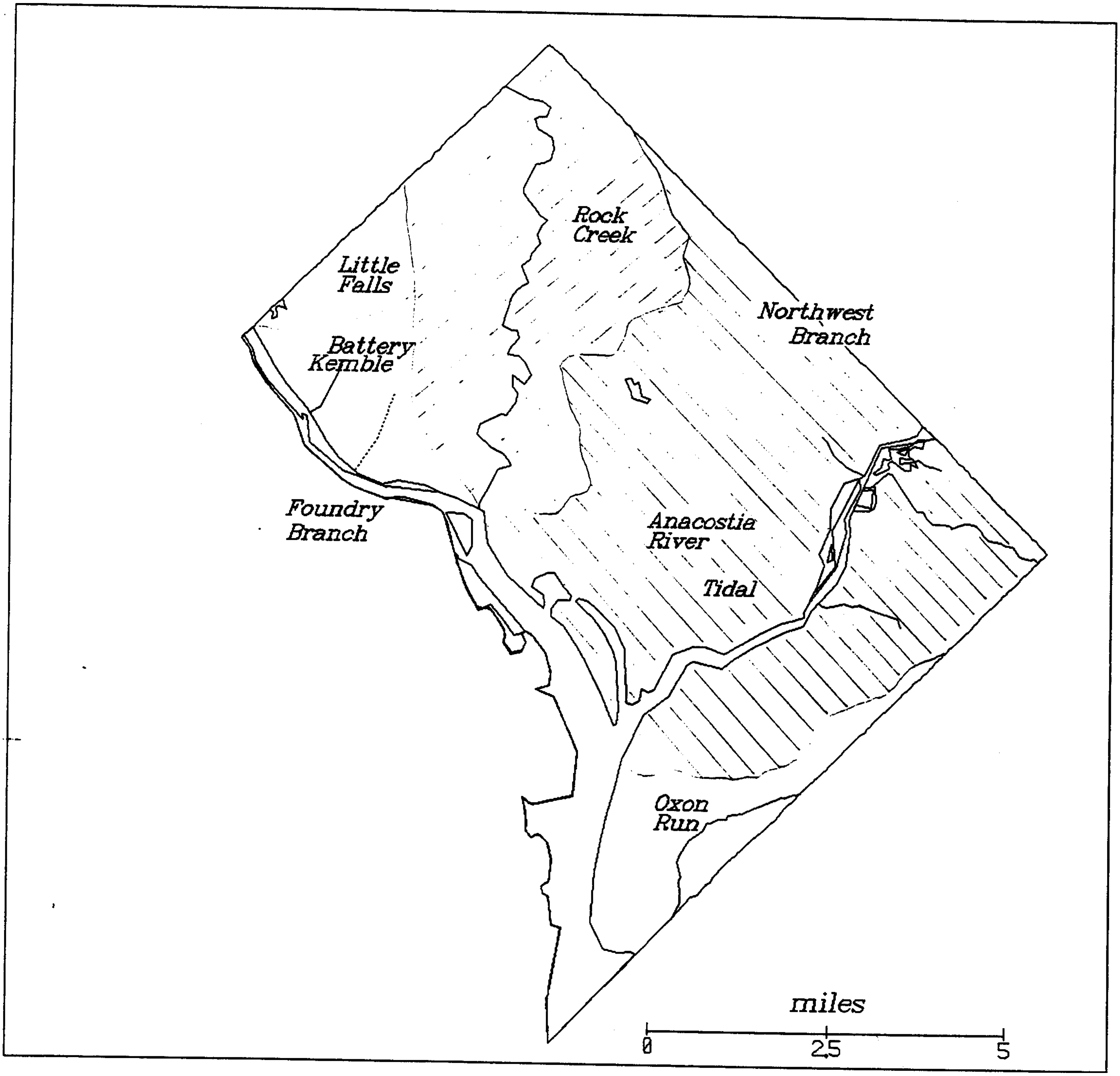


Figure 5. Sub-basin boundaries for the Anacostia River and Rock Creek

Mean flows for the Potomac and Anacostia rivers (unadjusted for diversion) as well as for Rock Creek are shown in Table 1 below. Lowest daily mean flow are 121 cubic feet per second (cfs), 1.4 cfs, 0.6 cfs and 0.5 cfs respectively.

Table 1. Mean flow values for District of Columbia rivers and streams (USGS, 1992)

Stream	USGS Gauging Station	Annual Mean Flow (cfs)	Lowest Annual Mean (cfs)	Highest Annual Mean (cfs)
Potomac	Little Falls Dam (1930-91)	11,070	4,900	18,580
Anacostia	Northeast Branch (1939-91)	84.1	49.3	150
Anacostia	Northwest Branch (1938-91)	47.2	20.8	96.9
Rock Creek	Sherrill Drive (1930-91)	62.5	16.1	142

3.1.3. Vegetation and Soils

Since the creation of the District in 1790, most of the native vegetation has been destroyed during urbanization and other anthropogenic activities, according to the District of Columbia Soil Survey (USDA, 1976). The relatively undisturbed park areas, such as Rock Creek, Ft. Dupont and Glover-Archbold, are the few areas where a number of species that were a part of the native vegetation still grow. Other areas of the District contain trees and shrubs that were brought in from other parts of this country and from other countries. Most of the soils in the District of Columbia have been affected in one way or another by the anthropogenic activities, resulting in the designation of an "Urban Land" soil: in many areas, several feet of miscellaneous artificial fill have been placed over streams, swamps, flood plains and tidal marshes. These areas are now mostly covered with roads, buildings or other structures. Also included are areas where more than 80 % of land is covered by impervious surfaces, irrespective of the presence of fill. Soil characteristics vary considerably in areas dominated by fill, cuts and impervious surfaces. Because of the impact of urbanization, vegetation and soils in the District of Columbia are of limited value in providing information on ground water.

3.1.4. Hydrageology

Heath (1984) classified the United States according to ground water regions (see Figure 6). Washington, DC is part of two of these regions,. namely the Piedmont and Blue Ridge Region and the Atlantic and Gulf Coastal Plain Region.

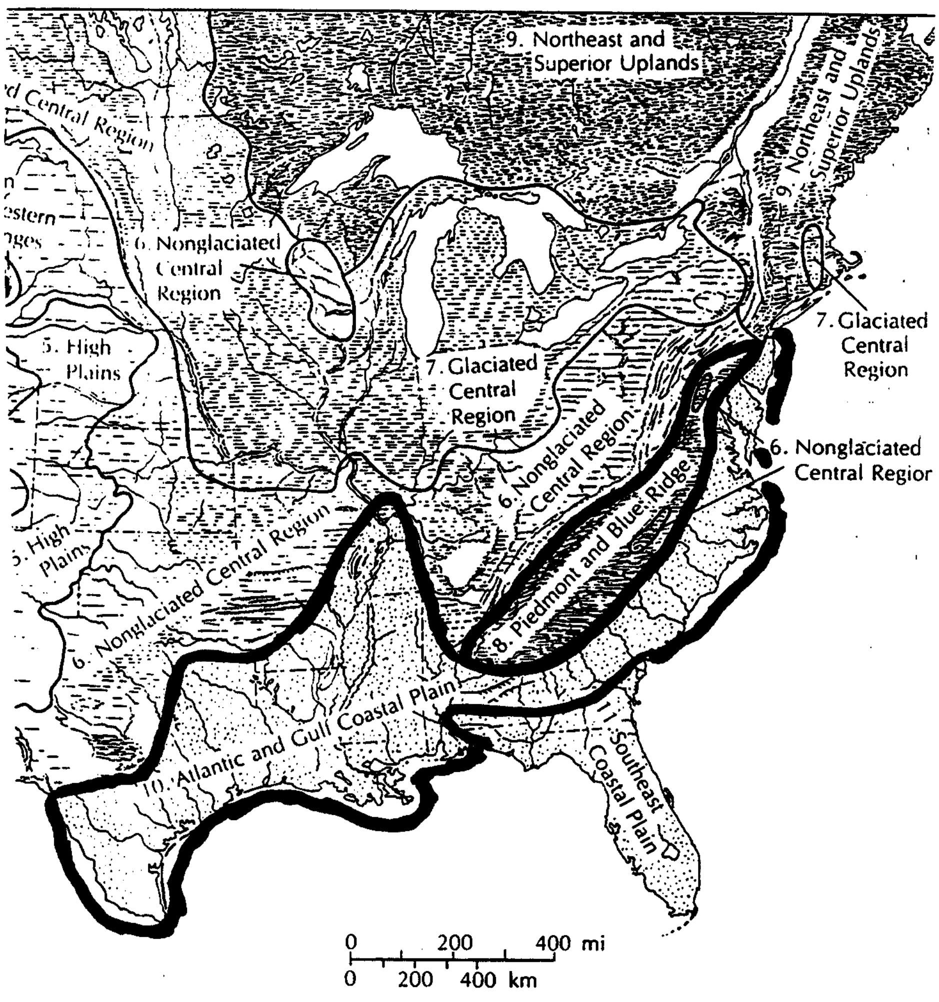


Figure 6. Eastern ground water regions of the United States (from: Heath, 1984).

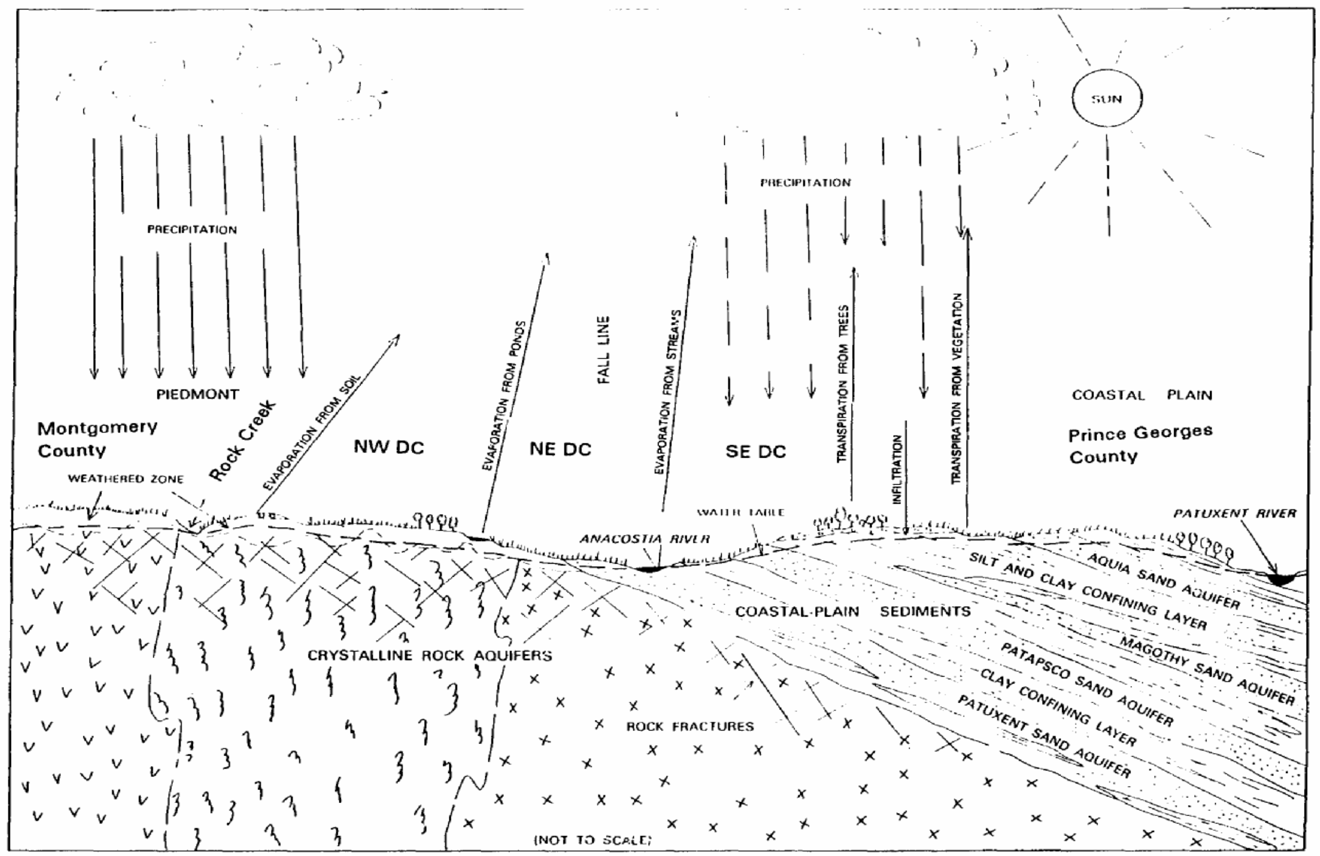


Figure 7. Hydrogeology and hydrologic cycle in the Fall Zone (adapted from: Froelich et al., 1980)

The hydrogeology in Washington, DC and its environs is very complex and encompasses the crystalline rocks of the Piedmont Province in the west and the sedimentary rocks of the Atlantic Coastal Plain in the east. Figure 7 shows schematically the major geologic features and the hydrologic cycle of this region.

Piedmont Ground Water Region

The Piedmont part of the region consists of low, rounded hills and long, rolling northeast-southwest tending ridges. The land surface in the Piedmont is underlain by clay-rich, unconsolidated material derived from in-situ weathering of the underlying bedrock (Figure 8).

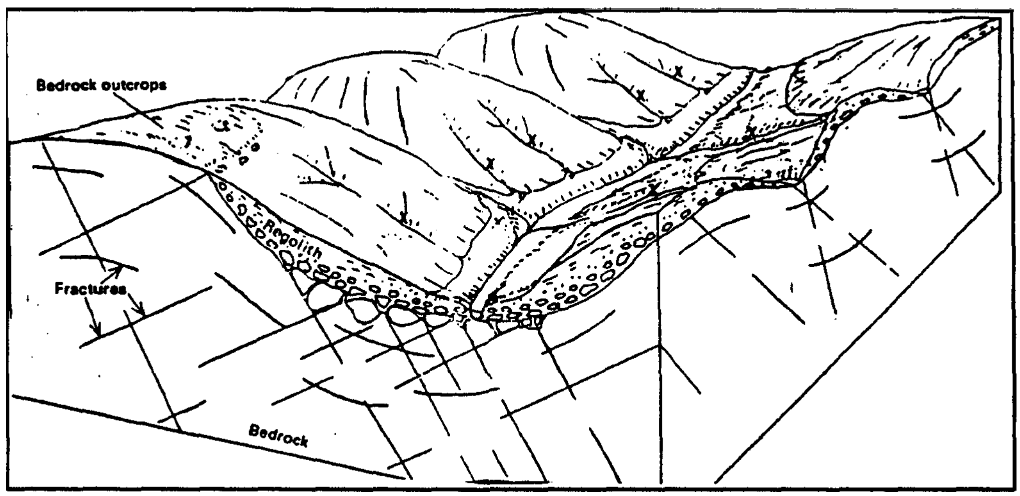


Figure 8. Topography and geology of the Piedmont ground water 1992

This material, which averages 33 to 65 feet in thickness and may be as much as 330 feet thick, is referred to as saprolite. In many valleys, especially those of larger streams, flood plains are underlain by thin, moderately well sorted alluvium deposited by streams. The term regolith is used to refer to the layer of unconsolidated deposits. The major geologic units in the District of Columbia Piedmont are the Kensington gneiss (Kg), the Georgetown mafic complex (Gm/U), and the Wissahickon Formation (Wp/Wd). The Kensington gneiss is medium to coarse, crystalline, layered to nearly massive, jointed quartz diorite gneiss. On valley slopes and uplands, it is overlain by weathered, sandy and silty, well drained saprolite as much as 120 feet thick. The Georgetown mafic complex is a mixed group of metaigneous and metavolcanic rocks consisting of fine to coarse crystalline foliated to massive jointed gabbro, tonalite, diorite, amphibolite and chloritic schist. The unit is overlain by 10 to 50 feet of poorly drained clay-rich saprolite. Also included in this unit are ultramafic rocks (serpentinite, talc schist and chlorite schist) with little or no saprolite. The Wissahickon Formation is comprised of the pelitic schist facies and the diamictite gneiss facies. The pelitic schist facies consists of fine to coarse crystalline, foliated quartz-mica schist and chlorite quartz schist. On uplands, the facies is overlain by up to 160 feet of reddish-brown, soft, micaceous, silty, well drained saprolite. The diamictite gneiss facies consists of medium to coarse crystalline, layered to massive jointed quartz-feldspar-biotite gneiss and is overlain by sandy, well drained saprolite. The saprolite can be up to 120 feet thick on uplands, but less than 25 feet thick where overlain by Coastal Plain strata (Froelich, 1975). Of these Piedmont geologic units, the Wissahickon Formation is the most important for ground water supply (Johnston, 1964). A new geologic map of the bedrock in northwest Washington, which may change some of the designations listed here, is currently under review at the US Geological Survey.

The general slope of the bedrock surface beneath the sediments is between 100 and 150 feet per mile toward the southeast. Although the generalized picture shows an evenly sloping plane surface, closely spaced borings at individual building sites reveal irregularities in the surface where detailed information is available. Such irregularities are the product of the events that comprise the geologic history of the area. The eroded surface of the bedrock was irregular at the time the earliest sediments were deposited. Erosion in more recent geologic time was responsible for additional irregularity. Under most of Washington, the bedrock is immediately overlain by the gravel, sand and in some cases clay of the lower part of the Potomac Group. To the west, where the bedrock rises to sea level and above, the Potomac deposits were deeply trenched and widely removed by erosion in later Cretaceous, Tertiary and Quaternary times. In consequence, the bared rock surface in some areas is overlain by sediments younger than those of the Potomac Group (Dayton, 1950).

In general, the Piedmont-Blue Ridge ground water region consists of a thick mantle of weathering residuum over fractured crystalline and metamorphic rock. Weathered zones in the metamorphic rocks of the Piedmont yield small to moderate amounts of water almost anywhere, with larger-yield wells possible on fracture traces. The regolith contains water in pore spaces between rock particles. Because of its larger porosity, the regolith functions as a reservoir that slowly feeds water downward into the fractures of the bedrock. The bedrock contains water in sheetlike openings formed along fractures. The fractures serve as an organized intricate network of "pipelines" that transmit water to springs, streams or wells. Although the hydraulic conductivities are similar to those found in the saprolite, bedrock wells generally have much larger yields because they have much larger available drawdown. The yield of bedrock wells depends on the number and size of penetrated fractures and on the replenishment of the fractures by seepage from the overlying regolith.

<u>Mid-Atlantic Coastal Plain</u>

The deeply weathered igneous and metamorphic rocks of the Piedmont are covered by the generally unconsolidated sediments of the Coastal Plain. In general, the Coastal Plain ground water region consists of complex sequences of interbedded (alternating and interfingering) sand, silt and clay which were deposited in a variety of sedimentary environments that are related to

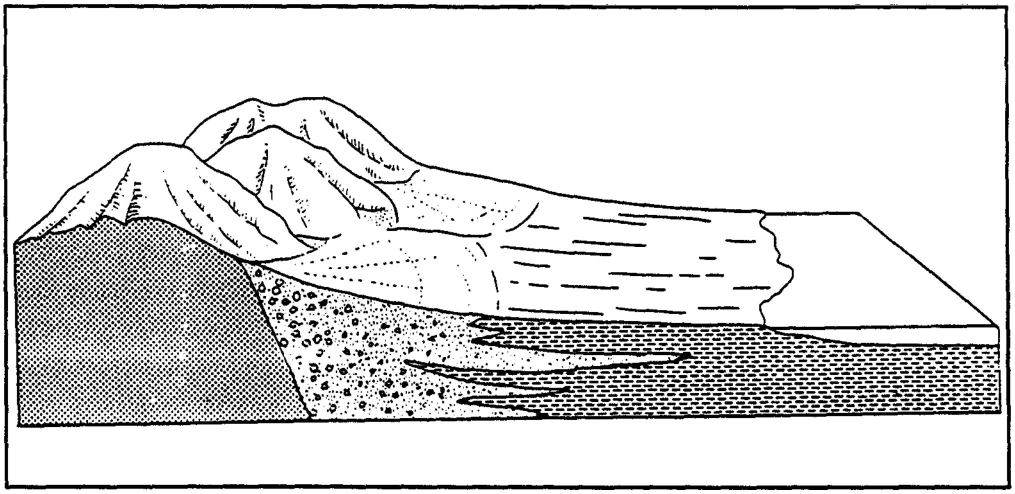


Figure 9. Topography and geology of the Atlantic Coastal Plain region (from Fetter, 1982).

sediment inputs and sea level changes (Figure 9). At the interior edge, along the Fall Line, the deposits thin out to a featheredge of a few inches and thicken toward the coast to approximately 800 feet at the southern border of the District

They consist of unconsolidated to consolidated continental and marine sediments. The sorting and grain size of sediments, as well as the thickness and distribution of sand and clay bodies, are determined by the environment of deposition and have a profound influence on aquifer characteristics. Decreasing grain size or degree of sorting results in decreasing hydraulic conductivity values. A thick aquifer with low hydraulic conductivity may have a lower transmissivity than a thin aquifer with high hydraulic conductivity. Wells that yield moderate to large quantities of water can be constructed almost anywhere within the region.

The major geologic units of the District's Coastal Plain are (from youngest to oldest) alluvium and artificial fill, river terrace deposits, upland gravel and sand, and the Potomac Group. Large areas of artifical fill occur primarily along the Potomac and Anacostia Rivers. The alluvial deposits consist of gravel, sand, silt and clay of the lowest stream terraces and stream beds. Deposits vary in thickness from a few inches to 25 feet or more. A series of flat-topped terraces at several characteristic elevations have been identified in the Washington area. These Pleistocene river terraces consist of a mixture of silty and sandy clays with sands and gravelly sands, interlayered and lensed in a complex pattern.

The complicated lithology in the terraces is the result of successive changes of sea level and volume of runoff during periods of glaciation and inter-glacial stages. At a time of ice-advance, sea level fell with respect to the land surface, stream gradients increased and sediment loads decreased, resulting in a period of erosion or downcutting. During glacier recession, stream flow increased, sea levels rose and comparatively coarse-grained materials were deposited. As the warming trend continued, the area was inundated and the finest grained sediments laid down. The terraces include the 25-foot terrace, the 50-foot terrace , and the 90-foot terrace (Figure 10). Each terrace exhibits a change in

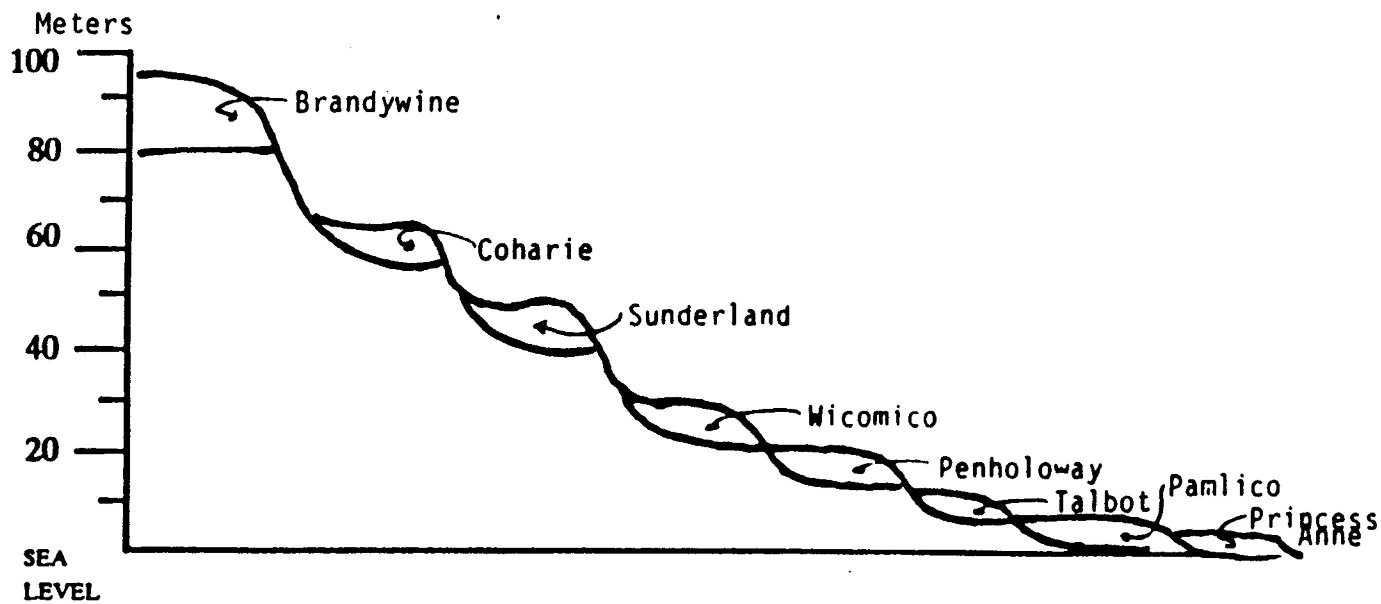


Figure 10. Diagrammatic cross-sections to illustrate the marine terraces

vertical gradation from coarse-grained and gravelly deposits at its base to sands, silts and clays at shallower depth, corresponding to the change from low sea level at the start of the ice retreat to high sea level at the interglacial period. The older 90-foot terrace has a thick base of gravelly sand with a cover of silty clay. The 50-foot terrace generally contains two cycles of the coarse to fine pattern, suggesting two cycles of ice advance and retreat without a strong erosion interval. The younger 25-foot terrace contains the most fine-grained deposits. The river terrace deposits (Qt) occur at various levels and have an average thickness of 30 feet. The basal part generally consists of unsorted boulders, pebbles and sand which grade toward the top into sand and loam. Locally, fossils and peat beds may be encountered. The upland gravel and sand deposits constitute remnants of a former plateau, much of which has been eroded. Gravel and sand occur with an average thickness of 30 feet and the coarser material is found at the base. The youngest stream terraces are grouped as recent river alluvium, together with artificial fill

Outcrops of the Calvert Formation (Tc), the Aquia Formation (Ta) and the Monmouth Formation (Km) are present as isolated occurrences in the District of Columbia. The Calvert Formation consists of very fine sand mixed with clay and occurs in thickness between 20 and 80 feet. The Aquia Formation has moderately fine sand with clay, and where weathered, with iron concretions. The thickness is generally less than 50 feet. Similarly, the thickness of the Monmouth formation rarely exceeds 50 feet of dark micaceous sand.

The Potomac Group consists of two facies: the clay and silt facies (Kpc) and the sand and gravel facies (Kps). The sand and gravel facies is part of the interstate Patuxent aquifer that provides drinking water to parts of Maryland. The unit overlies crystalline rock and consists of gravel, sand and arkose with occasional sandy clay lenses. The clay and silt facies is made up of silty clay with interbedded irregular sand and gravel lenses. Also called Anne Arundel Clay and Patapsco Formation, the unit forms the recharge area of the regional Patapsco Aquifer that is used as a drinking water supply in parts of Maryland.

Figure 11 shows the geologic map of the District of Columbia, indicating the locations of the geologic units discussed above.

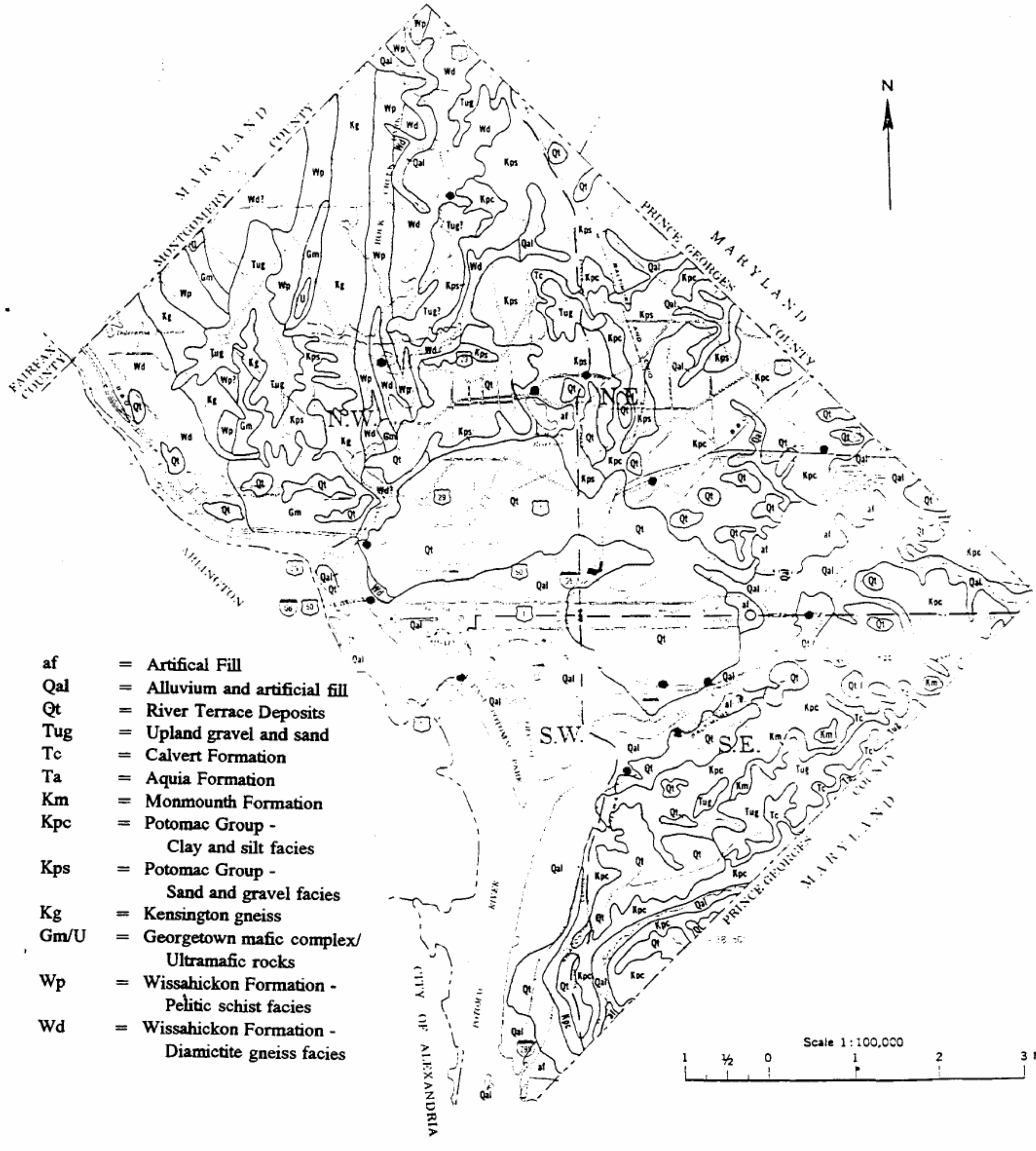


Figure 11. Preliminary geologic map of the District of Columbia (from USDA, 1976)

3.2. AQUIFER OCCURRENCE AND CHARACTERISTICS

For the purpose of this study, an aquifer is defined in general as a hydrostratigraphic unit that is saturated, permeable, and capable of yielding water to a well or spring. A hydrostratigraphic unit is a geological formation, group of formations, or part of a formation with. similar hydrologic characteristics. Based on these definitions, four aquifer types exist in the District of Columbia: 1) the crystalline rock aquifer in the Piedmont, 2) the perched aquifers in the Coastal Plain, 3) the surficial aquifer in the Coastal Plain, and 4) the Potomac Group Aquifer in the Coastal Plain. For each aquifer, the following pages describe the physical and hydraulic characteristics, recharge and discharge patterns, ground water/surface water interaction and ground water elevations. Table 2 shows the relationship between geologic series, stratigraphic unit and the local aquifers.

Table 2. Local Stratigraphy

Geologic Time	Stratigraphic Unit	Local Aquifer
Holocene to Pliocene Epoch	Fill Alluvium River Terrace Deposits Upland Gravel and Sand	Surficial Coastal Plain Aquifer
Miocene Epoch	Calvert Formation (Chesapeake Group)	Perched Aquifer
Paleocene Epoch	Aquia Formation (Pamunkey Group)	Perched Aquifer
Upper Cretaceaous Period	Monmouth Formation	Perched Aquifer
Lower Cretaceaous Period	Potomac Patapsco/Arundel Group Patuxent	Potomac Group Aquifer
Precambrian Era Lower Paleozoic Era or both	Kensington Gneiss Georgetown Mafic Complex Wissahickon Formation	Crystalline Rock Aquifer

To complement the already available ground water information, thirteen wells were installed during the Ground Water Resource Assessment Study (GWRAS). The well installation method varied by depth and aquifer material (see Table 3). Five wells were installed to reflect the major hydrogeologic provinces in the District of Columbia, namely the Potomac Group (MW-1, 2), the crystalline rock (MW 3), and the surficial terrace and alluvial deposits (MW-4, 5). To assess the impact of nonpoint source pollution, the remaining eight wells were installed in shallow ground water in community gardens (MW-A1,2,3 and MW-B1,2,3) and a golf course (MW-C1,2). MW A1,2,3 and MW B1,2,3 are located in the surficial terrace and alluvial deposits, while MW C1,2 tap ground water in the weathered crystalline rock. Information from all thirteen wells has been included in the following aquifer characterization. A general location map of the thirteen wells is provided in Figure 12. The well numbering system is alphanumeric, with numerals to indicate well locations and letters to indicate site locations. Thus, each Group A well was assigned a number, since only one well was installed at each site. Each Group B well was assigned a character to indicate the site, and a number to indicate the well.

Table 3. Well Installation Method

Well	Depth (ft)	Aquifer Media	Method
MW-1	250	Unconsolidated clay, sand	Hydraulic (Mud) Rotary
MW-2	50	Unconsolidated fill, sand, gravel, clay	Hollow-Stem Auger
MW-3	100	Massive, fractured rock	Air-Percussion Rotary
MW-4	30	Unconsolidated fill, sand, gravel, clay	Hollow-Stem Auger
MW-5	22	Unconsolidated fill, sand, gravel, clay	Hollow-Stem Auger
MW-Al,2,3	22	Unconsolidated fill, sand, clay	Hollow-Stem Auger
MW-B1,2,3	19	Unconsolidated fill, sand, gravel	Hollow-Stem Auger
MW-C1,2	18	Unconsolidated saprolite	Hollow-Stem Auger

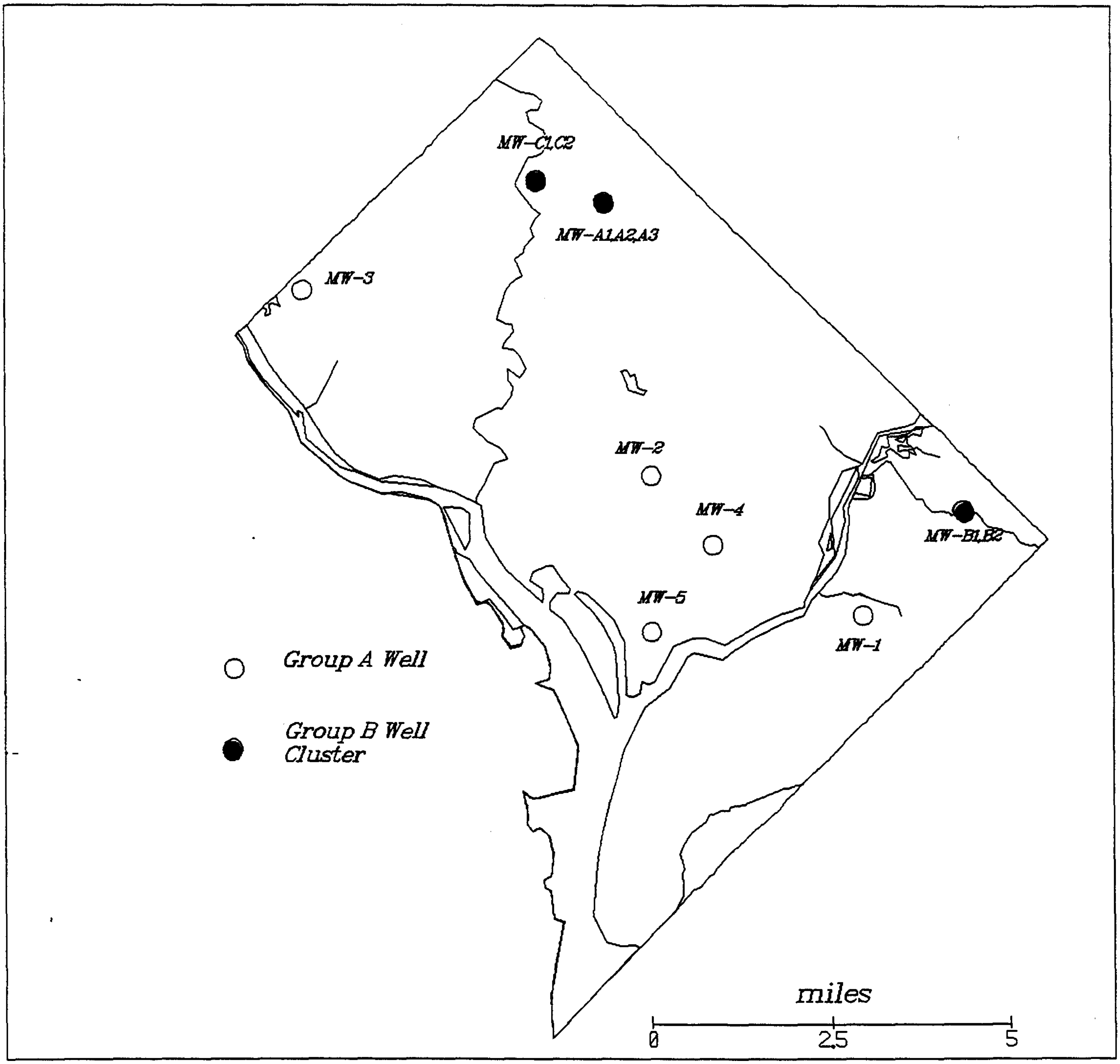


Figure 12. General location map of ground water monitoring wells installed during the ground water resource assessment study

3.2.1. The Crystalline Rock Aquifer

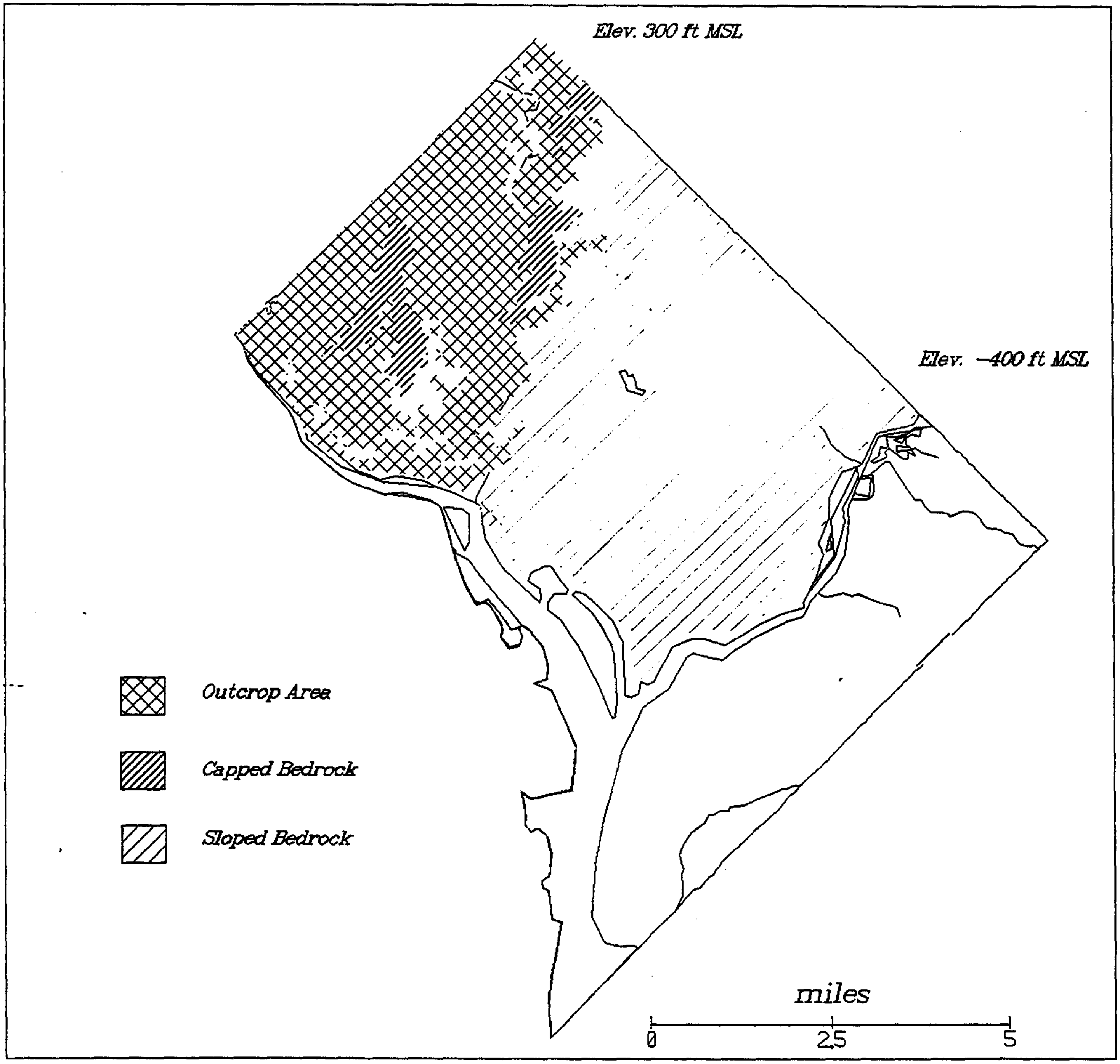


Figure 13. Areal extent of the crystalline rock aquifer.

Figure 13 shows the areal extent of the crystalline rock aquifer. Cross-hatched shades indicate the outcrop area, lines were used when boundaries had to be inferred. The bedrock aquifer occurs both exposed in the western part of the city and overlain by unconsolidated Coastal Plain sediments in the eastern part of the city. The top of bedrock in DC ranges from 230 feet above sea level at 5th and Tuckerman Streets, NW to 300 feet below sea level at the Capitol to 1000 feet below sea level along the southeastern boundary of the District. The depth of the aquifer reaches 400 feet below sea level along the Anacostia River. Below that depth, the occurrence of fractures is rare, so that the 400 foot contour on top of bedrock can be considered the boundary for the bedrock aquifer (Johnston, 1964).

Crystalline rock itself, because of its compact fabric, yields little water to wells. Ground water is contained in fractures and in places of contact between rock bodies as well as in the weathered material called saprolite which overlies the bedrock in various degrees of thickness. Saprolite results from chemical weathering of crystalline rock. The saprolite contains water in pore spaces between rock particles. The saturated thickness of the aquifer varies with the depth of the saprolite cover and precipitation. Weathered zones in the metamorphic rocks of the Piedmont yield small to moderate amounts of water almost anywhere, with larger yields possible on fracture traces. This ground water supply can be developed locally along joints and faults and can yield medium amounts of water under those conditions. The hydraulic conductivities of saprolite generally range from 0.003 to 3 feet per day. In the District of Columbia, the overall median permeability coefficient for decomposed rock is 1.44 ft/day, which is equivalent to the values commonly associated with silts, sandy silts, and clayey sands (Mueser et al., 1967). The material has porosities of 40 to 50 percent and a specific yield of 15 to 30 percent (EPA, 1992; Fetter, 1988). Transmissivity for shallow ground water in saprolite, as determined during the GWRAS, ranges from 34 to 587 gpd/ft (DC WRRC, 1993).

Most of the crystalline rocks in this area have been considerably disturbed by earth movement and so contain water-bearing strictures to some degree. However, evidence as to the course and amount of such flexures and faults is diffcult to obtain. The general trend of geologic uplifts and depressions has been along northeast-southwest axes, but there probably has been much local variation in trend and amount. A few dip-slip faults in the bedrock and overlying strata have been observed in the western part of Washington, but the displacement is small and apparently the faults are rather short, except for the Rock Creek shear zone. The bedrock contains water in sheetlike openings formed along fractures. The porosity of the bedrock ranges from 0.01 to 2 percent. The fractures serve as an intricate network of "pipelines" that transmit water to springs, streams or wells. Although the hydraulic conductivities of 0.003 to 3 feet per day are similar to those found in the saprolite, bedrock wells generally have much larger yields because they have much larger available drawdown. The yield of bedrock wells depends on the number and size of penetrated fractures and on the replenishment of the fractures by seepage from the overlying regolith. The overall median permeability coefficients for bedrock of all types is

0.58 ft/day (Mueser et al., 1967). The lowest yields of less than 10 gpm from bedrock wells have been reported for the Georgetown mafic complex, which lacks the reservoir function of thick layers of saprolite. The highest yields of more than 100 gpm were reported from wells in the Wissahickon Formation. Intermediate yields of up to 30 gpm were reported for the Kensington Gneiss. Average depth of wells drilled in the bedrock range from 104 feet to 198 feet (Johnston, 1964). Transmissivity as determined during the GWRAS is around 100 gpd/ft (DC WRRC, 1993).

Ground Water/Surface Water Interaction

Recharge/Discharge Patterns

Since the Piedmont has no water-bearing structural feature in the Washington area that has a continuous areal extent of more than a few miles, ground water in the Piedmont originates as precipitation in or near the local watershed. In forested areas, even on steep slopes, most of the precipitation seeps into the very permeable soil zone, and most of this moves laterally through the soil and a thin temporary saturated zone to discharge in surface depressions or streams. The remainder seeps into the regolith below the soil zone and ultimately into the underlying bedrock. Recharge to the ground water system occurs on the areas above the flood plain of streams such as Rock Creek, and natural discharge occurs as springs and as seepage into streams. The discharge areas for the bedrock aquifers are Rock Creek and the Potomac River as well as the sedimentary deposits of the Coastal Plain, where fractures intersect these overlying deposits. Contours on the top of the bedrock are commonly aligned parallel to the regional foliation. This suggests that subsurface routes of fluid migration may also be influenced by the orientation and inclination of these foliation planes.

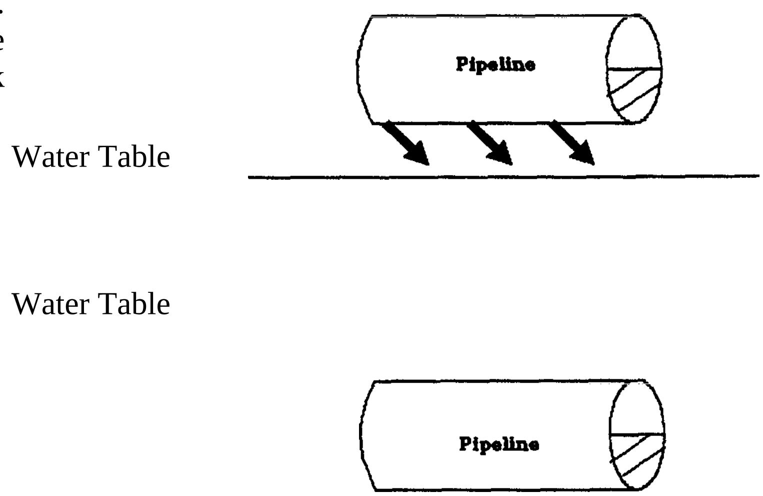


Figure 14. Ground water recharge and discharge related to water-bearing pipelines

In addition to the natural recharge and discharge areas, sanitary and storm sewers as well as drinking water pipelines traverse the bedrock aquifer and must be considered as potential recharge and discharge points. Figure 14 illustrates the principle involved: a water table located below the water-bearing pipeline is recharged from the pipe, while a water table located above the water-bearing pipeline discharges into the pipe. The extent of ground water interaction with pipelines in the bedrock aquifer is dependent on the location of the fractures with respect to the pipelines or reservoirs.

Generally, ground water in humid regions discharges into streams, providing base flow of the streams both during dry and wet seasons. The amount of discharge is directly proportional to the hydraulic gradient toward the stream. A normally gaining stream may temporarily become a losing stream during floods, if the flood crest is higher than the water table elevation. Then, the gradient is reversed and the stream may discharge its water to the ground water instead. The hydraulic gradient from the water table to the stream can be increased or even reversed by pumping a ground water well in the vicinity of the stream, for example during dewatering. The base flow of streams depends on the surrounding geology, topography, drainage pattern, and soils of the watershed. On crystalline bedrock, overland flow is high and base flow is low. Most precipitation reaches rivers as surface runoff, while ground water contributes very little water to streams. Ground water/surface water interaction in the bedrock aquifer is related to the events in the saprolite. The bedrock aquifer obtains most of its recharge from the overlying saprolite deposits. Where the deposits are small or missing, little water enters the bedrock. Where the bedrock aquifer is replenished from overlying saprolite, direct discharge to streams may occur in locations where fractures intercept the stream bed. For example, the shallow aquifer encountered during the well installation near Dalecaurlia Parkway was most likely in hydraulic connection with the nearby stream, since the fracure system extended into the stream bed (DC WRRC, 1993).

Figure 15 illustrates ground water flow patterns in the crystalline rock aquifer. Thick saprolite deposits would act as storage reservoirs for precipitation, slowly releasing the water to draining streams, resulting in perennial stream flow. Thin saprolite deposits would retain very little water, resulting in intermittent streams. Only Broad Branch and Soapstone Valley Branch are shown as perennial streams on the USGS quadrangle map of 1983, while all other tributaries are intermittent at least in their upper reaches. Klingle, Melvin Hazen and Piney Branch are shown as intermittent streams for the full length of their reaches, indicating that little ground water enters these streams. Since their reaches drain residential land, a possible explanation is that the extensive network of storm sewers captures much of the precipitation, so that rain water enters the streams at stormwater outfalls rather than through ground water seepage along the streams. Outside of the Rock Creek Park area, very little remains of the original drainage network, since most of the small streams have been filled or converted into sewers.

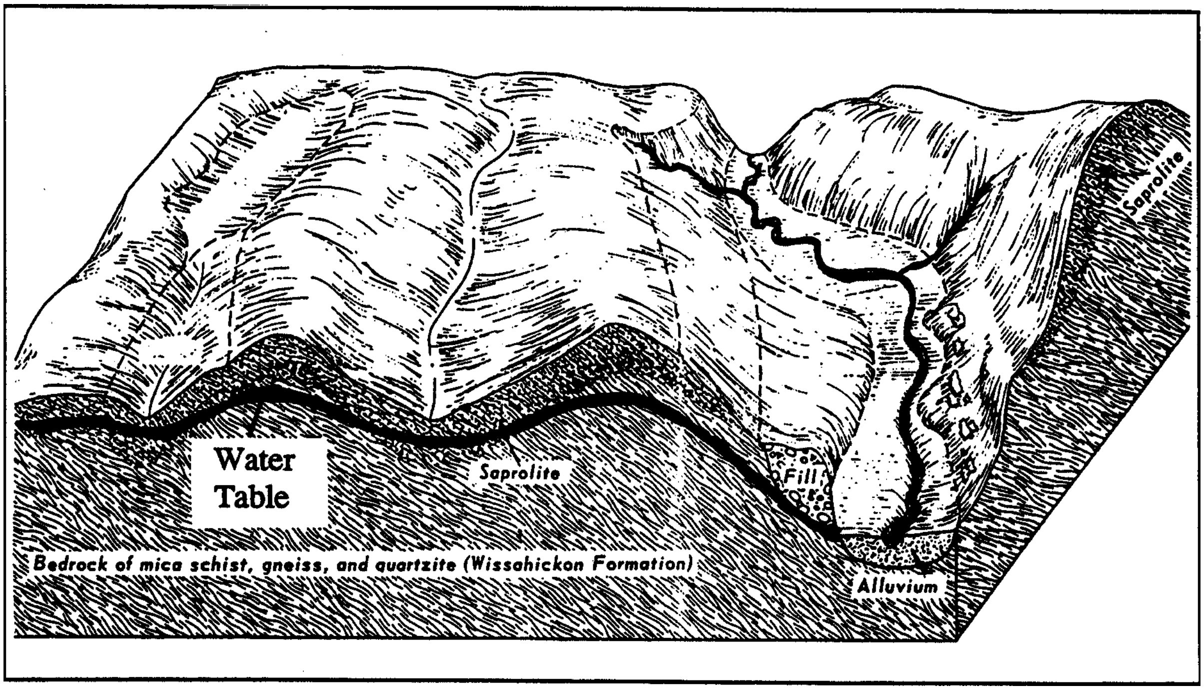


Figure 15. Typical ground water occurrence in the crystalline rock aquifer (adapted from: USDA, 1976)

3.2.2. The Perched Aquifers

Aquifers that occur as a layer of saturated soil above the main water table are called perched aquifers. In these cases, a layer of low permeability material forms a lens in more permeable materials. Water moving downward through the unsaturated zone will be intercepted by this layer and will accumulate on top of this lens. Water from a perched aquifer moves laterally above the low-permeability layer up to the edge and then seeps downward toward the main water table or forms a spring. Perched aquifers are usually not very large and most would supply only enough water for household use.

While ground water present in the form of perched tables may be sufficient for domestic water supplies, it is of overall little significance in the city's ground water system. However, ground water from perched tables eventually seeps downward to the water table (Figure 16) and may thus affect water quality in the water table aquifer, which in turn drains into surface waters such as the Anacostia River.

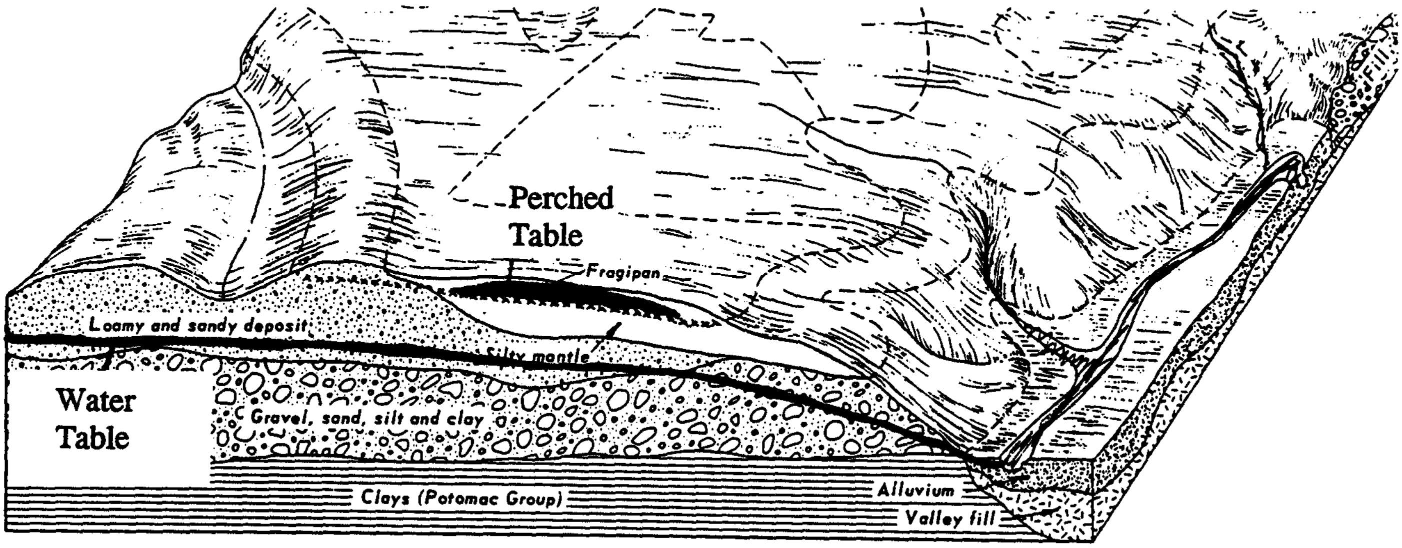


Figure 16. Ground water occurrence in the perched tables in the District of Columbia (Adapted from USDA, *1976).*

According to the USDA Soil Survey, perched tables are encountered within the top 6 feet of the soil profile in the downtown area as well as along the southeastern border of the District due to downward flow being unpeded by clay layers and fragipans. Figure 17 shows the areal extent of the perched tables based on USDA's definition. Little is known as to the exact locations, extent and duration of these perched table aquifers. The USDA soil survey describes them as temporary during the winter and spring only.

Other investigators (O'Connor and Kirkland, 1991; Schnabel Engineering Associates, personal communication, 1993) have classified as "perched tables" those ground water lenses that are associated with the Quaternary terraces. These ground water lenses often do not match the textbook definition of a perched table, because the underlying aquifers are mostly confined instead of unconfined. The possibility exists, however, that urbanization dewatering has in some places created perched tables where there used to be a contiguous water table aquifer.

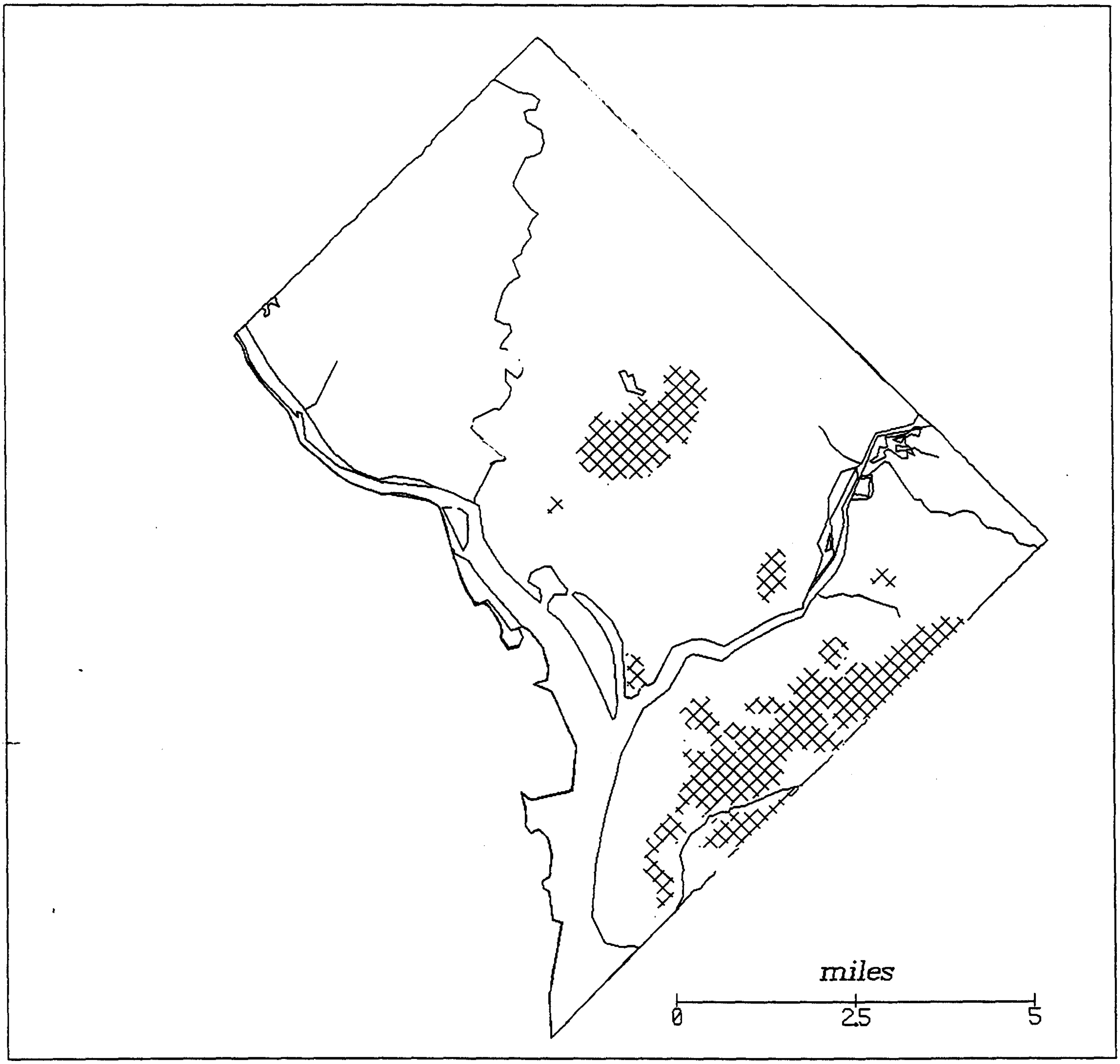


Figure 17. Areal extent of perched tables in the District of Columbia.

3.2.3. The Coastal Plain Surficial Aquifer

An aquifer close to the land surface, with continuous layers of materials of high intrinsic permeability extending from the land surface to the base of the aquifer, is termed a water-table aquifer or unconfined aquifer.

Figure 18 shows the areal extent of the Coastal Plain surfcial aquifer. The Coastal Plain surficial aquifer is comprised of the water table aquifer occurring in the unconsolidated Coastal Plain sediments of the District. The surf cial aquifer is composed of a veneer of Upper Miocene to Holocene age sediments that mantle Cretaceous and older Tertiary sediments. West of the Chesapeake Bay, the aquifer is composed primarily of Quaternary and possibly Tertiary sediments from upland (> 40 ft above sea level) and lowland (< 40 ft above sea level) deposits. The top of the surficial aquifer is the water table. In Washington, DC, the surficial aquifer is comprised of alluvium and artificial fill as well as river terrace deposits. As mentioned in chapter 3.2.2., the ground water occurring in the terrace deposits is sometimes also called "perched tables". For this assessment, those "perched tables" that occur below a depth of six feet are included in the surficial aquifer.Alluvium and artificial fill consist of gravel, sand, silt and clay of the lowest stream terraces and bottoms. The thickness ranges from a few inches to 25 feet or more. Large areas of fill are commonly encoutered along the Potomac and Anacostia Rivers. Gravel, sand and loam deposits with an average thickness of 30 feet comprise the river terrace deposits. The basal part is generally unsorted boulders, pebbles and sand. Locally, plant fossils and peat beds may occur.. Isolated occurrences of the terrace deposits as well as the upland sand and gravels and the outcrops of the Aquia, Calvert and Monmouth Formations have not been included in the delineation of the surficial aquifer. Due to the limited areal extent of most terrace deposits occuring outside the downtown area, it is assumed that the deposits occur above the water table. The Calvert, Aquia and Monmouth Formations appear to hold water only temporarily as perched tables.

The overall median permeability coefficient for the Pleistocene sands and gravelly sands is 7.2 ft/day (Mueser et al, 1967), equivalent to values for silty to fine sands. However, certain materials, particularly cohesionless single-size sands in the alluvium and terraces are of much higher permeability than the median values above. Highest values are equivalent to 144 ft/day to 720 ft/day (well sorted sands). During the GWRAS, wells were installed at four locations within the surficial aquifer. Depths to water varied from 24 feet to 8 feet. Transmissivities ranged from 195 to 3,000 gpd/ft, indicating locally productive layers.

<u>Recharge/Discharge</u>

The general recharge and discharge patterns in the surficial aquifer are shown on Figure 16 above. The water from the shallow water-table wells in the Coastal Plain originates as

Figure 18. Areas extent of the surficial aquifer in the Atlantic Coastal Plain of the District of Columbia

precipitation in or near the local watershed or basin. Generally, recharge to the ground water system occurs in the interstream areas, both where sand layers outcrop and by percolation downward across the interbedded clay and silt layers. Recharge through upward seepage from the underlying layers is also possible, but has not yet been documented. Historically, discharge from the system occured by seepage to springs, swamps, marshes and streams. However, the many springs, swamps and streams that once drained the surficial aquifer in the District of Columbia have disappeared. They have been filled, piped to sewers or dried up because of the increasing imperviousness of the land surface, which routed rainfall to the stormsewers instead of allowing infiltration into the ground. Today, most of the natural drainage from the surficial aquifer is into the Anacostia River and its few remaining tributaries, with some discharge directly into the Potomac River and some into Oxon Run.

In the urbanized surficial aquifer, several other factors affect recharge and discharge patterns. Recharge is diminished on the one hand due to largely impervious surface areas. On the other hand, recharge may augmented by seepage from water-bearing pipelines. Discharge in general is increased, particularly in the downtown area, where sump pumps and construction dewatering remove considerable quantities of ground water. In 1981, a sewer system evaluation attributed as much as 773, 908 gallons per day of sewer flow to ground water inflow (DC DES, 1983).

Ground Water/Surface Water Interaction

In the downtown area of the Coastal Plain surficial aquifer, few open streams have remained of the natural stream drainage system. Only the Anacostia River and Hickey Run remain, while Tiber Creek and many other small tributaries have been filled or converted into sewer lines. Consequently, direct ground water/surface water interaction is limited to these two streams. Kingman Lake and some wetlands along the northern boundary of the Anacostia River in the District also interact with the ground water. No quantitative data as to the extent of that interaction are available. Replacing the natural system of ground water/surface water interaction is an interactive exchange between ground water and the network of pipelines that transsects the area. Through stormwater outfalls, ground water may reach the surface water bodies on an indirect route. The interaction between ground water and water-bearing pipelines in the downtown area is shown on Figure 19.

On the eastern shore of the Anacostia, a few tributaries such as Watts Branch and Pope Branch serve as discharge points to the ground water. Due to the clay deposits underlying much of the drainage area of these eastern tributaries, ground water/surface water interaction is most likely very slow, except in the presence of gravelly, sandy terrace deposits overlying the clay.

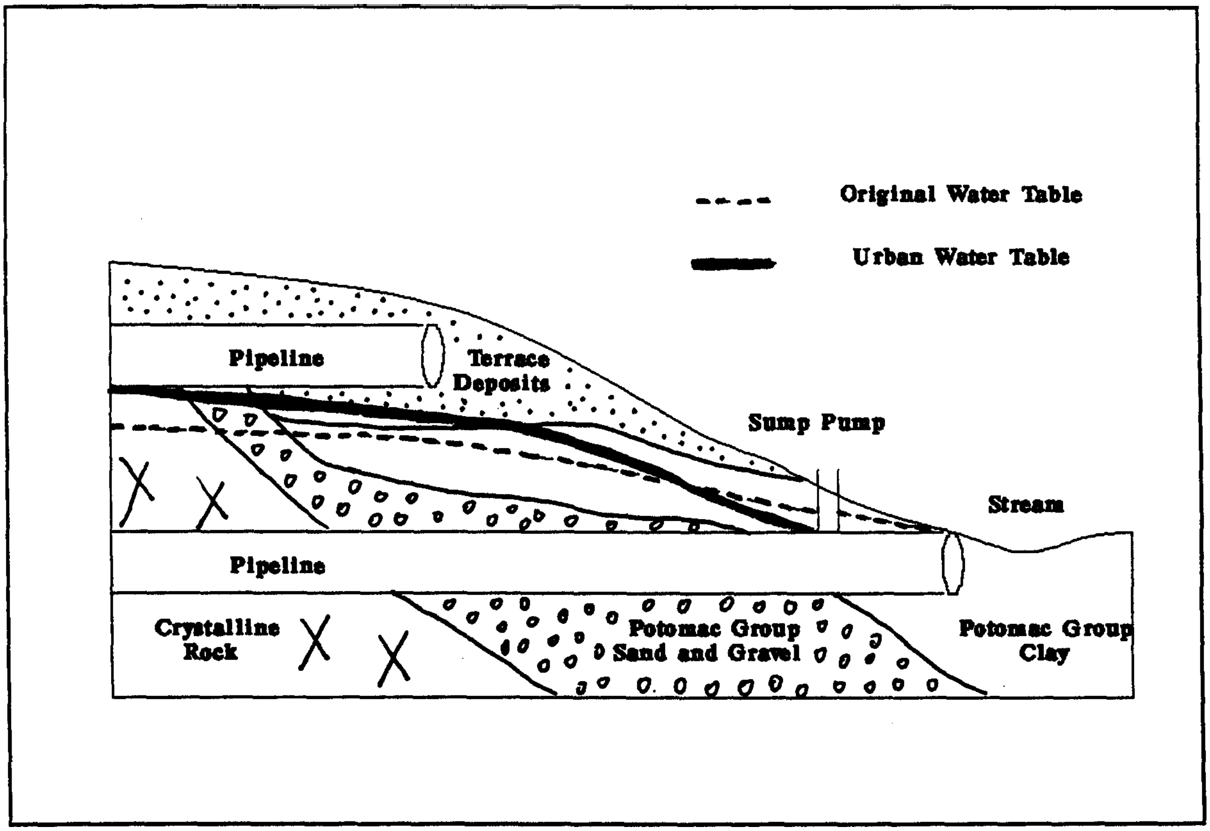


Figure 19. Interaction between pipelines and ground water in the surficial aquifer.

3.2.4. The Potomac Group Aquifer

Confined, or artesian, aquifers are overlain by a confining layer, or aquitard. The Potomac Group aquifer is a confined Coastal Plain aquifer actually comprised of three regional formations: the Patapsco Formation, the Arundel Formation and the Patuxent Formation. Differentiation among the three formations, however, is difficult due to their interfingering in the District, resulting in the designation of one local aquifer, i. e. the Potomac Group Aquifer (Froelich, 1975). Locally, each aquifer may contain confining beds, or a confining unit may contain water-bearing zones. However, on a regional basis, the aquifers and confining units form continuous hydrogeologic units in the Coastal Plain of Virginia, Maryland, Delaware and the District of Columbia. A description of the three units is based on the USGS RASA project (Vroblesky, 1991).

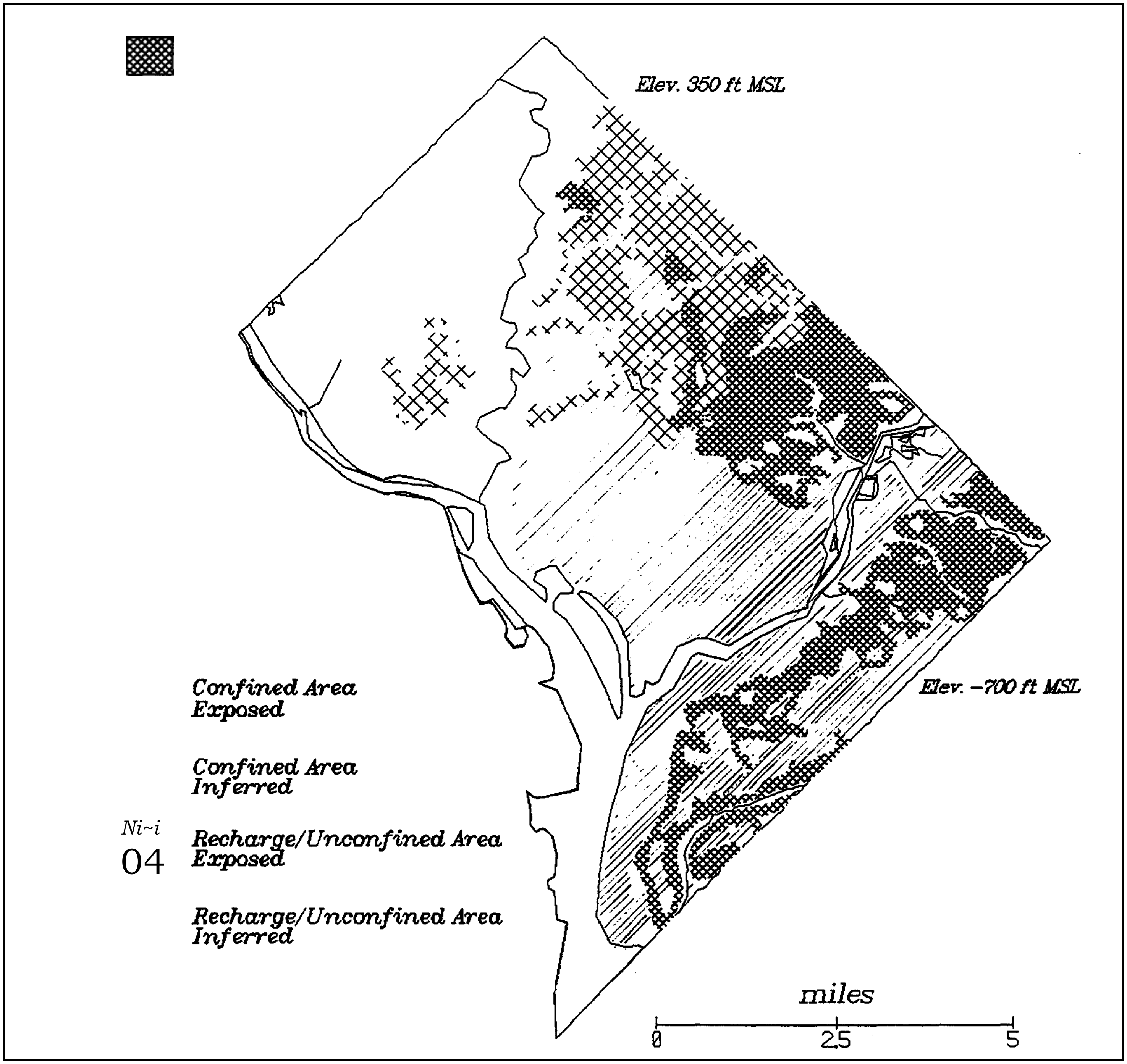


Figure 20. Areal extent of the Potomac Group aquifer.

Figure 20 shows the areas extent of the Potomac Group aquifer. Darker shades indicate the outcrop area of the aquifer, lighter shades were used when boundaries had to be inferred. The Cretaceous coastal plain sediments consist of a succession of wedge-shaped layers which were deposited in relatively shallow seas on the sloping bedrock surface by streams flowing eastward out of the interior. The interfaces of successive Cretaceous formations dip toward the southeast and the wedge thickens in the same direction.

The western boundary of the Patuxent Aquifer, or lower Potomac Group aquifer, is the outcrop area at the Fall Line. The aquifer extents to the Delmarva Peninsula. in the east. In general, the percentage of sand, sand thickness and transmissivity of the aquifer decrease southward from Baltimore to the Potomac River. Transmissivities of individual sand layers within the Patuxent aquifer near Baltimore are approximately 7,000 ft2/d, and the average storage coefficient is reported to be about 0.00026.

In the District of Columbia, the thickness of the Potomac Group increases toward the southeast where it exceeds 700 feet. Where the aquifer is confined, the top of the aquifer is the contact with the overlying Potomac confining unit. In the outcrop area, the top of the aquifer is the water table. In its unconfined state, the unit is hydraulically connected with the Coastal Plain Surficial Aquifer, with which it forms a single unconfined aquifer. The basal part of the Patuxent aquifer in the west of the District is gravel, sand and arkose with occasional sandy clay lenses, and overlying crystalline rock. The Patuxent aquifer is a multi-layered system. Sand layers associated with the basal sediments tend to be thick, irregularly bounded sheets having relatively high permeability. Near the upper part, the sand layers are thin, isolated lenses or ribbons having low permeability. Delineation of a single sand layer within the Patuxent aquifer is difficult over even short distances. Assuming hydraulic interconnection, all sand layers within the aquifer can be considered to act as a single aquifer. Water yields of wells in the Patuxent Formation were reported to range from 10 to 300 gpm, with an average of 80 gpm (Johnston, 1964). According to Mueser et al. (1967) The overall median permeability coefficient for the Cretaceous sands and gravelly sands of the Potomac Group aquifer is 4.32 ft/day (silty to fine sands), but cohesionless single-size sands of the Potomac group deposits are of much higher permeability than the median values above. Highest values are equivalent to 144 ft/day to 720 ft/day (well sorted

During the GWRAS, the Potomac Group aquifer was encountered near the outcrop area at a depth of 45 feet at New York Avenue and First Stmt, NW. Further downdip, the aquifer was found at a depth of 238 feet at Ft. Dupont Park. Transmissivities determined at the two sites ranged from 30 ft2/d (200 gpd/ft) to 1,440 ft2/d (8,000 gpd/ft), reflecting the great variability particularly in the outcrop area where interbedding is more common. Other field investigations encountered two, and sometimes three water-bearing layers in this formation (Darton, 1950; Schnabel Engineering Associates, personal communication).

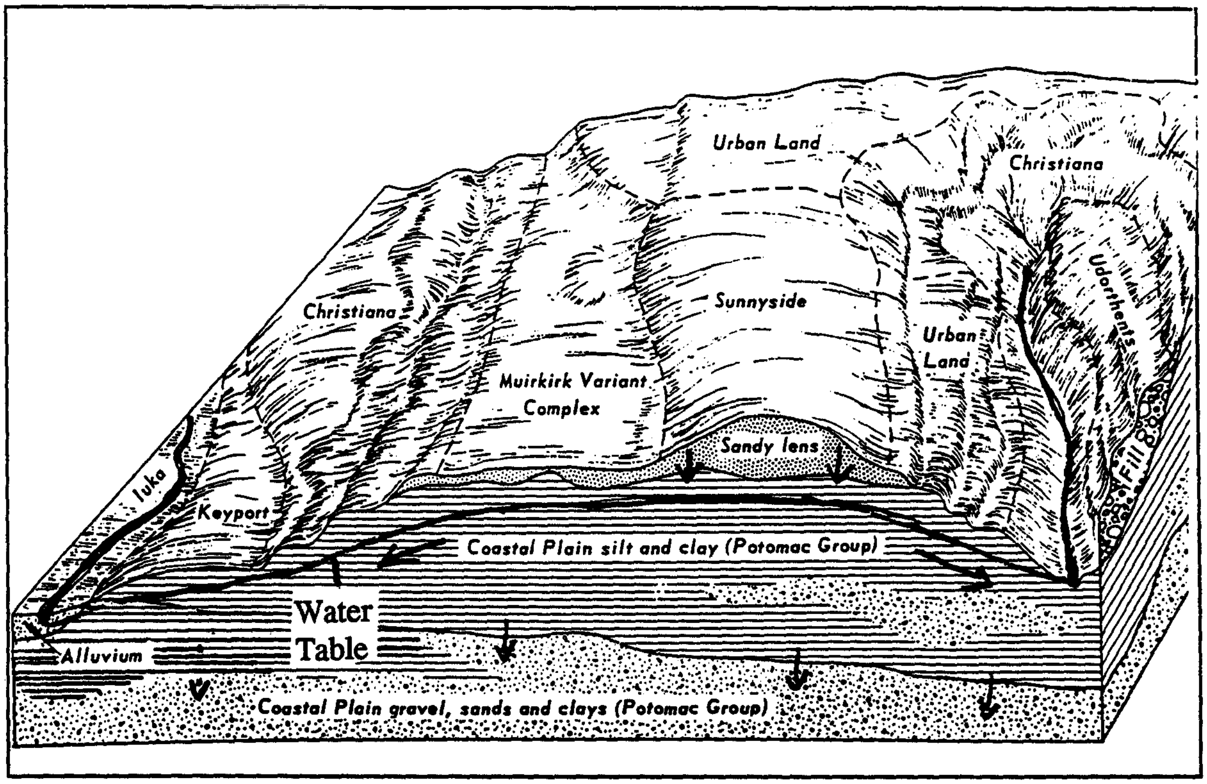


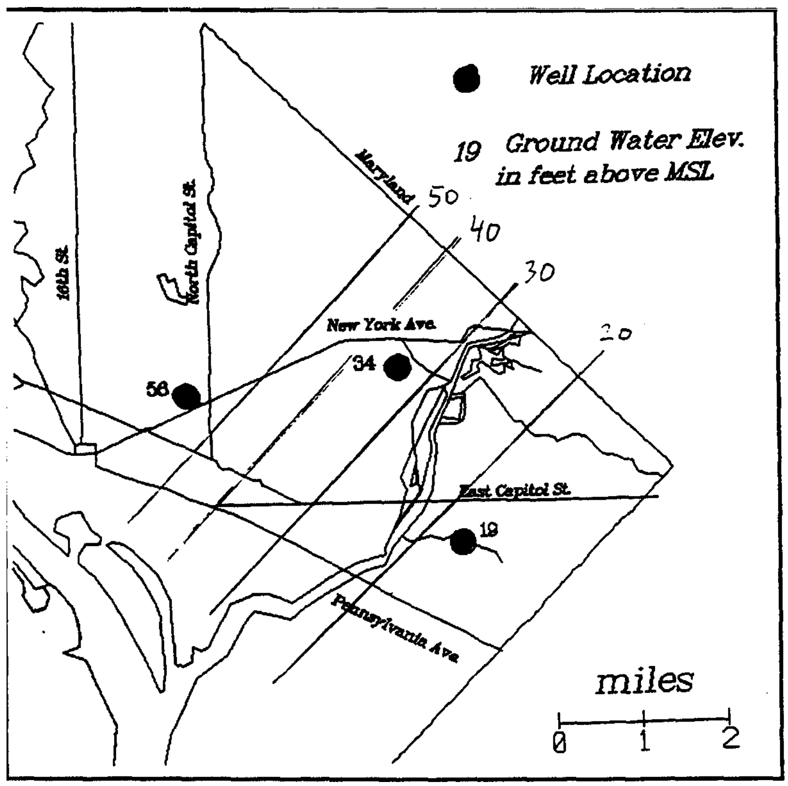
Figure 21. Ground water movement in the Potomac Group aquifer.

While the Potomac Confining Unit and the Patapsco Aquifer are differentiated on a regional basis, in the District of Columbia, the two formations as classified not as separate units, but rather in conjunction as a unit called Patapsco Formation and Arundel Clay. The associated clay, with very limited water-bearing capacity, is the predominant sediment in the District of Columbia. The clay is dense, massive or laminated, and variegated in shades of red, gray, brown, and purple. During the drilling process, the unit can be identified by its toughness and resistance to penetration. The Potomac confining unit in the eastern part of the District consists of pink, red and gray silty clay with interbedded irregular sand and gravel lenses that grade into clay. The unit contains plant remains, fossils, and lignite. This clay unit forms the confining layer for the Patuxent aquifer. Ground water in this confining unit moves very slowly and is of no consequence in the determination of water yielding aquifers. However, contaminants can traverse this unit, albeit slowly. With the hydraulic connection of the clay unit to both the underlying drinking water aquifer and adjoining surface waters (i.e. Anacostia River and its tributaries), the potential contaminant transport within the unit could have far-reaching effects.

Recharge/Discharge

In the Coastal Plain, most of the confined ground water originates in the outcrop area of the aquifer involved, which lies in the northern part of Washington. Additional recharge sources are sewer and drinking water pipelines which traverse the entire local outcrop area of the Potomac Group Aquifer. With increasing proximity to the Anacostia River, the aquifer dips below the pipelines, which at that point run through the Anne Arundel clays. Some seepage from the clay layer into the aquifer may also exist. While the clay ususally acts as a barrier for downward flow, urban construction for bridges, tunnels and highrises has the potential to penetrate the clays, causing a "short-circuit" to the underlying aquifer. Figure 21 shows some of the recharge and discharge patterns in the Potomac Group aquifer.

Discharge from the water table portion of the aquifer in the outcrop area is primarily to the confined aquifer. Some ground water may also be discharged into the McMillan Reservoir and into sewer and drinking water pipelines. Seepage springs along the boundary with the confining unit used to serve as discharge points, but have been filled or piped into sewers. Finally, discharge may occur into the surficial Coastal Plain aquifer in the District. Excepting the outcrop area, natural discharge from the confined Potomac Group aquifer is unlikely within the District of Columbia. Dewatering activities and localized use of the aquifer as a source of irrigation water (e.g. at the National Arboretum) provide artificial discharge points. To the east, ground water is withdrawn from the aquifer as a drinking water supply, and eventually ground water discharges into the Atlantic Ocean.



Fig= 22' Potentiometric surface in the Potomac Group Aquifer

Ground Water/Surface Water Interaction

The only surface water body within the area of the confined Potomac Group aquifer is the Anacostia River. However, the aquifer is several hundred feet below the surface so that direct ground water/surface water interaction would be non-existent. Upward seepage through the clay is probably also limited. In the outcrop area, some interaction may exist between the ground water and the McMillan Reservoir.

Potentiornetric Surface

The potentiometric surface grades from 56 feet above mean sea level at New York Avenue, NW to 19 feet above mean sea level at Ft. Dupont Park. Using the elevation of 34 feet above mean sea level which was measured at the National Arboretum (Schnabel Engineering Associates, personal communication), a contour map was constructed as shown in Figure 22.

3.3. GROUND WATER ELEVATIONS AND FLOW PATERNS

3.3.1. Ground Water Elevations

In natural ground water systems, the depth to water varies depending on local topography and season. Generally, the greatest depths to water occur in uplands and during the dry season. The lowest depths to water occur in lowlands and during the wet season. Figure 23 shows the water level measurements taken during the GWRAS in feet above mean sea level. Measurements in the confined aquifer denote the elevation of the potentiometric surface. The general gradient in the surficial aquifer follows the topographic relief.

Since the potentiometric surface of the Potomac Group aquifer has already been discussed, and no wells were installed in the area of the perched tables, the following paragraphs are concerned with ground water elevations in the Piedmont crystalline rock aquifer and in the Coastal Plain surficial aquifer.

Ground water in the Piedmont rocks is usually thought of as being under unconfined conditions. In that case, influent seepage moves along open fractures at a rate dependent upon the amount of water supplied by the weathered overburden and the size and inclination of the openings. If the openings are interconnected, one water table will result; single fractures or group of fractures may have separate water tables, depending upon the altitude of the point of discharge. However, ground water under artesian, or confined, conditions also exists. The artesian pressure in fracture aquifers is caused by water moving downward along an inclined structural feature, such as a joint or fault, the upper block or so-called hanging wall acting as a confining

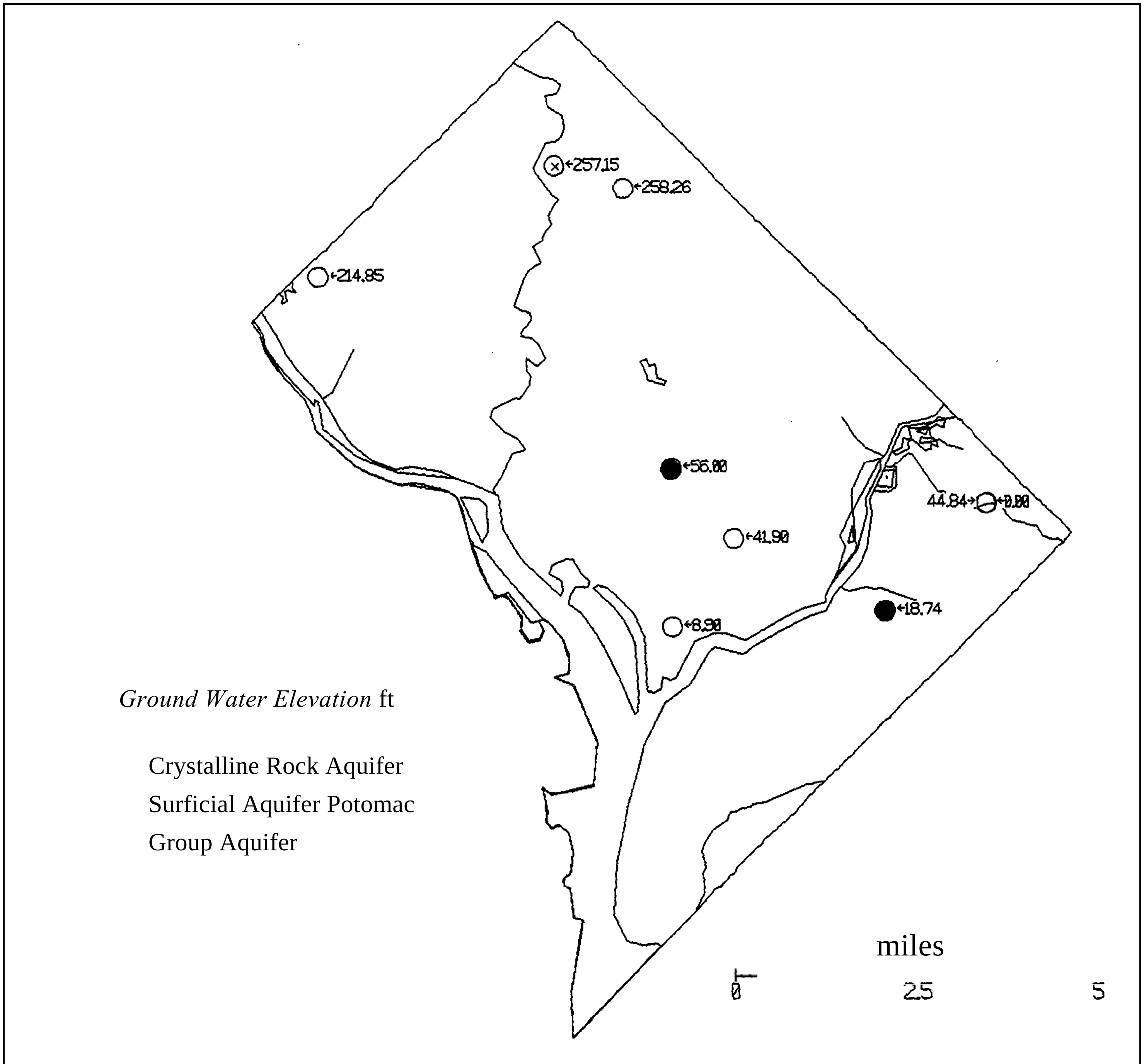


Figure 23. Average ground water elevations measured during the GWRAS in feet above mean sea level

layer. During the GWRAS, both cases were encountered during the installation of the bedrock well at Dalecarlia Parkway (MW-3). A shallow fracture zone was encountered at a depth of approximately 20 feet. Ground water in the shallow fracture zone occurred under unconfined conditions and was hydraulically connected to the adjacent stream. Separated by a zone of massive granitic gneiss, a second fracture zone occurred at a depth of approximately 60 feet. Ground water in this second zone was under artesian pressure. To avoid mixing of waters from the separate fracture zones, the upper zone was sealed. Water tables and potentiometric surfaces in bedrock aquifers are difficult to obtain without extensive field investigation. Since ground water occurs along discrete fractures, the location and interconnection of the fractures needs to be known in addition to water level measurements for an analysis of the ground water elevations.

During the GWRAS, ground water in the unconfined crystalline rock aquifer was encountered at 10 and 12 feet depth for the monitoring wells installed at the Rock Creek Park Golf Course (MW-Cl, C2). The wells are located in the valley of Rock Creek. Two additional boreholes drilled in higher elevations failed to intercept the ground water table by depth 15 feet and 25 feet respectively. Given the variability of the saprolite cover, the water table contours most likely change significantly with the season. In dry weather, all water from the saprolite aquifer may be drained into streams and the underlying bedrock, while water levels would rise during wet season. For the two wells installed during the GWRAS, water levels fluctuated by about two feet, with the lowest elevations measured in July and the highest elevations measured in April.

3.3.2. Ground Water Flow Patterns

Figure 24 shows the ground water flow patterns in the surficial aquifer as inferred from water level measurements and topography. Only the drainage divides of the Potomac tributaries were included in this analysis. These are the Anacostia River (including Northwest Branch), Rock Creek, Battery Kemble, Foundry Branch, and Little Falls. More localized flow patterns are associated with the smaller tributaries to Rock Creek and the Anacostia River.

An additional factor in Washington, DC is the urban character of the watersheds. In the surficial aquifer in downtown Washington particularly, pipelines and METRO tunnels serve as effective barriers to ground water flow, raising the water table on the upgradient side and lowering it on the downgradient side. Additionally, anthropogenic recharge and discharge areas cause ground water sources and sinks that can significantly alter the water table contours: water table highs may be caused by recharge from these structures, and water table lows can result from discharge into the structures. Well readings during the sewer system evaluation in 1981 and 1982 brought evidence of the impact of these urban structures on the ground water table: water levels in one well dropped 20 feet after a nearby water main break was repaired. Detailed measurements of ground water elevations are necessary to obtain water table contours of some

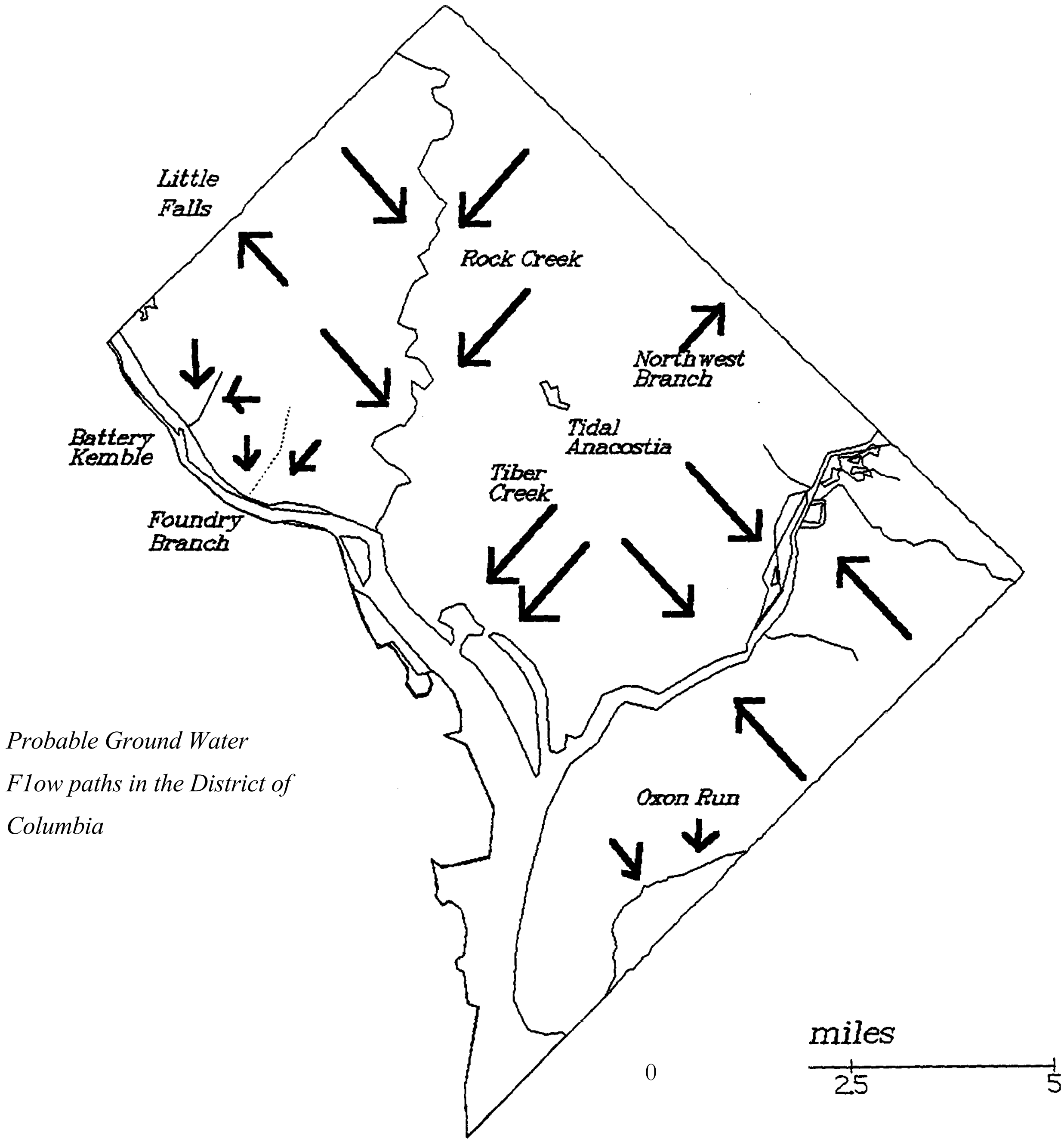


Figure 24. Probable ground water flow paths in the District of Columbia

accuracy. Additionally, the shape of the water table may change temporarily with construction dewatering. The depth to water varied from 8 to 25 feet.

The underground utility system of sewers, water pipes and sump pumps may have created micro flow systems around these artificial recharge and discharge areas, as illustrated in Figure 25. Steeper than natural gradients around artificial discharge areas likely result in increased velocities. Additionally, the presence of coarser-grained materials around pipelines, originating from old stream channels, may result in preferred flow paths along the pipelines.

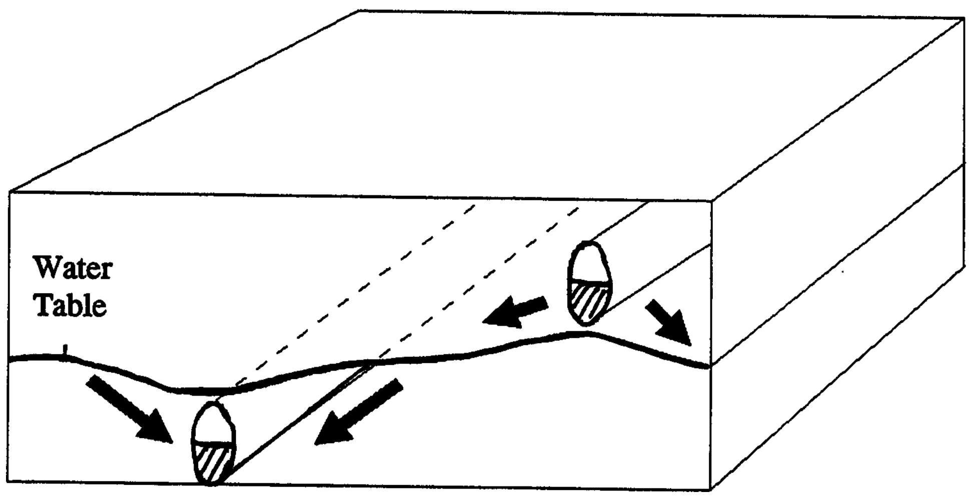


Figure 25. Effects of pipeline recharge and discharge on the water table.

Figure 26 shows the complex occurence and flow patterns of ground water in the District of Columbia. Both local and regional flow patterns exist in the District of Columbia. The local flow systems correspond to the surface water drainage basins of the Potomac River, the Anacostia River, Rock Creek and Oxon Run. Some differences can be expected in the downtown area, where the sewering of Tiber Creek has resulting in a rerouting of surface water runoff from the Potomac River to the Anacostia River. Ground water, however, may still follow the natural topographic gradient and discharge directly to the Potomac River. Preferred flow paths have been determined for the buried stream channels in the downtown area (Matheson et al., 1992).

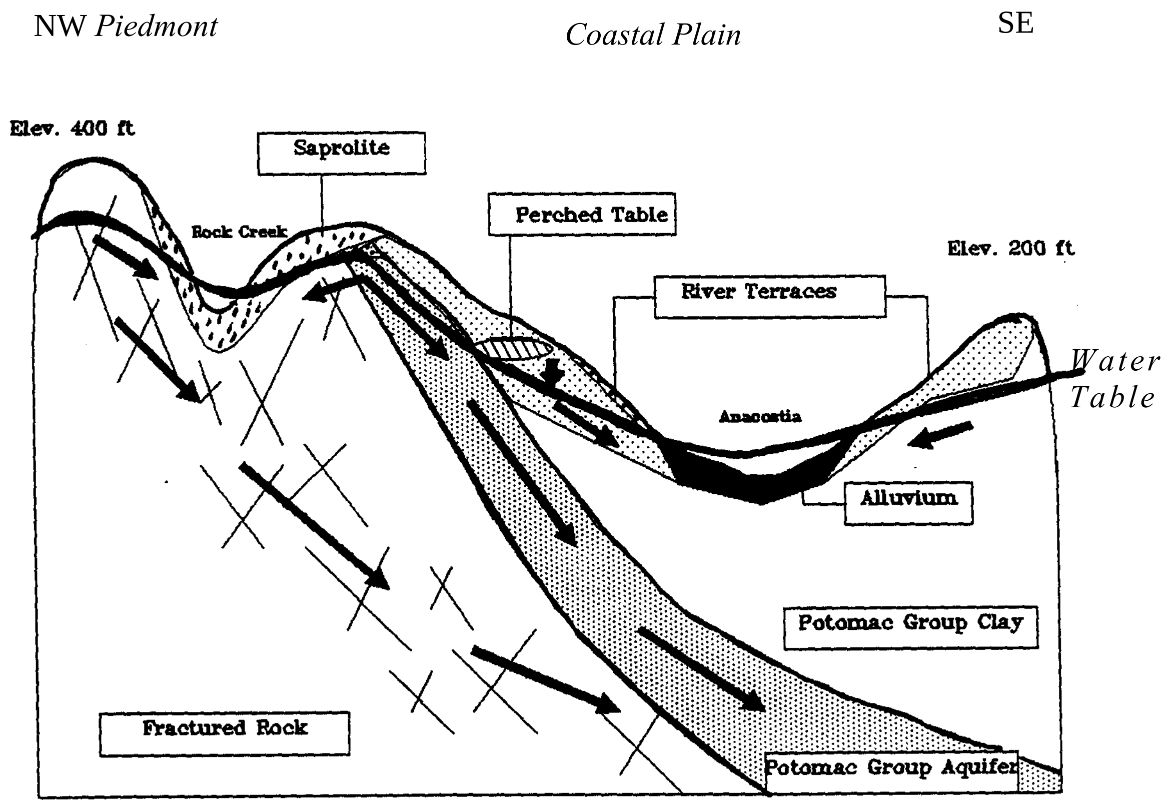


Figure 26. Ground water occurrence and flow patterns in the District of Columbia

The regional flow systems are those that transcendend local drainage divides due to geological conditions and are comprised of the Potomac Group aquifer and the crystalline rock aquifer. Ground water in the crystalline rock aquifer can travel under confined conditions along fractures that run below the discharge areas for water-table flow. It is surmised that such water will discharge into the overlying Potomac Group. Ground water in the Potomac Group confined aquifer moves out of the District's boundary to eventually discharge into overlying aquifers or directly into the Atlantic Ocean. Table 4 summarizes the local aquifers together with the corresponding geologic units, the aquifer media and the hydraulic properties as ascertained from literature and field work.

Table 4. Aquifer Occurrence Summary

Aquifer Name	Geologic Units (Froelich, 1975)	Aquifer Media	Hydraulic Conductivity	Transmissivity	Depth to Water
Crystalline Rock Aquifer	Kg,GmfU(minor) Wp, Wd (major)	fractured and weathered granite/gneiss	0.003-3 ft/d 1.44 ft/d 0.58 ft/d	34-587 gpd/ft 100 gpd/ft	10-50 ft 100-200 ft
Perched Aquifer	Tug, Qt, Tc, Ta, Km, Kps	silt, sand and gravel	unknown	unknown	< 6 ft
Surficial Aquifer	Qal, Qt	silt, sand and gravel	7.2-144 ft/d	195-3,000 gpd/ft	8-50 ft
Confined Potomac Group Aquifer	Kps	sand and gravel	4.32-720 ft/d	30-1,440 gpd/ft	40-700 ft'

Depth to water-bearing stratum

4. GROUNDWATER QUALITY

This chapter describes the ambient ground water quality as determined during the GWRAS, as well as existing and potential contamination sources with an impact on ground water quality.

4.1. AMBIENT GROUND WATER QUALITY

Ambient ground water quality is determined by the mineral composition of the soils and rocks through which ground water percolates, and by the residence time of the water in these materials. Ground water quality may differ greatly from place to place within a hydrogeologic unit and between adjacent units. Urban activities are superimposed on this natural system in the District of Columbia. During the GWRAS, current ambient ground water quality was assessed in the five Group A monitoring wells distributed among the three major hydrogeologic units (excepting the perched tables). Additional information was obtained from the sampling of the eight Group B shallow monitoring wells installed to assess the impacts of non-point source pollution. In this report, the results are expressed as averages from all sampling events. Results from the Group B cluster wells were also averaged among each other, since they were very similar. Only one exception was necessary: Of the three wells at Lederer Gardens (MWB1,2,3), ground water from the upgradient well MW-B1 exhibited a distinctly different geochemical character. This well is therefore represented separately.

For the interpretation of results provided below, it must be kept in mind that ground water quality in shallow aquifers can change considerably within days or hours, since these aquifers are not well protected from natural or human-induced events at the surface. While the quarterly measurements provided a good indication of the annual change, they cannot do justice to short-term changes, as shown by weekly measurements, that are necessary to obtain a more comprehensive understanding of the system (US EPA Office of Research and Development, 1990). Consequently, since the natural quality of shallow ground water varies widely, background concentrations are not finite but represent a range of values that may vary by an order of magnitude for major constituents (e.g. TDS), and by two or three orders of magnitude for minor constituents (e.g. nitrate). The results presented here should therefore be considered as general annual trends.

4.1.1. pH, Temperature, and Specific Conductance

Figure 27 shows the average values of pH, temperature and specific conductance that were measured during the field sampling program of the GWRAS. For the wells installed in the Atlantic Coastal Plain surficial aquifer, ground water is of acid character with pH fluctuating around 6. The only exception was found in the three wells at Peabody Gardens, where organic material was found at approximately the depth of the water table, indicating a potential for

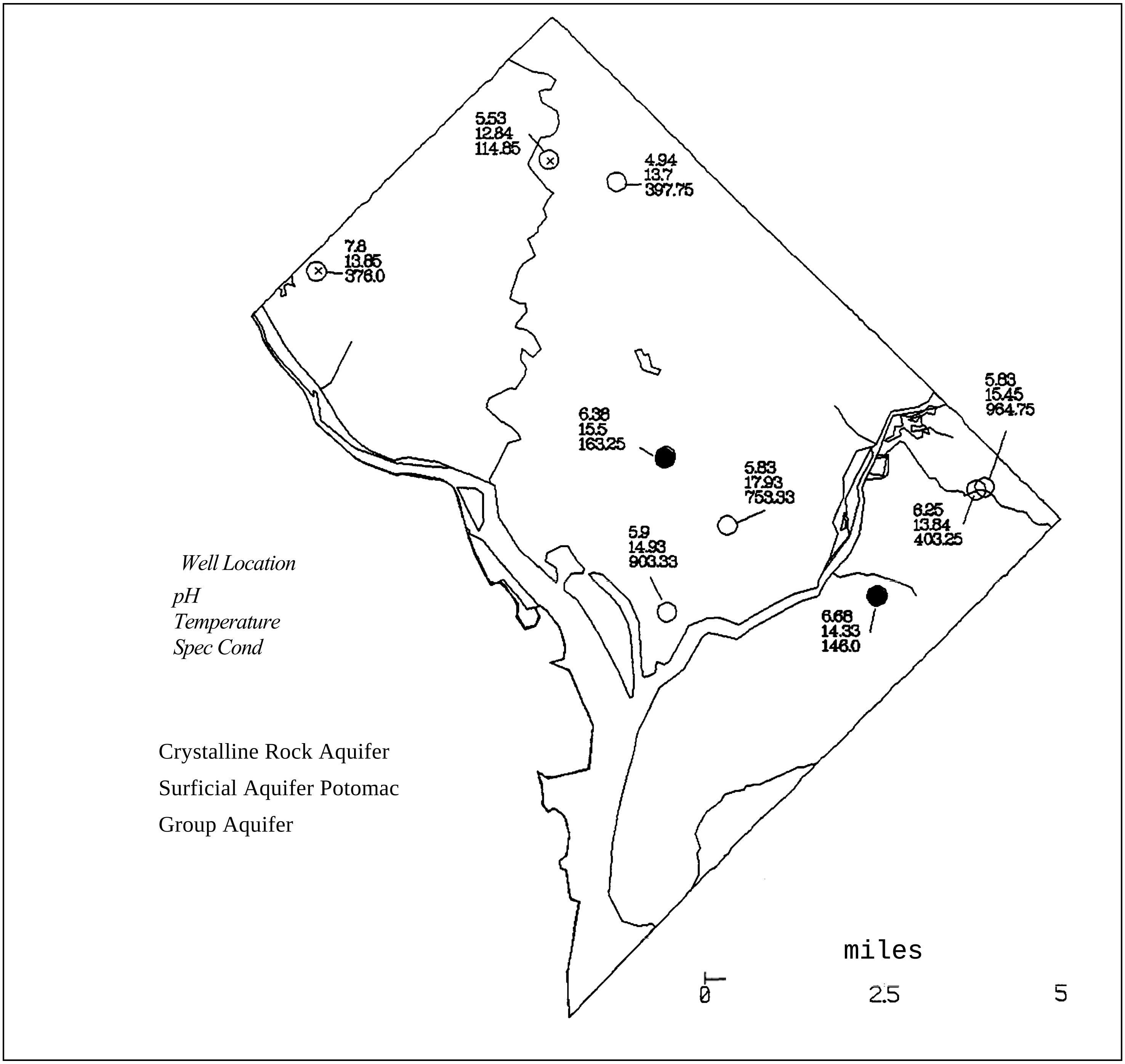


Figure 27. Average pH, temperature and specific conductance, 1992-93

acidification. On average, pH is slightly higher for ground water obtained from the confined aquifer of the Potomac Group. The values of 6.38 and 6.68 found for water in that aquifer are within the range found by Johnston (1964), which fluctuates between 5.2 and 7.8 for the Potomac Group's Patuxent Formation. The pH at MW-3, which represents the Piedmont crystalline rock aquifer, fluctuates around 7, indicating a more basic character of the ground water intercepted by that well. In the wells intercepting ground water in the saprolite, the average pH of 5.53 is significantly lower and at the bottom of the range found by Johnston (5.6 -7.5).

Temperature values in the surficial aquifer range from 13.7 to 17.93 degree Celcius, in the Potomac Group Aquifer from 14.33 to 15.5 degree Celsius and in the Crystalline Aquifer from 12.84 to 13.85 degree Celcius. In comparison, Johnston found values of 15.55 for the surficial aquifer, from 13.33 to 17.77 for the Patuxent Formation and from 12.22 to 16.11 in the Wissahickon Group. As a rule of thumb, the natural ground water temperature is approximately equal to the mean annual air temperature, which in the District of Columbia is 13.88 degree Celsius. This mean temperature is exceeded by more than one degree in wells MW-2, MW-4, MW-5, and in well MW-Bl. All four wells are located in densely urbanized areas, where heating of surface and shallow subsurface materials from solar radiation on concrete and asphalt surfaces, fossil-fuel combustion and heat loss from pipelines probably lead to the increased temperatures. For MW-2, which taps the confined aquifer at a depth considerably lower than the depths of the other three wells, thermal losses from buried pipelines are the most likely cause.

The highest values of specific conductance were found in wells MW-4, MW-5 and MW-B1, once again indicating the effects of urbanization on the shallow ground water. Two other shallow well locations, i. e. Peabody Gardens and the two other wells at Lederer Gardens, show much lower conductance values, which can be attributed to their distance from urban structures and, in the case of Lederer Gardens, the proximity to tree-lined Watts Branch. Ground water in the crystalline rocks has variable conductance ranging from 115 to 380 micromhos/cm for ground water in weathered rock and fractured rock respectively. In the confined Potomac Group aquifer, conductance values fluctuate around 150 micromhos/cm.

4.1.2. Total Dissolved Solids

The amount of Total Dissolved Solids (TDS) in ground water is a general measure for comparing and evaluating water quality. Ground water with TDS concentrations of over 500 mg/1 is considered undesirable due to its potential adverse physiological effects, objectionable taste or corrosiveness.

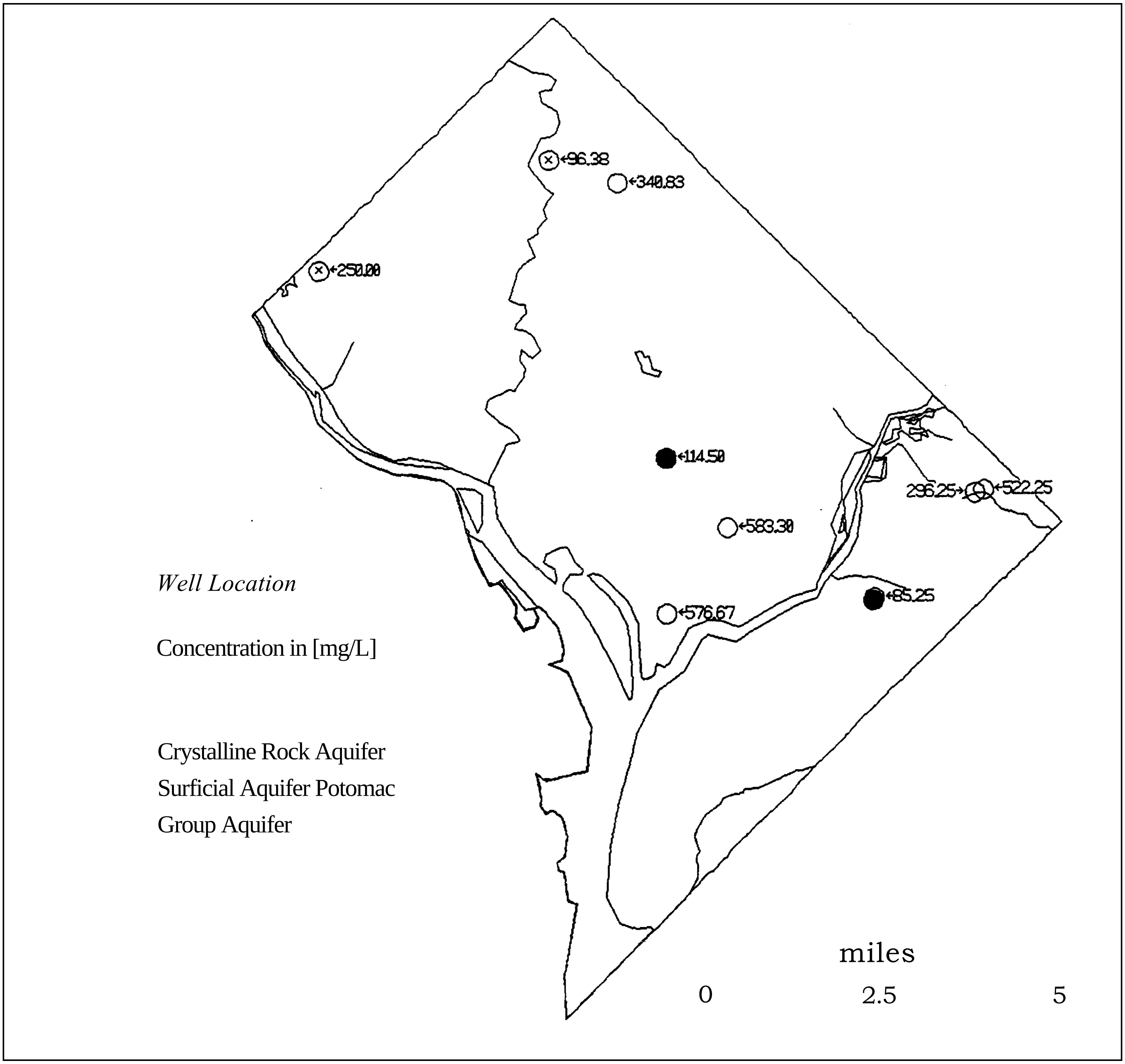


Figure 28. Average Total Dissolved Solids, 1992-93

Of the five Group A wells, TDS concentrations exceeded EPA's Secondary Maximum Contaminant Level (SMCL) of 500 mg/1 in ground water from MW-4 and MW-5 as well as in MW-B1 (Figure 28). In a recent study on ground water resources of Philadelphia, Paulachok (1991) found TDS values exceeding 1,000 mg/1 in a similar hydrogeologic setting. This would indicate that ground water quality in the District of Columbia has been less affected by urbanization. Some effect can be observed, however, since Johnston (1964) found no values exceeding 360 mg/1 with the exception of one heavily polluted well, where in 1958 a concentration of 801 mg/1 was measured.

4.1.3. Inorganic Parameters

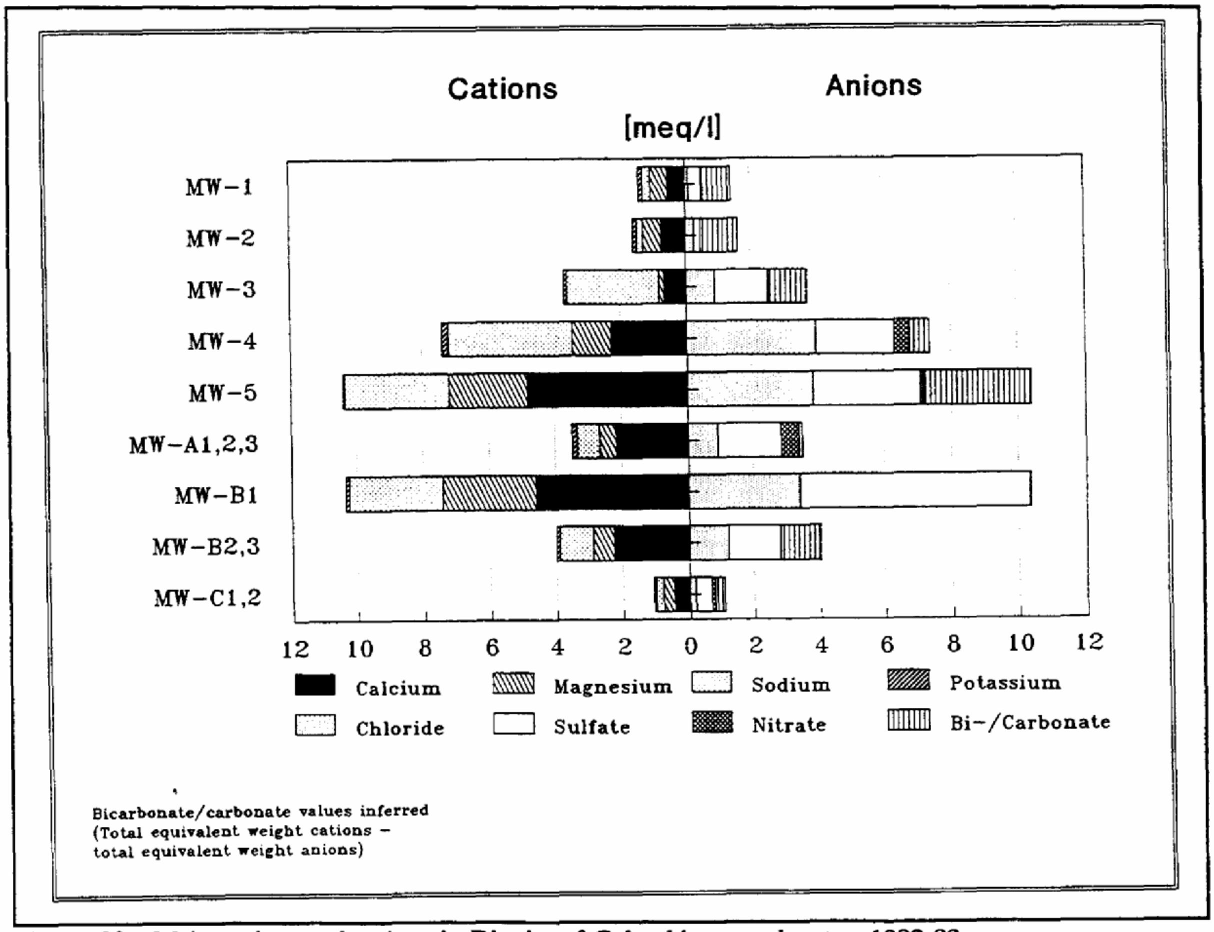


Figure 29. Major anions and cations in District of Columbia ground water, 1992-93

To determine the difference in ground water character, as evidenced by the conductance values, the major cations (calcium, magnesium, sodium and potassium) and the major anions (chloride, sulfate, nitrate and carbonate/bicarbonate) were plotted in average mMiequivalents/liter. Since carbonate and bicarbonate were not measured, the concentrations had to be estimated by subtracting the total equivalent weight of the anions from total equivalent weight of the cations. The results as shown on Figure 29 substantiate the different character of the ground water obtained from the wells.

In order to classify the waters, the concentrations were converted to percentages and plotted on a Trlinear diagram (Figure 30) to determine the hydrochemical facies.

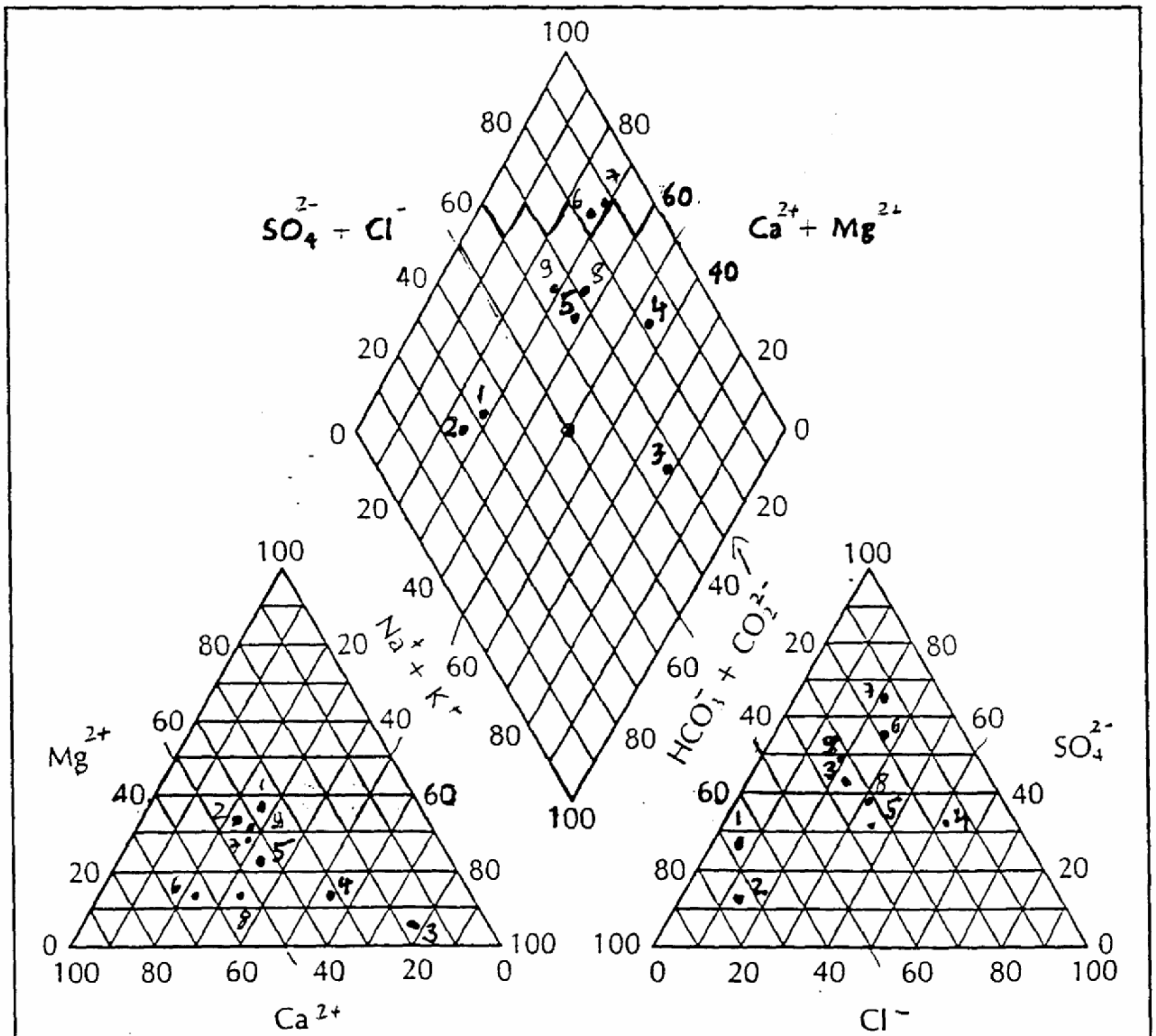


Figure 30. Trilinear diagram for ground water in the DC GWRAS, 1992-93

The analysis resulted in the following characterization:

Potomac Group Aquifer:	(1) MW-1	
	(2) MW-2	HCO_3+CO_3, Ca+Mg Group
Crystalline Rock Aquifer, fractured:	(3) MW-3	$S0_4$+Cl, Na+K Group
Crystalline Rock Aquifer, weathered:	(9) MW-C1, C2	$S0_4$+Cl, Ca+Mg Group
Surficial Aquifer:	(4) MW-4	$S0_4$+Cl, Na+K Group
	(5) MW-5	$S0_4$+Cl, Ca+Mg Group
	(6) MW-A1, A2, A3	$S0_4$+Cl, Ca+Mg Group
	(7) MW-B1	$S0_4$+Cl, Ca+Mg Group
	(8) MW-B2,B3'	$S0_4$+Cl, Ca+Mg Group '

denotes use of average for wells in one location

4.1.4. Inorganic Contaminants

A variety of inorganic parameters were measured during the GWRAS (Table 5), some of which are discussed in this section of the report. The parameters iron, chloride, sulfate and nitrate were selected because they are indicative of water quality problems. The wells were installed away from known contamination sources to determine ambient water quality. Elevated levels of these parameters show potential problem areas, where ambient ground water quality at the present time may include contaminants as background elevations.

Concentrations of iron exceeded its SMCL of 0.3 mg/1 in ground water samples from almost all wells (Figure 31). At wells MW-1, MW-2, MW-3 and MW-5, iron concentrations always exceeded the SMCL of 0.3 mg/1. For the two wells in the Potomac Group Aquifer (MW-1 and MW-2), this is almost certainly due to natural leaching from iron-rich aquifer material: Johnston (1964) found iron concentrations of up to 4.3 mg/1 in various wells tapping the Patuxent

Formation of the Potomac Group. Ground water in the shallower wells may be affected by urban impacts in addition to the natural leaching effect. Chloride (Figurer 32) and sulfate (Figure 33) were found in all wells, but as a rile did not exceed their respective SMCLs of 250 mg/l. Well MW-B1 at Lederer Gardens proved the exception to the rule with average sulfate levels of 332.5 mg/1. Nitrate (Figure 34) exceeded the MCL of 10 mg/1 in two locations: at the Peabody Garden site and at the downtown well at

T le 5. Inorganic Contaminants (regulated by EPA) Investigated during the GWRAS

Arsenic	Mercury
Barium	Selenium
Cadmium	Silver
Chromium	Chloride
Copper	Fluoride
Iron	Nitrate
'Lead	Sulfate

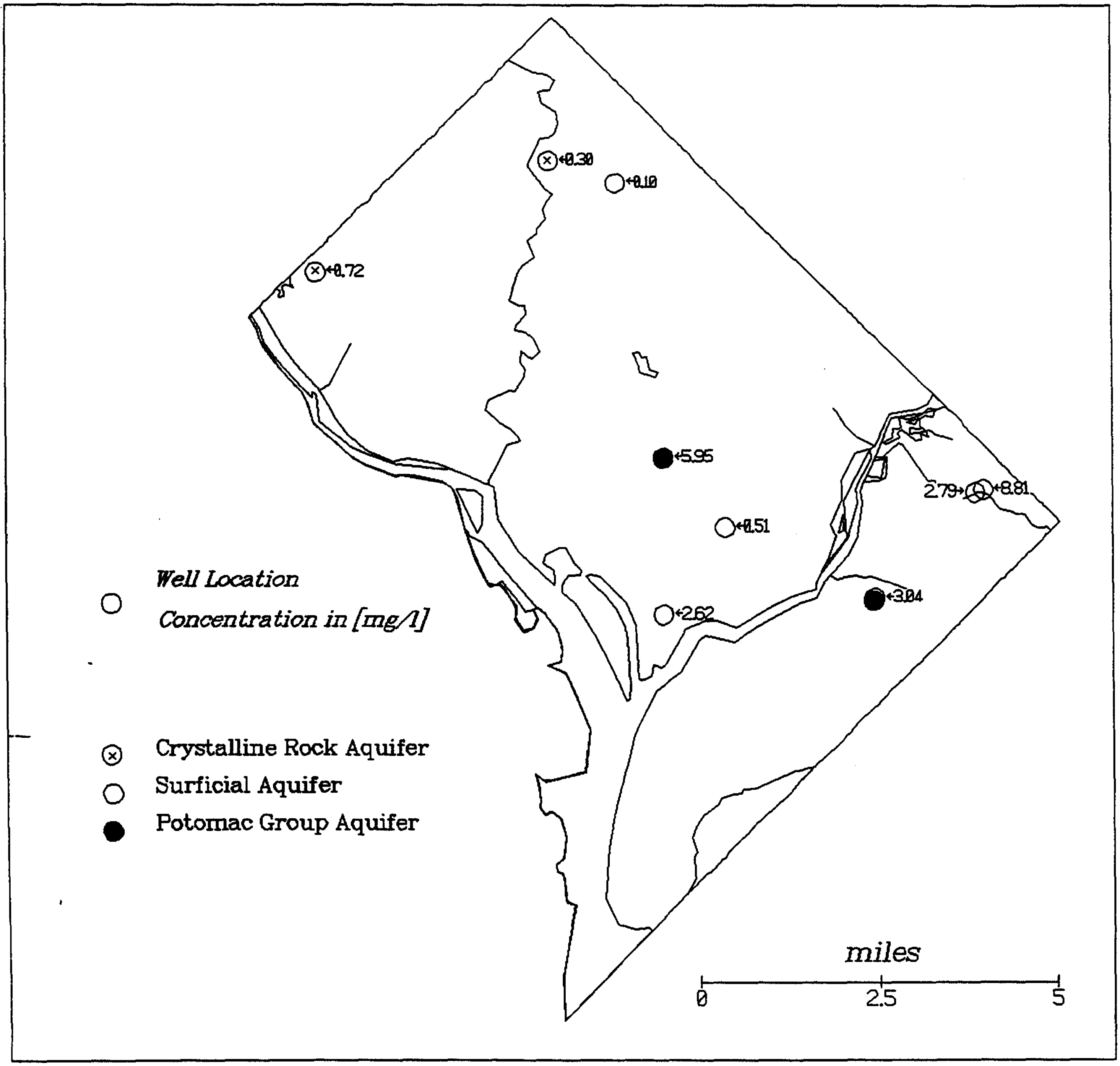


Figure 31. Average iron concentrations, 1992-93

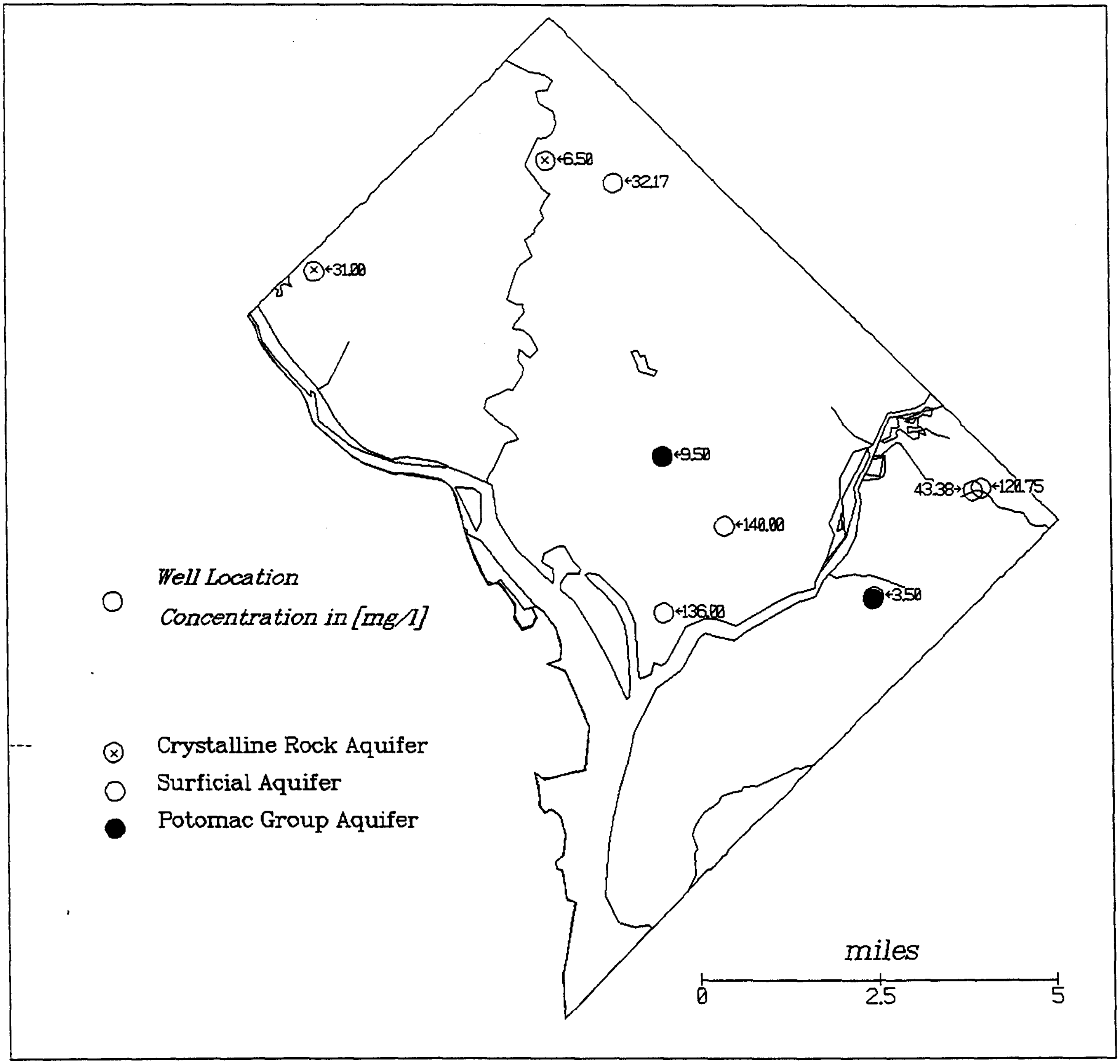


Figure 32. Average chloride concentrations, 1992-93

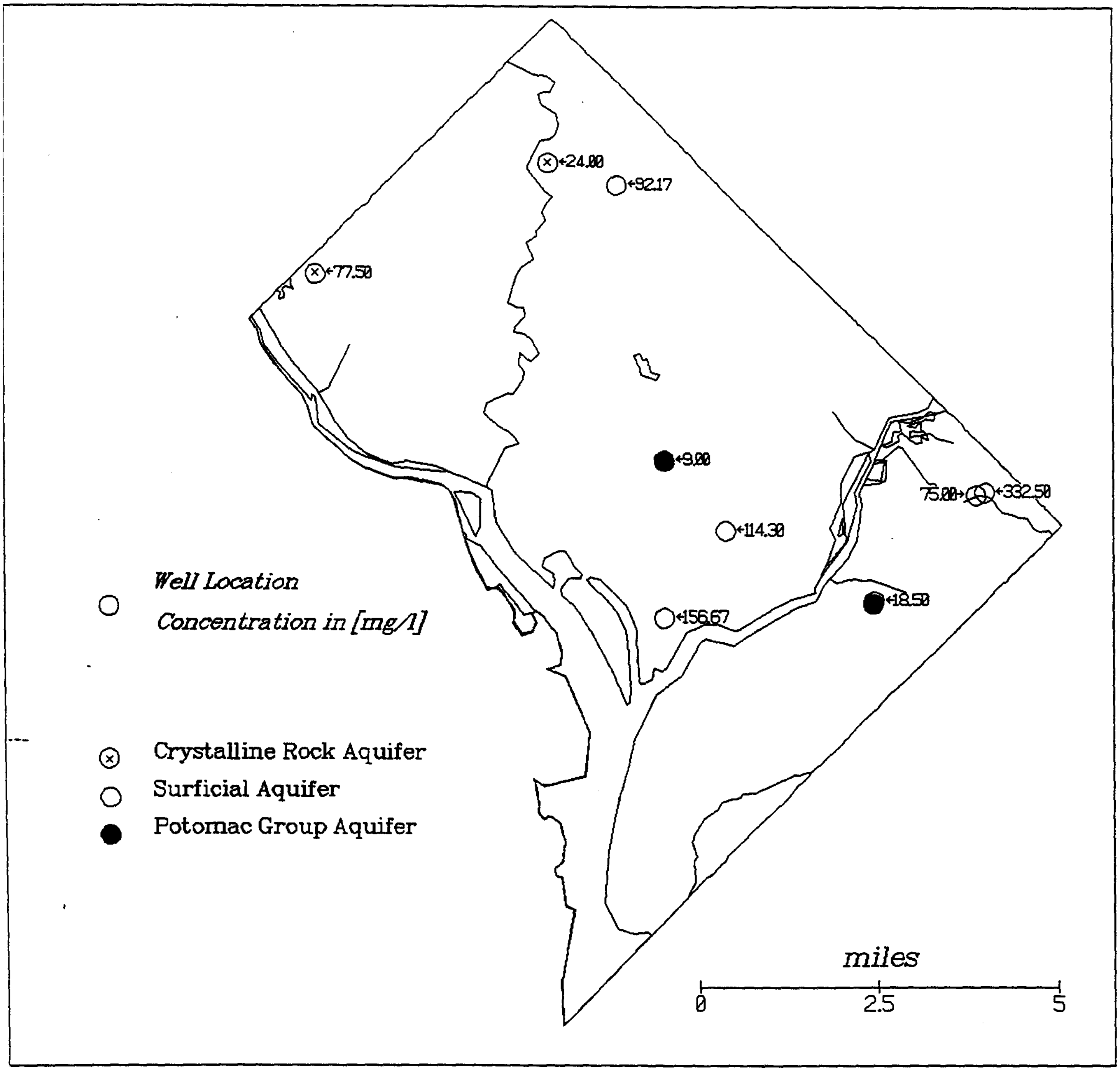


Figure 33. Average sulfate concentrations, 1992-93

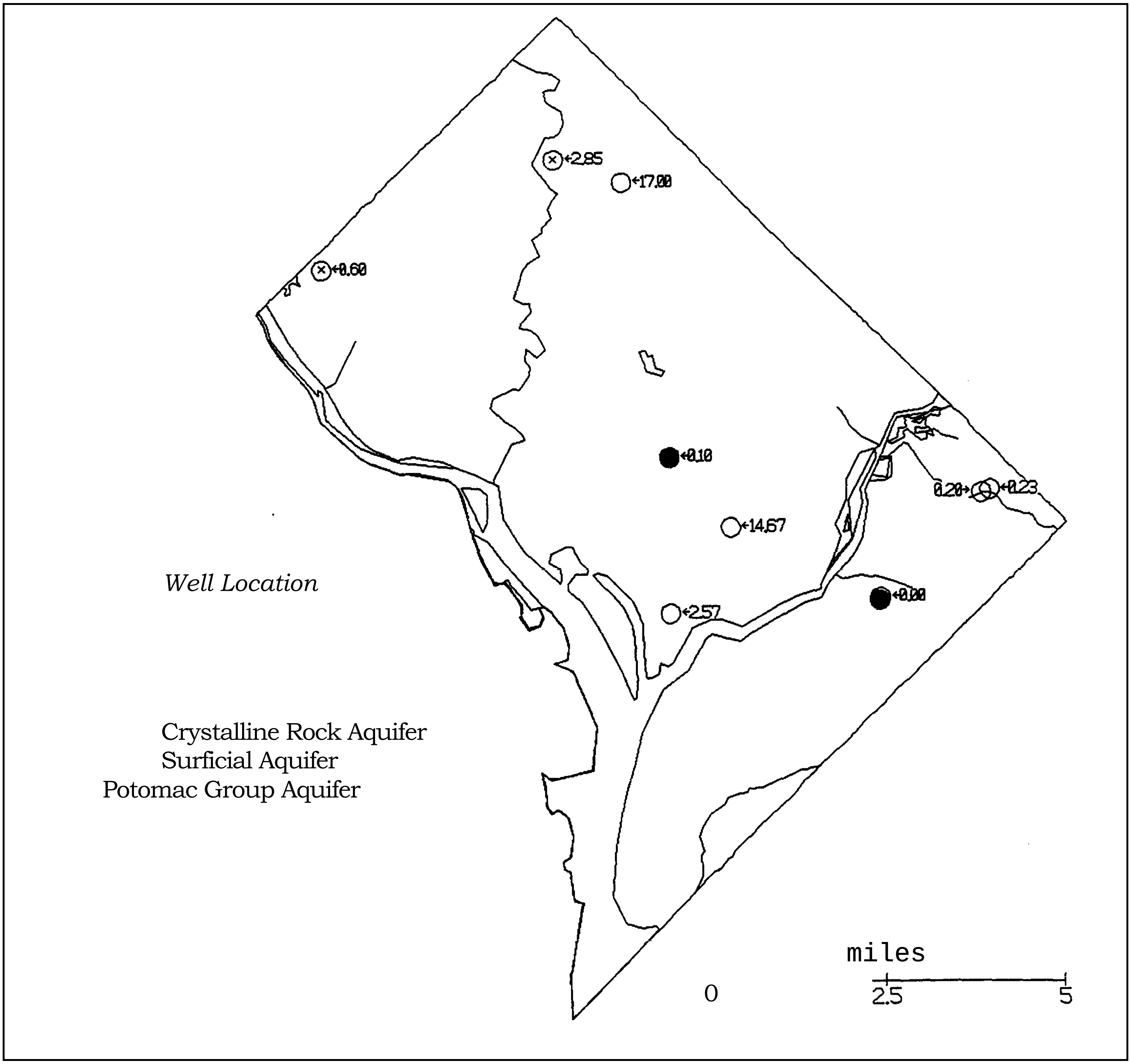


Figure 34. Average nitrate concentrations, 1992-93

Massachusetts and Constitution Avenues. It is considered unlikely that this is due to anthropogenic causes: the river terrace deposits underlying the sites are described by Froelich (1975) as containing peat beds, which may contribute nitrate to the ground water. Natural leaching appears to be the more probable cause.

Lead was found in a concentration of 0.015 mg/1, equaling the detection limit, only once at MW-2 in October 1992.

4.1.5. Organic Contaminants

During the GWRAS, ground water samples were analyzed. for a number of pesticides, herbicides, volatiles and semi-volatiles (Table 5, Table 6).

Of the substances of interest, the pesticide Chlordane was the only substance detected during the GWRAS. Concentrations of 2 ppb were measured in water samples taken from MW-5 during October 1992 and April 1993, but the detected concentration of 2 ppb does not exceed the Maximum Contaminant Level (MCL) specified by U.S EPA (0.002 mg/1, Title 40 CFR Part 141.61).

Table 6. Pesticides
Investigated During
and Herbicides
the GWRAS

Chlordane	2,4-D
Endrin	2,4,5-TP'
Heptachlor	Dicamba
Heptachlor Epoxide	MCPP
Lindane	
Methoxychlor	
Toxaphene	
Dieldrin	
alpha-Chlordane	
gamma-Chlordane	
Isofenphos	
Alachlor	
Atrazine	
Chlorpyrifos	

Table 7. Volatiles and
Investigated' During the
Semi-Volatiles
GWRAS

Benzene	1,4-Dichlorobenzene
Carbon Tetrachloride	Cresols (3)
Chlorobenzene	Hexachlorethane
Chloroform	Nitrobenzene
1, 2-Dichloroethane	Hexachlorobutadiene
1,1-Dichloroethene	2,4, 6-Trichlorophenol
Methyl ethyl ketone	2,4,5-Trichlorophenol
Tetrachloroethene	2.4-Dinitrotoluene
Tiichloroeth'ene	Hexachlorobenzene
Vinyl Chloride	Pentachlorophenol
	Pyridine

Except for the water samples collected in January and April 1993 at MW-4, no volatile or semi-volatile organic compounds were detected in ground water samples. Chloroform was detected at MW-4 once at 7 wg/l (January 1993) and once in a concentration below the quantitation level (April 1993). The method detection limit for chloroform is 5 Wg/l. Both detected concentrations are well below the MCL of 100 Ntg/1.

4.2. EXISTING CONTAMINATION SOURCES

4.2.1. Underground Storage Tanks

Figure 35 illustrates the principle of ground water contamination from leaking underground storage tanks. Storage tanks are by far the leading threat to ground water in the District. There are some 10,000 underground storage tanks around the city, the majority of which contain heating oil or gasoline. EPA estimates that about 25 % of the underground storage tanks are leaking. EPA is currently funding an Underground Storage Tank/Leaking Underground Storage

Tank program for the District. The program, under the Department of Consumer and Regulatory Affairs, is responsible for UST regulation and monitoring of all tanks with a capacity larger than 1,100 gallons as well as oversight and enforcement of clean-up operations. As of August 1993, there were about 450 leaking underground storage tanks at various stages of monitoring and/or remediation work. Water quality analysis includes

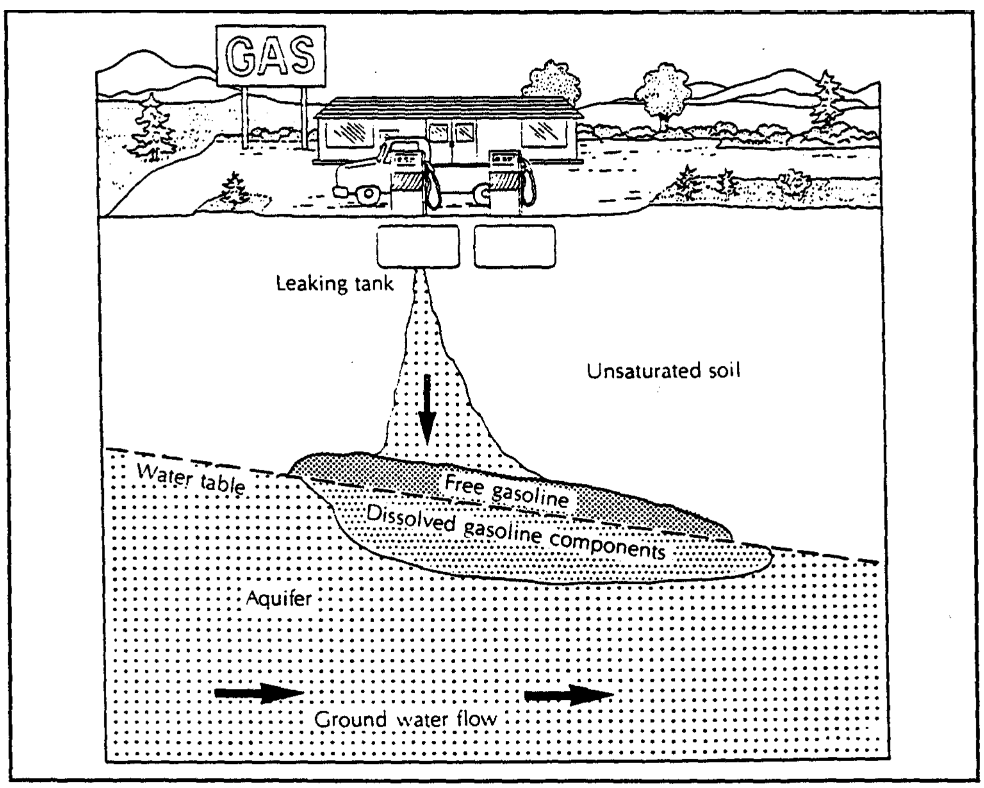


Figure 35. Impact of a leaking underground storage tank on the ground water (from Fetter, 1988)

some 35 compounds, with benzene, toluene, ethylbenzene and xylene on a routine basis. LUSTs are found mainly in the downtown area and along major roads. This is due to the degree of underground work and development occurring in these areas and is not necessarily a true indication of the distribution of LUSTs in the city.

4.2.2. CERCLA Sues

Sites where hazardous substances have been released into air, land or water are regulated under the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA). Also called "Superfund", this act requires the Environmental Protection Agency (EPA) to establish a list of sites in need of priority remedial action. The list is referred to as the "National Priority List" (NPL). In the District of Columbia, there are 23 sites listed in the CERCLA database, none of which have been upgraded to NPL status. Some have been cleaned already, others are currently undergoing remedial action. Most of the sites are located in the downtown area in the terrace and alluvial deposits of the surficial aquifer. Some he in the gravels and sand of the upland terraces and the Potomac Group aquifer. In the Piedmont bedrock, no sites are listed at this time, but an ammunition dump was found in Spring Valley near the Dalecarlia Reservoir in the spring of 1992.

4-1-POTENTIAL CONTAMINATION SOURCES

Contaminants can reach the ground water either from one-time sources, such as a spill, or from continuous sources such as leaking underground storage tanks. Table 8 illustrates the potential sources of ground water contamination identified for the District of Columbia. The list is based on EPA's Source Description Summaries as provided in the 1987 publication "EPA Activities Related to Sources of Ground-Water Contamination" . Some of the potential impacts of land use on the ground water are shown in Figure 36, and a short discussion of the potential extent of each contamination source is provided below.

Table 8. Sources of Potential Groundwater Contamination in DC (adapted from: DC WRRC, 1991)

Potential Sources	Potential Problem	Pollutant
	NONPOINT SOURCES	
Residential/ Institutional Activities	Handling, Use, Disposal of Materials, Over-application	Chemicals Pesticides
Commercial Activities	Handling, Use, Disposal of Materials, Leaks	Hydrocarbons Chemicals
Industrial Activities	Handling, Use, Disposal of Materials, Leaks	Hydrocarbons Chemicals
Transportation Corridors	Accidental Releases, Leaks, Over-application	Hydrocarbons Chemicals Pesticides
Graveyards	Poor Maintenance, Leachate	Pesticides Metals
Community Gardens/ Golf Courses	Poor maintenance, over-application	Pesticides
	POINT SOURCES	
Landfills/Open Dumps	Leachate	various
CERCLA sites	Leachate	various
Storage Tanks	Tank Failure, Leaks, Spills	Hydrocarbons Chemicals
Maintenance Yards	Handling, Use, Disposal of Materials, Leaks	Hydrocarbons Chemicals
Stockpiles	Leachate	various
Pipelines	Leaks	Bacteria

4.3.1. Nonpoint Sources

The nonpoint source category of potential contamination sources includes open space activities, residential activities, commercial and industrial activities as well as community gardens, golf courses, cemeteries and transportations corridors. Within the activities groups, individual events may be classified as point sources, for example accidental spills. However, in the aggregate the cumulative effect is not dependent on any one event or source, so that a nonpoint classification is justifiable. Similarly, the transportation corridors category is comprised of a variety of potential sources that were grouped together for this analysis.

Table 9. Land Usage in the District of Columbia (from: DC Office of Planning, 1990)

Land Use Category	Percent Area
Residential	48.07
Low Density	21.48
Moderate Density	23.00
Medium Density	2.57
High Density	1.02
Public and Institutional	38.74
Federal	6.76
Local Public Facilities	3.18
Institutional	3.87
Parks	24.93
Commercial	4.28
Low Density	1.85
Moderate Density	0.56
Medium Density	0.17
Medium-High Density	0.34
High Density	1.36
Production and Technical	3.13
Mixed Use	5.78
Total	100.00

Table 9 and Figure 37 show the areal extent of each major land use category (open space, residential, public/institutional, commercial, and industrial) in the District of Columbia. Not included in the description is mixed land use, which constitutes a combination of the major land use categories.

Open space covers about 25 % of the District's land surface. The major contaminants that can be expected to enter the ground water from open space areas are pesticides, herbicides and fertilizer. In the District, the vast majority of open space land is park land under the control of the National Park Service, which strictly limits pesticide and other material applications. It is therefore unlikely, that open spaces pose a large threat to the ground water. A limitation to that assessment is the risk of improper disposal, which would impact more because open space has a high degree of perviousness.

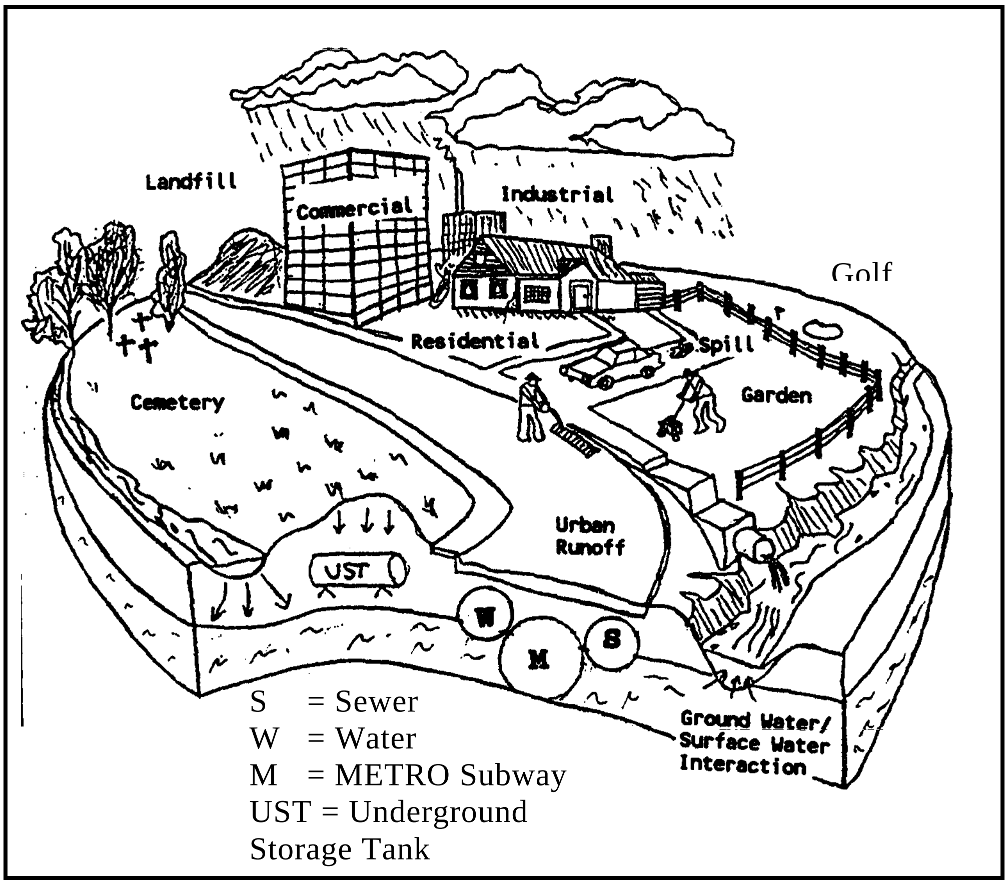
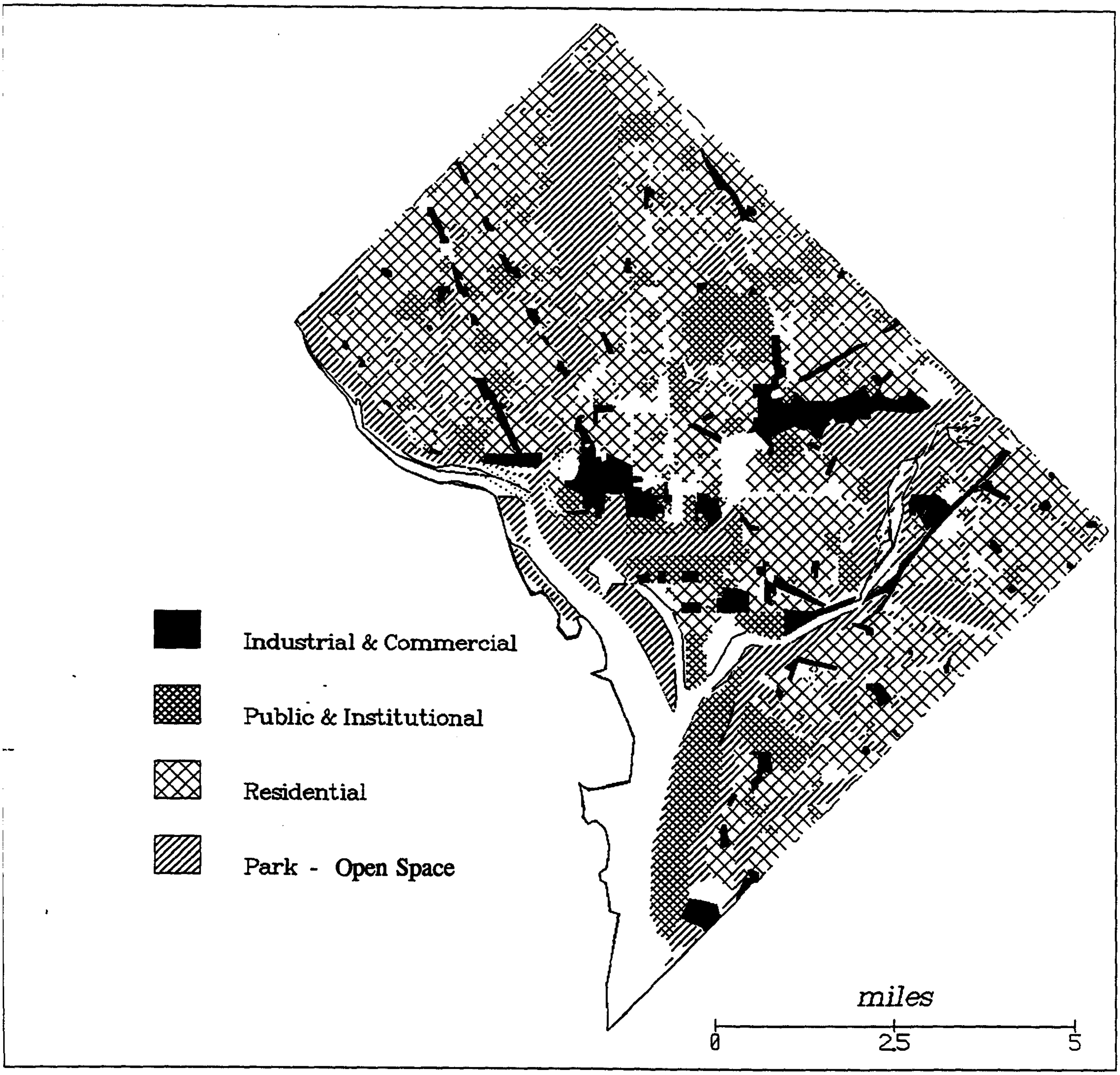


Figure 36. Potential land use impacts on the ground water

Residential areas are subject to indiscriminate disposal of oil, batteries, cleaning materials and animal carcasses as well as over-application of pesticides, fertilizers and herbicides. A wide variety of household products including cleaners, pesticides and automobile products are consumed each year. The proper usage and disposal of household waste hinges on a systematic



Fgure 37. Major land use categories in the District of Columbia (based on DC Office of Planning, 1990)

public education program and the availability of means to dispose of wastes properly and easily. It can be estimated that, in the absence of such program, a significant amount of waste is introduced into the ground water either directly by leaching or through sewer and storm drains that are corroded by these products. Another type of problem is caused by roof drainage pipes that are present in a number of older homes. Many single family homes of earlier design have roof and pavement drains that extend into the ground. It is estimated that these drains contribute about 20 % of the ground water recharge. The drainpipes act as injection wells for urban runoff. These pipes discharge directly into the ground, with the consequence that pollutants in rain water, on the roof or on the ground can be directly introduced to the ground water. These drains may significantly affect the ground water quality in the District and must be taken into account. Quantitative information about residential disposal practices in the District is not available. However, with almost 50 % of the city area in the residential category, the impact of residential disposal must not be neglected.

Public and institutional land use covers approximately 14 % of the land. Federally owned land other than park land is concentrated north and south of the Mall and in relatively large tracts such as the Walter Reed Army Medical Center, U.S. Soldier's Home, St. Elizabeth's hospital and the Boning/Naval Complex in outlying areas of the District. Also included in that category are 142 embassies and a number of city agencies as well as schools and 10 universities. Potential pollution sources include the over-application of pesticides, herbicides and fertilizer to the lawns and gardens associated with public and institutional land use, negligent disposal of hazardous material, and spills.

Commercial and industrial activities are potential hazards on 7.41 % of the District's land. Service, financial, and retail businesses are the largest sectors of the city's economy, but of these only the service sector has been in a period of growth. The growth industries in the 80s were office support services, communications, printing and publishing, wholesaling, transportation services, food services and tourism support services. Other industries include tank farms, cleaning and laundry establishments, maintenance yards and utility plants. The downtown business district contains most of the commercial uses in the city.. Also called the Central Employment Area, the area extends generally from North Capitol Street in the east, Pennsylvania Avenue in the South, 15th Street in the west and M Street in the north. The area is entirely within the northwest quadrant of the city and has in recent years been expanded to include the Connecticut Ave and K Street area. The New York Avenue corridor and the Red Line Metrorail corridor through the city's northeast quadrant contain the vast majority of the District's industrial and manufacturing land uses. Leaks and spills may occur in commercial and industrial land use areas during delivery, transfer and transfer of raw materials and end products. During material storage and processing, contaminants may be released due to leaks, spills, accidents, improper operation, and improper maintenance.

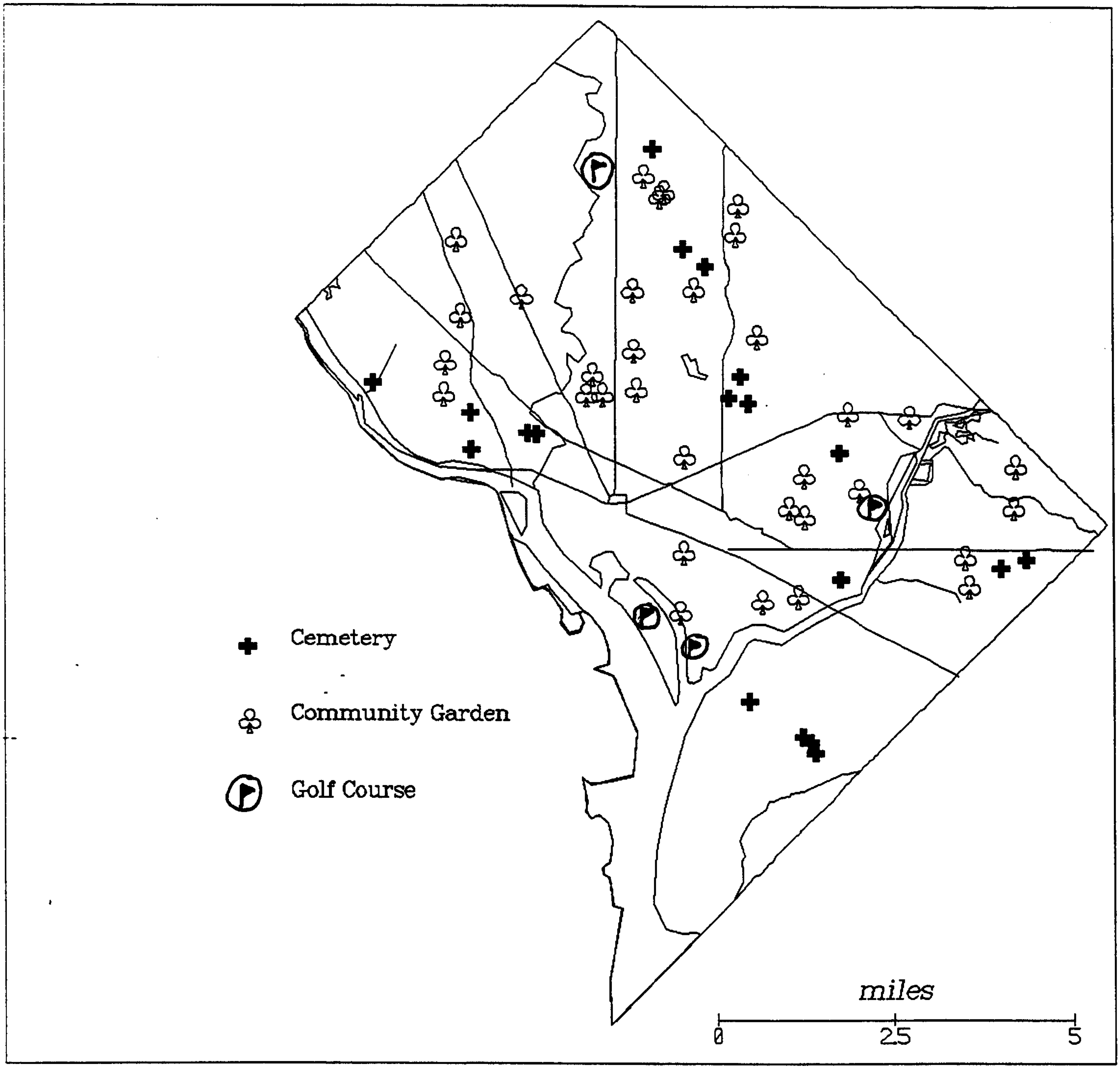


Figure 38. Location of cemeteries, community gardens and golf course in the District of Columbia

Ground water contamination from *cemeteries* (Figure 38), may include metals, non-metals and micro-organisms. The District of Columbia has thirteen cemeteries and their impact on the ground water quality should not be neglected for two reasons: The larger cemeteries are located on well drained local topographic highs that serve both as recharge areas and spring sources for many streams. Many sites are on critical recharge sites such as Rock Creek and Soldier's Home Cemeteries or on the banks of streams as is Oak Hill and Congressional. In addition, the majority of graveyards, including the still active Rock Creek Cemetery (1790s), have been in operation for over 100 years.

At the time of this report, Washington, DC has 34 community gardens. (Figure 38) Nine gardens are under the control of the National Park Service, while the remaining gardens are managed by the city. The application of pesticides and herbicides is not formally controlled and is the most significant potential pollution source from community gardens.

Of the four golf courses (Figure 38) present in the District, three are controlled by the National Park Service. The 1991 record of pesticide use on all three golf courses together shows approx. 620 gallons and 1227 pounds of pesticide applied. Using only the amount of active ingredient, approximately 400 lbs. were applied in 1991. The fourth golf course, under Department of Defense management, is located on Ft. McNair, and information regarding application of pesticides, herbicides and fertilizer is not available.

During the GWRAS, two community gardens and one golf course were investigated for potential leaching of pesticides and herbicides into the ground water. The investigation focussed on the pesticides and herbicides listed in Table 6, none of which were detected during the study. While this result is neither necessarily transferrable to all other golf courses and community gardens, nor representative for other sources of pesticides and herbicides, the fact that none of the pesticides and herbicides were found in the local ground water is encouraging and indicative of the value of good management practices such as those implemented by the National Park Service.

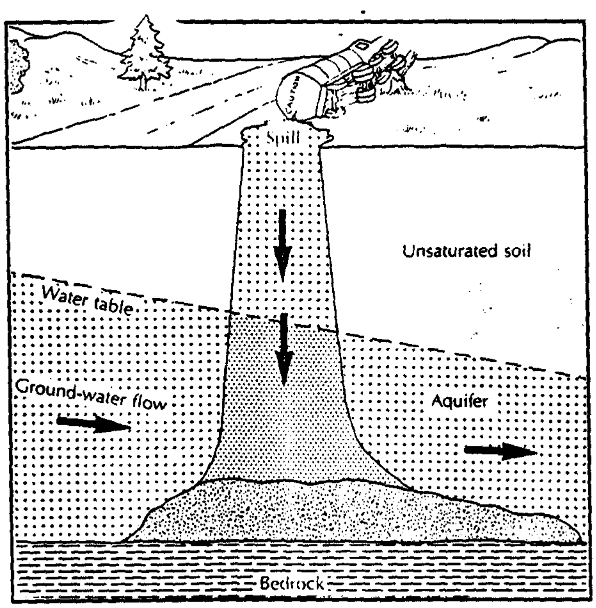


Figure 39. Effect of a roadside spill of an organic liquid denser than water (from Fetter, 1988)

Transportation corridors affect ground water quality through accidental spills (Figure 39) during materials transport and through road salting and pesticide application along roads and railroads. Roads and railroads are located in those areas with predominantly commercial and

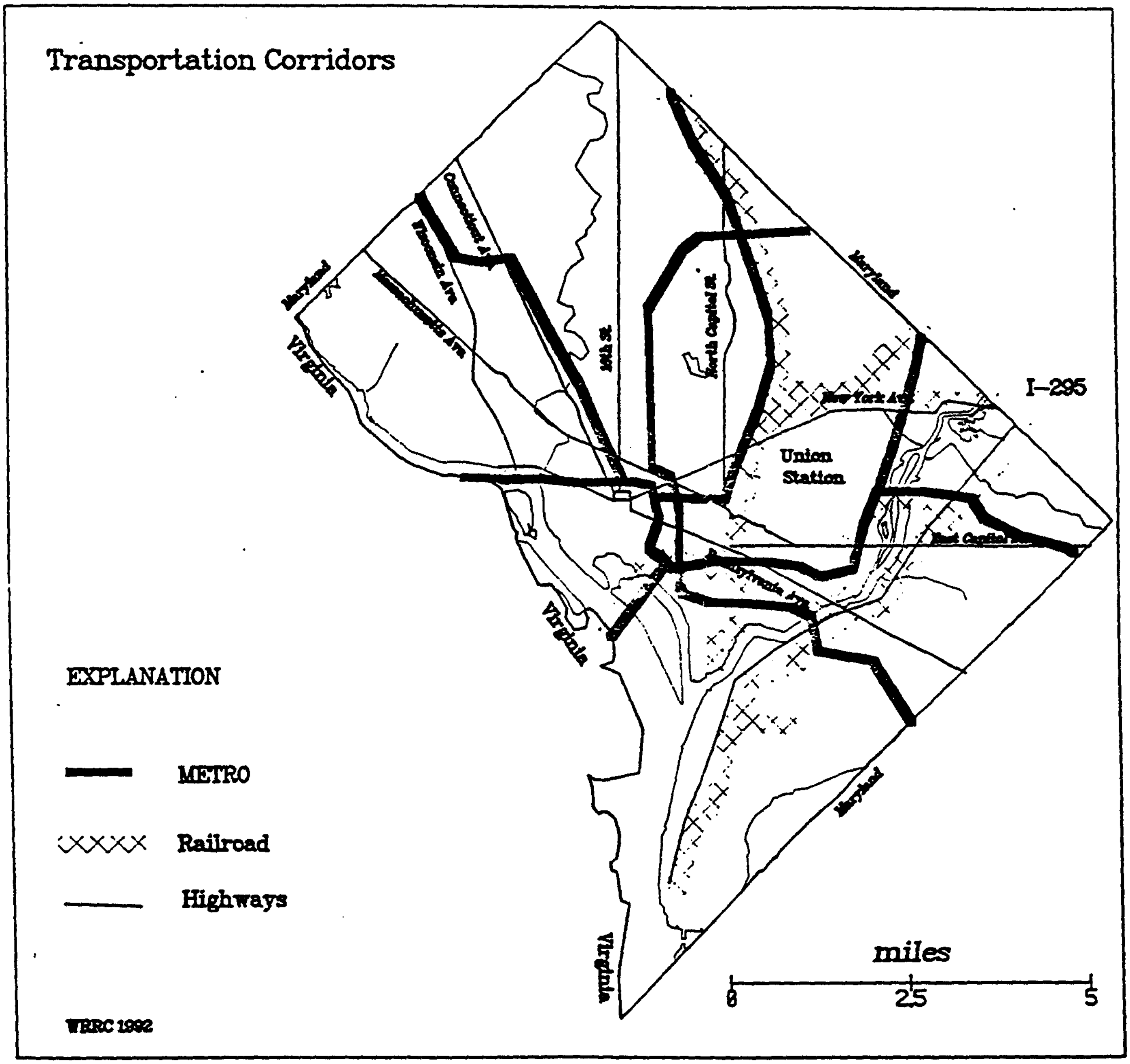


Figure 40. Major transportation corridors in the District of Columbia

industrial activities (Figure 40). During material transport on roads, accidental spills of varying extent and frequency occur. The D. C Fire Department Hazardous Materials Response Unit responds to accidental releases of liquid and solid hazardous materials. Most of these incidents are minor in extent and are rectified by the department at the time of report. Records of unplanned/accidental releases that may affect ground water quality are scattered among the various offices such as the Department of Consumer Regulatory Affairs (DCRA) and the DC Fire Department. Because of the mild climate, street salting is unlikely to be a major factor in ground water contamination.

The Street Maintenance Division of the Department of Public Works services over 1200 miles of roadway using on the average 12 to 16 tons of salt per year. In extremely mild winters however, no salting is carried out. The practice of hauling and piling of snow after salting can introduce a point-source for high concentration salt. Because most of the city's streets are provided with a runoff collection system, it can be estimated that the highest concentration of salt is transported into the storm and combined sewer drains. Another potential contaminant from railroad lines was revealed in a survey of certified pesticide applicators in Virginia, Maryland and the District of Columbia. The survey was conducted by the Extension Service of the University of the District of Columbia (1981). From a 34% return of the survey from commercial, federal and state applicators, the following use for the period 1979-1980 was documented: by far the largest amount of fungicide and herbicide in the city was used for clearing railroad tracks and grounds. While the numbers encompass an area larger than the city itself, the proportions speak for themselves. The gravel layers under the railroad lines may compound the impact of this large amount of pesticides applied to railroad corridors.

4.3.2. Point Sources

Some of the most serious sources of contamination are heating oil or gasoline leaks from *underground storage tanks* (Figure 41), which constitute both an existing and a potential threat to ground water quality. Large quantities of petroleum may leak through an aquifer over many years without being detected. Until recently, most underground storage tanks were made of unprotected carbon steel. Now they are more likely to be of coated steel and fiberglass. The typical service station tank has a capacity of 4,000 gallons. EPA currently predicts a 77% chance of leakage after 16 years. According to a survey made by the American Petroleum Institute, 92.3 % of all leaks from steel tanks are caused by corrosion. A number of factors speed up metal corrosion. Installation and operational practices as well as a variety of chemical reactions are leading causes. As a remedial measure, petroleum companies such as Exxon, Shell and Texaco are replacing unprotected steel tanks with fiberglass tanks. Figure 36 shows the distribution of USTs with a capacity of 12,000 and 10,000 gallons. In both cases, a concentration of tanks downtown and along major transportation corridors can be noted. However, only 178, or less than 2 %, of all USTs in the city are displayed on the map.

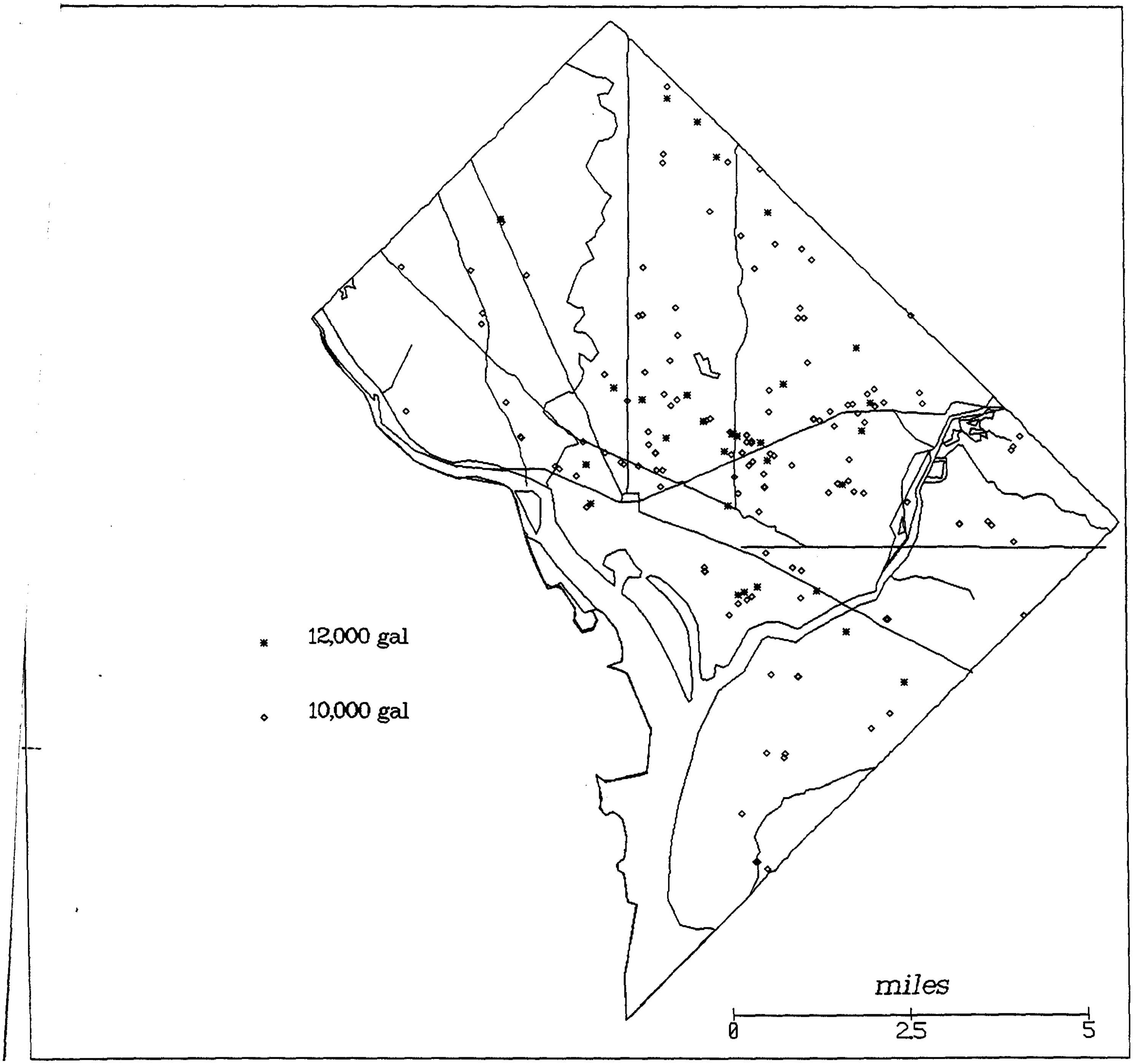


Figure 41. Location of underground storage tanks with 10,000 and 12,000 gallon capacity

Since all land use groups, whether residential or industrial, have USTs and since tanks are more likely to age beyond the 70 % likelihood of corrosion in residential than in industrial areas, the threat to ground water from LUSTS must be considered city-wide.

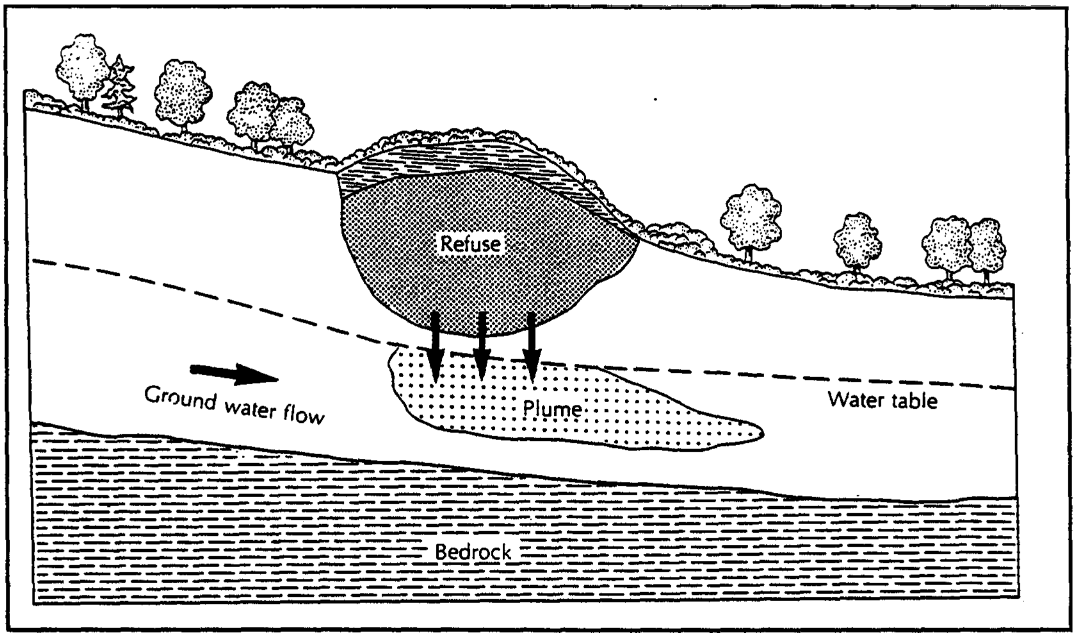


Figure 42. Leachate migration from a landfill to the water table (from Fetter, 1988)

Figure 42 illustrates the leaching process from a landfill to the ground water. The disposal of hazardous waste is currently prohibited in the District of Columbia, and there are no operational *landfills.* (Figure 43). It has been recorded that about eighty sites were used as landfills or open dumps in the past (USGS 1986). All were basically municipal waste disposal sites although some illegal dumping of hazardous material cannot be ruled out. These illegal dumping sites are continually being uncovered during construction excavation. The largest citylandfills in the District, the Kenilworth Landfills, were in operation from 1942 to 1970. Their location along the Anacostia River indicate that the impact of these landfills, from leachate and fly ash, on the ground water and the Anacostia River may be significant. The Oxon Run municipal landfill is similarly located along the Potomac River and also poses a potential threat to both ground and surface water. "God's dump", located in SE Washington, is one of three known illegal dumping site. The nature and quantity of the materials disposed there while the dump was active (1970s) are unknown. In identifying the sources of ground water contamination, an examination of the historical as well as current land uses and their implications to the area is necessary. A case in point is the World War II ammunitions depot that was discovered in the vicinity of one of the GWRAS wells.

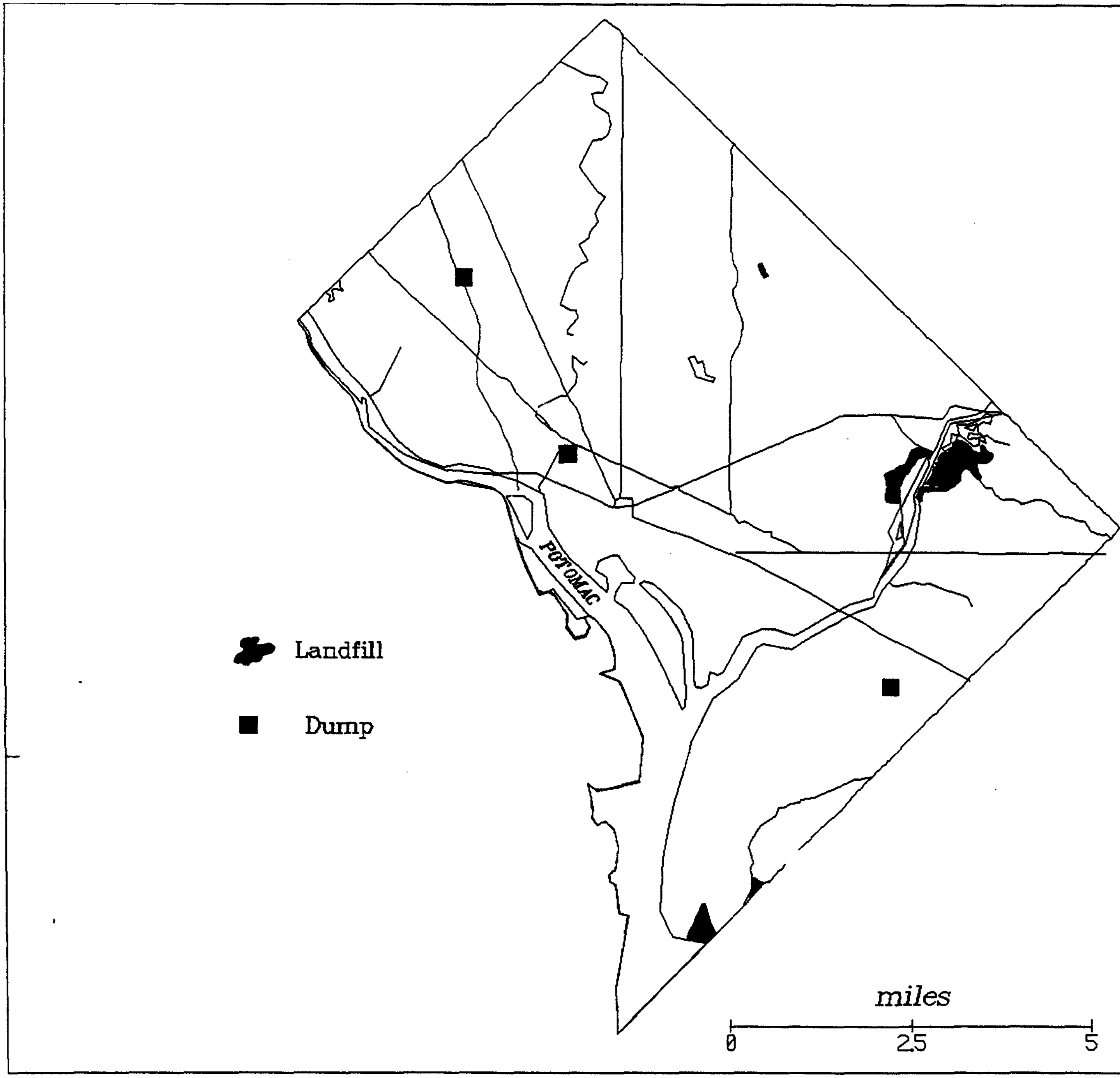


Figure 43. Location of landfills and dumps in the District of Columbia

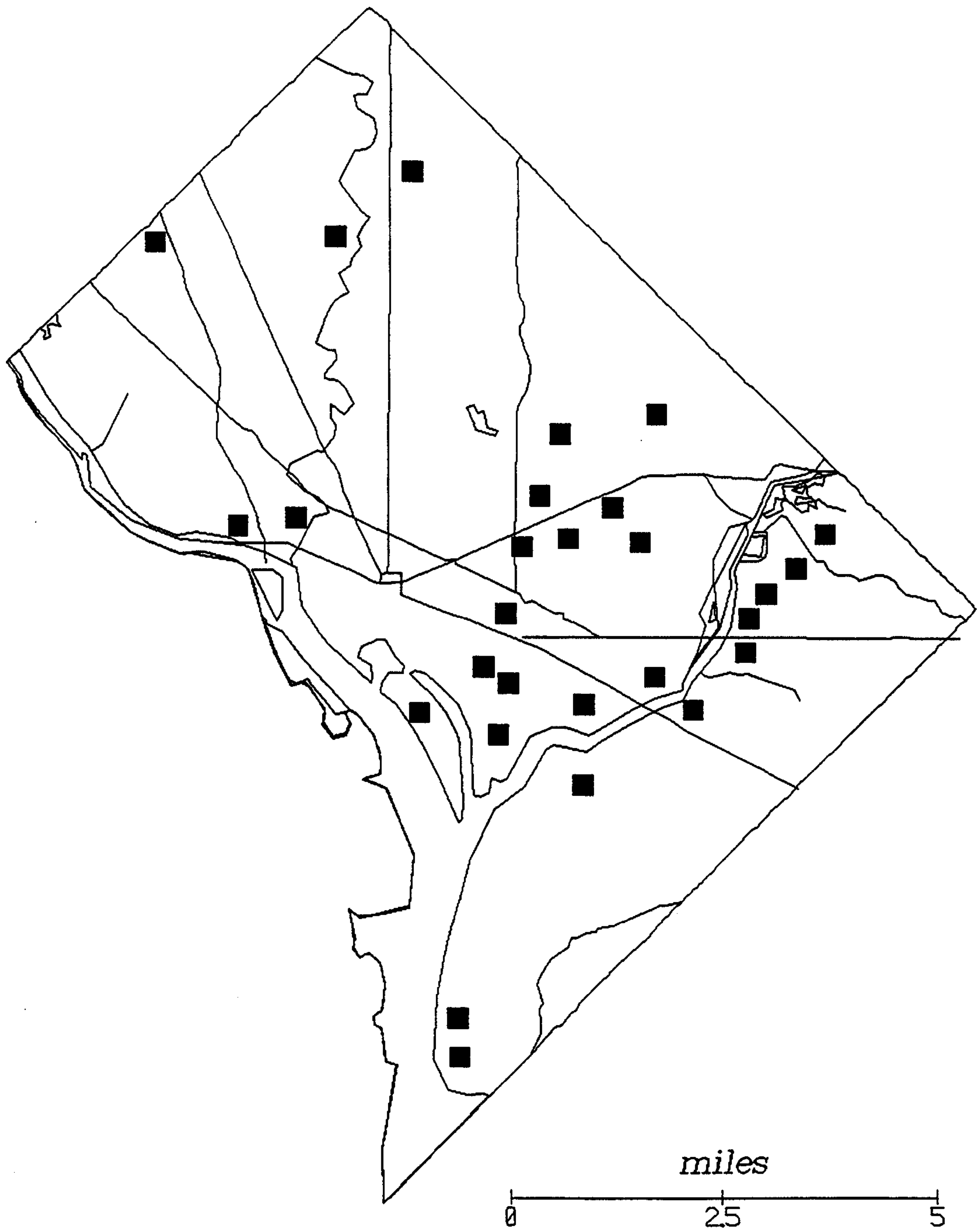


Figure 44. Maintenance yards in the District of Columbia

Maintenance yards (Figure 44), for example vehicle depots for city transportation, fire and police stations, as well as auto servicing stations are sources of a number of contaminants, particularly waste oil. Solvents and acids are also potential contaminants. In Washington, DC the major yards are found in all hydrogeologic settings, with the majority located in the terraces and alluvial deposits. The yards displayed on Figure 44 are from a variety of categories: bus yards, railroad yards, city maintenance yards, National Park Service maintenance yards, taxi yards, junk yards, utility plant yards and impoundment lots. While the maintenance yards themselves may be paved, contaminants can reach the ground water through seepage on site and from urban runoff detention basins, leaky stone water drains and surface water/ground water interaction. Some of the threat from yards results from historic practices: indiscriminate disposal of waste oil, spraying of arsenic for weed control and leaks from railroad cars carrying chemicals.

Figure 45 shows a variety of *materials stockpiles* in the District of Columbia, adapted from a list of storage piles for substances used during production by EPA (1987). The three main stockpiles of salts in the city are maintained by the Street Maintenance Division of the Department of Public Works. The tank farms consist of a number of above-ground storage tanks. Above-ground storage tanks are very limited in number in the District. Four tank farms and one ink storage tank are shown on Figure 45.

The water-bearing *pipelines* in the District of Columbia include storm drains, sewers, and water pipes. The District has both combined and separate storm and sewer lines (Figure 46). The combined sewer system constitutes 40 percent of the total drains. Some sewer line leaks are expected particularly in the older parts of the city. For instance, more than 35 per cent of the lines in the downtown area are at least 80 years old. In an Infiltration/Inflow study of the area nearly one-fourth of the extraneous flow was attributed to ground water and ten percent was due to water main leaks (DC DES, 1979). This indicates the likelihood of significant exfiltration from sewage and waste water lines in areas where the ground water table is at a lower level than the pipelines. The water distribution system has over 1,400 miles of buried pipe. Conduits for waterbearing utilities are located three or more feet below the street surface. These utility lines affect the natural ground water flow pattern and pollutant migration, and they can also contribute to ground water quality degradation.

The potential pollution sources are distributed throughout the city, with the result that each of the three major aquifers (surficial aquifer, Potomac Group aquifer and crystalline rock aquifer) could experience water quality degradation because of them.

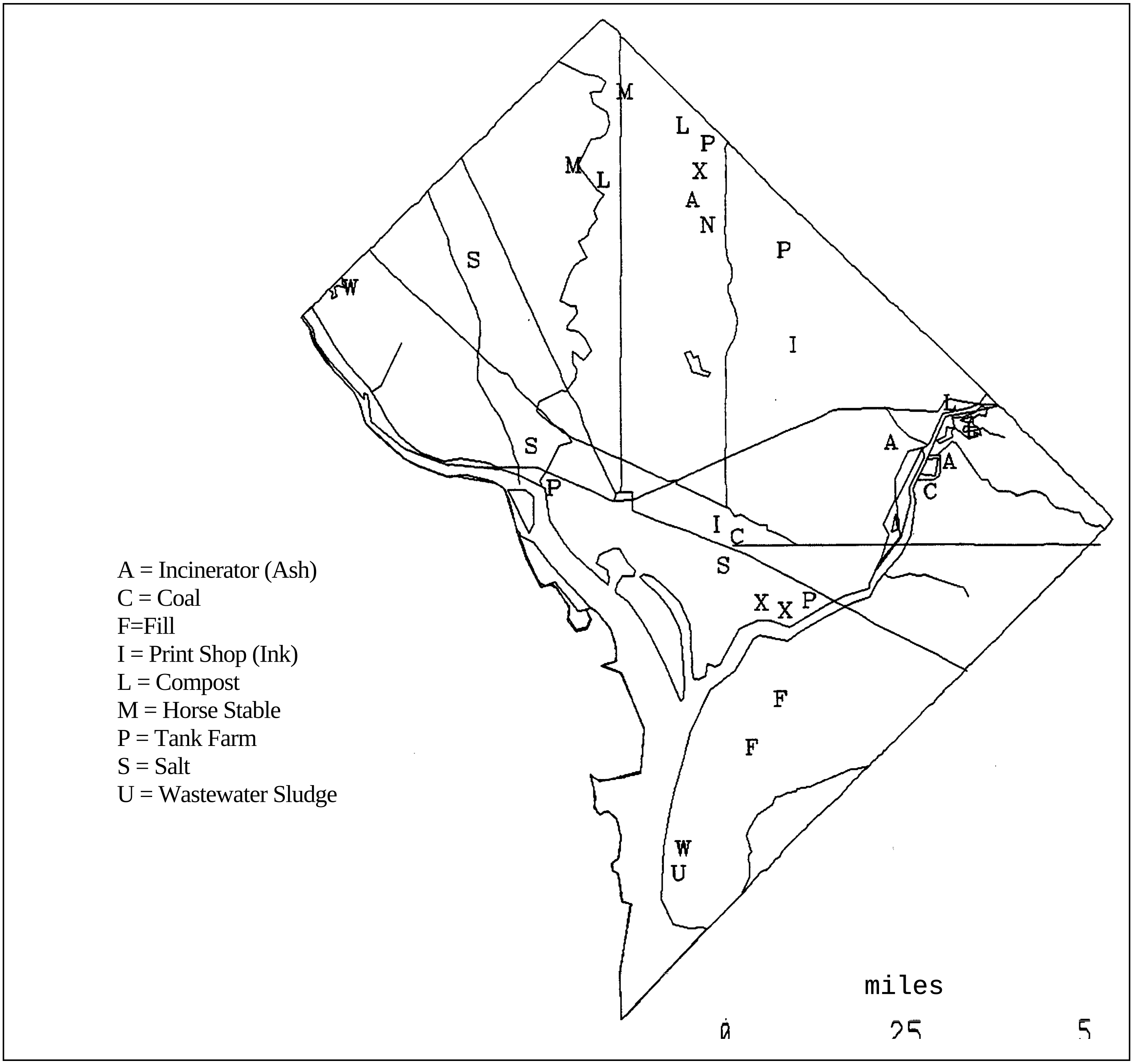


Figure 45. Materials stockpiles in the District of Columbia

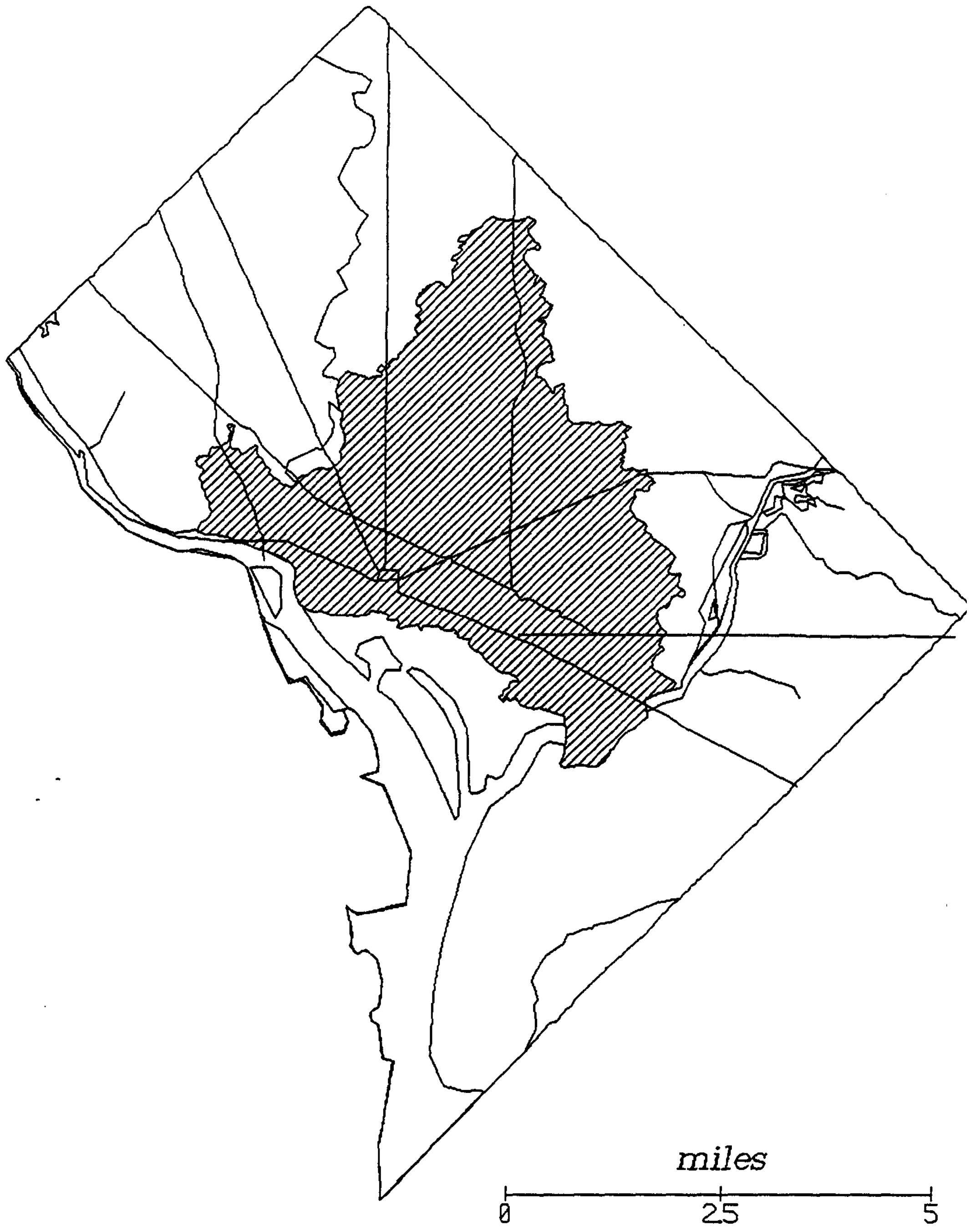


Figure 46. Combined sewer area is the District of Columbia

5. RECOMMENDATIONS FOR A COMPREHENSIVE STATE GROUND WATER PROTECTION PROGRAM

The findings of the GWRAS are the basis for the following recommendations for a Comprehensive State Ground Water Protection Program (CSGWPP). The elements of this chapter are outlined in EPA' s guidance document "Final Comprehensive State Ground Water Protection Program Guidance" (EPA Office of the Administrator, 1992). After a brief definition of a CSGWPP, recommendations will be tendered for the management and protection of ground water in the District of Columbia.

5.1. DEFINITION OF A COMPREHENSIVE STATE GROUNDWATER PROTECTION PROGRAM

A CSGWPP consists of a set of six Strategic Activities, which foster more efficient and effective protection of ground water through more cooperative, consistent and coordinated operation of all relevant federal, State and local programs within a State. The six Strategic Activities are:

Establishing a ground water protection goal to guide all relevant federal, State, and local programs operating within the State;

Establishing priorities, based on characterization of the resource, identification of sources of contamination, and programmatic needs, to guide all relevant federal, State, and local programs and activities in the State toward the most efficient and effective means of achieving the State's common ground water protection goal;

Defining authorities, roles, responsibilities, resources, and coordinating mechanisms across relevant federal, State, tribal, and local programs for addressing identified ground water protection priorities;

Implementing all necessary efforts to accomplish the State's ground water protection goal consistent with the State's priorities and schedules;

Coordinating information collection and management to measure progress, re-evaluate priorities, and support all ground water related programs; and

Improving public education and participation in all aspects of ground water protection to achieve support of the State's protection goal, priorities, and programs.

5.2. GROUND WATER. PROTECTION GOAL

Establish a ground water protection goal to guide all relevant programs in the state

Historic categories of ground water protection goals include:

- non-degradation;
- anti-degradation;
- prevention, reduction or remediation of contamination to the extent possible;
- differential protection based on relative risks to human health or the environment; and
- differential protection based on relative use and value of the ground water

EPA has defined its ground water protection goal "to prevent adverse effects to human health and the environment and protect the environmental integrity of the nation's ground water resource". This general definition was subsequently expanded to a three-tier approach:

- prevention of contamination whenever possible;
- prevention of contamination based on the relative vulnerability of the resource, and where necessary the ground water's use and value;

At a minimum, water quality for ground water currently used or reasonably expected to be used as drinking waters should attain Maximum Contaminant Levels as established under the Safe Drinking Water Act. Ground waters in close hydrologic connection to surface waters should

Table` 10. The uses and values of ground waters in the District of Columbia perceived during the GWRAS ' (in EPA categories)

Current Use Value:	drinking water *supply* of adjacent jurisdictions (Potomac Group aquifer) maintenance of streamflow and associated ecosystems (surficial aquifer, crystalline rock aquifer, Potomac Group confining unit)
Future" Use Value:	alternative drinking water supply (Potomac Group aquifer, crystalline rock aquifer) alternative non-drinking water supply (Potomac Group aquifer, crystalline rock aquifer, surficial aquifer)
Intrinsic Value:	existence value, i.e. clean ground water exists/protection of residents from contamination (all aquifers) bequest value; i.e. clean ground water will' be, available to future generations (all aquifers)

attain water quality standards as established under the Clean Water Act.

The State of Virginia has created an "anti-degradation policy which mandates the protection of existing high quality waters and provides for the restoration of all other State waters to such condition of quality that any such waters will permit all reasonable public uses (State Water Control Law, Va. Code §62.1-44.2)". The State of Maryland has defined its ground water protection goal as "to protect the physical, chemical and biological integrity of the ground water resource, in order to protect human health and the environment, to ensure that in the future an adequate supply of the resource is available, and in all situations, to manage that resource for the greatest beneficial use of the citizens of the State" (Ground Water Protection Program 1992 Annual Report, MD Dept. of the Environment).

In the District of Columbia, the GWRAS has shown slight to no degradation of the general ground water quality. Ground water uses and values include drinking water supply to neighboring counties, potential water supply for the city itself (both drinking and non-drinking water), interaction with ground water as well as current and future protection of residents from harmful effects of contaminated ground water (see Table 10). Consequently, the following ground water protection goal is recommended for the District of Columbia:

District of Columbia
Ground Water Protection Goal

To prevent the degradation of *all ground waters from human activities to the extent possible, and to restore degraded ground waters to a level of quality that will sustain the perceived uses and values of ground water in the District of Columbia*

5.3. PRIORITIES FOR GROUND WATER PROTECTION

Establish priorities, based on characterization of *the resource, identification of sources of contamination, and programmatic needs, to guide all relevant federal, State, and local programs and activities in the State toward the most efficient and effective means of achieving the State's common ground water protection goal*

A State's ground water protection priority setting should be based primarily on consideration of the following characteristics (EPA Office of the Administrator, 1992):

- Intrinsic sensitivity, hydrogeologic regimes and flow patterns, geologic/hydraulic parameters, and local hydrogeologic setting;
- Quantity and potential yield;
- Ambient and/or background ground water quality as determined by monitoring;
- Potential for remediation where contamination already exists;
- Reasonably expected future use based on demographics, land use, remoteness, quality and availability of alternative water supplies;
- Values attributed to ground water resource (current use, future use, intrinsic values);
- Interactions and potential contamination impacts between surface and ground water and the value of ground water quality to the maintenance of ecosystem integrity; and
- Inter jurisdictional characteristics.

The District of Columbia's five hydrogeologic regimes are evaluated and ranked in Table 11. The Potomac Group has a high intrinsic sensitivity, and a high quantity and potential yield. Water quality is good, with the only degradation in iron concentrations stemming from natural leaching. Some indication of potential degradation has been observed in the shallower well tapping the Potomac Group aquifer at New York Avenue, NW. Potential for remediation from the most likely source of contamination, i.e. Underground Storage Tanks, is high. The Potomac Group aquifer is already a water source in adjoining jurisdictions, and due to its ground water quality and quantity it is also the most likely aquifer to be developed as a water supply within, the District of Columbia. Consequently, the protection of this aquifer should be given the highest priority.

The surficial aquifer and the crystalline rock aquifer have variable intrinsic sensitivity and quantity due to the preponderance of preferred flow paths caused by highly variable hydraulic conductivities, for example from buried stream channels or fractures. Water quality particularly in the surficial aquifer shows signs of degradation due to urban activities. However, the degradation appears localized, which offers the opportunity for remediation. Both aquifers could potentially be developed for local emergency water supply and both aquifers interact with surface waters. These aquifers should be protected with medium priority.

Table 11. Suggested ranking of ground water protection priorities

Potomac Group Aquifer:	Depth to water	40-700
	Hydraulic conductivity	350 ft/d.
	Quantity	high
	Land Use	residential, institutional, some industrial
	Sources	all sources
	Threat	users, residents, water table
	Ground Water Value	current, future, intrinsic
Surficial Aquifer:	Depth to water	0-50
	Hydraulic conductivity	70 ft/d.
	Quantity	medium
	Land Use	all uses, residential = %max
	Sources	all sources
	Threat	residents, surface waters, confined aqu.
	Ground Water Value	current, future, intrinsic
Crystalline Rock Aquifer:	Depth to water	0-300
	Hydraulic conductivity	3 ft/d
	Quantity	medium
	Land Use	open space, residential, some industrial and institutional
	Sources	all sources
	Threat	residents, surface waters, confined aqu.
	Ground Water Value	current, future, intrinsic
Potomac Group Clay:	Depth to water	0-50
	Hydraulic conductivity	< 1 ft/d
	Quantity	high
	Land Use	open space, residential, industrial
	Sources	all sources
	Threat	residents, surface waters
	Ground Water Value	current, future, intrinsic
Perched Tables:	Depth to water	< 6
	Hydraulic conductivity	2 ft/d
	Quantity	low
	Land Use	mostly residential
	Sources	dump, cemeteries, UST
	Threat	residents, water table
	Ground Water Value	intrinsic

The Potomac Group confining unit and the perched tables are ranked with the lowest priority based on their hydrogeological characteristics, and not because of any lack of potential contamination. Both hydrogeologic regimes yield little water because of their low hydraulic conductivities and limited areal extent respectively. However, ground water contamination within these units may reach surface waters, albeit slowly through the clays or via a detour through seepage to the water table, and pose a threat to citizens' health. While the units are ranked with the lowest priority, ground water within them should still be protected to the greatest possible extent.

The suggested ranking in Table 11 should be opened to discussion and comments from the public and the District of Columbia's ground water related agencies (see 5.4.). Basic definitions and approaches for coherent priority setting including the input from the public and agencies need to be established prior to establishing programmatic funding for ground water protection. A survey of perceptions and expectations of ground water use and values can aid in developing a binding list of priorities for ground water protection. A priority list would also be a useful tool in determining future research and data needs, for example on the extent of ground water/surface water interaction or on the impact of specific land use categories on the ground water.

5.4. DEFINING ROLES AND AUTHORITIES

Define authorities, roles, responsibilities, resources, and coordinating mechanisms across relevant federal, State, tribal, and local programs for addressing identified ground water protection priorities

To achieve an efficient CSGWPP requires an assessment of all programs related to ground water in the District of Columbia. Figure 47 shows the groups that should be given an opportunity to participate in the development of a CSGWPP and suggestions for their involvement. Supported by an inventory of laws and programs potentially applicable to ground water protection within each agency, this assessment will result in an interactive mechanism to optimize data collection, funding, and achievement of program goals within the District of Columbia. Additionally, citizen groups, universities, and private consulting firms may provide suggestions for the establishment and management of a CSGWPP. Areas of cooperation may include:

- Prioritization of ground water protection goals and activities
- Regulatory aspects
- Data collection and sharing under various programs
- Data management and analysis
- Source identification under various programs Permitting for ground water monitoring Policy and planning
- Enforcement Remediation
- Public education and participation

Of particular importance is the area of data sharing among private, city and federal agencies. Private environmental consulting firms have a wealth of data on stratigraphy, ground water levels and routine water quality parameters such as pH, temperature and specific conductivity. While it may be to time-intensive to obtain data from past projects, a mechanism should be established to provide these data to the District government in the future. The city has obtained a set of ground water monitoring wells from the GWRAS that should be combined with data from its Underground Storage Tank Program. Monitoring wells have also been installed for water main and sewer inflow/outflow studies and for METRO dewatering activities. Federal agencies monitor sump pumps installed in some buildings which should also be included in the city's ground water data base. Source identification under various programs should be combined in a single data base.

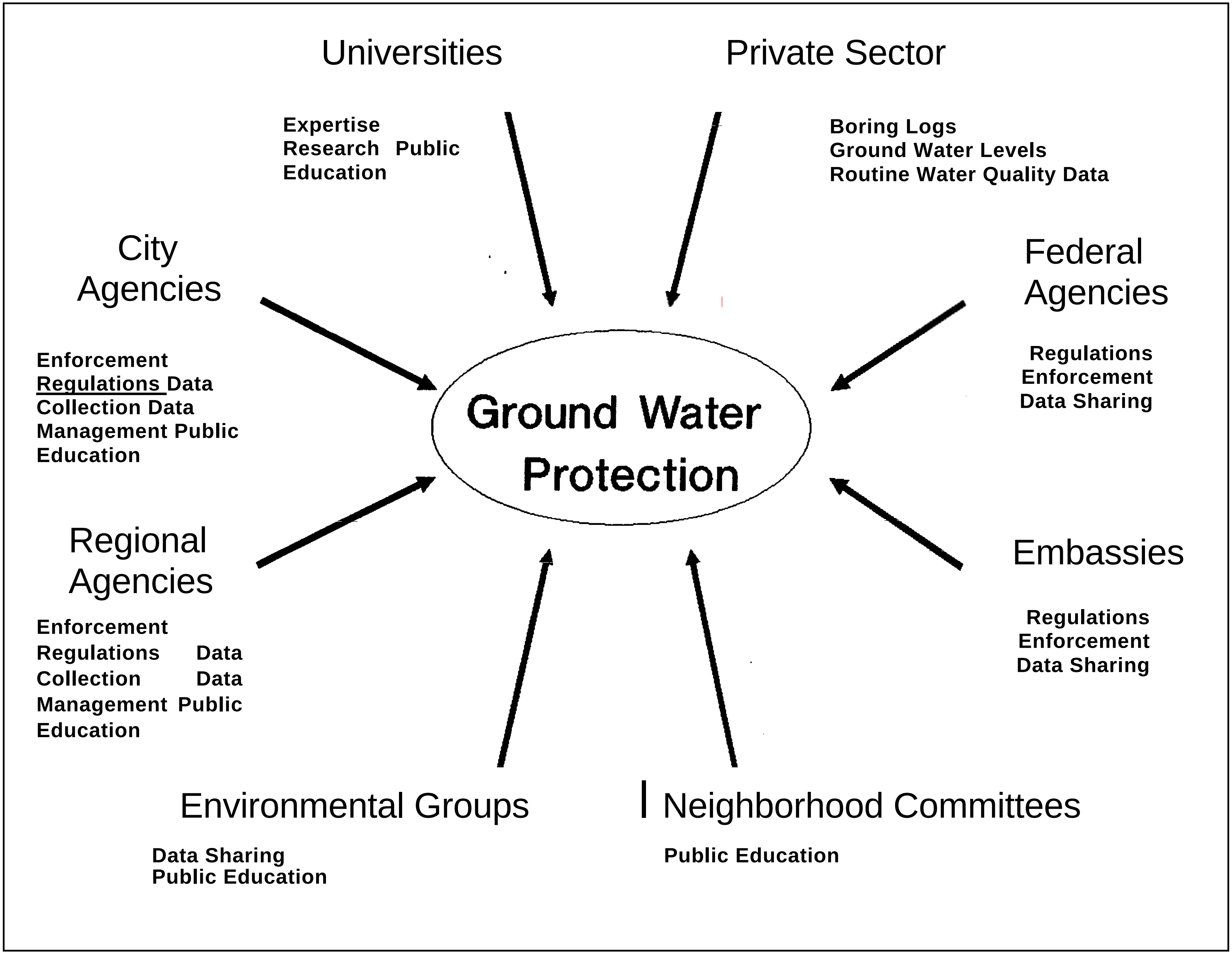


Figure 47. Organizational cooperation for ground water protection

A number of agencies that should be considered during the organizational assessment are listed in Table 12.

Table 12. Suggested organizational participants in the CSGWPP

Department of Consumer *and Regulatory Affairs*

- Office of *the Director*
- Office of" Compliance
- Business License Division
- Permit Processing Division
- Pesticides, Hazardous Waste and Underground Storage Tank Division
- Water Resources Management Division (water quality control, water quality monitoring, environmental laboratory)
- Soil Resources Management Division (stormwater management)

Department of Public Works

- Policy and Planning
- Solid Waste Control
- Sanitation Services
- Sludge Management
- Engineering Services
- Wastewater Treatment
- Water Services
- Sewer Services

Department of *Recreation and* Parks

- *Youth* and *Urban* Garden Branch

Department of *Public Health*

Fire Department

University of the District of Columbia /*DC Water Resources Research* Center

Due to the District of Columbia's unique position as the nation's capital, a significant percentage of the city's land surface is not owned or controlled by the city government. Consequently, cooperation with land-owning federal agencies, such as the Department of Defense, the Department of Agriculture and the National Park Service, as well as foreign embassies would add a much needed dimension to comprehensive ground water management and protection. Access to land owned by non-city agencies would facilitate data collection, and data sharing among all agencies would preclude duplicate efforts.

5.5. INFORMATION COLLECTION AND MANAGEMENT

Coordinate information collection and management to measure progress, reevaluate priorities, and support all ground water related programs

In the management and protection of ground water resources, which include pollution control and abatement, proper management of the acquired data from the available sources in the District of Columbia is needed. The importance of data sharing among agencies and groups that routinely collect ground water related data has already been discussed in chapter 5.4. The management of these data in appropriate data bases is a must for successful implementation and management of the District's CSGWPP. Storing data in a central, computerized data base will allow rapid retrieval and updating of all ground water data. Data bases for geologic information, ground water levels, water quality and pollution sources are as necessary as are data bases for determining trends in ground water quality and elevations. Date can be stored in EPA's STORET data base, which is currently being updated. Date entry should start upon completion of the update. Geographic Information Systems (GIS) are a valuable tool in the spatial analysis of hydrogeologic data, and full advantage should be taken of that opportunity. Additionally, a local data base using for example the LOTUS 1-2-3 spreadsheet would provide a system of checks and balances, particularly for ground water quality and water level data.

5.5.1. Standardization of Data Format

In establishing a ground water data management system, it is important to standardize the format in which data are collected and submitted. Figure 48 gives an example of a well construction data form that could be used as a standard format. The form is based on EPA's "Definitions for a Minimum Set of Data Elements", but was expanded to include some additional data.

Data Source/Point of Contact

Environmental Consulting Firm, Inc.

Latitude	*Method Used to Determine Latitude*	*Accuracy*
+38550000	Map/83/24,000/1985	+/-0.05

Longitude	*Method Used to Determine Longitude*	*Accuracy*
-76850000	Map/83/24,000/1985	+1-0.05

Description of Entity

Well MW-1 (specific well site represented by coordinates)

Altitude	*Method Used to Determine Altitude*
C/+75F I	C/29/10/15/1992

State FIPS	*County FIPS*
DC11	D0001

Well Identifier	*Well Use*
MW-1 EM	

Type of Log	*Well Depth at Completion*	*Screened/Open Interval*
D	I 14.8F	4.8/14.8/F

Boring Log (if possible)

0-2 fill/ 5-6.5 clay/6.5-8 .0 sand/10-11.5 sandy clay/15-16.5

Installation Date	*Depth to Water encountered*	*Static Water Level*
04/15/1993	114.8F I	13 F

pH	*Temperature*	*Specific Conductance*
6.8	13.5 C	234 micromho/cm

Figure 48. Sample well construction data form

5.5.2. Long-Term Monitoring

The State of Maryland has recently completed a five-year background study on ground water quality. During that study, 51 wells were sampled for inorganic parameters, 40 sites for pesticides, and 31 sites for volatile organic carbons. Sampling frequencies varied from quarterly to once for the whole study period. Generally, Maryland has a limited ambient monitoring network with samples taken once every four years (Maryland Dept. of Environmental Services, personal communication). The State of Virginia discontinued its ambient monitoring network in the early 80s (Virginia Water Control Board, personal communication). Based on parameters measured in USGS, EPA and adjoining state programs, a long-term ground water monitoring program (see Table 13) was suggested in the Sampling and Analysis Report for the Group A wells.

Table 13. Ground Water Monitoring Program Parameters and

U.S. Geological Survey — Frequency: generally once; per year

pH	Sulfate	Aluminum	Mercury
Temperature	Chloride	Barium	Molybdenu
Specific	*Fluoride*	Beryllium	Nickel
Dissolved Oxygen	Dissolved Nitrite	Cadmium	Arsenic
Total Dissolved	Dissolved Nitrite and Nitrate	Chromium	Strontium
Hardness	Dissolved Ammonia	Cobalt	Zinc
Calcium	Ammonia and Dissolved	Copper	H^Z/H' ratio
'Magnesium	.Total Phosphorus	Iron	0'8/0'e ratio'
Sodium	Dissolved Phosphorus	Lead	Radon
Potassium	Orthophosphate	Lithium	*Tritium*
Alkalinity	Dissolved Organic Carbon	Manganese	Silica

U.S. *Environmental Protection Agency* — Frequency: *not* applicable

Drinking Water Parameters for Ground Water	*Ground Water Quality Parameters*	*Ground Water Contamination* Indicators
Arsenic Radiochemistry	Chloride	pH
Barium Coliform Bacteria	Iron	Speck Conductance
Cadmium Endrin	Manganese	Total Organic Carbon
Chromium Undane	Phenols	Total Organic
Fluoride Methoxychlor Lead	Sodium	
Toxaphene Mercury		

Following the completion of the GRAS, a permanent monitoring program should be implemented (Table 14) as soon as possible. The monitoring program should include all thirteen wells installed, i. e. both Group A and Group B wells. This monitoring network would ensure a long-term recording of quality background data as a standard to determine any deterioration in ground water quality. The monitoring program should address the following objectives:

To learn more about ground water in the District of Columbia, routine parameters such as water levels, pH, specific conductance and temperature should be measured at each well installed during the GWRAS. The measurements should be taken once each month for at least a year to gain insights into the aquifers' response to precipitation events. After the one-year period of intensive measurements, the measuring frequency could be reduced.

To monitor for the deterioration of ground water quality, EPA's ground water contamination indicator parameters (pH, specific conductance, TOC, and TOH) and ground water quality parameters (Cl, Fe, Mn, SO_4, and phenols) should be measured at each well and quarterly.

To monitor specific problem areas identified during the GWRAS, measurements of nitrate at MW-4, of chlordane at MW-5, and of COD at MW-1 should be taken at least once per year. This will allow an assessment of whether the problem is permanent or temporary, and of any changes in concentration. This objective would necessarily change with time, depending on a resolution of the identified problem and responding to any new problem areas.

To obtain a long-term record of general ground water quality, parameters such as metals, other inorganics, radon and isotopes should be measured regularly. We recommend annual ground water quality analyses.

Table 14. Recommendations for long-term ground water monitoring program

Month / Parameters	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Background water level, pH, spec. cond., temp.	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Indicators TOH, TOC, TDS, Cl, Fe, Mn, Na, SO_4, phenols	•				•				•				•				•	
Well - specific COD, NO3, Chlordane (variable)					•												•	
General metals, other inorganics, DO, radon, isotopes					•												•	

5.5.3. Expansion of Monitoring Network and Further Research

In addition to the existing wells, an additional set of wells should be installed to investigate differences in water quality for specific land use categories and point sources such as landfills. As was discussed earlier, the GNVRAS was not intended to determine impacts from residential, commercial/industrial and institutional/federal/public land uses. Studies aimed specifically at potential contamination sites will provide an indication of ground water quality around pollution sources, for example salt stockpiles and the industrial corridor in the northeast of the city.

A one-year investigation of radiochemistry should be conducted to determine baseline radiochemistry such as gross alpha, gross beat and radium.

Sewer leakage may introduce bacteria into the ground water. To determine the impact of sewer leaks on ground water quality, the GWRAS wells should be sampled for the presence of bacteria.

Additional research is also warranted in the area of ground water/surface water interaction. A sampling program along priority streams and rivers in the District of Columbia would provide much needed information. The effect of urban runoff on shallow ground water should be investigated by monitoring one or more of the shallow wells located in the vicinity of major roads.

Using the priorities set under Strategic Activity 2, these impacts should be assessed to further shape the District's CSGWPP. The data gained from the new studies would in turn redefine the priorities established earlier.

A variety of public education and participation programs should be implemented to increase awareness of the District of Columbia's ground water resource. Fact sheets, workshops, lectures, conferences, and field trips are important tools for this activity. A resource and feasibility assessment targeting groups and agencies already involved in public outreach should ensure wide dissemination of ground water related information.

5.6 PUBLIC EDUCATION

Improve public education and participation in all aspects of ground water protection to achieve support of the State's protection goal, priorities, and programs

5.7. IMPLEMENTATION

Implement all necessary efforts to accomplish the State's ground water protection goal consistent with the State's priorities and schedules

Table 15. Implementing steps for a Comprehensive Ground Water Protection Program in the District of Columbia

- Finalize ground water protection goal
- Prioritize ground water protection activities
- Define ground water protection program
- Conduct organizational resource assessment
- Create organizational structure for ground water protection program
- Develop and implement comprehensive data management system: sharing, collection, management, and reporting of ground water data
- Expand monitoring network
- Conduct additional research
- Develop and implement public education program

6. FINDINGS AND RECOMMENDATIONS

1. Thirteen ground water monitoring wells were installed to assess the quality and quantity of ground water in the District of Columbia.

2. Three major and one minor aquifers have been identified: for the Piedmont hydrogeologic province, the crystalline rock aquifer; and for the Atlantic Coastal Plain hydrogeologic province, the Potomac Group aquifer, the surficial aquifer and the perched aquifers, which are of limited areal extent.

3. The physical and hydraulic characteristics vary widely among the four aquifers and within each aquifer. Highest transmissivities were found for the Potomac Group aquifer and localized areas within the surficial aquifer.

4. The ambient water quality showed high concentrations in iron and, in some cases, nitrate. Effects of urbanization were detected mostly in shallow wells tapping the surficial aquifer, which exhibited high Total Dissolved Solids, chloride and sulfate concentrations. Concentrations of chloroform and chlordane were detected in two shallow wells in downtown Washington, DC. No other pesticides/herbicides or volatiles/semi-volatiles were detected in any of the other wells.

5. The low degradation of the District of Columbia's ground water makes imperative the implementation of a comprehensive ground water protection program to preserve the resource for current and future uses and values.

6. The ground water protection goal for the District of Columbia has been preliminarily defined as follows: ***To prevent the degradation of all ground waters from human activities to the extent possible, and to restore degraded ground waters to a level of quality that will sustain the perceived uses and values of ground water in the District of Columbia***

7. Based on the different values and uses of ground waters as current and future drinking water supply (Potomac Group aquifer), current and future non-drinking water supply (Potomac Group aquifer, surficial aquifer, crystalline rock aquifer) and interaction with other water bodies (surficial aquifer, crystalline rock aquifer, perched aquifers and Potomac Group confining unit), the areas of highest priority were identified as the Potomac Group aquifer, the surficial aquifer and the crystalline rock aquifer.

8. To ensure the successful implementation of the District's ground water protection program, the protection goal and priorities identified in this report should be given exposure to representatives of all city agencies that should participate in the city's ground water protection program.

9. An organizational assessment should be conducted to explore and modify the roles, including the regulatory and organizational framework of city, federal and private agencies to include ground water protection.

10. A comprehensive data management system needs to be developed to accommodate the variety of geographic, hydrogeologic and water quality data that are part of a ground water protection program.

11. A long-term monitoring program should be implemented as soon as possible to ensure the continuous background data acquisition needed to identify overall changes in ground water quality. The monitoring network should include all wells installed during the GRAS.

12. Additional studies need to be conducted to obtain much needed information on ground water flow patterns (particularly in the Piedmont crystalline rocks), water quality impacts of specific land use categories and point sources, and ground water/surface water interaction.

13. To involve the public in the development of the CSGWPP, a public outreach program should be developed drawing on existing structures and organizations to develop materials designed to increase awareness of the District's ground water resource.

14. The results of the GWRAS and the recommendations for a CSGWPP outlined above indicate the potential for preserving the District of Columbia's ground water resource. Quick action is now imperative to maintain the momentum generated by this study and to ensure that the opportunity for effective ground water management and protection is not lost.

7. REFERENCES

Achmad, G., 1991. Simulated Hydrologic Effects of the Development of the Patapsco Aquifer System in Glen Burnie, A.A. Co., Md: Md Geol. Surv. Rep Inv. 54, 90p.

Cain, D., D.R. Helsel, and S. Ragone, 1989. Preliminary Evaluations of Regional Ground-Water Quality in Relation to Land Use in Ground Water vol. 27, #2, p. 230-244.

Cooperative Extension Service, UDC, 1981. A Survey of Pesticide Operators in DC, MD and VA.

DC Code: Chap. 11 of Title 21 DCMR: Water Quality Standards of DC

DC Dept. of Consumer & Regulatory Affairs, 1992. Well Construction, Maintenance and Abandonment Standards for DC Proposed Rulemaking Chap 12 Title 21 amended to Law 5-188 - DC Register

DC Dept. of Consumer & Regulatory Affairs, 1992. Ground Water Amendments to DC Water Quality Standards, Chapter 11 SEC. 1104-1112- Title 21. Notice of Final Rulemaking-DC Register.

DC Dept. of Env. Services, 1983. Sewer System Evaluation Survey, Vol. 3, Drainage Area Tiber Creek.

DC Office of Policy & Evaluation, 1990. Indices, A statistical index to DC Services, 412p.

DC Office of Planning, 1990. District of Columbia Generalized Land Use Map.

DC DES, WRMA, 1979. By Broad Potomac's Shore: The Water and Sewerage Systems of DC 32P.

DC Law 5-188, 1984. Water Pollution Control Act

DC Water Resources Research Center, 1991. Background Report on DC Ground Water Resource Assessment Study, Report #103

DC Water Resources Research Center, 1991. Proceedings of Groundwater Symposium, Report #107

DC Water Resources Research Center, 1993. Well Drilling and Field Operations Report Group A Wells. DC WRRC Report No. 126.

DC Water Resources Research Center, 1993. Well Drilling and Field Operations Report Group B Wells. DC WRRC Report No. 127.

DC Water Resources Research Center, 1993. Sampling and Analysis Report Group A Wells - Phase II. DC WRRC Report No. 136.

DC Water Resources Research Center, 1993. Sampling and Analysis Report Group A Wells - Phase III. DC WRRC Report No. 137.

DC Water Resources Research Center, 1993. Sampling and Analysis Report Group B Wells. DC WRRC Report No. 138.

Darton, N.H., 1896. Artesian Well Prospects in the Atlantic Coastal Plain Region: USGS Bull. 138, p. 151-166.

Darton, N.H., 1914. Undergroundwater of DC, in USGS WSP 114, p. 114-135.

Darton, N.H., 1950. Configuration of Bedrock Surface in DC: USGS P.P. 217, 42p.

EPA, 1986. RCRA Groundwater Monitoring Technical Guidance Document. OSWER Directive 9950.1.

EPA, 1988. Model Assessment for delineating wellhead protection Areas, EPA 440/6-88-002.

EPA Office of the Administrator, 1992. Final Comprehensive State Ground Water Protection Program Guidance. EPA 100-R-93-001.

EPA Office of Ground Water, 1992. Ground Water Resource Assessment - Technical Assistance Document (Draft).

EPA Office of Ground Water Protection, 1987. Wellhead Protection- A decision-makers guide EPA 440/6-87-009, 20p.

EPA Office of Ground Water Protection, 1987. EPA Activities Related to Sources of Ground Water Contamination.

EPA Office of Ground Water Protection, 1988. Survey of State Ground-Water Quality Protection Legislation Enacted 1985-1987, SG-2, EPA 440-6-88-007.

EPA Office of Research & Development, 1990. Handbook Ground Water, Vol. 1: Ground Water and Contamination, EPA 625/6-90/016a

EPA Office of Water, 1987. Improved Protection of Water Resources from Long-Term and Cumulative Pollution. EPA 440/6-87-013

EPA Office of Water, 1990. Guide To Ground-Water Supply Contingency Planning For Local and State Governments- Tech Assistance Document, EPA 440/ 6-90-003, 83p +

EPA Office of Water, 1990, A Review of Sources of Ground-Water Contamination From Light Industry- Tech asst. Doc., EPA 440/ 6-90-005, 48p.

EPA Office of Water, 1990. Progress In Ground-Water Protection & Restoration. EPA 440/6-90-001, 52p.

EPA Office of Water, 1992. Definitions for the Minimum Set of Data Elements for Ground Water Quality. EPA 813/B-92-002. 98 p.

EPA Office of Water & Wisc Geol Surv, 1991, Delineation of Wellhead Protection Areas in Fractured Rocks, EPA 570/9-91-009, 144p.

EPA & USGS, 1988. Hydrologic Mapping Needs For Ground-Water Protection & Management-- Workshop Report, EPA 440/ 6-90-002, 33p.

EPA Office of Water & Tx Bur of Geol, 1991. Wellhead Protection Strategies For Confined-Aquifer Settings, EPA 570/9-90-008, 168p.

Fetter, C.W., 1988. Applied Hydrogeology. Merrill Publishing Company, Columbus, OH.

Froelich, A.J., 1975. Preliminary Geologic Map, District of Columbia, USGS Open File Report, 8 pp.

Froelich, A.J., J.T. Hack and E.G. Otton, 1980. Geologic and Hydrologic Map Reports for Land Use Planning in the Baltimore-Washington Urban Area: USGS Cir 806, 26p.

Hansen, H.J., 1969. Depositional Environments of Subsurface Potomac Group in Southern Maryland, AAPG Bull. v.53 #9, p.1923-1937.

Heath, R.C., 1984. Groundwater Regions in US: USGS WSP 2242,

Heath, R.C., 1989. Basic Ground-Water Hydrology; USGS WSP 2220, 84p.

Johnston, P.M., 1964. Geology and Ground-Water Resources of Washington, DC and Vicinity: USGS Water Supply Paper 1776, 97p.

Matheson, G.M., E. Ridge and J. Schneider, 1993. Impact of Buried Stream Channels on Contaminant Hydrogeooogy in Washington, DC. In: Proc. AEG/ASCE Symp. Geohydrlogic Site Assessments - An Overview. Baltimore, MD.

McCartan, L., 1990. Geologic Map of the Coastal Plain and Upland Deposits, Wash. West Quad DC: USGS OF 90-654, prelim. 16p., Scale 1:24,000.

Meng, A. III, and J. Harsh, 1988. Hydrogeologic Framework of the Virginia Coastal Plain: USGS PP 1404-C, 82p.

Moore, J. and J. Jackson, ed, 1989. Geology, Hydrology, & History of the Washington, DC Area, AGI Pub, Alex., Va 114p.

Mueser, Rutledge, Wentwortlh, & Johnson, 1967. Final Report for Subsurface Investigation for National Capital Transit System WMATA: Vol. I-- Conn. Ave. Route.

National Capital Planning Commission, 1976. Toward a comprehensive Landscape Plan for Washington, DC.

Nutter, L.J. and E.G. Otton, 1969. Ground Water Occurrence in the Maryland Piedmont: MD. Geol. Surv. R.I. 10.

Nyer, E.K. and G.J. Skladany, 1989. Relating the Physical and Chemical Properties of Petroleum Hydrocarbons to Soil and Aquifer Remediation: GW Monitoring Rept., Winter, NWWA, p.54-60.

Obermeier, S.F., 1984. Engineering Geology and Design of Slopes for Cretaceous Potomac Deposits in Fairfax Co., VA and Vicinity: USGS Bull. 1556, 88p.

Obermeier, S.F. and W.H. Langer, 1986. Relationships Between Geology and Engineering Characteristics of Soils and Weathered Rocks of Fairfax Co. and Vicinity Va.: USGS PP 1344, 30p.

Obermeier, S.F. and J.V. O'Connor, 1989. Engineering Geology of DC, AGU Guidebook for IGC T-234, 7p.

O'Brien and Gere, 1983. Final Report: Combined Sewer Overflow Abatement Program, DS Dept. of Environm. Services.

O'Connor, J.V., 1984. Chesapeake Bay's Underground Comes to Light. In: Current, Jour marine Ed.

O'Connor, J.V., 1986. Groundwater Along the Fall Zone: Overview: Jour VAS v.37#2 p.107.

O'Connor, J.V., 1988. Remote Sensing Assessment of Northern Virginia: Jour VAS 39 #2, p.155.

O'Connor, J.V., 1989. Groundwater Concerns in the Nation's Capital Beyond Potability. In: Proceedings of Ground Water Issues and Solutions in the Potomac River Basin/Chesapeake Bay Region, NWWA,Dublin OH, p.l-8.

O'Connor, J.V., 1990. DC's Groundwater: Past is Prologue to the Future. In: Proceedings for ASCE/AEG Sym. Geotechnology and the Environment (Bait)

O'Connor, J.V., 1990. Bay Lessons from DC Groundwater Regime. In: Proceedings from the Chesapeake Experience, Alliance for the Chesapeake Symposium Feb 90, EPA-CB-TR-53-90, P.68-71.

O'Connor, J.V., 1991. Geology of Washington, DC: UDC GeoGuidebook 25, 70p.

O'Connor, J.V. and H.M. Watt, 1991. Urban Ground Water: The DC Model in Abstract. v. 16, Geol. Assoc. of Canada, Toronto May 91, p. A92

O'Connor, J.V. and J. Kirkland, 1991. Correlation between Groundwater Levels and Pleistocene Terraces in Mid-Downtown, DC: GSA Abs vol 23 #1, pl10.

Otton, E., 1955, Ground Water in Southern Md: Md Geol surv. R.I. 15

Papadopulos, S.S., R.R. Bennett, F.K. Mack, and P.C. Prescott, 1974. Water from the Coastal Plain Aquifers in the Washington, DC, Metropolitan Area. USGS Circular 697.

Paulachok, G.N., 1991. Geohydrology and Ground-Water Resources of Philadelphia, PA: USGS wsp 2346, 79p.

Powell, J. and J. Abe, 1985. Availability and Quality of Ground Water in the Piedmont Province of Virginia: USGS WRI Rept. 85-4235, 33p.

Reed, J. Jr., and S. Obermeier, 1982. The Geology Beneath Washington- the Foundations of a Nation's Capital. In: Legget,R.F. (ed) Geology Under Cities: GSA reviews in Engin. Geol. vol. V, p.1-24.

Schneider, J., J.V. O'Connor, F.M. Chang, C. Wade and H.M. Watt, 1992. Urban Land Use Activities and the Ground Water - A Background Survey of the District of Columbia. DC WRRC Report No. 125.

Sinnott, A. and E.M. Cushing, 1978. Summary Appraisals of the Nation's Ground-Water Resources--Mid-Atlantic Region: USGS P.P. 813-1, 32p.

USDA, 1976, Soil Survey of District of Columbia.

USGS, 1988. Ground-Water Studies in MD: Water Fact Sheet USGS. Open File Report 88-133

USGS, 1988. Ground-Water Studies in VA: Water Fact Sheet USGS Open File Report 88-135

USGS, 1988. USGS National Water Summary: Water Supply Paper 2275. Ground-Water Resources: MD & DC, p. 243-246.

USGS, Washington West; Washington East, Alexandria and Anacostia Quadrangles: 7 112 min series. Scale 1:24,000..

USGS, Water Resources Data- MD, DC,& Del. for Water Year 1991

Vroblesky, D.A., and W.B. Fleck, 1991. Hydrogeologic Framework of the Coastal Plain of Md., De.„ and DC: USGS P.P. 1404-E, 45.p

Watt, M., J.V. O'Connor, and H. Truong, 1984. Groundwater Problems in the Mid-Atlantic Fall Line Cities: DC WRRC Report 62, 74p.

Williams, G.P., 1977. Washington, DC's Vanishing Springs and Waterways: USGS Cir. 752, 19p.

Wilson, J.M. and W.B. Fleck, 1990. Geology and Hydrologic Assessment of Coastal Plain Aquifers in the Waldorf Area, Charles Co., MD.: Md. Geol. Surv. Rep. Inv. 53, 138p.

APPENDICES

APPENDIX A: List of Acronyms

APPENDIX B: Glossary of Terms

APPENDIX C: Plates of GWRAS Field Work

APPENDIX A
- LIST OF ACRONYMS -

Kg - Kensington Gneiss

Kam - Monmouth Formation

Kpc - Potomac Group clay and silt facies (Patapsco/Arundel Formation)

Kps - Potomac Group sand and gravel facies (Patuxent Formation)

LUST - Leaking Underground Storage Tank

MCL - Maximum Contaminant Level

METRO - METROpolitan subway system of the District of Columbia

MW - Monitoring Well

NCPC - National Capital Planning Commission

NOAA - National Oceanographic and Atmospheric Administration

NPS - National Park Service

PPB - Parts Per Billion

PPM - Parts Per Million

RASA - Regional Aquifer-System Analysis

RCRA - Resource Conservation and Recovery Act

SMCL - Secondary Maximum Contaminant Level

QA/QC - Quality Assurance/Quality Control

Qal - Alluvium and artificial fill

Qt - River terrace deposits

STORET - STOrage and RETrieval water quality data base

LIST OF ACRONYMS

ASCE - American Society of Civil Engineers

CERCLA - Comprehensive Environmental Response, Compensation and Liability Act

COD - Chemical Oxygen Demand

CSGWPP - Comprehensive State Ground Water Protection Program

CWA - Clean Water Act

DC - District of Columbia

DCRA - Department of Consumer and Regulatory Affairs

DES - Department of Environmental Services

DCFD - District of Columbia Fire Department

DC WRRC - District of Columbia Water Resources Research Center

EPA - Environmental Protection Agency

FCWA - Federal Clean Water Act Ft - Foot

GIS - Geographic Information

System GPD/FT - Gallons Per Day Per Foot

Gm/U - Georgetown Mafic Complex/Ultramafic Rocks

GWRAS - Ground Water Resource Assessment Study

HAZMAT - HAZardous MATerials response unit of the DCFD

Ta - Aquia Formation

Tc - Calvert Formation

IDS - Total Dissolved Solids

TOC - Total Organic Carbon

TOH - Total Organic Halides

Tug - Upland gravel and sand

UDC - University of the District of Columbia

USDA - United States Department of Agriculture

USGS - United States Geological Survey

UST - Underground Storage Tank

UST10/ - Underground Storage Tank with 10,000/12,000 gallons
UST12 capacity

Wd - Wissahickon Formation/Diamictite gneiss facies

WRRC - Water Resources Research Center

Wp - Wissahickon Formation/Pelitic schist facies

APPENDIX B
- GLOSSARY OF TERMS -

GLOSSARY OF TERNS

Alluvium	- Sediments deposites by flowing rivers; depending on the location in the floodplain of the river, different-sized sediments are deposited
Aquifer	- Geologic formation, group of formations or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs
Aquitard	- Confining bed, e.g. layer of consolidated or unconsolidated material that restricts the movement of water into or out of a confined aquifer
Artesian Aquifer	- Confined aquifer in which ground water is under pressure and will rise above the overlying confining bed if given an opportunity to do so, e.g. through a well (SEE Confined Aquifer)
Base Flow	- That part of stream discharge from ground water seeping into the stream
Bedrock	- Consolidated rock underlying unconsolidated surface materials such as soil
Boring	- A hole advanced into the ground by means of a drilling rig
Brackish	- Water having a salt content between 0.5 and 16 ppt (parts per thousand)
Chlorine	- Bleaching, oxidizing and disinfecting chemical agent used in waste water purification
Coastal Plain	- Lowland area extending in a gentle slope inland from the shoreline of an ocean
Combined Sewage	- Sewage containing both domestic sewage and surface water or stormwater, incl. flow in heavily infiltrated sanitary sewer systems and flow in combined sewer systems

Confined Aquifer - Aquifer bounded below and above by impermeable beds or beds with distinctly lower permeability than the aquifer itself

Confining Bed - Impermeable unit overlying or underlying an aquifer and preventing or impeding movement of water into or out of the aquifer

Consolidated Sediment - Firm and rigid sediment masss caused by the natural interlocking and/or cementation of mineral grain components

Contamination - Process of becoming impure; damage to the quality of water resources by sewage, industrial waste or other matter

Diamictite Gneiss - Medium to coarse crystalline, layered to massive, jointed quartzfeldspar-biotite gneiss with scattered quartz pods and schist and amphibolite cobbles

Digitizing - Process of computer-coding points along various boundaries (e.g. watershed, land use zones, geologic units) in a coordinate system

Discharge - The volume of water flowing in a stream or through an aquifer past a specific point in a given period of time

Discharge Area - An area in which there are upward components of hydraulic head in the aquifer; ground water is flowing toward the surface in a discharge area and may escape as a spring, seep, or baseflow, or by Evapotranspiration

Drainage Basin - The land area from which surface runoff drains into a stream

Drainage Divide - A boundary line along a topographically high area. that separates two adjacent drainage basins

Evapotranspiration - The sum of evaporation from soil and surface waters and transpiration from plants

Fall Line - Line joining water falls on numerous rivers that mark the point where each river descends from the upland to the lowland.

Fertilizer - Compound containing nutrients to stimulate plant growth

Flood Plain - Lowland bordering a river and subject to flooding when the river overflows its banks

Ground Water - Water beneath the Earth's surface in a layer of rock or soil called the saturated zone because all openings are filled with water

Hardness - A measure of the magnesium, calcium and iron content dissolved in water

Herbicide - Compound, e.g synthetic organic chemical, used to control plant growth

Heterogeneous - Pertaining to a substance having different characteristics in different locations; a synonym is nonuniform

Hollow-stem auger - A drilling device whereby a hole is rapidly advanced into sediments

Homogeneous - Pertaining to a substance having identical characteristics everywhere; uniform is a synonym

Hydraulic Conductivity - Rate at which water moves through aquifer material under a unit hydraulic gradient

Hydrochemical Facies - Bodies of water with separate but distinct chemical compositions

Hydrogeology - Science dealing with subsurface waters and related geologic aspects of surface waters

Hydrologic Cycle - Continuous sequence of processes in which water passes from the atmosphere to the land or oceans and back to the atmosphere

Impermeable - Not permitting passage, e.g. of water

Impoundment - Body of water formed by confinement, e.g. liquid waste reservoirs

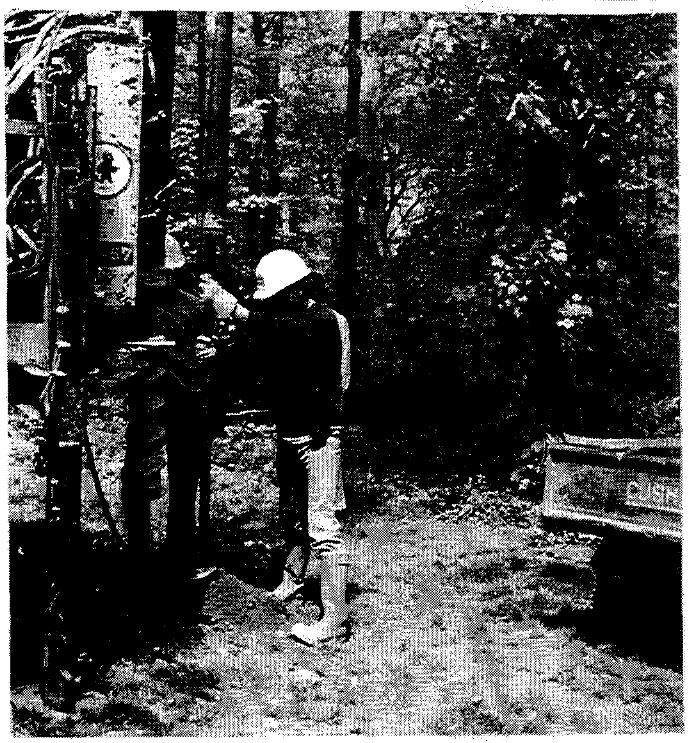
Land Cover	- Natural and artificial covers of the land surface
Land Use	- Human activities which are directly related to the land
Landfill	- The disposal of solids and, in some cases, liquid and semisolid wastes by burying the material at shallow depths, usually in unconsolidated deposits
Leachate	- Solution formed when water percolates through soluble material, e.g. liquid from percolation of precipitation through landfill wastes
Nonpoint Source	- A diffuse discharge which originates over a broad area, such as storm water runoff
Nutrient	- An element or compound, primarily nitrogen and phosphorus, that is necessary for plant growth, development and reproduction
Pelitic Schist	- Fine to coarse crystalline, foliated quartz-mica schist and chlorite quartz schist with fine garnets
Perched Aquifer	- A region in the unsaturated zone where the soil may be locally saturated because it overlies a low permeability unit
Permeability	- .Property of soil or rock to pass water through it
Pesticides	- Chemical compounds used to control undesirable plants and animals
Piedmont	- Metamorphic and crystalline rock covered by a mantle of weathered residuum (saprolite); separated from the Coastal Plain by the Fall Line
Point Source	- Specific source of pollution
Pollutant	- Substance which causes impurity, e.g. in water
Potentiometric Surface	- A surface that represents the level to which water will rise in a tightly cased well; the water table is a particular potentiometric surface for an unconfined aquifer

Pumping test	- A test made by pumping a well for a period of time and observing the change in hydraulic head in the aquifer to determine well capacity and the hydraulic characteristics of the aquifer
Recharge Area	- An area in which there are downward components of hydraulic head in the aquifer and where infiltration moves downward into the deeper parts of an aquifer
Regolith	- Upper layer of unconsolidated deposits
River Terrace	- Gravel, sand and loam deposited at various elevations during the Pleistocene epoch; basal part is usually unsorted boulders, pebbles and sand, grading to finer deposists toward top part
Saprolite	- A soft, earthy decomposed rock, typically clay-rich, formed in place by chemical weathering of igneous and metamorphic rocks
Topography	- Physical features of a geographical area, particularly land elevations
Tributary	- A stream or other body of water which contributes its water to another and larger stream or body of water
Unconfined Aquifer	- An aquifer in which there are no confining beds between the zone of saturation and the land surface; water table aquifer is a synonym
Unconsolidated Sediment	- Sediment not formed into a compact mass, loosely associated or soil-like
Urban Runoff	- Storm water from city streets and gutters containing litter, organic and bacterial wastes
Water Table	- Surface of a ground water body at which the water pressure equals the atmospheric pressure

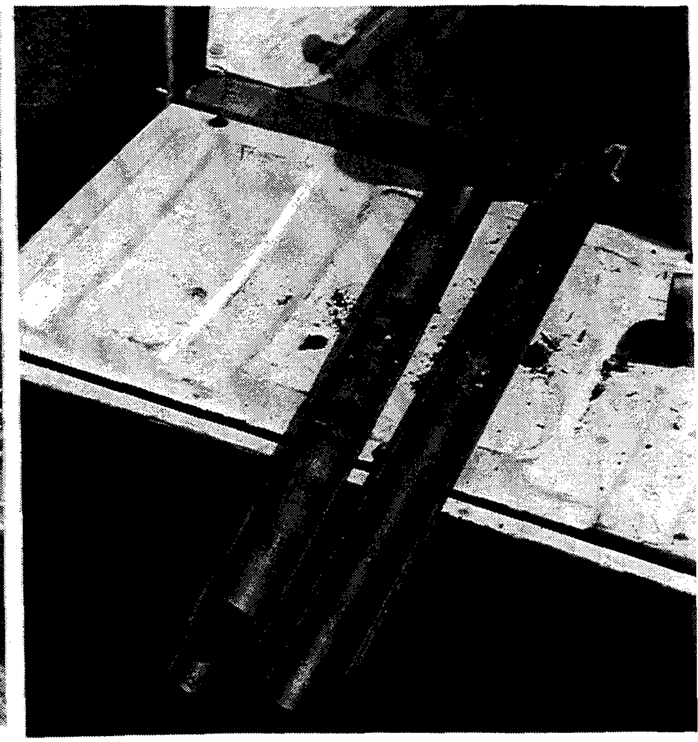
APPENDIX C
- PLATES OF GWRAS FIELD WORK -

Hallow-Stem Augers - 6" inside diameter augers for installing 4.5" outside diameter PVC monitoring wells at the Peabody GUM she in Northwest Washington, DC

Assembly of the hollow-stem auger drilling rig by Geomatrix, Inc. at the the Peabody Garden site,

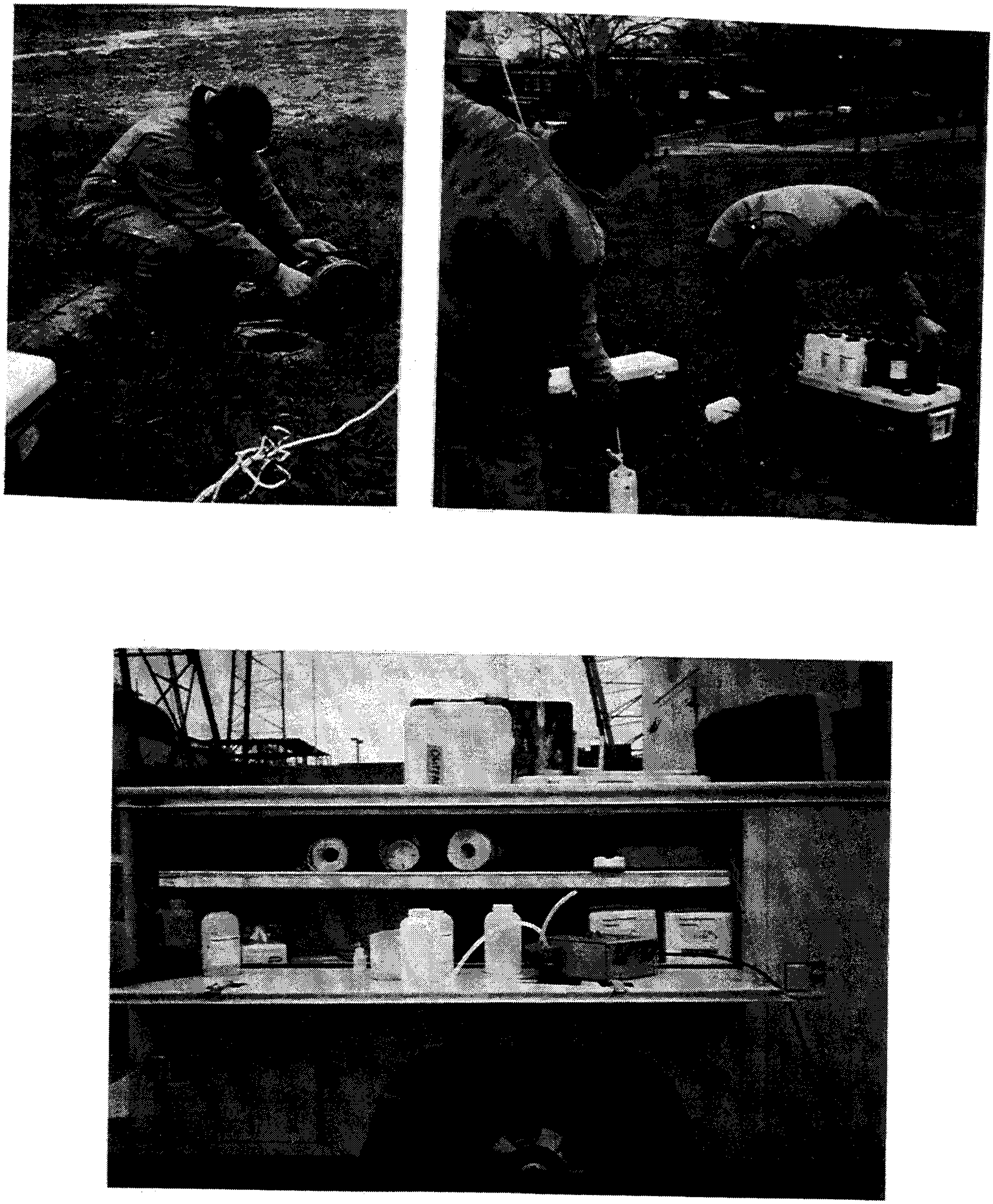


Obtaining split-spoon samples at the Rock Golf Course. The samplers were driven to collect undisturbed samples from the strata immediately below the cutting head of the auger column.



Soil sample taken with split spoon Creek sampler.

Measuring the water level through the hollow-stem auger at the Rock Creek Park golf course



Sampling activities by Gascoyne Laboratories, Inc, at Peabody Gardens.