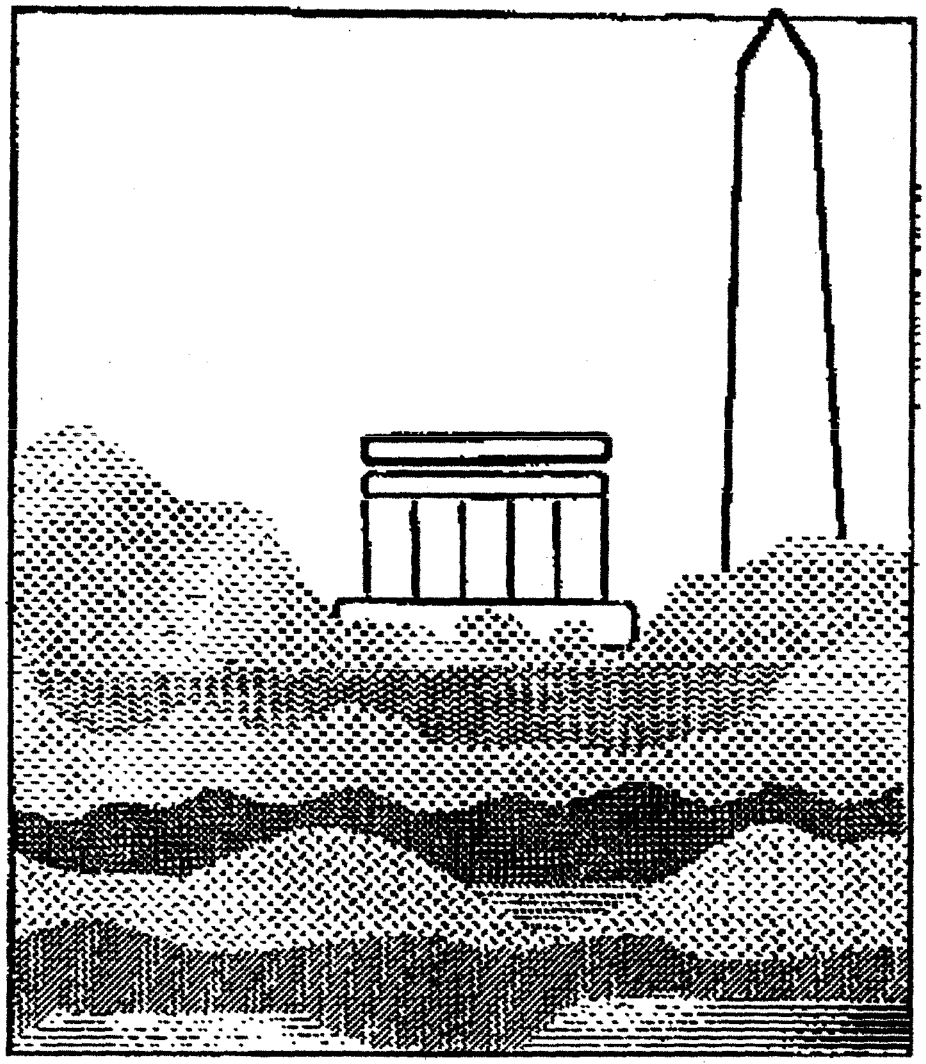
DC WRRC Report No. 103

Background Study of the Ground Water in the District of Columbia

Assessment of the Groundwater in the District of Columbia



The DC Water Resources Research Center
University of the District of Columbia
Washington, D.C.

May 1992

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Background Study of the Groundwater in the District of Columbia

Assessment of the Groundwater in the District of Columbia

Submitted To

The Water Hygiene Division D.C. Department of Consumer and Regulatory Affairs Washington, D.C.

BY

The DC Water Resources Research Center
University of the District of Columbia
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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

PREFACE

Ground water is a resource of immense value that is being heavily used by people in the United States. Some estimates indicate that over ninety seven percent of the people in the rural areas of this country use ground water for various purposes ranging from agriculture and livestock development to drinking. Though used extensively and the rate of use is increasing rapidly, the protection of ground water from contaminants and its preservation has been neglected for decades. Due to this negligence, ground water contamination has become a national problem in recent years.

Deeming ground water contamination severe and recognizing the urgent need to protect our ground water resource, the United States Environmental Protection Agency (US-EPA) released the ground water protection strategy in August, 1984. EPA also urged the states to develop protection strategy, to adopt a ground water classification system, to establish protection standards, to enact specific statutes, and to create an organizational structure for the administration of programs. "Assessment of Ground Water in the District of Columbia" is a project conceived to generate baseline data for the protection of ground water in the District of Columbia. The project will be executed in three phases. Phase I focuses on background information, development of a detailed work plan, quality assurance and quality control of data, and a data management plan. Phase II involves well construction, sampling and analysis, and ground water modeling. The final phase of the project includes sampling and analysis and preparation of the final report with findings, suggestions, and recommendations. Three other ongoing projects, approved under the Water Research Institute program for fiscal year 1990, also focus on various aspects of ground water. These projects include:

0 "Urban Land Use Activities and the Ground Water: A Background Survey"
investigated by Drs. Chang, Wade and Prof. O' Connor, University of the District of Columbia.
0 "Development of New Techniques for Rapid Identification of Pollutants in Ground Water"
investigated by Drs. Montaser, Schmidt, Caress and Perros, George Washington University.

0 "Field Measurement of Ground Water and River Water Levels and
Calibration and Verification of the Ground Water Numerical Model"
investigated by Drs. H.P. Pao and Ling, the Catholic University of America.

The Water Resources Research Center of the District of Columbia (DCWRRC) plays a central role in water resources development, management, and research in the District. The project on "Assessment of Ground Water in the District of Columbia" is an example of the Center's commitment to play a significant role in the protection and preservation of ground water in D.C. While the various tasks of the projects are divided among a consortium of universities including George Washington,

Catholic University, Howard University, and the University of the District of Columbia, the Center plays a pivotal role in coordinating the project activities undertaken by the universities. The project is founded by the Water Hygiene Branch (WHB) of the District of Columbia Department of Consumer and Regulatory Affairs (DCRA). This project was initiated by Dr. Dave Kargbo, now with EPA Region III. We are deeply appreciative of giving us the opportunity to get involved in such an important project. I greatly acknowledge the financial support of DCRA and their close cooperation for the implementation of the project. I also thank Drs. F. Chang, C. Wade and Prof. 0 ' Connor for their efforts in the successful implementation of the project, Mr. Sreenivas and J. Bekele for the preparation of the report. I also extend my gratitude to various individuals and agencies (see appendix), especially the U.S. EPA, U.S. Geological Survey (USGS), the National Water Data Exchange, Schnabel Engineering, Geomatrix, Spectralytix, and DCRA offices of the Environmental Control Division for providing all available information for the successful implementation of this project.

Finally, the contents of this publication do not necessarily reflect the views and policies of DCRA/WHB, nor does mention of trade names or commercial products constitute their endorsement by the DCRA/WHB.

Dr. H.M. Watt
Principal Investigator

1.0 INTRODUCTION

1.1 Overview

Ground water is a common pool resource of immense value, and its preservation and protection has attracted much attention in recent years. This largest available source of fresh water confined to the underground is a mirror image of surface water and remains as the sole source of stream supply during dry periods. The inevitable link between ground water and surface water points to the fact that changes in ground water quality eventually affect the quality of surface water. As the use and development of this vital resource continues, the quality of ground water becomes a major issue and necessary steps are to be taken to protect it.

Ground water is a widely tapped resource in the U.S. that is used in large quantities for both domestic and industrial purposes. It is the source of drinking water for fifty three percent of the total U.S. population and for more than ninety seven percent of the rural population (USGS, 1988). The District of Columbia (Fig. l) has an abundant supply of ground water that is unused now. In 1980, the District of Columbia (DC) depended almost entirely on surface water supplies. Hospitals, government facilities, industries, and embassies used only 0.8 million gallons per day of ground water for emergencies. This usage of ground water represents only 0.2 percent of the total water supply in the District of Columbia.

Although, ground water in the District is not greatly used, nearly three-quarters of the land in the District of Columbia forms a recharge area for the lower Potomac aquifer system which supplies water to many counties in Maryland and Virginia. Information regarding the quality and quantity of ground water in the District is not available at the present time.

The enhanced use of ground water for various purposes in the U.S. and the imminent threat of man-made contamination to this resource has alerted EPA to develop and issue a Ground Water Protection Strategy. This strategy emphasizes monitoring the ground water by collecting, chemical, physical, geological, biological, and other environmental data. The federal' and state governments have also begun to legislate on the protection of ground water. The Clean Water Act (CWA) and its amendments also require states to assess their water resources.

The District of Columbia, like Philadelphia, Wilmington, Baltimore, and Richmond, lies in the Middle Atlantic Fall Line (Fig 2). Like most other urban areas, the District of Columbia is on a fast track of development. As urbanization progresses, more industries and businesses will be attracted to the area exerting accelerated demand and pressure on natural resources, including ground water. Developmental activities like constriction, remodeling, tunnelling etc. are likely to have a significant impact on the ground water resources of the area. Besides this, there are multitudes of other human

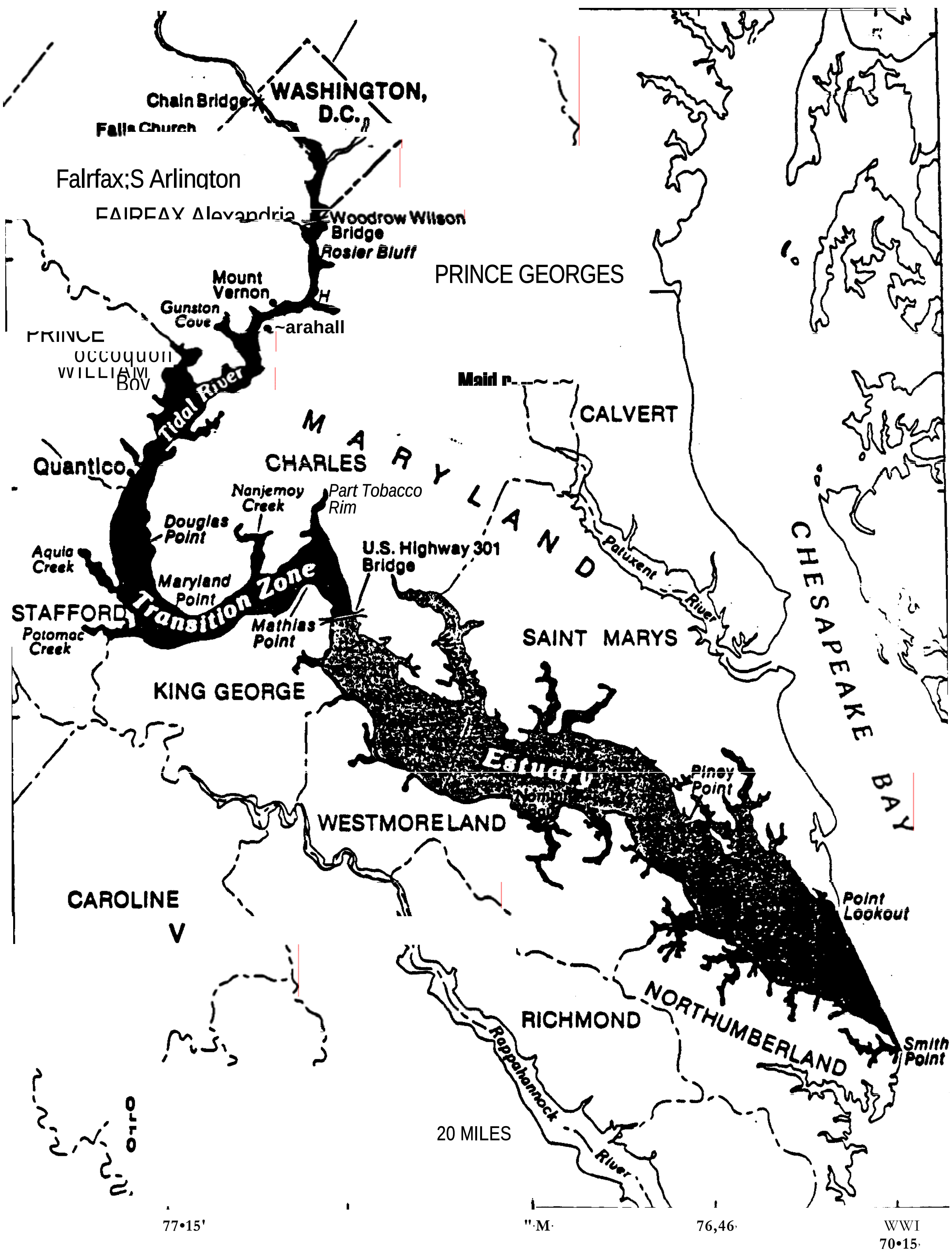
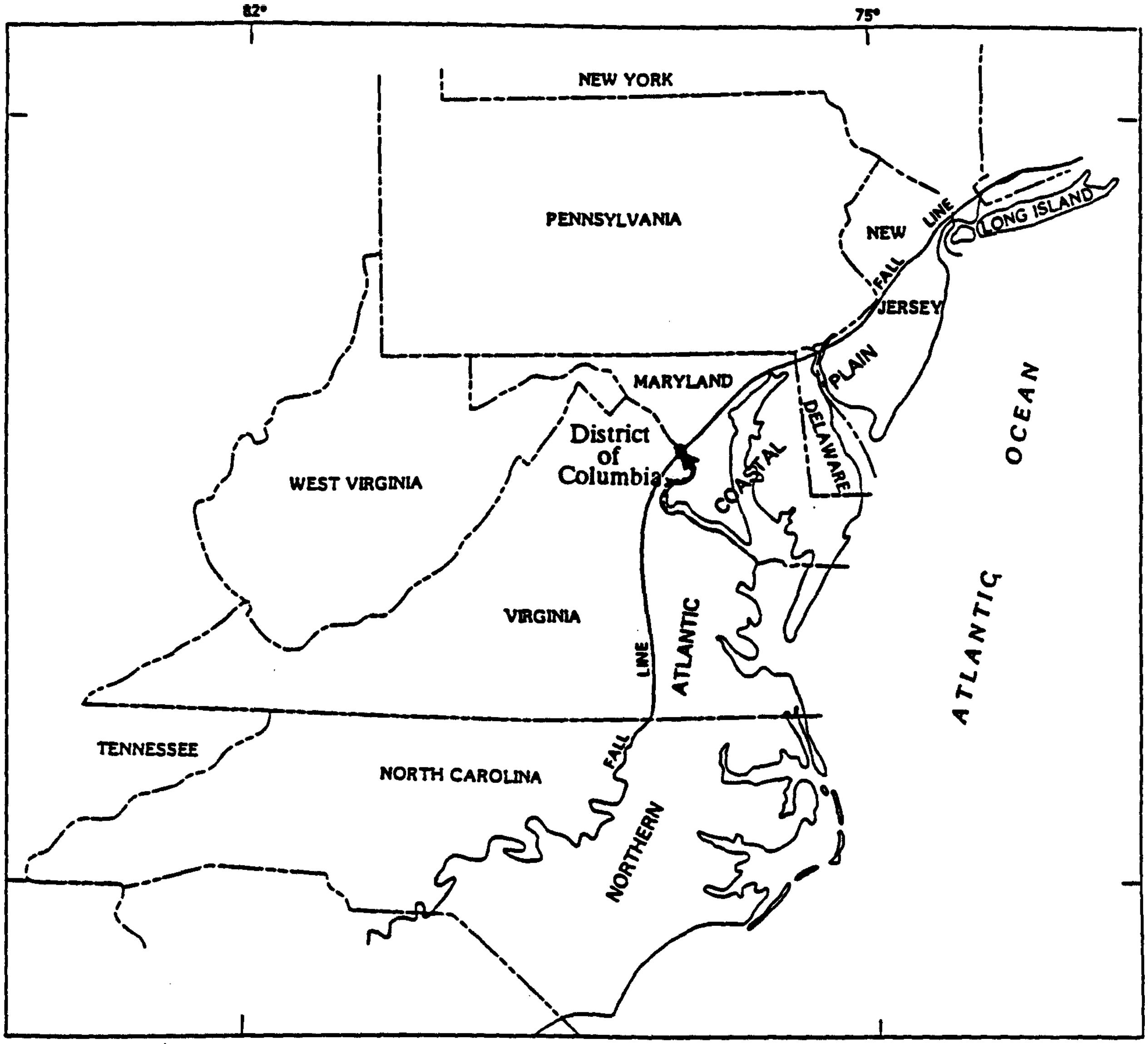


Figure 1. General map for Washington, D.C Area showing the General latitude and longitude.



0 100 200 MILES

0 100 200 KILOMETERS

Figure .2. Fall line in the Middle Atlantic Region.
USGS PP 1404E

activities threatening the quality of ground water. Since very little of the ground water is utilized in D. C. , the need for information was not deemed critical in the past. Ground water control can be a major concern in the construction of foundations and sub-basements. Conditions are particularly difficult to evaluate in an urban setting where a network of utility and subway lines alter the natural geology. Knowledge of the ground water regime minimizes the adverse long and short term side effects that may develop because of design decisions. Knowledge of the quality and quantity of ground water will allow flexibility in responding to water supply emergencies in times of drought and water quality problems. This is important particularly in critical areas such as health care facilities. Both the natural and induced interconnection of the ground water in the District of Columbia with the Potomac and Anacostia Rivers emphasizes the fact that the state of our rivers and ultimately of the Bay region is closely related to the conditions of the ground water in the District of columbia.

A consortium of universities in D. C. has been organized to investigate the quality and quantity of ground water in the area. The result of the project will give a vivid picture of the status of ground water in the District of Columbia and will provide environmental managers the information necessary to take steps to protect this precious resource. The data can be used for regulatory purposes and to respond to federal and local regulations. The background information and data collected during the present project can be used as a valuable source to develop future ground water-related projects in the District.

1.2 Objectives and Tasks

Under the Federal Clean Water Act (CWA) and its subsequent amendments, the states are required to undertake an assessment of the quality and quantity of ground water in each jurisdiction. States are also encouraged to develop strategies for the protection of ground water and to establish state programs for the implementation of the strategies. The District of Columbia Water Pollution Control Act of 1984, and the subsequent delegation of the act to the director of the Department of Consumer and Regulatory Affairs (DCRA), requires DCRA to regulate the restoration of the cleanliness and purity of local waters, including ground water in the District of Columbia.

The objective of this study is to assess the quantity and quality of ground water in the District of Columbia and the surrounding regions. The data collected during the project may also be used for other federal and state pollution control programs. These include the non-point source pollution control strategy under Section 2050)(5) and 319 of CWA and Leaking Underground Storage Tank program under the Hazardous Waste Management laws and regulations.

In addition to the legal requirements, there are other significant reasons to protect the ground water from contamination. These include:

1. Future use of ground water as an alternative water supply in emergencies;

2. Protection of surface water drinking supply due to surface water/ground water interrelationship;
3. Protection of District residents from potential health hazards of ground water contamination from such sources like leaking underground tanks; 4. Prevention of the contamination of drinking water in the Prince George's County aquifer as the District lies on the recharge zone of this aquifer; and 5. Reduction of the financial burden on the construction industry resulting from the effect of contaminated ground water on construction materials and to prevent adverse effects to on-site workers.

The study is divided into the following five tasks and the scope of each task is specified in Table 1.1.

1. Background report
2. Work plan
3. Well construction
4. Ground water modelling
5. Sampling and analysis

TABLE 1.1

TASKS AND SCOPE

TASK No.	TITLE	
1.0	**BACKGROUND REPORT**	(a) Survey of literature on ground water in the District of Columbia, Prince Georges County, Montgomery County, Arlington County and Alexandria City. (i) Geology and hydrology such as general geologic setting, physiographic divisions, borehole locations, geologic cross sections, precipitation, stream flow, water table, ground water surface water relations. (ii) Identify existing wells, well logs, locations, pumping records, water use, chemical and physical characterization, lithologic materials, geophysical data; (iii) Principal aquifers, water distribution, perched

unconfined,

(iv) Aquifer characteristics, such as hydrologic boundaries and their connections, recharge zones, hydraulic conductivity, transmissivity, specific discharge, storage co efficients.

(b) Land use and water quality -to identify land use and potential source of pollutants, such as chemical storage tanks (under and above ground), landfills and waste dumps (past and present), septic systems, hazardous substance storage and disposal, chemical spills, surface impoundments, road salting;and ground water quality.

(c) Pollution potential map of the District: Land use effects on ground water quality.

(d) Identification of monitoring wells: selection of existing wells, selection of location for well drilling.

2.0 WORK PLAN

Summary of phase I, geologic and hydrologic data (DC, MD, VA) such as hydraulic conductivity, transmissivity, storage coefficient, flow boundaries, flow rates, movement and direction, evaluation, method of hydrologic connections, selection of well locations, method of well construction, type of figures and maps, potentiometric surfaces, principal aquifers, aquifer parameters, hydrogeologic parameters, potential yield, geologic cross sections, potential discharge/recharge locations, ground water quality, ground and surface water interaction. Survey of well locations and well elevation data.

Ground water model selection / development and application.

Detailed budget and schedule

-- Detailed budget- phase I
-- Detailed schedule- phase II and III
-- Estimated budget- phase II and III

Organization for assessment

-- Key steps
-- Responsible individuals

QUALITY ASSURANCE/QUALITY CONTROL	Data collected will be: precise, accurate, representative, comparable, and legally defensible. Data processed will have scientific validity
DATA MANAGEMENT PLAN	Sample management and tracking document control and inventory include field data, lab analysis data, computerized data format (ENVIS)

PHASE III

3.0 WELL CONSTRUCTION	Well drilling, physical analysis, well logs, slug tests and/or pumping tests, ground water level, chemical analysis, screening for volatile organics.
4.0 GROUND WATER MODELING	Development/selection of 3-D model, selection/ application/verification of model: evaluation of existing field data, application (new and existing data), IBM PC compatibility.
5.0 SAMPLING AND ANALYSIS	Selection of sampling wells: sampling and analysis: indicator parameters ground water elevation, pH, conductivity, temperature, color, total organic carbon (TOC), total dissolved solids (IDS), total suspended solids (TSS), total organic halogens (TOX), chemical oxygen demand (COD),

		inorganic parameters (list provided), organic parameters (list provided), volatiles, semi volatiles, pesticides.
6.0	**FINAL REPORT**	Summary of findings of tasks 1. to 5.0: Suggestions on the District's ground water management, use, long term monitoring, quantity and quality.

1.3 Previous Works

A survey of the literature on ground water in the District of Columbia shows that there is only a few published works on the subject. Some of the major works-that deserve mention include Darton (1896, 1914), Johnson (1965) and Williams (1976). Darton's (1896, 1914) reports examine the quantity and quality of the Coastal Plain artesian system for industrial purposes. The report also deals with the uses and chemical analysis of well water in the District. In a later study Darton (1950), gives a series of cross sections traversing the city. From an extensive compilation of data from 1890 to 1940, he shows the wedge-shaped Coastal Plain sedimentary formations overlying the Piedmont bedrock (Fig. 3 - 7). Johnston's (1965) paper discusses the ground water characteristics and gives details on general chemistry based on geology and an analysis of existing wells on each quadrant of US Geological Survey topographic maps. Sommerville's (1930) report on ground water in the city examines pollution in Rock Creek Park and Williams (1976) takes a historical perspective to the ground water problem while discussing the vanishing springs and rivers in the District.

In addition to the investigations of various individuals, there are a few reports on ground water prepared by the agencies. The Regional Aquifer System Analysis (RASA) program by the U.S. Geological Survey (1978-1984) focuses on basic data collection as ordered by the Congress to obtain a handle on ground water as a national resource. As an extension to the RASA study, Meng and Harsh (1988) published the 'Hydrogeolgic Framework of the Virginia Coastal Plain'. The paper discusses the extension of ground water into the District of Columbia and the detailed stricture contour maps of the interstate aquifers for the Potomac Group. USGS circular 1002 gives a summary of the Coastal Plain and Piedmont aquifers. A detailed background assessment of ground water in the city was done by the DC Water Resources Research Center (DCWRRC,1984). The study examines the geological complexity of the fall line cities and

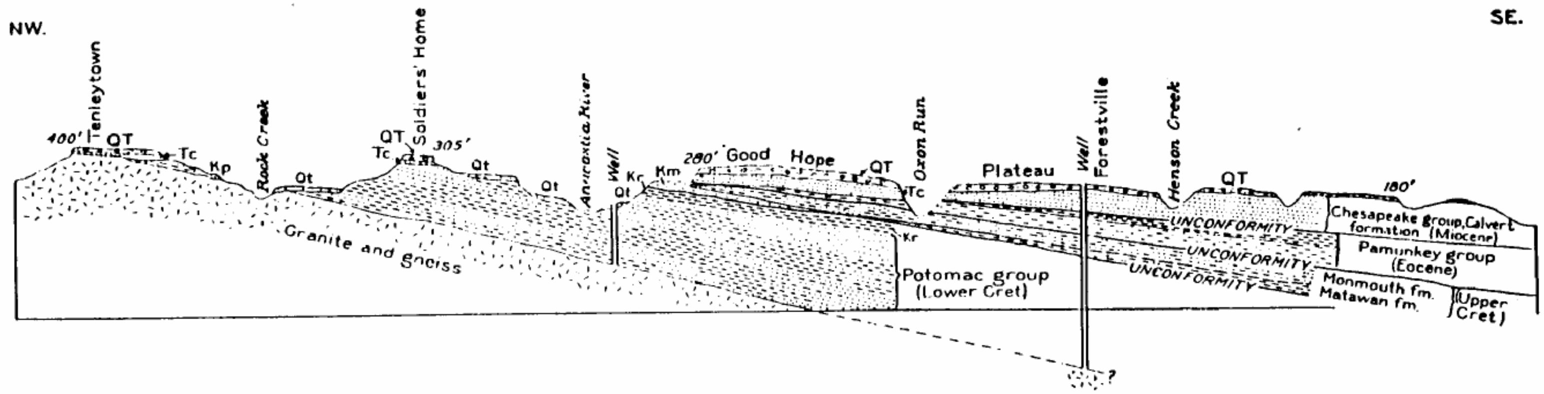


Figure 3. Geologic section across the District of Columbia area, showing the succession and general relations of the principal sedimentary formations. (Barton, 1950)

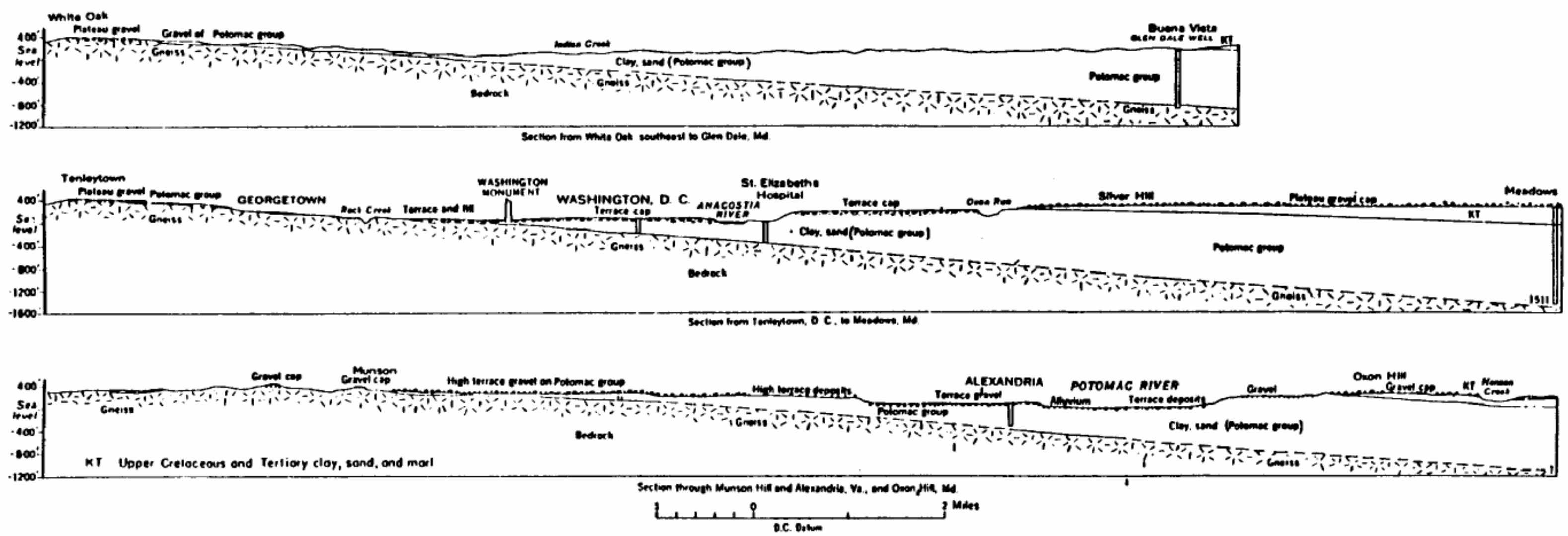


Figure 4 Sections across the Coastal Plain-Piedmont overlap in Maryland, District of Columbia, and Virginia, showing relations of bedrock floor. (Darton, 1950).

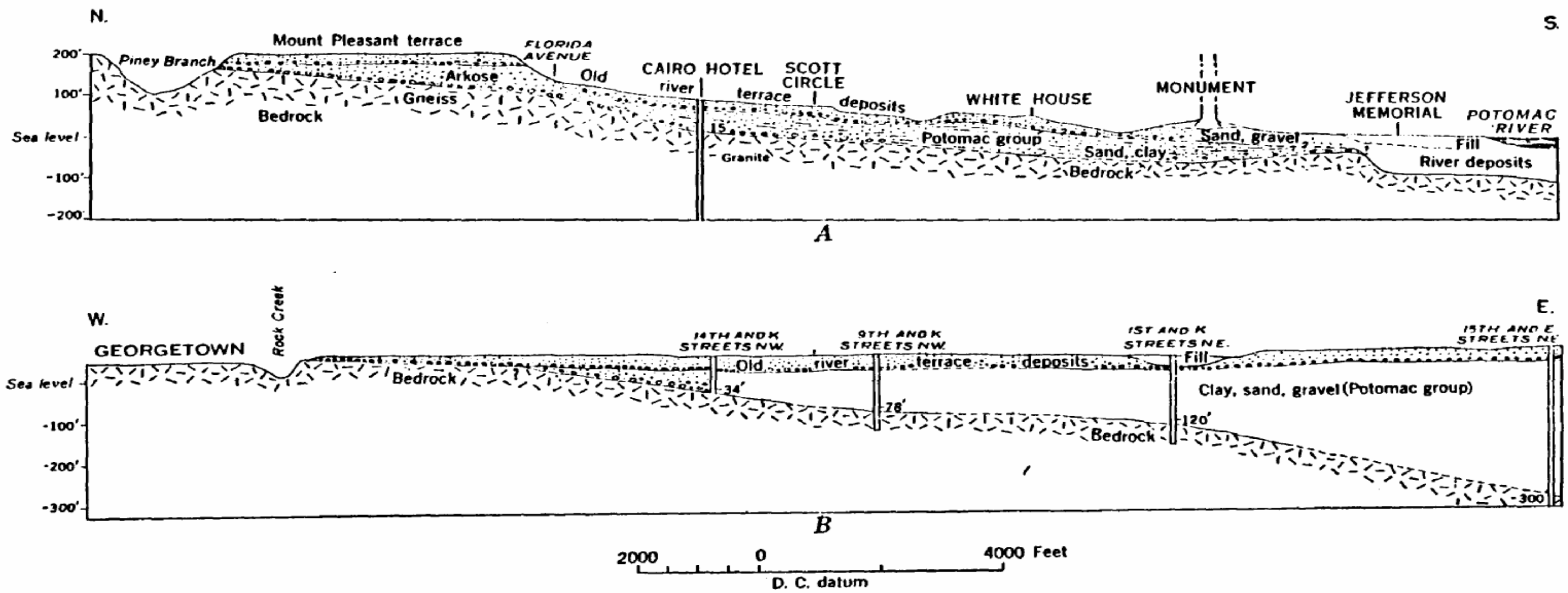


Figure 5 Sections through Washington showing relations of bedrock and overlaying formations. A, North to south along Sixteenth Street; B, West to east from Georgetown to Fifteenth and E Streets NE (Darton, 1950)

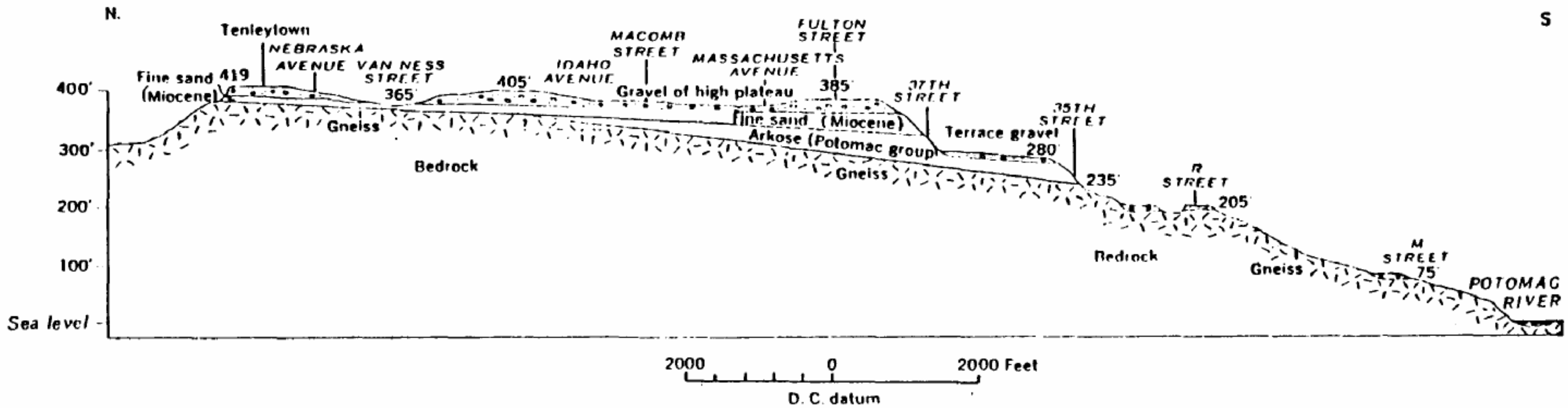


Figure 6 Section along Wisconsin Avenue from Tenelytown to Potomac River. (Darton, 1950)

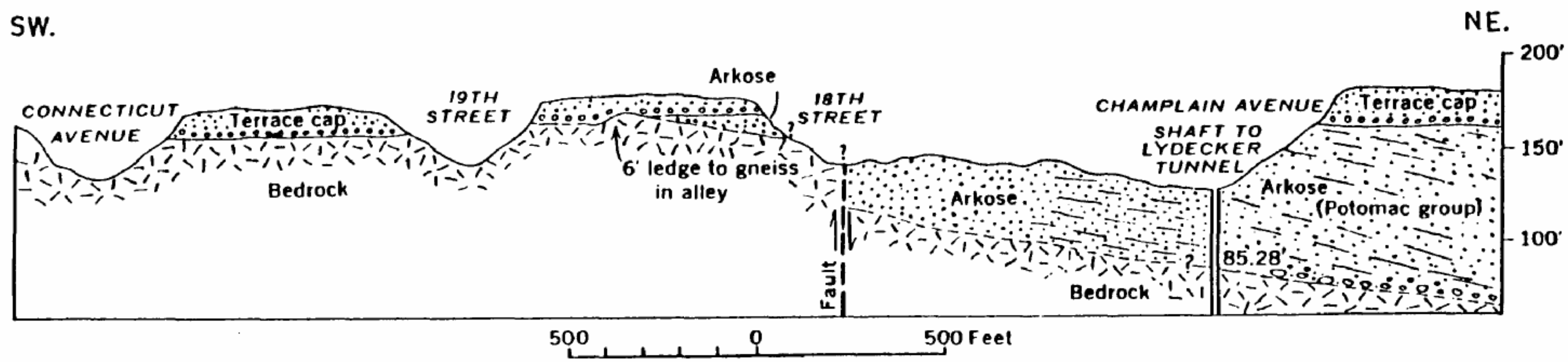


Figure 7 Section across fault at Eighteen and California Streets looking north (Darton,1950).

the impact of urbanization. It also contains an annotated bibliography The Center also produced a review report on the fall line Cities ground water (DC-WRRC report #62). The Metro subway construction reports and a series of Sewer System Evaluation Survey reports for the city (1984) and the USGS National Summary series are some of the other publications pertaining to ground water in the District.

2.0 GEOLOGIC AND HYDROLOGIC PROCESSES OF GROUND WATER RESOURCES

The District of Columbia is blessed with abundant ground water resources. Springs, construction dewatering, and flow in local streams all attest to this. The District is one of the cities along the Fast Coast, on the fall line where both the Atlantic Coastal Plain and Piedmont Provinces constitute the geological foundation (Fig. 8).

2.1 Physiography and General Geology of the District of Columbia

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. Physiographic provinces include the Coastal Plain and the Piedmont (USGS, 1964). The fall line, which separates the Piedmont Province on the west from the Coastal Plain Province on the east, bisects the area diagonally from northeast to southwest. (Johnson 1964)

The Piedmont consists of hard crystalline and metamorphic rocks derived from sedimentary and older igneous rocks by dynamic and contact metamorphism. The composition of the rocks of the Piedmont is mainly at various alteration stages of the Wissahickon formation. These include: (1) schist, phyllite, and quartzite of the Wissahickon formation; (2) altered mafic and ultramafic rocks, greenstone and serpentine; (3) the Laurel Gneiss of Chapman, 1942 (derived from the Wissahickon by hydrothermal alteration); (4) the Sykesville Formation of Jonas, 1928, which consists of highly altered remnants of the Wissahickon Formation, together with intrusive biotite granite, quartz diorite, and associated rocks; and (5) later granite intrusive rocks such as the Bear Island Granodiorite of Cloos, 1953. One may easily conclude that the structures of the crystalline rocks are very complex. Over time, these rocks have been folded, crumpled, jointed, and then weathered and decomposed to form an upland plain.

East of the fall line, the sediments of the Coastal Plain lie upon a bedrock surface. These sedimentary rocks are composed of unconsolidated formations ranging in age from the Cretaceous period (144 million years) to the present. Some of the formations were deposited by streams flowing from the Piedmont Province and others were deposited in shallow marine environments. Each formation tilts away from the Piedmont Province and usually becomes thicker and younger as it nears the Atlantic Ocean. A large volume of the sediment is subdivided into formations which have become

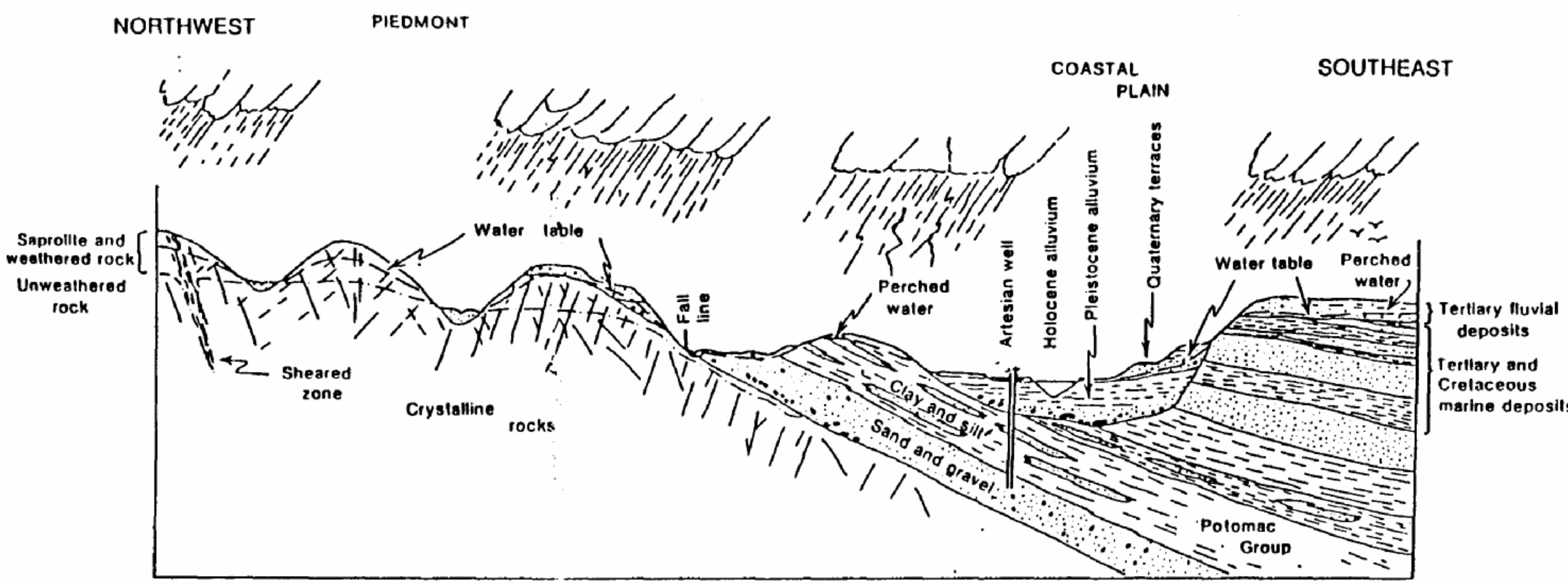


Figure 8 Diagramatic sketch showing typical groundwater conditions in the Washington area.

[Engineering Geolology of Cities. Obermeier S and J.C. Reed, Geological Society of America] strata of similar origin, composition, and age. The major geologic formations of the Coastal Plain are the Patuxent, Patapsco, Magothy, Aquia, and Tertiary-Quaternary sediments.

2.2 Ground Water and Hydrologic Cycle

To understand ground water resources, a brief description of its role in the hydrologic cycle is necessary. The hydrologic cycle is a continuous process in which water is transported from the atmosphere to land by precipitation; from land to the ocean by runoff and ground water flow; and from the oceans, back to the atmosphere by evaporation and by evapotranspiration from vegetation.

The hydrologic cycle is global in nature and encompasses many sub-cycles. The precipitation that falls on the ground is dispersed in several ways. A major part of water, temporarily retained in the soil, is ultimately returned to the atmosphere by evaporation and evapotranspiration by plants. A portion of the water runs through soil surface into stream channel, while other portion infiltrates into the soil profile. The infiltrate initially passes through the zone of aeration, filling up the spaces between the particles of soil with air and with water. The water may either disperse into capillary pores or pass through the zone of aeration into the ground water. Water not retained in the zone of aeration reaches the water table, below which all spaces and pores are saturated with water. Water movement, within the saturated zone, is principally a slow seepage downward and sideways until it discharges into a lake, stream, or the ocean.

The depth to the ground water table varies depending on local topography. Both, depth to water table and ground water movement, may vary seasonally. During rainy seasons, when the water table is high, water recharges into streams providing base flow. During dry periods, when the water table is lower than the channel bottom, the channel water seeps out to recharge ground water.

Any water bearing stratum or geologic formation that is capable of transmitting water in sufficient quantities to permit development is known as an aquifer. In the unconsolidated sediments of the Coastal Plain, in general, large particles, such as sand and gravel, make the best aquifers. In the consolidated rock areas of the Piedmont highly fractured and weathered rocks make the best aquifers. Aquifers may also be defined as confined and unconfined, depending upon whether a water table or free surface does or does not exist under atmospheric pressure.

In addition to aquifers, an aquifuge is a formation that may contain large amounts of water but water transmission rates are not high enough to permit effective utilization. Also, an aquiclude, composed of impermeable materials, such as clay or unfractured rock, does not transmit or yield significant quantities of ground water.

The relative impermeability of clay or unfractured rock is an important factor in an underground hydrologic system. In areas where permeable and impermeable layers alternate, water may become trapped at great depths at pressures greater than atmospheric pressure. If a well is drilled into a sandwich layer, hydrostatic pressure forces water upward above the level of the sand, in some cases, above the top of the well. The well is referred to as an artisian well. The level to which water may rise in an artesian well defined as the piezometric or potentiometric level of the confined aquifer. This piezometric level is analogous to the water table in an unconfined aquifer.

2.3 Ground Water Resources of the District of Columbia

2.3.1 General Geologic Setting

Washington, D. C. lies on the Atlantic fall line. It is one of many fall line cities along the East Coast from N.Y. City to Macon, Georgia. The fall line is a longitudinal zone of falls along the streams. This critical boundary of waterfalls occurs as the eastern rivers waters leave the Piedmont bedrock of the west for the soft erodible sediments of the Coastal Plain to the east. This geomorphic boundary separates the bedrock of the Piedmont Plateau Province from the consolidated and unconsolidated sediments of the Atlantic Coastal Plain Province. As stated earlier, the Piedmont Plateau is made up generally of hard igneous and metamorphic rocks which come from sedimentary and older igneous rocks by dynamic and contact metamorphism. In 1964, Paul Johnston classified the Piedmont Plateau into five major groups: (1) schist, phyllite, and quartzite of the Wissahickon Formation; (2) altered mafic and ultramafic rocks as greenstone and serpentine; (3) the Laurel Gneiss of Chapman, 1942, derived from the Wissahickon by hydrothermal alteration; (4) the Sykesville Formation of Jonas, 1928, (5) later granitic intrusive rocks. The Coastal Plain is made up of sedimentary rocks which are generally unconsolidated. Four major formations of the Coastal Plain include (1) recent alluvium, terrace deposits; (2) Pamunkey Group ; (3) Patuxent of Lower Cretaceous; and (4) Patapsco and Arundel of Upper Cretaceous.

2.3.2 Maps

Geologic maps of the city have been prepared by state and federal geologists from time to time. The USGS Folio Atlas 70 (Keith & Darton, 1890s) was the first comprehensive sets of maps of the rocks and their economic potential. The water studies were later covered by Darton (1896, 1914) in a USGS report on artesian flow for industrial potential along the east coast. A detailed account of use and potential future use of ground water in the District of Columbia is included in the report. The state of Maryland prepared geologic maps for both Montgomery and Prince George's Counties in the early 1950s (Cloos) and included the District on the state maps. The USGS reprinted the earlier Darton's map of the District of Columbia in the USGS Bulletin 952 as an insert (1952). The sedimentary map (Darton, 1947) for the District was also revised by the USGS. Later, the water review for the metropolitan area by Johnson (USGS WSP 1776) included a general geology map as an insert (1964). This map is now revised, including the use of new terms.

In the 1970s, as part of the USDA soil survey of the District of Columbia, a geologic map (Scale 1:24,0000) was prepared by Froelich and others of the USGS. This is the latest available citywide geology map. The small insert map in DC Minerals booklet (1978), by the Maryland Geological Survey, is a very general map of the region. The USGS is currently preparing a geologic map of the Washington West Quadrangle (Drake, A.A.) based on the latest tectonic information as part of a series which includes the already published geologic quadrangles of Northern Virginia.

Though there are only a few geologic maps available, a review of these maps shows that the names of the rock units and their formations have changed with time and knowledge. There are also slightly different names used by state and federal agencies for the same rock. The Metro subway system reports also use their own nomenclature for the rock units encountered in their excavations.

Coastal Plain and Piedmont Plateau units that bore different names with time are presented below:

Coastal Plain:

Wicomico, Sunderland Formation ....Terrace 1,2,3,4 (TI, T2, T3, T4)

Patapsco, Arundel, Patuxent Formation ....Potomac Group (Kps, Kpc)

Piedmont plateau:

Wissahickon Formation, Sykesville Formation ....Wissahickon Group

Georgetown Gabbro.............. Mafic Complex

2.3.3 The Piedmont Province

The Piedmont is characterized by rolling hills. The topography is between 0 and 400 feet in the city and cut by numerous tributaries to the major streams. These streams are controlled by fracture systems. While the drainage pattern is dendritic, analysis of large segments of Piedmont streams indicated rectangular control.

The Piedmont Plateau Province contains four major different rock units: schist, gneiss, metagabro, and metagranite. The most important factor is the complex rock structure derived from tectonic activity. This tectonic rock includes a variety of folded systems, thrust and normal fault systems, and six major joint fracture sets. The structure controls the rate of flow of ground water. The decayed Piedmont metamorphic rock, known as saprolite, is created by ground water flow and acts as a ground water sponge. Saprolite in the northwest can range from 0 to 300 feet (0-100 meters) in thickness. Due to the tightness of the bedrock in Washington, D.C, water yield is very low (below 400 ft).

The Piedmont's bedrock was metamorphosed a few times and uplifted to its present level at or just below the surface. The majority of rocks represent segments of former continental shelf and slope deposits of the pre-Atlantic ocean that were meta morphosed into mica schists, metagraywacke, and boulder gneiss. These major units were intruded or thrusted into by plutonic igneous activity that is also metamorphosed. The igneous activity includes the older Georgetown mafic-ultramafc complex and the subduction type Kensington granite now altered to metatonalite or granite gneiss. The small pods of soapstone relate to the mafic complex. These Piedmont rocks are folded, faulted, and highly jointed by earlier tectonics. Both the strike/dip of the beds or rocks with the numerous organized fracture systems allow water to penetrate into the mostly impervious rocks. Infiltration and percolation of the subsurface water creates chemical interactions that alter and decay the bedrock and influence water chemistry. This chemical interaction along the fracture systems sets up the formation of saprolite.

The permeability for the Piedmont Province formations ranges from 4 X 10^{-5} feet per second for bedrock to 1 X 10-^{4} ft/s for decomposed rock (saprolite). Water yield from various formations of the Piedmont Province are given in Table 2.1. (Johnston, 1964)

Table 2.1

Water geld of the Piedmont Formations

Formation	Range From (g p m)	Range To (g p m)	Average (g p m)
Wissahickon Formation	0.2	110.0	14.0
Mafic Rock Formation	3.0	10.0	6.0
Laurel Gneiss	0.8	30.0	10.0
Sykesville Formation	2.0	100.0	12.0
Kensington Granite Gneiss	0.5	30.0	9.0

The water bearing materials of Wissahickon Formation of the Piedmont contain magnetite, quartz veins, and metasandstone and metaconglomerate beds composed of muscovite, chlorite, albite, and quartz. Based on observations in 324 wells in the Wissahickon Formation area, the ground water yield ranges from 0.2 to 110 gallons per minute (gpm) and has an average of 14 gpm. The average depth of the 324 wells in this formation is 118 feet. The lithologic properties of mafic rocks include tonalite, gabbro, meladiorite, amphibolite, chlorite and fiotite schist, soapstone, and undifferentiated mafic rocks. The water yield from five wells in mafic rock formation area ranges from

3 to 10 gpm and has a mean of 6 gpm. The average of these five wells is 104 feet. The major lithologic components of Laurel Gneiss of Chapman, 1942 are garnet and staurolite. The Laurel Gneiss formation has a water yield ranging from 0. 8 to 30 gpm and a mean of 10 gpm. Based on measurements of fifteen wells, the average depth of the wells is 198 feet. The Sykesville formation of Jonas, 1928 has quartz-mica schist and gneiss and quartzite with intrusive granitic rocks containing inclusions of schist and quartz. From water yield records of 142 wells, the yield ranges from 2 to 100 gpm and has an average yield of 12 gpm. The average depth of these 142 wells in Sykesville formation is 124 feet. Including the geologic formation of Bear Island Granodiorite of Cloos, 1953, and Kensington Granite Gneiss of Cloos, 1951, the undifferentiated granite formation contains sheared and massive intrusive rocks. The range of water yield is 0.5 to 30 gpm in 38 wells while the average yield is 9 gpm and the average depth 138 feet.

2.3.4 Coastal Plain

The first and oldest rock unit of the Atlantic Coastal Plain is the Potomac Group (Cretaceous, 120-65 million years). This massive deltaic paleo-environment is divided into sandy or clay units to the south and three formations to the north: the Patuxent, the Patapsco, and the Arundel (Hansen, 1969). In the Coastal Plain area, the geologic formations of recent alluvium, Pimlico, Wicomico, Sunderland and terrace gravels contain clay, silt, sand, gravel, and boulders. The water yield of this formation is very small and mainly supplies to many shallow dug wells. The Brandywine and Bryn Mawr Terrace Gravels contain gravel, sand and silt. The Niocene Age Chesapeake Group has the lithologic characteristics of diatomaceous earth, sand, silt, sandy clay, and clay. The water bearing properties are similar to recent alluvium which only yield small supplies to many shallow dug wells. The Patapsco Formation and Arundel Clay includes dark gray clay containing lignitized wood and saurian bones, and is overlaid by massive maroon clay and varicolored sand and clay. These formations also contain sand lenses grading into clay lenses. The water yield of 11 wells in these formations ranges from 10 to 120 gpm, and has an average yield of 40 gpm. The Patuxent Formation contains large round pebbles, fine sand, and thin lenses of white or iron-stained clay. Record of 45 wells in the Patuxent shows a water yield of 10 to 300 gpm with an average water yield of 80 gpm. No average well depth has been documented for any geologic formations in the Coastal Plain.

The recharge area of the Patuxent lies just east of the fall line. There is a gentle dip (tilt) of the sedimentary layers to the southeast. The sandy layers serve as a confined aquifer in Southern Maryland and was studied under the USGS RASA program. This is an interstate aquifer. The high natural iron content and micro-paleoenvironment pockets of high sulfur need to be addressed as well as the buried and preserved ancient environments of deltaic swamps, bayous, stream channels and floodplains that affect ground water flow both as perched and focused flows. Sandy lenses within the red clay units are associated with springs and landslides (slumps). Red clay when excessively wet becomes quickclay. Gray clay layers are the reduced environments which contain coal fossils and high sulfur. Isolated aquifers units occur in Northwest Washington and the main aquifer unit occurs on either side of the Anacostia River. Both the geology and soil maps of the District of Columbia clearly illustrate the surface distribution of the Potomac Group (Figures 9 and 10). Recharge area is primarily on the west side of the Anacostia River.

The rise or fall of sea level and the associated adjustment of drainage systems like the Potomac created an East Coast landform of terraces. This occurred over the last 10 million years of geologic history and is related to the occurrence of the Great Ice Age (2 million years). The origin and number of terraces are still debated by geologists. They are taken as fluvial and estuarine forms by most geologists with a break at 100 feet elevation between the two creation processes. The number of terraces and associated escarpments or cliffs is a minimum of four major or maximum of seven above current sea level (Fig. 11). The material of a terrace consists of gravels, sands, and clays related to meandering river channels, beaches, swamps, and marshes. Preserved as deposits, these past environments yield springs, perched tables, and hard to map pockets that usually escape systematic drilling.

The nature of the gravels, sands, and clays that comprise the Atlantic Coastal Plain play an important part in controlling the ground water behavior. Understanding the paleoenvironments and the deposition of the sediments is critical to planning and management of Coastal Plain aquifers. The most recent general survey has been under the USGS RASA program where all the major Coastal Plain aquifers were analyzed and delineated. State ground water reports, on the quantity and quality of ground water in each aquifer, are published by the USGS for 1980 and 1986. The Maryland geologic survey has completed studies on quality and computer models for the bordering aquifers of the Coastal Plain. Special studies have been published by doctoral candidates from The George Washington University's geology program. The Potomac Group aquifers are the major source that occurs in the District of Columbia. The recharge area for Patapsco, Arundel, and Patuxent units occurs in the city and strikes slightly NE/SW across the jurisdictions into the neighboring states. For the interstate underground connection, both the Tiber Creek and Anacostia drainage basins and the depth of the aquifers need to be understood. The regional dip for the Coastal Plain units is to the southeast into Maryland. There is some water lost to the Potomac and Anacostia but the clay units of the Potomac Group acts as an aquitard. High iron and sulfur contents occur in the units. Numerous pyritized or marcarsized fossil logs or nodules were excavated at the Fort Totten Station of the metrorail Green Line during construction. The landslides across the city in the hazardous Potomac clays also show the relationship of the units on either side of the Anacostia Estuary. While no documented spa has come

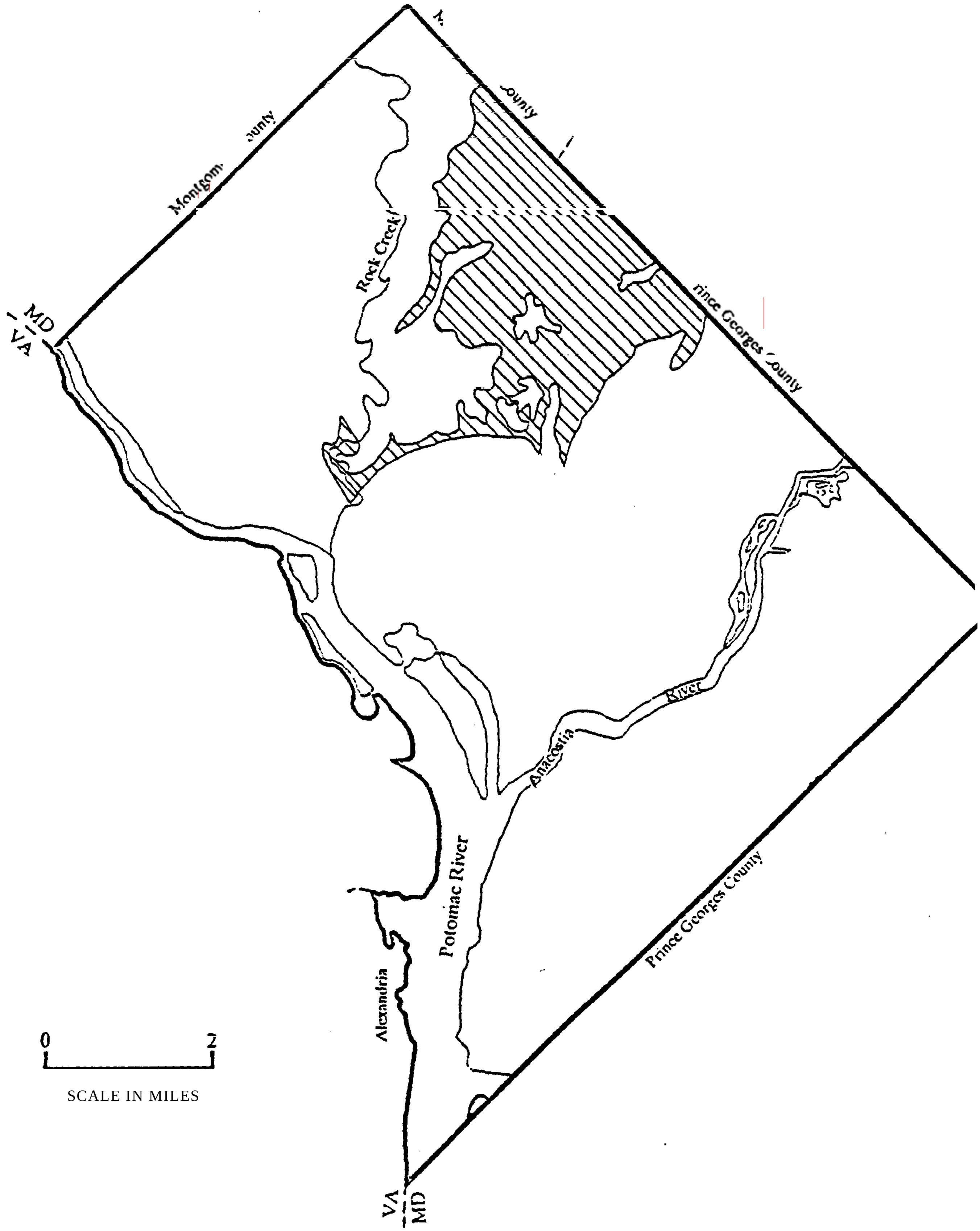


Figure 9: Recharge of the Lower Potomac Confined Aquifer in the District of Columbia

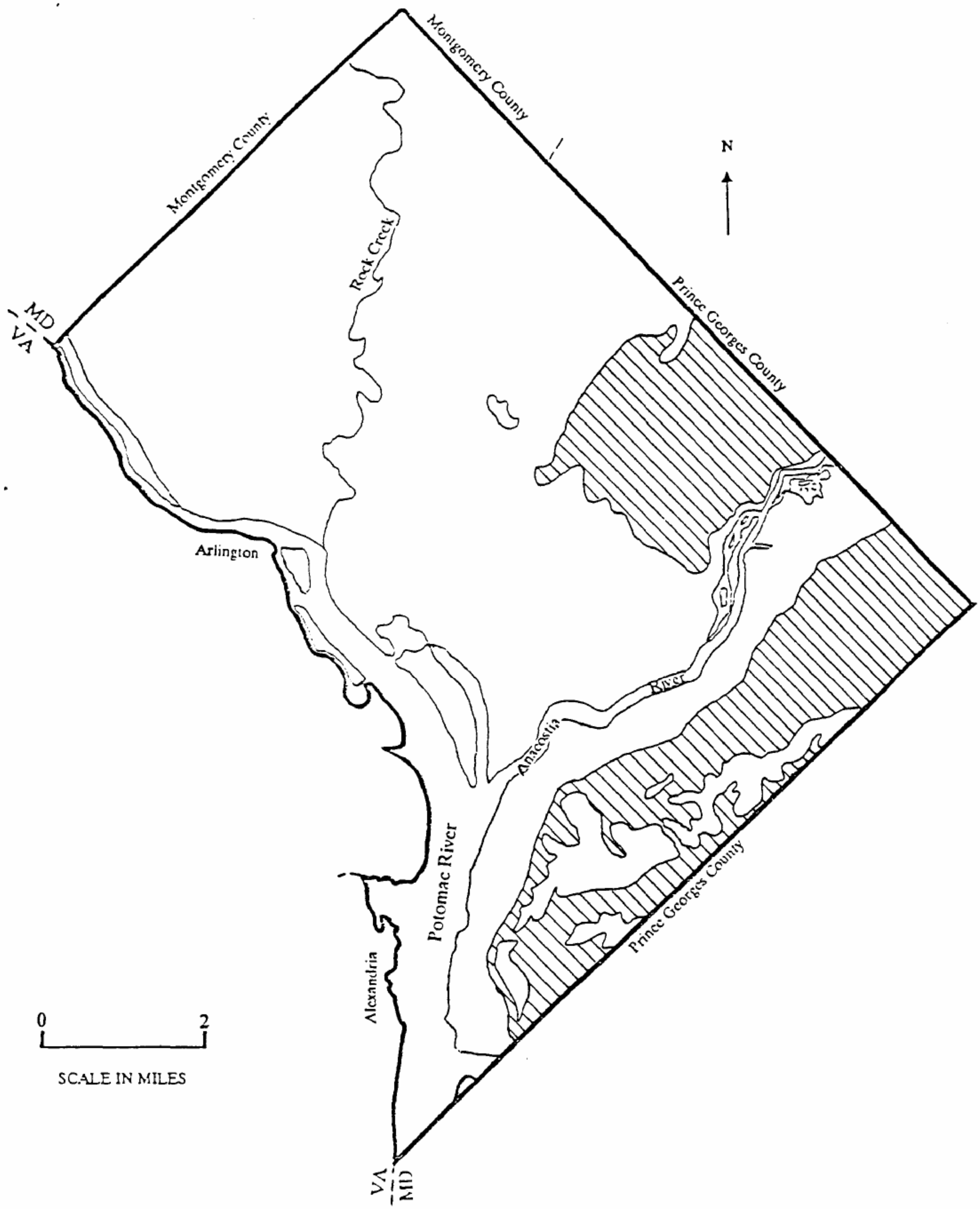
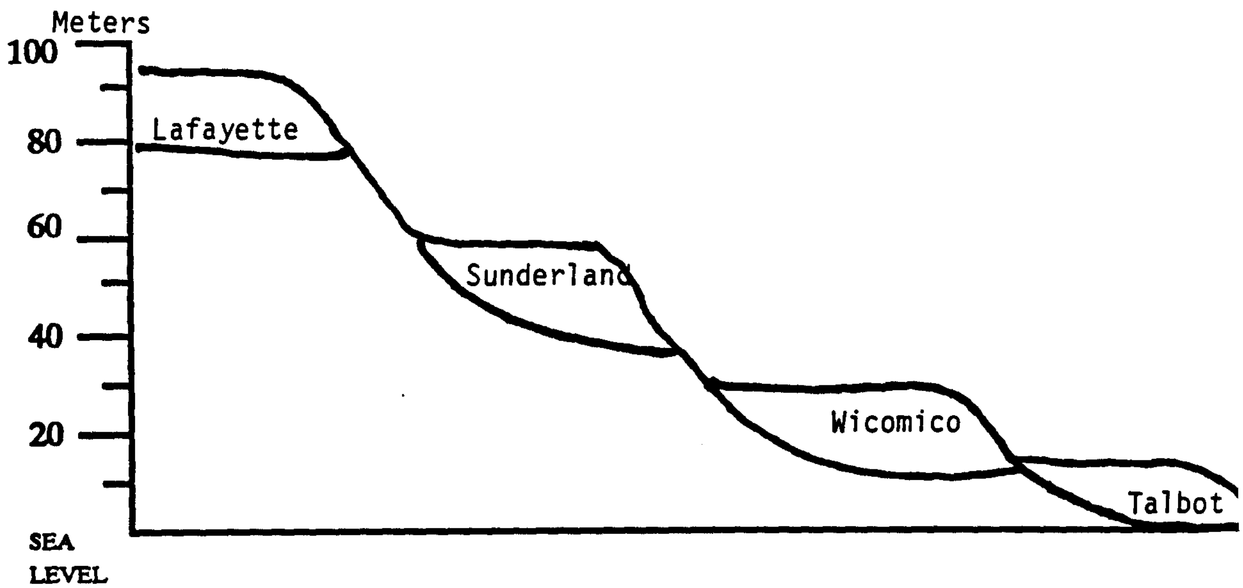


Figure 10 Recharge zone of the Upper Potomac Confined Aquifer in the District of Columbia.



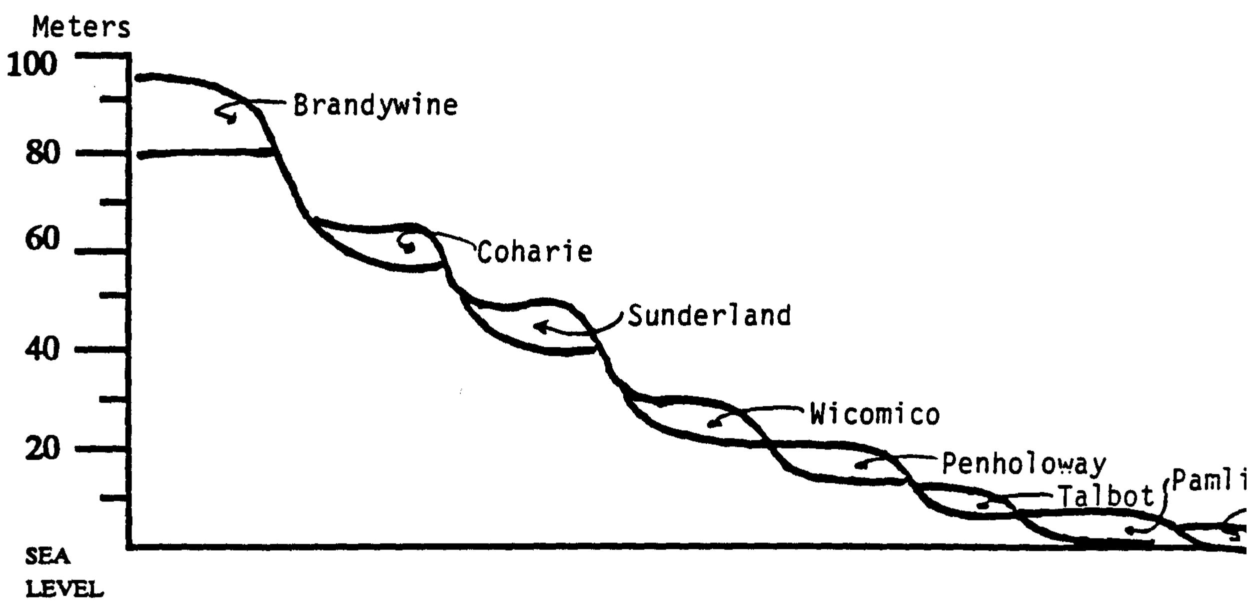


Figure 11: The marine terrace concept

to light within the District of Columbia, mineral health spas at Bladensburg and Arlington thrived in the eighteenth and nineteenth centuries and provided curative tonics using the natural water containing iron and sulfur.

The terrace gravels representing the former river bottoms tend to lose their water fairly quickly as headwater springs, general springs, or boundary seeps because of their elevation and hillside exposures. Iron capstone layers and sand pockets or lenses representing microenvironments from the original depositional environments allow for numerous perched tables. Some perched tables have substantial water volumes depending on their dimensions.

The permeability in the Potomac Group aquifers ranges from 3 X 10^{-4} ft/s for the Cretaceous gravely sands to 5 X 10^{1} ft/s in the Pleistocene sand and gravelly sands. Water yield for the Potomac Group formations is given in Table 2.2 below. (Johnston, 1964)

Table 2.2

Water Yield of the Potomac Group Formations

Formation	Range From (gpm)	Range To (gpm)	Average (gpm)	
Patapsco Formation and Arundel Clay	10.0	120.0	40.0	
Patuxent Formation	10.0	300.0	80.0	*(DC Confined Aquifer)

2.3.5 The Urban Cover

Urbanization has had a significant impact on the hydrogeology of the area. Four hundred years of land use has altered the natural terrain and the ground water to a great extent. Interferences to ground water flow and to ground water chemistry include: quarries, industrial or institutional wells, cemeteries, dumps, valley cut and fill, road grading, dredging deposits, and land use. Building construction also has had an impact due to deep excavation, tunnels, loss of recharge cover, trenching for utility lines, and roof drain injection. The constant changes of land surfaces of DC has affected the quality and quantity of our ground water resource. The urbiscape, covering the native geology, leads to special ground water hydrologic processes. The basic aspect of this new geology is illustrated in the geochemistry and geophysics of dumping fill along stream valleys in SE. The Mall and Ellipse are compacted fills. The Potomac Park and the Tidal Basin areas house planted cherry trees which grow in holes that act as tubs drowning their roots. The grass is irrigated daily with city water. Potomac and Anacostia submarine sediment has been dredged and used as landfill to create new parklands. This practice has altered the shoreline over the last two hundred years. Both estuarine rivers are now two-thirds as wide as they were when the District of Columbia was first founded.

The city, by the turn of the last century, had many industrial and institutional wells. A view of wells across the city and the aquifers are given in Darton's Cross Section. The railroads, ice houses, breweries, asylum (St. Elizabeth) and reform school (Fort Lincoln), all tapped the subsurface water resource. As the city grew to its present limits, many tributaries were filled in and the remaining major tributaries were made into sewers. Water leaks still percolate along the pipelines. Utility lines also contributed to the change in the flow of ground water. Each linear belt or foundation causes ground water flow to alter its course, sometimes creating ponds or underground erosion. The leaking of water supply and sewer lines into the ground influence the quantity and quality of ground water. The quantity of water lost depends on pipe maintenance, their age, and local disruptions. In establishing ground water basins for the city, care must be taken to assess the current buried or lost stream basins and design characteristics of utility corridors. Landslide events that occurred in recent times are evidence of the problems associated with the nature of the Coastal Plain soils and urban activities. Some of these events are listed in Table 2.3.

Table 2.3
Major Landslide Events

NE	Rhode Island Avenue Metro Station Parking lot
NE	West Virginia Avenue
SE	I-295 at St. Elizabeths
SE	O Street at Branch Avenue
SE	Banning Road Park
SE	Hillcrest Drive

Cemeteries around the city form a major environment affecting the chemical quality of ground water. Many of the large burial sites are in critical areas, such as Rock Creek and Soldier's Home Cemeteries on the banks of streams (ex. Oak Hill and Congressional Cemetery). Some cemeteries are on the D.C. boundary and, hence water does cross the political boundaries. Data on longevity and composition of metal and wooden caskets, and on the chemistry and behavior of bodies and embalming fluids in the soil are being collected by the Mortuary Science Department of the University of the District of Columbia. For many years, public health laws have governed the proximity of cemeteries to the position of wells. Legal city dumps and sanitary landfills within the city boundaries are well documented. Also, documentation of many illegal dumps, such as "God's Dump", show the impact on ground water. While major toxic or radioactive waste disposal sites are not currently known, numerous spill sites of recent or historical notoriety have been exposed as a result of the application of leaking underground storage tank regulations (LUST) and of changes in environmental laws on land transfer and land use.

The metro rapid transit system has provided the most recent additional data on the city's ground water regime. Dewatering of sites for the subway and for high-rise construction has drastically altered the underground water despite the city's laws on "no net disruption". Recent data (1989) around the Union Station-North Capital area indicate that the ground water is not bouncing back under these conditions. Assumptions on water loss predict that the hydrogeology has been altered, that ground water zones have been eliminated due to the volume of construction, and that blockage of the infiltration and percolation routes have occurred.

As there is an inevitable link between ground water and living organisms, qualitative changes in ground water must also affect the quality of life. This influence has special significance when the organisms which depend on ground water become the endangered species. For example, at the National Zoo in D.C., an isopod which lives in a spring is now classified as an endangered species.

The impact of pesticides and fertilizers on the soil and water zones needs special attention. Bioremediation, especially for petroleum spills needs to be addressed.

2.4 Sources of Ground Water in the District of

About a quarter of the precipitation on D.C. enters the ground water. Average annual precipitation is 40 inches, thus ground water recharge is about ten inches. Snowmelt, early spring rains or late fall rains are the principal source of recharge with natural drawdown occurring in the summer months. Hurricanes, that strike the city once in a decade or so, increase the water table. While most ground water comes from infiltration of meteoric water, there is a small amount of water connate trapped in older sedimentary units. The water table lies about 15 feet below the surface but has been lowered by Metro and high-rise constructions to the extent that in some highly disturbed areas the water table is at about 25 feet below surface. Tidewater has a special effect on the daily rise and fall of the ground water table, especially along the shoreline in the Coastal Plain. In addition the water table level fluctuates seasonally three to five feet.

The bedrock of the Piedmont Province in the Northwest portion of the city has secondary porosity and permeability due to fracture systems. The bedrock, however, is sufficiently tight below 400 feet so that water has little or no movement in these cracks. Chemical disintegration of the bedrock occurs by the action of water in saprolite at the bedrock-saprolite boundary. This boundary depends on the thickness of the saprolite and fosters exposed springs on hillsides. The Piedmont stream valleys are ground water fed, especially the tributaries of Rock Creek, Little Falls Branch, and Foundry Branch. The Atlantic Coastal Plain province which comprises about 70 percent of the city has a different ground water regime. The consolidated and unconsolidated sediments are divided into highly porous gravels, porous sands, and swelling clays. The deposits are representative of the ancient sedimentary environments. The paleo swamps, marshes, channels and deltas are key to the migration of ground water and the creation of perched tables and confined aquifers especially within the oldest sedimentary unit, the Potomac Group. Springs and landslides are common within this unit. A unique feature of the Coastal Plain is a series of terraces left behind by the fluctuations of the sea level over the last ten million years. Each terrace has a corresponding escarpment or cliff where the ground water bleeds out. Gullies and waterfalls occurred over each terrace and swamps on the back of each terrace. The upper terraces (above 90 feet) represent fluvial deposits of former Potomac River beds and form the drainage divides of the city.

Numerous streams have been lost across the city (Figure 12). As filled-in tributaries, they are now conduits of (under)ground water. A proposed general ground water divide is shown in Figure 13. It is believed, however, that utility and subway lines have redirected some ground water flow, and in other cases, foundations of high-rises have dammed or squeezed ground water flow in these buried streams.

Other factors in the urbiscape have a major impact on the hydrogeologic cycle in the District. Leaky pipes, reservoirs, and irrigation systems used by the National Park Service and other agencies also contribute to the flow and volume of ground water.

3.0 WATER RESOURCES DEVELOMENT

3.1 Water Supply History

Native Indians and early settlers selected sites close to shoreline springs to take advantage of the cool natural ground water on both sides of the city. The early settlers recognized their dependence on the delicate springs and settled around them. Shallow wells were dug to provide the water supply for both the residents of Georgetown and the agricultural estates in the rest of the District.

As early as 1800, six municipal springs were in operation to supply water to downtown Washington. These include the City Spring, Caffrey's or Hotel Spring, 13th St. N.W. Spring, Franklin Park Spring, City Hall Park Spring, and Smith Spring. Williams (USGS Circular 752) gives a detailed account of many of the early springs in downtown. In 1802 Thomas Jefferson approved a bill allowing the sinking of wells and the installation of pumps in the streets. Presently, the Jenkins Spring at the Capitol and the C St. Spring at Marshall Park are dry downtown historical ground water monuments. The well pump in the Georgetown University Quadrangle, the cistern well pump in the

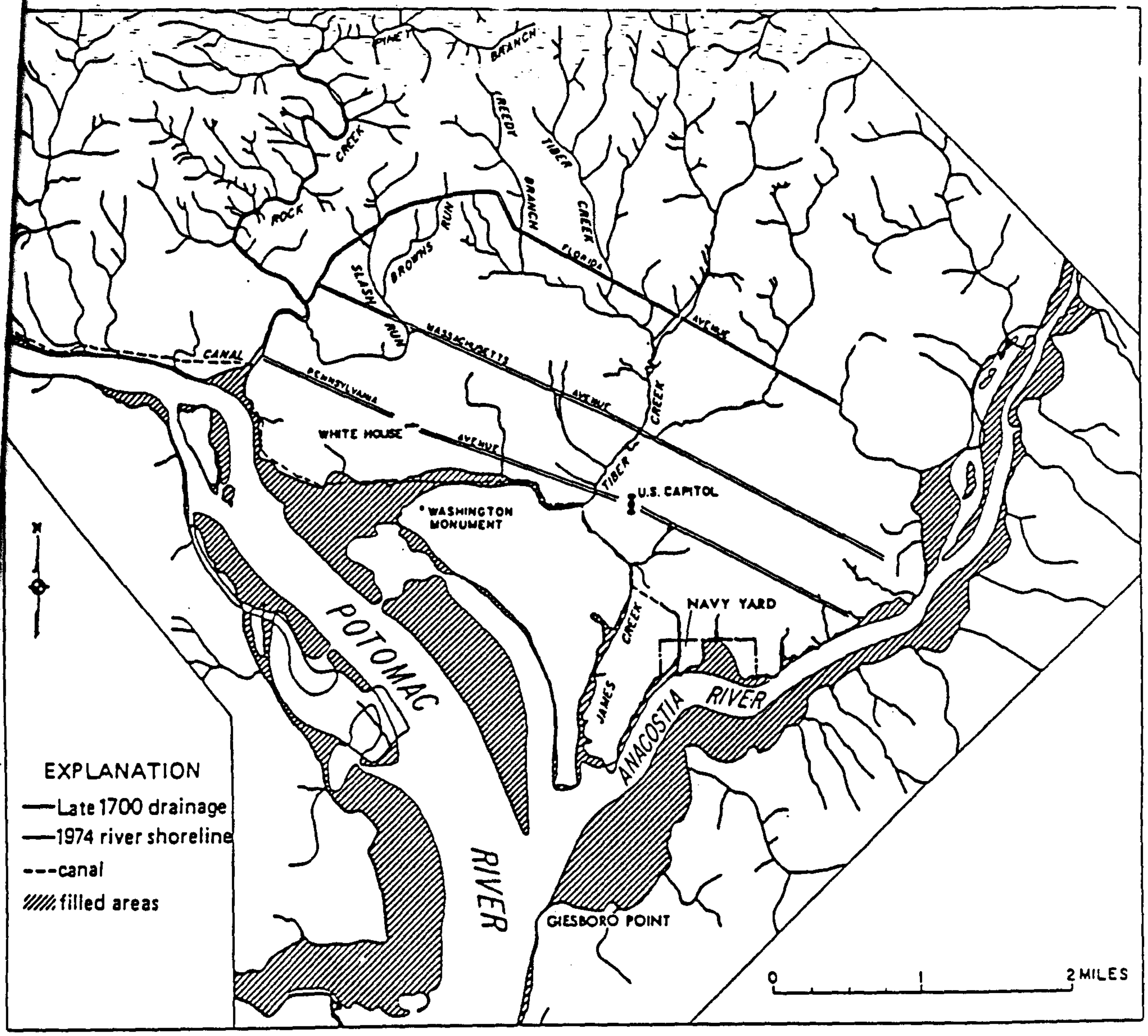


Figure 12 Stream network and river shorelines of the central Washington, D.C., area in the late 1700's, compared to 1974 river boundaries.

(Williams, USGS,1977).

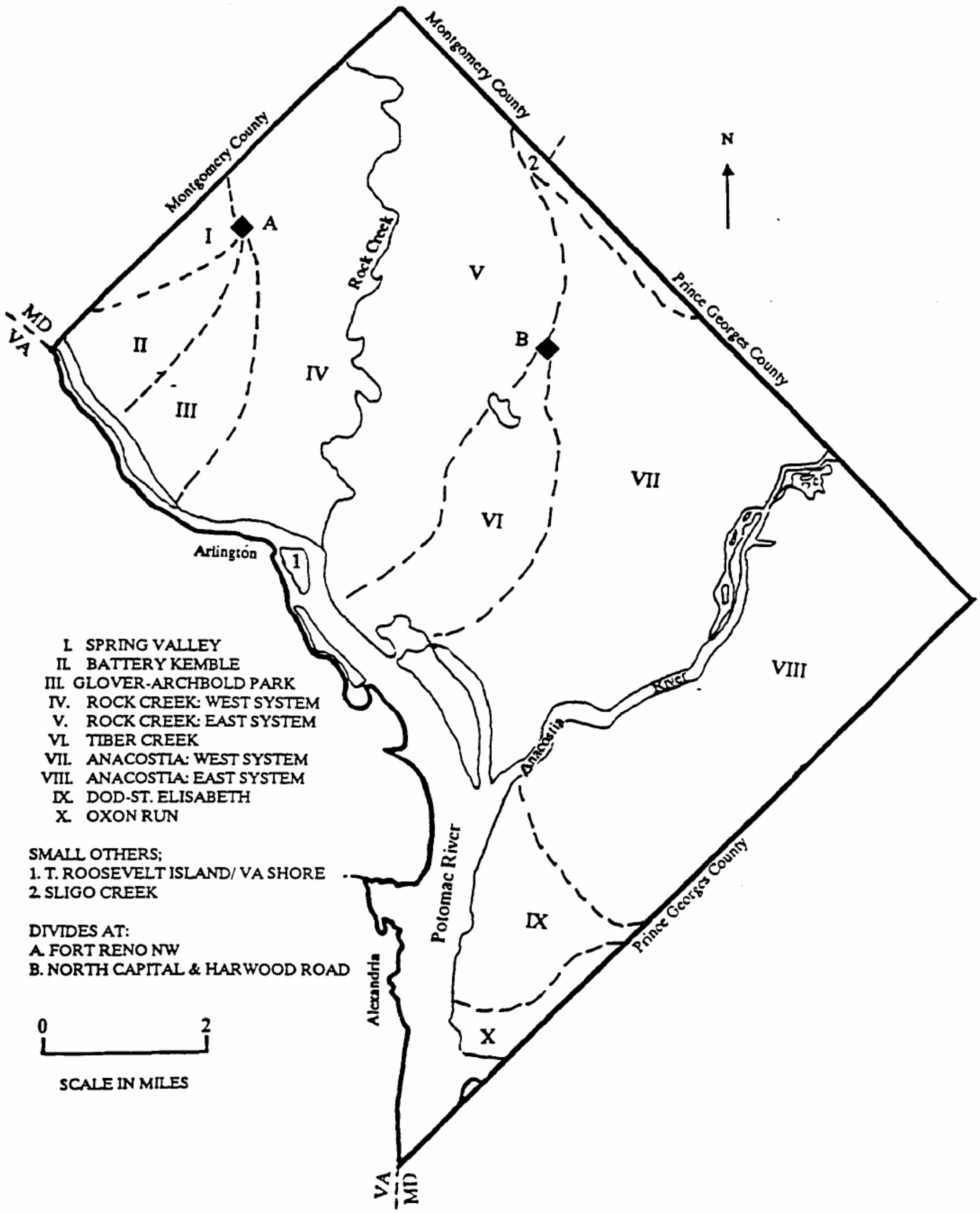


Figure 13 Proposed groundwater basins for the District of Columbia.

kitchen of Frederick Douglass's house, the active springhouse of Pierce Mill, the water wheels at the springhouse for Dumbarton Oaks estate, and the piped spring at Rock Creek Park Cemetery are all examples of historical use of ground water in the city. Industrial wells were equally numerous at the turn of this century. These wells, their uses and quality are documented in Darton's report on artesian studies of the east coast (USGS, 1908). Before the turn of the century, outlying agricultural areas, like the slaughterhouse at Tenleytown, had windmills to pump the water from the ground.

In the 1850s, through the efforts of the U.S. Army Corps of Engineers, the city switched to a formal water supply system drawn from the Potomac. A system of conduits was built to carry water from Great Falls to a series of reservoirs along the banks of the river. This system is still in use and over time has been expanded. In addition to the Dalecarlia and Georgetown reservoirs, the Reno, Van Ness, and W Street reservoirs were built in the Northwest sector and are covered to prevent water contamination and water loss by evaporation. The Reno reservoir has been further developed with time to include water towers. McMillan reservoir was built at the turn of the 20th century on the old Smith Spring site. It is a major sand filter system and has a large uncovered lake of filtered water. The other water holding areas for the East side of the city are Brentwood, Fort Stanton reservoirs and the GoodHope Water Tower.

Today, the city relies on the surface waters of the Potomac and the aqueduct system for its water supply. Because of the total dependence on the Potomac River as the source of water for the city, interest is again turned to the city's ground water as an alternative source in an emergency. While there is abundant ground water, uncertainties exist about sustained yield and water quality. Recent evidence indicates that dewatering by urban construction may be excessive and if so, may have drastically altered the ground water regime in the downtown area with slow recovery.

The population of the District has increased steadily until it began to decline in the last few decades. The number of Native Americans on the shores of the Anacostia River were in the low hundreds when the sailor Henry Fleet met them. The arrival of settlers later changed the land use. The early settlers cleared the land and built small towns and large estates. In the eighteenth century, the tobacco trade fostered three local cities, Bladensburg, Georgetown, and Alexandria. The creation of the Nation's Capital in the 1790s added momentum to the population growth. The planning and layout of the city of Washington established the current street pattern and encouraged the construction of many houses and shops. People came to Washington and stayed. After the War of 1812 and the Battle of 1814, the city's population increased and the commerce of the area thrived from shipping and trade. As the economy expanded, the government prospered and the city grew. The major water supply initiatives in 1850s indicate that ground water could no longer supply the demand needed to sustain this growth. The Civil War brought drastic changes to population growth in the capital city. Many soldiers, along with large numbers of freed slaves, stayed after the war. The creation of the Freedmen's Bureau and affordable land and housing assisted the continued increase in the number of African-Americans in D.C., especially at Barry's Farm in Anacostia. Each war since the Civil War has resulted in a major increase in the city's population, thus taxing city services and housing. Post World War I development led to the construction of numerous high-rise apartments and the growth of neighborhoods in Northwest Washington. World War II had the greatest impact on the city. The post-war boom saw the major development of the city extending up to the Maryland borders. Housing projects and single family houses were built rapidly. In the 1950s, forests were cleared and remaining farms were removed for construction purposes. By the 1960s D.C. had attained its largest population and also the loss of its ground water use with urban sprawl. Slowly, the population shift out of the core city resulting in a decrease in city population. The District, however, still has more citizens (600,000) than five other states and supports a large commuter work force that migrates in and out of the city on a daily basis. Tourism is also a major economic force in the city.

4.0 GROUND WATER QUALITY OF THE DISTRICT OF COLUMBIA

Ground water as a natural resource has drawn national and international attention during the last several years. Although the District of Columbia currently does not use ground water for drinking purposes, it could be stored for future use or used as an alternative source of water in emergencies.

A major threat to ground water is the introduction of hazardous contaminants during the process of their generation, transportation, and disposal into the ground water. The myriad of chemicals, some 250,000, that are introduced each year, adds a new dimension to the problem. For many contaminants, the tolerance level or the toxic level of exposure is not yet determined. What is more difficult to determine is the effect of long-term, low-level exposure.

In an urban setting, underground structures significantly affect the rate and direction of the flow of ground water. Under these conditions, conventional methods are inadequate to determine the migration of contaminants. Controlling the spread of contaminants in an urban setting also raises its own challenges and uncertainties. It is, therefore, critical to identify the sources of potential ground water contamination to address water quality problems.

4.1 Ground Water quality in the Fall Line

In the Mid-Atlantic region, the quality of ground water differs from location to location depending on hydrogeology. Generally, the outcrop area in Coastal Plain contains soft and slightly acidic ground water with excessive amounts of iron and total dissolved solids in certain local areas.

There are a number of ground water quality problems in the fall zone. Some of these are due to natural processes, while others result from human activities. High iron concentration along with salinity and hardness are prevalent in the region.. Hardness is commonly understood as the soap consuming property of fresh water and is due to the carbonates and bicarbonates of calcium and magnesium. Free acids, heavy metals and other alkaline-earth metals also affect hardness. (Table No. 4.1 summarizes field determination of pH, hardness and specific conductance, etc., of ground water in Washington, D.C.). In Washington, D.C., the water from aquifers is soft to moderately hard ranging from 2-175 ppm. Water in the Piedmont zone is dominant in calcium bicarbonate, while water in the Coastal Plain is dominant in calcium and magnesium bicarbonates with dissolved solids ranging from 23 to 801 ppm (average 87 ppm). The concentration of iron has been found to exceed the permissible U.S. Public Health Service standard of 0.3 ppm. Zinc and chloride and sulfates are also present in the ground water. Excessive amounts of fluoride, oil contaminants, hydrogen sulfide and methane gas also influence the ground water quality to some extent. Because District residents are served by public water supply that uses surface water, little or no attention has been given to the presence of radioactivity in ground water. In the surrounding metropolitan areas, Fairfax, Howard, Montgomery, and Prince William counties, assessment of well water for radioactivity is conducted. USEPA's National Inorganics and Radionuclides Survey (NIBS) reported that the population-weighted radionuclides for Maryland are 0.486 pCi/L for radium 226, 1.00 pCi/L for radium 228, 266.1 pCi/L for radon 222, and 0.08 g/L for uranium; for Virginia 0.215 pCi/L for radium 226, 1.00 pCi for radium 228, 485.4 pCi/L for radon 222. From a geological point of view, the District's ground water is derived from the coastal plains and piedmont water supplies, the same two sources that supply the surrounding areas. Radioactivity in ground water in the District of Columbia, therefore, should be expected to parallel that which has bee reported in the surrounding counties. Since no data is available on radioactivity in the ground water of the District of Columbia, it should be tested to check the contamination level.

Ground water pollution caused by human activities in the fall zone manifests itself in a variety of ways. Though acid mine drainage affects mostly surface water, in coal mining areas of Pennsylvania, Maryland, Virginia, and West Virginia, it may also be a source of ground water contamination. Pumping of wells near sources of contamination may directly or indirectly induce aquifer contamination. Such problems have been cited

Table No. 4.1

Groundwater Chemical Analyses at Crosstown Water Main Tunnel, Georgetown, D.C. (Mathews 1982)

Parameters		Piedmont Borings	
	B-19	B-11 (60ft)*	B-9 (97ft)*
1. Clhoride in ppm cl	42.4	38.0	41.0
2. Sulfide in ppm	0.66	0.28	0.0
3. Sulfate in ppm	127.5	250.0	57.5
4. pH	6.3	6.65	6.7
5. Conductivity in Microhoms/cm	420.0	550.0	330.0
Resistivity in Ohms/cm	2381	1818	3030
6. Hardness in mg/l $CaCo_3$	116.0	164.0	174.2
7. Acidity in mg/l $CaCo_3$	5.0	21.0	28.4
8. Alkalinity in mg/l $CaCo_3$	91.3	87.0	117.2

* Number in parentheses is depth from which samples were obtained.

in Long Island, New York, and Atlantic City, New Jersey. High levels of nitrate concentrations have been identified in wells affected by cesspools, septic tanks, and fertilizers from agricultural lands. However, in the fall line cities, the most serious ground water contamination is due to the following: salts from winter road de-icing, leakages from dumpsites and landfills, accidental or intentional disposal of hazardous and industrial wastes, and a variety of leaks.

Ground water can also have corrosive effects on concrete or metallic structures, under certain conditions. Chloride, sulfide and sulfate in ground water increase corrosion in concrete. In Washington, D.C., winter de-icing may be the cause of foundation stricture problems in the public monuments such as the Lincoln Monument. A pH less than five will also have the same effect on concrete. Ground water conductivity is a major factor in metal corrosion. The conductivity is usually between 300 and 550 micro-ohms per centimeter. When the conductivity is greater than 1000 micro-ohms per centimeter, a cathodic protection is required. It has been found that, in general, ground water in the Washington, D.C., area does not attack steel or concrete used in pipelines unless the ground water is already polluted or the soils contain chemical residues.

The quality characteristics of the ground water are measured through chemical analysis, physical analysis and biological analysis. The chemical parameters include both organic and inorganic constituents, while the physical parameters include temperature, color, turbidity, odor, and taste. The biological analysis is mainly to determine the presence or absence of coliform bacteria. The presence of coliforms, which are normally found in the intestines of humans and animals, indicates the possible contamination of ground water with sewage.

Data on ground water quality in the District is lacking. The disposal of hazardous waste is prohibited in the District of Columbia. Records of some unplanned/accidental releases, that may affect ground water quality, are scattered among various offices such as the Department of Consumer and Regulatory Affairs (DCRA) and the D. C. Fire Department Hazardous Materials Response Unit (DCFD HAZMAT). In most cases, information on ground water contamination is reported by consumers who may detect changes in taste, smell, or color of their water supply. The District has a disadvantage in that its entire water supply comes from surface water. Contaminants in ground water may go undetected for long periods of time and may cause damage beyond any feasible remediation. It is therefore important to identify the sources of potential ground water contamination.

4.2 Land Use

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. The District's function as the nation's capital has been an important element in shaping its land use. The federal government occupies 40 percent of the city's land and the city government occupies about 5 percent. Some 8 percent of the land is occupied by embassies, chanceries and international, educational, cultural, and scientific institutions and 47% privately owned. About 95 percent of the city's land is used for residential, public and semi-public parks and recreation, public rights-of-way or remains vacant. The remaining 5 percent of land is zoned for commercial, manufacturing, and industrial activities. The trend for land use, over this century, shows that the percentage of commercial and industrial use has remained unchanged while a sharp drop in vacant land is complemented by an increase in residential, public and semi-public, and parks and recreation lands (Fig. 14). The District is basically an urban center. Unlike the major urban centers of the region, such as Baltimore, Philadelphia, and Richmond, the District of Columbia has a relatively small industrial-manufacturing sector. Therefore, the most visible ground water pollution problems associated with industrial or agricultural settings are not obvious. This seemingly fortunate situation may lead to an oversight of ground water contamination. Figure 15, showing the location of the commercial and industrial corridors, relative to the outcrop of the regional aquifer system, clearly illustrates the danger as the industrial section, though relatively small, lies directly over the recharge area of the Potomac Group aquifer.

4.3 Ground Water Contamination

As discussed earlier, contamination generated from oil and gas products, road salts, industrial sites, and from pesticides and herbicides are prevalent in most urban areas. Some of the other serious sources of contamination include heating oil or gasoline leaks from underground storage tanks. Gasoline penetration to the ground water from petroleum sources occurs in several ways. In hard rock shells, ground water flow is likely to be a few feet per year range and therefore the contamination is slow. But in carbonate areas where the ground water flow is sometimes in feet per hour, pollution can spread quickly. A petroleum contamination plume is usually narrow in width and may not occur through the entire thickness of the aquifer thus making it difficult to detect. Large quantities of petroleum may leak through an aquifer undetected over many years.

In urban areas, gasoline leaks must be controlled at the stations. Most underground storage tanks are made of unprotected carbon steel. The typical service station tank has a capacity of 4,000 gallons. Half of all the buried steel tanks leak after 15 years. According to a survey made by the American Petroleum Institute, 92.3 percent of all leaks from steel tanks are caused by corrosion. A number of factors such as installation, operational practices, and chemical reactions accelerate metal corrosion. As a remedial measure, petroleum companies such, as Exxon, Shell and Texaco, are replacing unprotected steel tanks with fiberglass tanks.

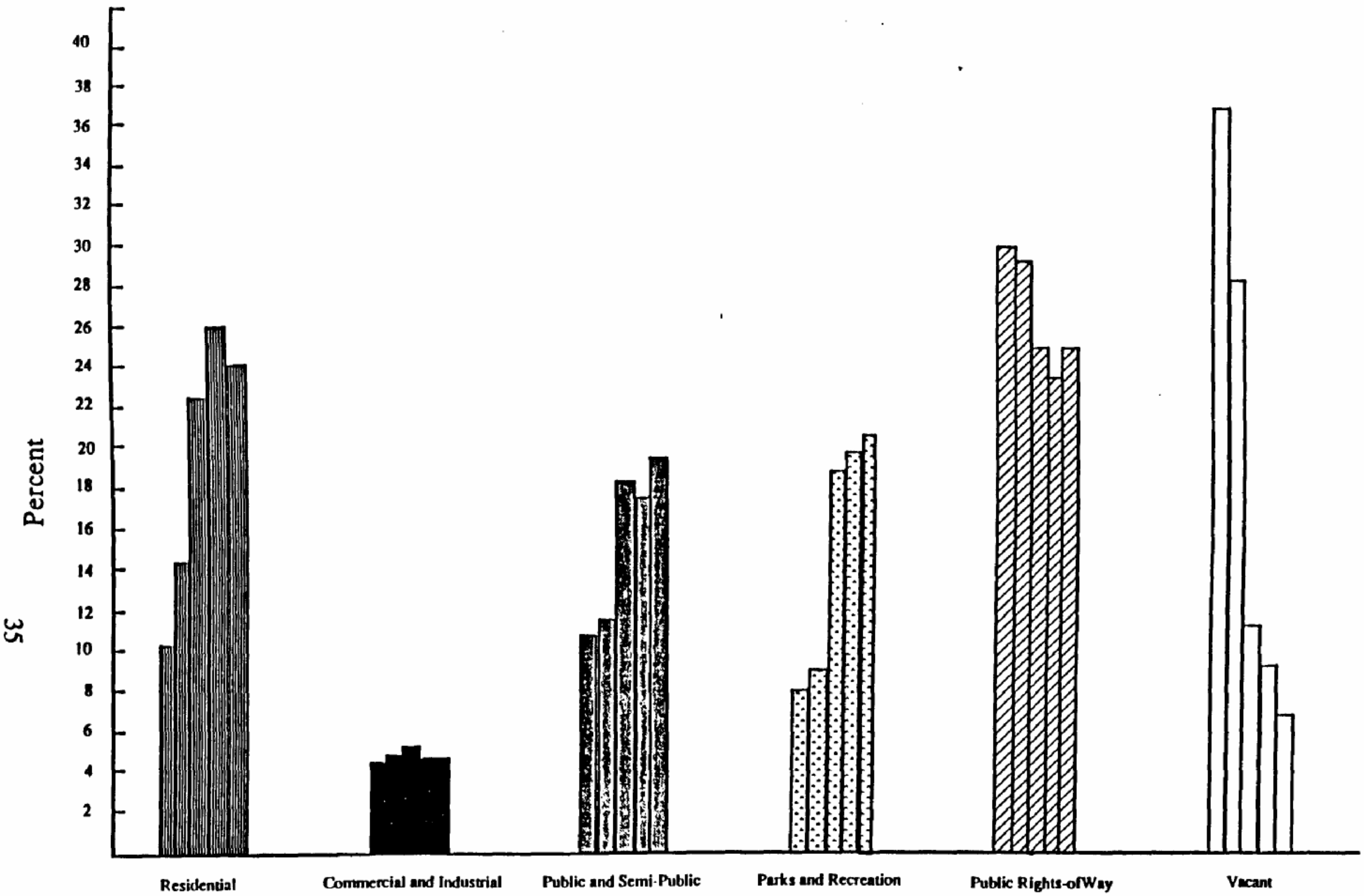


Figure 14 Change in land use in the District of Columbia. Consecutive bars in each category represent the percentage of land in that category for the years 1910, 1927, 1948, 1968, and 1977, respectively.

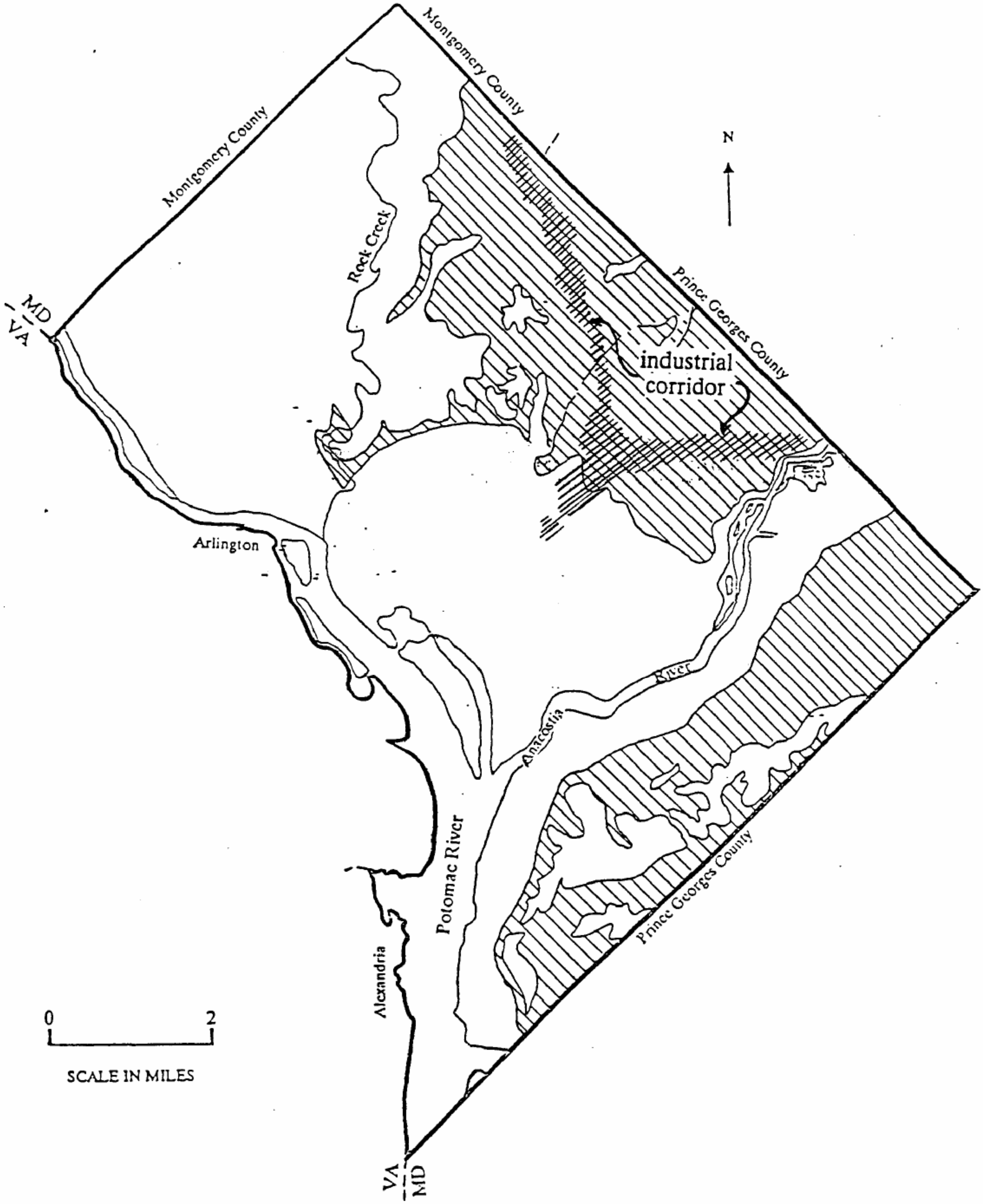


Figure 15 Location of Commercial and Industrial corridors relative to outcrop of the regional aquifer.

4.4 Potential Sources of Ground water Contamination

The potential sources of ground water contamination are broadly divided into two sections namely impacts of construction on ground water in the District of Columbia and other potential sources.

4.4.1 Impacts of Construction on Ground water in the District of Columbia:

The ground water table is influenced by such factors as seasonal changes of infiltration, variation of river levels, presence of sewer systems and other pipelines, temporary or permanent pumping, and dewatering associated with construction activities.

Ground water condition in urban areas, such as the District of Columbia, has also a significant impact on construction and tunneling. Factors such as geologic boundaries, perched water tables, water table fluctuations, vertical mixing, and the hydraulic gradient, all impact engineering construction. In excavations, exposure of soil and rock boundaries may lead to the creation of springs, seeps, and in fillings (the bath tub effects). The FBI Building and the new Intelsat complex in Washington, D. C., are examples of the above. The perched water tables are usually found in sandy lenses in the impermeable clays. Because they are hard to map, perched water tables tend to cause unexpected construction problems. The Metro subway tunneling in Washington, D.C., encountered a few of these perched water tables. The vertical mixing has a dual effect. One is to modify the porosity-permeability balance which can create compaction and flow problems that result in construction delays and/or design changes. The other effect is the vertical chemical mixing which can cause corrosion or contamination. Water table fluctuations may produce quick-state clays, when water is introduced, and dry compaction when water level is lowered. Finally, any kind of ground constriction perpendicular to local ground water flow will change the velocity and direction of flow. The ground water table in Washington, D.C., is typically 10 to 40 feet below ground. During underground constriction for subways, utility pipelines and sewer systems, a series of engineering problems may be encountered. These problems include 'dewatering, addwatering, erosion, deterioration of material or leaks caused by blasting due to air drying or softening in the presence of water, settlement loosening or excavation. A few specific cases encountered in D.C. are detailed below.

Certain projects in Washington, D.C., now being built or recently completed, provide examples of foundation constriction problems and solutions. An example of cut and cover construction is provided by the 1,000-feet center section of the mall tunnel of the Inner Loop Freeway, crossing the mall between 2nd and 3rd Streets, N.W. Because this section intersects the former Tiber Creek Channel, many constriction dewatering difficulties were encountered. The ground water level was approximately 25 feet to 30 feet above subgrade. The total amount of water pumped out during the dewatering process was close to 250 gallons per minute. Periodically it was necessary to flush the educator system with water from city mains to eliminate corrosive or clogging materials which interfered with the educator operation. A series of approximately 40 piezometers were placed near adjacent government buildings to monitor the drawdown created.

In the District of Columbia, construction contracts such as the one previously described, may include a provision to recharge the ground water to avoid consolidation settlements caused by drawdown. Lowering the water table through pumping not only causes subsidence, but also may cause deterioration of foundation material. For many historical buildings, such as Gallery Place, Evening Star, and the Pavilion (Old Post Office), which are built on wooden piles, the water table must be maintained by addwatering on the northside and dewatering on the southside.

During the early phases of sewer tunnel construction to the Navy Yard, between L and Half Street, S.E., dewatering was accomplished by deep wells placed at a minimum spacing of 300 feet. While the pumped quantity was relatively small, it was reported that the use of wells significantly reduced sloughing of materials when clean cohesionless sand was encountered. In general, for some locations, it may be necessary to use well point or grouting methods to cut down or eliminate water flow during dewatering.

A broad range of activities covering both policy and scientific issues on national ground water protection are undertaken by the EPA. In its effort to develop an effective national program, the EPA has compiled a comprehensive list of sources of actual or potential ground water contamination (USEPA, 1984). The list is given in Table 4.2 below.

TABLE 4.2

SOURCES OF GROUND WATER CONTAMINATION

Category I - Sources designated to discharge substances

Subsurface percolation (e.g., septic tanks and cesspools)

Injection wells Hazardous waste Non-hazardous waste (e.g., brine disposal and drainage)

Non-waste (e.g., Enhanced recovery, artificial recharge, solution mining, and in-situ mining)

Land application

Wastewater (e,g., spray irrigation)
Wastewater byproducts (e.g., sludge)
Hazardous waste
Non-hazardous waste

Category Z - Sources designated to store, treat, and/or dispose of substances; discharge through unplanned release

Landfills

Industrial hazardous waste
Industrial non-hazardous waste
Municipal sanitary

Open dumps, including illegal dumping (waste)
Residential (or local) disposal (waste)
Surface impoundments Hazardous waste Non-hazardous waste
Waste tailings

Waste piles
Hazardous waste
Non-hazardous waste
Materials stockpiles (non-waste)
Graveyards
Animal burial
Above ground storage tanks

Hazardous waste	Non-hazardous waste
Non-waste	Underground storage tanks
Hazardous waste	Non-hazardous waste
Non-waste Containers	Hazardous waste
Non-hazardous waste	Non-waste

Open burning and detonation sites
Radioactive disposal sites

Category 3 - Sources designated to retain substances during transport or transmission

Pipelines

Hazardous waste
Non-hazardous
Waste Non-waste

Materials transport and transfer
operations Hazardous waste
Non-hazardous waste Non-
waste
Category 4 - Sources discharging substances as consequences of other
planned activities Irrigation practices (e.g., return flow)
Pesticides applications
Fertilizer applications Animal
feeding operations De-icing
applications Urban runoff
Percolation of atmospheric pollutants
Mining and mine drainage
Surface mine-related Underground mine-related Category S -
Sources providing conduit or inducing discharge through altered
flow patterns Production wells
Oil (and gas) wells
Geothermal and heat recovery wells
Water supply wells
Other wells (non-waste)
Monitoring wells Exploration wells Construction excavation Category 6- Naturally
occurring sources whose discharge is created and/or exacerbated by human activity
Ground water - surface water interactions
Natural leaching

Salt-water intrusion/brackish water upcoming (or intrusion of other poor-quality natural water)

Source: Office of Technology Assessment, Protecting The Nation's Ground water from Contamination. October 1984.

The sources of potential ground water contamination identified for the District of Columbia are listed in Table 4.2. and the location of selected sources of contaminants are shown in Fig 16.

Table 4.3 Sources of Potential Ground Water Contamination in The District of Columbia

Potential Sources	**Potential Problem**
Landfills	Leakage
Open Dumps	Leakage undocumented materials and/or sites
Residential Disposal	Accidental spill, drain corrosion
Materials Stockpiles	Leakage
Graveyards Storage	Critical location vis a vis ground watersheds, age
Tanks Pipelines	Leaks
Materials Transport	Leaks, redirection of flow
Pesticide Application	Accidental releases Over application
De-icing/Road salting	Snow piling after salting
Urban Runoff	Wide range, auto servicing stations
Percolation of Atmospheric Pollutants	Emissions, pesticides
Other Wells	Improper capping
Construction Excavations	Buried containers, spills, redirection of
Ground water/Surface Water Interactions	Sump pump effluent, Dewatering
Natural Leaching	Sulfur, iron

4.4.2 Other Sources of Ground Water Contamination

The extent of potential problem from each of the sources are reviewed below. The definitions for the sources are extracted from USEPA's publication, "EPA Activities Related to Sources of Ground-Water Contamination".

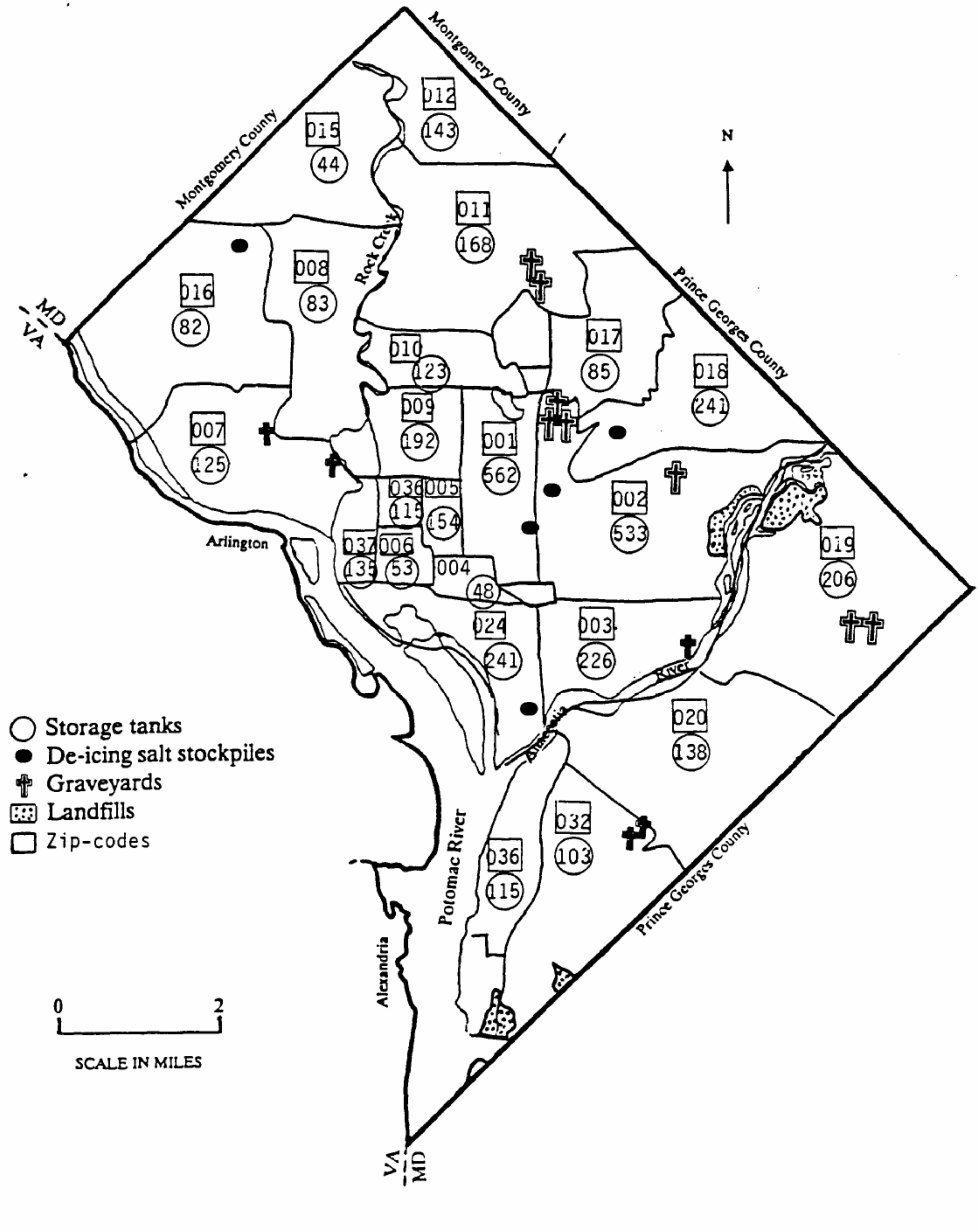


Figure - 16 Location of selected sources of potential contamination in the District of Columbia.

Definition

Historically, landfills have been the most common method for disposing of solid wastes. These wastes are classified as either hazardous or nonhazardous. DCRA regulations define hazardous waste and specifically exclude various waste products such as domestic sewage wastes, irrigation return flows, certain radioactive wastes, and some industrial wastes. Municipal landfills receive solid waste products that generally, but not always, are nonhazardous. Industrial landfills receive wastes from industries, and these wastes typically are hazardous.

Extent of Potential Problem

Currently there are no operational landfills in the District of Columbia. It has been recorded that about eighty sites were used as landfills or open dumps in the past. All were basically municipal waste disposal sites although some illegal dumping of hazardous material cannot be ruled out.

The largest landfills in the District, the Kenilworth Landfills, flank the Anacostia River upstream from the Anacostia Park. The Kenilworth dump was in operation from 1942 to 1970. The impact of these landfills, from leakage and fly ash, on the ground water and the Anacostia River may be significant. In its soil survey of the District of Columbia, the U.S. Dept. of Agriculture study established that the soil properties in the District are by and large unfavorable for landfill facilities Soil permeability, slope, depth to bedrock, depth to. seasonal high ground water, and susceptibility to flooding were the basic evaluation criteria for suitability. Only a few selected sites are recommended for use provided careful and extensive design considerations are made.

Some institutions still maintain dumps for their yard waste, leaves and other biodegradable materials.

4.4.2.2 Open Dumps

Definition

A dump is a land disposal site where solid wastes are deposited without regard for the design operation, or maintenance of the site. At such sites, dumping usually is unauthorized and unsupervised, and the wastes are left uncovered. A wide variety of types of wastes have been deposited in open dumps.

Extent of Potential Problem

In earlier years of its development, the city had a number of open dumps (USGS 1986). It can be assumed that most of the historic dumps were municipal waste disposal sites. These sites are continually being uncovered during constriction excavation.

"God's dump", located in S.E. Washington, is one most recent illegal dumping site. The nature of the material disposed is unknown. Some leaching is currently taking place.

4.4.2.3. Residential Disposal

Definition

Practices in this category encompass the indiscriminate, unsupervised disposal of household wastes into gutters, sewers, storm drains and backyard burning pits. Supervised disposal in municipal landfills is not covered.

Extent of Potential Problem

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 public education program. It can be estimated that, in the absence of such a 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. Quantitative information about disposal practices in the District is not available.

4.4.2.4. Materials Stockpiles

Definition

Storage piles for substances produced or used in a production process. Materials in stockpiles include crushed stone, copper ore, iron ore, uranium ore, potash, titanium, phosphate rock, gypsum, coal, sand, and gravel.

Extent of Potential Problem

Due to the largely non-industrial character of the District of Columbia, material stockpiles in the city are few. Coal, gravel, sand and gravel and crushed stone are maintained by utility companies and cement and asphalt plants.

4.4.2.5. Graveyards

Definition

Cemetery, burial ground.

Extent of Potential Problem

There is a national law establishing a minimum distance between burial grounds and supply wells. A special consideration of graveyards in a ground water study for the District is needed on two accounts: the location and the length of time the graveyards have been in operation. The still active Rock Creek Cemetery has been in operation dace 1712. Twelve out of thirteen cemeteries in the District lie within the outcrop of the Potomac Group aquifer system. The larger cemeteries are located on well-drained local topographic highs that serve both as recharge areas and spring sources for many streams. Than; type of caskets, casket liners and embalming fluids used over time need to be studied.

4.4.2.6. Storage Tanks

Definition

Storage tanks include above ground and underground tanks. Above ground storage tanks: stationary devices designed to contain waste or non waste materials. These tanks for chemical storage are used in industrial, commercial, and agricultural operations, as well as at individual residences.

Underground storage tanks: consist of buried tanks and associated piping systems used to store petroleum products, other chemicals, and wastes. Industries use tanks primarily for fuel storage, but also for storage of a wide range of other substances, such as acids, metals, industrial solvents, technical grade chemicals, and chemical wastes. Commercial enterprises and residences utilize the storage tanks almost exclusively for fuel storage.

Extent of Potential Problem

Storage tanks of hazardous substances are by far the leading threat to ground water in the District. There are some 5,000 underground storage tanks around the city, mostly fuel and petroleum tanks. EPA estimates that about one-half of the underground storage tanks are leaking. EPA is currently funding an UST program for the District. The program, under the DCRA is responsible for UST regulation and monitoring, as well as oversight and enforcement of clean-up operations. As of May 1990, there were about 75 leaking underground storage tanks at various stages of monitoring and/or remediation work. Depending on the products released, some 35 compounds are analyzed for benzene, toluene, ethyl benzene, and xylene on a routine basis.

4.4.2.7. Pipelines

Definition

Pipelines transport, collect, and distribute wastes as well as non-waste products. Principal wastes are municipal sewage, while non-wastes include petroleum products, natural gas, ammonia, coal, and sulfur.

Extent of Potential Problem

The District has both combined and separate storm and sewer lines. 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 more than 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 water main leaks (Sewer System Evaluation Survey Vol. 1). This indicates the likelihood of significant exfiltration from sewage and wastewater lines during low ground water table months. Major steam pipelines run through the downtown area as part of the heating system for several federal and city buildings. These create a thermal imbalance impacting on the underground microbiology. Approximately 1,200 miles of natural gas main is maintained by the gas company. The lines run at a depths of two to three feet below the ground surface, well above the average ground water level of about 12 feet. The water distribution system has over 1,400 miles of buried pipe. These and other utility lines affect the natural ground water flow pattern and pollutant migration.

4.4.2.8. Materials Transport

Definition

Material transport and transfer operations refer to the movement of substances by vehicles, such as truck and railroad, along transportation corridors. The category also includes handling facilities, such as airport and loading docks.

Extent of Potential Problem

During material transport accidental spills of varying extent and frequency occur. In the year of 1987 alone the D. C. Fire Department Hazardous Materials Response Unit responded to 150 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. Some of the major ones requiring extensive clean-up procedures are forwarded to the D.C. Department of Consumer Regulatory Affairs.

4.4.2.9. Pesticide Application

Definition

Pesticides are chemicals used to control insects, weeds, and other undesirable organisms. Most pesticide use is in agricultural operations (69-72 °b). Government agencies and industrial/commercial organizations account for another 21 % and the remainder consists of home and garden use.

Extent of Potential Problem

Much of the recreation land in the District is under the National Park Service which does not allow use of pesticides. Users of pesticides include the city government, private homes, and institutions. Most of pesticide use in the city involves lawn and garden care, street trees spraying, and rodent control. A survey of certified pesticide applicators 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. Insecticides used amounted to 716.25 gallons and 3,171.5 pounds, fungicides 167 gallons and 465 pounds, herbicides 161,094 gallons and 653,747 pounds, and rodenticides 17,754 pounds. The largest users of insecticide are private households and city tree maintenance crews. The largest amount of fungicide and herbicide in the city is used for clearing railroad tracks and grounds. Commercial establishments consume the bulk of rodenticides for outdoor use. Lawn fertilization and spraying by companies is currently under scrutiny for controls by the city.

4.4.2.10. De-icing/Road salting

Definition

This category includes year-round stockpiles of salt as well as application of salt to improve driving conditions on snow and ice-covered roads.

Extent of Potential Problem

There are five stockpiles of salt in the city maintained by the Street Maintenance Division of the Department of Public Works. The salt is contained on a concrete platform and is covered. The Division services over 1200 miles of roadway using on the average 12 to 16 tons of salt per season. 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 the streets, for most of the city are provided with a runoff collection system it can be estimated that the highest concentration of salt is transported into the storm and combined drains. However recharge through river beds can be a major source of ground water contamination.

4.4.2.11. Urban runoff

Definition

Urban runoff is the portion of total rainfall that flows over the land surface. The runoff is often channeled by drainage networks and contains a broad array of contaminants associated with urban activities. Major contaminants are automobile emissions.

Extent of Potential Problem

Several thousand single family homes of earlier design are provided with 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. Contaminants, such as animal waste (pet dropping), garden pesticides and leakage of rooftop materials, are directly introduced to the ground water through these wells. This unique design significantly affects the ground water quality in the District and must be taken into account. 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. Waste oil pollution that took place at Hickey run is a threat to both surface and ground water.

4.4.2.12. Percolation of atmospheric pollutants

Definition

This category includes the dry deposition of pollutants between storms or transported in snow and water during storms. These pollutants result from a variety of sources, including automobile emissions and various industrial processes. Acid rain is one type of atmospheric pollutant transported via percolation.

Extent of Potential Problem

Atmospheric pollutants are dependant on the greater meteorologic conditions. The sources of air pollution often extend across jurisdictions. The regional standards set forth by the Federal Clean Air Act control measures to minimize the adverse impacts of poor air-quality.

The DCRA maintains a number of ambient air quality stations in the District for monitoring lead, ozone, carbon monoxide, sulfur dioxide, nitrogen dioxide, and suspended particulate concentration. Pollution levels in the District of Columbia have been well below the National Ambient Air Quality Standards (NAAQS) throughout the last decade. The general trends for the eighties show that there is a decline in lead, a slight increase in sulfur dioxide and nitrogen dioxide. The levels of ozone and carbon monoxide generally fluctuate with meteorological conditions: higher concentration of ozone are reached during summer months on hot and sunny days when there is little air movement, whereas a buildup of carbon monoxide is detected during late fall and winter months, particularly in areas of traffic congestion. The total suspended particulate levels also fluctuate possibly with activities associated with construction in a particular site. The District of Columbia receives an average annual precipitation of 40 inches. About 10 inches goes to ground water recharge.

4.4.2.13. Other wells

Definition

These are wells used for a variety of monitoring and exploration activities.

Extent of Potential Problem

Numerous wells for various purposes have been drilled in the city. The following types of wells were identified:

1. Construction wells
2. Sewer line monitoring wells
3. UST wells
4. Historic wells
5. Industrial deep wells
6. Drainage pipe injection wells
7. Springs - headwaters of streams
8. Pumps - sump, historic, cooling

Since the District of Columbia does not require a permit for drilling wells, there is no central location for documentation. All information remains with the agency/ individual drilling the wells).

Construction dewatering wells constitute by far the most numerous: as many as 12 to 20 wells per city block were identified. Several Metro construction reports (published and unpublished) contain well records. Water quality is not analyzed for all construction wells even though about one million gallons per day of ground water is discharged into the city's storm and sewer drains. The implication of this practice is that contaminants may be spread through drain leaks and river bed recharge. In addition there is no mechanism to ensure the proper capping (destruction) of these wells to prevent pollution from entering after dewatering has ceased.

As part of the city's sewer system evaluation survey, a network of monitoring wells was installed in some sections of the city. Ground water elevation record was the purpose of the wells. Since the completion of the study in mid 1980s, those wells that remain are secured with bolted cover or PVC threaded cap.

Wells under the UST program, however, are constructed specifically for water quality monitoring purposes (see section 6. Storage Tanks). The proper capping of the wells is part of the UST program procedures. The remaining types of wells are discussed elsewhere in this report.

4.4.2.14. Ground water/surface water interactions

Definition

In certain settings the elevation of surface waters are above the local ground water table, a situation which favors downward leakage of these surface waters. Contaminants can be transported to and recharge or contaminate underlying ground water by this mechanism.

Extent of Potential Problem

The Potomac River and the Anacostia River constitute the two major surface water bodies in the District of Columbia. The interaction between the rivers and the ground water is both induced and natural. The old streams under the city act as ground water conduits. A considerable amount of land has been reclaimed along both rivers, adjacent to the recent alluvium of sand gravel and silt deposits. In and around these areas there is evidence of the close interconnection of the surface water and ground water. For instance ground water level observations for a downtown construction revealed that a tidal fluctuation of two feet in the Potomac River resulted in an associated half a foot fluctuation in ground water level. A significant amount of effluent from the numerous sump pumps of downtown buildings (over 1.7 million gallons per day from seven buildings alone) reaches the rivers through storm drains discharging into the rivers. It is estimated that ground water contributes to about a quarter of the Potomac River flows.

4.4.2.15. Natural leaching

Definition

Natural leaching refers to the dissolution of geologic materials which then filtrate into the ground water.

Extent of Potential Problem

An analysis of the regional aquifer system for dissolved solids, hardness, nitrate plus nitrite, chloride, and sodium was conducted by the US Geological survey (1986). The data was collected in Maryland over the period of 1938-1986. The study indicates that the natural water quality of the Potomac Group and Piedmont Blue Ridge aquifers is satisfactory for most uses.

5.0 FINDINGS

5.1. Background Information

Washington D.C., the nation's capital lies in the fall zone which is the boundary between the Piedmont Plateau and the Atlantic Coastal Plain regions. Each region has a unique hydrogeologic regime. The Piedmont has fractures in its igneous and metamor phic bedrock from which low water flows. The saprolitic weathered zones have high water and the boundary between bedrock and decayed rock provides numerous springs on hillsides. Coastal Plain aquifers are extremely productive and may be classified as follows: perched tables, unconfined, and confined aquifers. The volume of ground water is based on the nature of fluvial, estuarine, and coastal paleoenvironments that host the gravel, sand, and clay deposits. The natural ground water conditions are generally expected to be good. The natural chemistry of the Coastal Plain ground water is acceptable, although the water is slightly high in iron and sulfur.

The evolving urban cover on the original landscape creates its own superimposed ground water regime. Since the mid-1960s three major engineering efforts have disrupted and altered the natural ground water regime in the city. These are (1) the burial of all utility lines and the associated trenching which diverts and ponds ground water; (2) the dewatering necessary to construct the Metro subway system in five crisscross lanes through the city; and the construction of high-rise buildings, especially in the downtown corridor. Recent studies indicate that dewatering has reached its limit in certain downtown areas because in these areas rebound recharge is not taking place, that is, dewatering which has reached more than one million gallons a day, suggests that this large water supply may meed protection, monitoring, and quantity assessment. Numerous city ground water sheds are related to surface drainage. Delineation of a ground watershed system for the District is included in this report. The lower Potomac Group aquifer has a large recharge area in the north central region of the District. To the east side of the city, it underlies a thick layer of associated red clay. Perched ground water tables are associated with the fluvial/marine terraces. The semi-diurnal tidal system with a tidal range of a meter governs the movement along the city's coastal zone and is impacted by the seawall system at the surface area. The influent-effluent seepage along this coastal plain shoreline is significant for construction below sea level.

The 14th Street Northwest corridor between G Street and Florida Avenue shows no water level change from the 1960s to the 90's. But the Union Station corridor data shows that the water table has not recovered from dewatering in 1989.

Single family neighborhoods are good recharge areas. Construction features, such as roof drains that act as drainpipe injection wells are part of the recharge mechanism for the District.

There are many physical hazards that may affect the quantity and supply of the city's ground water, such as landslides, and leaks from wastewater disposal, domestic water supply pipes, and underground storage tanks. Golf courses, landscape gardens, street tree spraying, irrigation, and riding stables all may lead to small-scale urban agricultural ground water problems. Historical sites of probable contamination need to be studied to assess any potential threat. Land use is extremely critical for controlling contaminant migration.

In the ground water studies of D.C. there is no permit or record keeping system for ground water related information. There are, however, five major studies of ground water in the District that were made during this century. These provide data for the geology and ground water behavior in the city. A systematic field exploration was organized by the members of the research team. Some sites identified as direct impact areas are listed in Table 5.1.

Table 5.1

FIELD EXPLORATION OF CITY GROUND WATER SITES

LOCATION	**ISSUE**
NW	
Pierce Mill Spring House	Historical and functioning Georgetown University
Historical well Rock Crock Cemetery	Replaced septic system; METRO monitoring well
National Zoo (Hays Spring)	NFWS endangered species site (isopod)

Dumbarton, Mingle,	
Hazen, Soapstone	HeadwaterSprings
Spring Valley	Toponomy
Fort Reno plateau	Ground waterDiv.
Pierce Mill Quarry	Fracture Seepage
METRO Red Line	Water Table Data
Cross town Water tunnel	Water Table data
Embassy Wells (VanNess Complex)	Use unknown
C & O Canal shore	Creosote plant Spill remains
	Historic cleaning fluid spill

NE

Fort Totten: Green Line Metro	Water Table: dewatering
East Capital Station: METRO	Cross-section
Banning Road: 9th Dist/Met B&O	UST site
Kenilworth Landfill NPS	Methane gas, no out leakage
Children's Bicen. Island	Hazardous waste dump site
Rhode Island Ave METRO	Infiltration for slide

SE

God's Dump (illegal site)	Leakage
O St Slide	Mass wasting, slurry wall
Frederick Douglass House NPS	Well pump in kitchen
Ely Place seeps	Geologic boundaries
St. Elizabeths Hospital	Historical well/ water
Metro Green Line	
Congressional Cemetery	Flanking Anacostia

SW

St. James Canal	Buried drainage, sewer leaks
Metro Yellow Line	Cross section data

DOWNTOWN CONSTRUCTIONS

North Capital & G St.	Dewatering & no recovery 25 feet deep
North Cap. & Mass Ave.	Natural water chemistry: S & concrete
Smithsonian	
Market Sq. Sth St. & Pa. Ave. Federal	Perched tables and dewatering
Triangle	Daily pumping rates
National Theatre and Marriott	Nitrogen freezing case study
Smithsonian along Constitution	Daily pumping rates

Metro yellow, blue lines
C & P underground 17th and Mall
Lincoln Memorial
C and 4th Streets
Capitol Hill (Jenkins Spring)
Braddocks Well (1-66 ramp)
Tidal Basin and East Potomac
Mayflower Hotel

Cross sections downtown
Flooding and fill
Tidal fluctuations
Historical spring
Historical grotto spring reconstruction
Fill and ground water
Cherry tree root drainage & replacement
Historic wetlands buried

The Metro tunnel data give the most comprehensive ground water information. These data are scattered in many published and unpublished reports. Compilation of the data would entail a major project. Other construction data, particularly for the downtown area, may be available from the geotechnical firms that have worked in the area. Wells that still exist are too shallow, have little background data and no data control for quality assurance needed for sampling.

The city's ground water has a rich and important social, economic and scientific history. In the 1980s, over a million gallons per day were discharged from downtown construction into the storm sewer system without regard for quality or treatment. Dewatering was poorly monitored and the requirement for metering was altogether abandoned. The federal side is not taxed and the construction side, previously required by law to have metered disposal, either has non functioning meters or no. meters. In reality, the city collected less than 5 % of this mandated disposal fee over the last decade.

Foreign soil for the many embassies in the city adds a very special legal aspect to data gathering on ground water. Given the size of land in the city under federal control and use, federal and city coordination in ground water studies is essential. Studies on the military complexes along the Anacostia have just been completed as part the Department of Defense Chesapeake Bay assessments.

The geographic data collection is the best method for a comprehensive ground water information system.

5.2. Special Research Needs

Based on this background investigation of the District of Columbia's ground water, the following are recognized as special areas of concern which need further attention and research:

1. Large cemeteries are located on well drained local topographic highs. They serve both as recharge areas and spring sources for city streams.
2. In certain city neighborhoods, domestic roof drains on permeable ground provide about 20 percent of the overland recharge or are directly injected into the soil. This injection process has proven to be detrimental in areas

prone to landslide on the Christiane soils.

3. Dewatering during construction generally lowers the water table below the foundation bed. Pumps are utilized to complete the dewatering. Deeper underground structures for parking at high-rise buildings create larger drawdowns and exert a larger stress on the urban ground water system. Dewatering an urban area is the inverse analog to the rural/ suburban percolation tests.

4. Extracted ground water in D.C. is pumped directly into the Potomac through the city storm sewers. Sediment laden from water construction is filtered through tandem 55 gallon drums or baffled dumpsters settling tanks. Where there is no downtown open space, barrels and dumpsters are used as temporary sediment control ponds. On the average, there were ten major downtown projects per year during the 1980s. Conservative calculations indicate that approximately 1/2 million gallons of underground water were being removed downtown daily. Recent field checks indicate that some city blocks are not recovering from dewatering while the law requires it. There is a greater quantity of sump water pumped from the federal enclave into the same sewers on a daily basis. Over 1.7 million gallons per day is pumped from eight buildings the Constitution and Pennsylvania Avenues.

5. The laws and regulations controlling ground water use and abuse have been changed at all political levels. Underground storage tanks must have monitoring systems. Historic springs and recharge areas are now being protected. The EPA laws govern monitoring and remediation of past spills. The role of the interstate and intercounty ground water migration have altered rights from individuals to states for the common good. In D.C. the one true federal endangered species is an isopod related to the quality of ground water and springs. FWRA laws and ground water in the city involves rat poison in subway waters, spraying street trees, and chemical care of golf course and garden pests and weeds. Much of the recreation land for golf and public gardens in D.C. is under the National Park Service which does not allow use of these substances.

6. Buried landscapes, in a 200-year evolution of the urban environment, also haunt us through the ground water regime. Buried stream valleys, sewered or not, become slow conduits of contaminant migration. The chemistry of estuarine dredge spoil and sludge create a new infiltration medium for ground water interaction.

The history of each neighborhood's land use may leave problems, especially where heavy industry was replaced by other users. Filled-in and built-on tidal marshes and bogs still contribute to nightmarish floods, especially in times of excessive high water for those locations. Abandoned wells, quarries, pits, and landfills within the city boundaries may complicate tracking and accumulating ground water problems or contributing to the deterioration of ground water because these sites were not labeled or recognized as point sources or point repositories. The history of the development of the urban environment is an important link in the study of ground water geomorphology.

6.0. CONCLUSIONS AND RECOMMENDATIONS

As noted in the discussions earlier, the ground water in the District of Columbia has not been used for drinking and other purposes since the 1940's. This project has focused on bridging the gap in the knowledge of ground water in the District of Columbia and in the problems related to water conservation. The recommendations given below are the result of the First Phase of the investigation: literature review, interview of several agencies and organizations, first hand information and field visits to many construction sites, and other sites of interest to ground water condition in the city.

The recommendations on subsequent studies of this project are provided in separate reports entitled "Work Plan: Assessment of Ground water in the District of Columbia" and "Quality Assurance/Quality Control and Data Management: Assess ment of Ground water in the District of Columbia". Additional recommendations pertaining to ground water protection strategy, data compilation, and short and long term study needs are forwarded herein. The specific recommendations of this study are presented in the following four categories:

6.1- Ground water protection strategy 6.2- Ground water data compilation 6.3- Short-term pilot study for monitoring and sampling 6.4- Long-term research

6.1 Ground Water Protection Strategy

Unlike surface water, which has been studied and is very well coordinated in the region, ground water studies are lacking because the District receives its water supply from surface water. Lately, the District has initiated steps to protect this often overlooked, yet precious resource. Perhaps the most critical elements in ground water resource management are the legal and institutional mechanisms and the public awareness.

In general terms, the potential aquifer restoration strategies are source control of waste, waste treatment, and disposal clean-up plans. However, it is recommended that the long-term objective of the D. C. ground water protection strategy focus on a plan to develop and administer the regulatory activities necessary to protect the resources, including classification, quality standards, monitoring, compliance enforcement, and interagency coordination. The methods which are specific to the District of Columbia will be listed in the final report.

6.1.1 Resource Management

The Department of Consumer and Regulatory Affairs -(DCRA) Environmental Control Division - Water Hygiene Branch (DCRA-ECD-WHB) is assigned the task of developing guidelines for the protection of ground water in the District of Columbia. The DCRA is mandated to establish necessary management tools and controls for ground water protection and to assess the risk of contamination. Additional steps that can be taken for further development of guidelines and supplementing existing regulations include:

plan review and land use controls for compliance with ground water protection strategy.

review of standards for building design and construction

enforcement of the operating standards for the transport, storage, and use of pesticides and hazardous materials.

participation in the emergency response team and review the evaluation of the extent of damage to ground water in accidental spills.

refine and reintroduce the District's ground water protection act. Commensu rate with its activities, it is recommended that the office should have a fully staffed permanent Ground Water Office under the Water Hygiene Branch of the ECD-DCRA. The Underground Storage Tank (UST) program under the DCRA-ECD-Pesticides and Hazardous Waste Management Branch is a very successful program which could serve as a model to a permanent ground water program.

6.1.2 Legal and Institutional

Due to the interstate, inter-jurisdictional nature of ground water resource protection, cooperation with federal and local government agencies and other regional and private agencies is imperative. Issues in identifying and/or setting up the framework for long and short term cooperative activities, and specifying roles with respect to these activities need to be addressed. Due to the specific nature of the subject, it is recommended that the legal and institutional aspects of ground water be addressed in a separate study.

6.1.3 Education and Awareness

Public education is essential not only in building public support, but also to reduce potential pollutants from urban runoff, to prevent residential disposal of harmful household products, and to minimize pesticide use. Public awareness is also a powerful tool for potential pollution alert. Therefore it is recommended that a comprehensive public outreach and education program be developed utilizing exhibits, conferences, publications, and other audiovisual methods. These activities can also be introduced in the D. C. public schools as part of an environmental awareness program for minorities.

6.2 Ground Water Data Compilation

A good grasp of the ground water resource entails a thorough appraisal based on a quantitative analysis. A wealth of ground water-related information may be found scattered among private and public agencies. Often the data is collected as part of some projects not related to ground water and hence requires an extensive screening. Some of this information may not be available to the public. These facts have been a major concern throughout the background study. The creation of a centralized location for data management is essential.

6.2.1 Ground Water Information Repository Center

It is recommended that a Ground water Information Repository Center be established at the Water Hygiene Branch of the DCRA-ECD. The objective of such a center will be to serve as repository for information on legislative, administrative, fiscal and technical matters on ground water. The center will also serve as a screening and transfer station to the major national database systems, such as STORET, and NAWDEX. Thus the center should be equipped with a state-of-the-art information management system that is compatible with major national and regional systems.

6.2.2 Database Management

It is recommended that a information management system for the ground water be developed that is integrated with the surface water and the soil information system. A preliminary survey may be conducted to develop mapping system such as grid system. The type of base maps to be developed may include ground water sub-basins, surface drainage areas, ground water quality monitoring locations, industrial discharges, land use map, soil types, ground water contamination sites, and underground storage tanks.

Additional data should be collected, including hydrogeological, chemical, and others with regard to both quantity and quality. Data from the monitoring wells, drilled in the District of Columbia, should be included in the major ground water data base. A computerized data management system should be developed to compile and centralize the District's ground water-related data. All ground water data collected should be evaluated as to its utility and adequacy.

6.2.3 Classification System

In the data collection scheme, it is important to develop a classification system for wells. The classification should take into account the geological characteristics and the specific urban land uses in the District of Columbia. Such classes of wells include construction, observation, institutional, industrial, UST and sewer monitoring wells, etc.. It is also recommended that a standard reference manual for identification of each class of wells be prepared for distribution at the time of drilling permit issuance.

6.2.4 Well Drilling Permit System

The data collection can be enhanced by instituting a well drilling permit system and requiring well drillers to submit their logs. A nominal permit fee to cover the cost of permit application processing may be charged.

6.3 Short-term Pilot Studies for Sampling and Monitoring

There are a number of monitoring wells in the District at any given time. These wells are installed for specific purposes and the operation period and substances sampled are limited to meet those specific purposes. There are no systematic, continu ous ground water quality monitoring wells in the District of Columbia. It is recommended to construct at least three observation wells in three distinct zones of interest; one in the Piedmont region, a second one in the Arboretum to tap deeper Patuxent aquifer, and the third in the perched water tables. These wells would provide the preliminary data for the design and implementation of a longer term monitoring program.

6.3.1 Urban Ground Water Control

The urban cover is made up of filled ground, previously built underground structures, and a complex network of water pipes, utility lines, sewers, foundations, and subbasements. These structures make the ground water picture dynamic and difficult to control. Additionally there are many complications above ground. A combination of these makes the control of urban ground water extremely complex. It is recommended to study and develop methods of controlling ground water under cities. Finally identify vulnerable areas, especially with regard to ground water recharge, and protect these from potential pollution sources.

6.3.2 Construction of wells and their impacts

There is no standard for well/bore hole drilling procedures in the District of Columbia. It is recommended to establish and/or adopt a set of standards for drillers operating in the city. The companies involved in drilling in the city should be required to provide the piezometric water level data and geological data to the DCRA-ECDWHB. This can be enforced in conjunction with the well permitting system for drilling. The metering and billing requirement for dewatering should be enforced.

6.3.3 Ground Water Quality

The ground water quality has been significantly modified by the urban activities of the past fifty years. It is estimated that the District of Columbia has relatively good quality ground water in abundant quantities. However, it is believed that numerous activities that the city has undertaken may have negatively impacted the quality of ground water. It is recommended that all future activities, especially those related to construction and underground storage tanks, be monitored to assess the impact on the quality of ground water. It is also recommended that the city approve, by zoning and ordinance laws, land use activities that are compatible with adequate ground water protection.

6.3.4 Cost and Economics

The cost and economics involved in ground water protection in the District of Columbia have not been fully assessed. Although ground water may not be used for drinking, it has a significant impact on the city. Sump pump and construction dewatering effluent are regularly discharged into city sewers, thus contributing to the wastewater treatment costs. An indirect cost is also associated due to river and stream pollution. Ground water pollution control measures normally taken include intercepter systems, surface capping and liners, and physical contaminant barriers, such as sheet piling, grouting, and slurry walls. The costs of these measures are presented in " Aquifer Restoration-State of Art" by Knox and others (Noyes Publication). This is summarized below:

<u>**Capital Costs Labor & Maintenance**</u>

Interceptor - Shallow drainage	$500-$700/Acre $1,500/Year
Surface Capping	$20,000-$30,000/Acre --
Sheet piling(60-ft deep)	$38,000- 56,000/1000ft (construction cost only)
Grouting cutoff system	$142-$357/Cu-ft
Slurry Walls (soft soil)	$1,500-2,000/100ft
(60ft-deep) (Boulder Strata)	$3,000-4,000/100ft

A comprehensive and transferable information on the cost of remedial measures for the District is lacking.

6.3.5 Computer Modeling

It is recommended to further screen public domain ground water models for flow and contaminant transport. However, intensive collection of input data related to hydrogeology, aquifer elevations, permeability, and other related parameters are re quired. There are a variety of statistical procedures and models that can be used to evaluate the District's ground water data. These statistical models can give significant insight -into the environmental processes, compared to less complicated qualitative methods. It is important to carefully select and collect data for the model to be used in the District of Columbia. More specific recommendations are made in Task 2 report 'Quality Assurance/Quality Control and Data Management Plan' (DC WRRC Report No. 104).

6.4 Long-term Study Needs

Major research data needs and the scientific uncertainties regarding ground water protection in urban areas are to be identified. This should also include institutional management and fiscal studies.

6.4.1 Ground Water Monitoring Network

Develop a well head delineation program for the District of Columbia involving the neighboring counties.

6.4.2 Surface Water and Ground Water Interaction

The interaction between the ground water and surface water in the District is both induced and natural. Many springs in the District are manifestation of this interaction. Construction and urban activities have clearly impacted this relationship. To establish a quantitative relationship of the surface and ground water, a more in-depth study considering the complex setting of the D. C. area is required. Protection of ground water in the District may directly benefit the surface water quality and vice-versa.

6.4.3 Possible Uses of Ground Water in the District of Columbia

Nationally, half the water supply comes from ground water. In rural areas, ground water accounts for over 90% of the water supply. Ground water is used for a variety of purposes, including public supply, domestic, commercial, industrial, mining thermoelectric power, agricultural etc. According to the USGS "National Water Summary 1987", (Water Supply Paper 2350), ground water is still available in D.C. but quantities are not sufficient to supplement surface water resources. However, ground water in D. C. is believed to be of good quality and could serve as a back-up for watering recreation parks and golf courses and for cooling purposes.

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

Cleaves, E., 1989, Appalachian Piedmont Landscapes from the Permian to the Holocene in Gardner and Sevon, Appalachian Geomorphology, Elsevier, p. 159-179.

Costentino, A.7. and Stephenson, 1991, City of Magnificent Distances- the Nation's Capital- A checklist, Geog and Map Division of Lib of Congress, 31p.

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

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

DC C&RA Water Hygiene Branch, 1990, Water Quality Assessment Vol L 1990 Report to EPA and Congress-- Sec 305 (b) Clean Water Act, 93p.

DC C&RA 1992, Well Construction, Maintenance and Abandonment Standards for DC Proposed Rulemaking Chap 12 Title 21 amended to Law 5-188 (DC Register)

DC C&RA 1992, Groundwater Amendments to DC Water Quality Standards, Chapter 11 SEC. 1104-1112- Title 21. Notice of final Ruemaking-DC Register.

DC Office of Planning, 1983, Comprehensive Plan for the Nation's Capital, 175p.

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

DC WRRC and DCRA (ECD/WHB), May 1990, Proceedings of a Seminar on Ground-water Assessment in the District of Columbia: Background Discussions.

DeFries, Ruth S., 1986, Effects of land use history on Sedimentation in the Potomac Estuary, Md; USGS Water Supply Paper 2234-K, 23P.

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. 1947, Sedimentary Formations of DC, USGS special Geol Map.

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

Froelich, A.J., Hack,J.T. and Otton, E.G., 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.

Hansen, H.J., 1968, Md Geol Surv Rep. Inv. 7 (DC Well Logs) plates.

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

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

Heflin, L., 1968, Engineering Geology-Its Role in the Development and Planning of the Washington METRO: Jour. Wash. Acad Sci.v.58 #7, p.165-170.

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

Longstreth, R., ed., 1991, The Mall in Washington, 1791-1991, Nat. Gall. of Art Studies in Hist. Art #10, 328p.

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.

McKenna D. P. , S. C. Schock, E. Mehnert, S. C. Mravik and D. A. Keefer, Agricultural Chemicals in Rural Private Wells in Illinois: Recommendations for a Statewide Survey: Illinois State Geological Survey, Illinois State Water Survey, 1989 Cooperative Ground water Report 11.

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

Moody, D. and others, 1988, National Water Summary 1986- Hydrologic Events and Ground-Water Quality: USGS Water Supply Paper 2325, p.287-295

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

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

Muester & Johnson Metro Drilling Logs for subway system

National Park Service, 1989, Washington DC: NPS Handbook 102, 175P

National Park Service, 1991, Chesapeake & Ohio Canal: NPS Handbook 142,111p

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

Nyer, E.K. and Skladany, G.J., 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. & Langer, W.H., 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. & O'Connor, J.V., 1989, Engineering Geology of DC, AGU Guidebook for IGC T-234, 7p.

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

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

O'Connor, J. V., 1991, Urban Geology of Washington,DC: A Bicentennial Overview in Abst. v. 16, Geol Assoc of Canada for Toronto 91 (May), p. A92

O'Connor, J.V. and Kirkland, J., 1991, Correlation between Groundwater Levels and Pleistocene Terraces in Mid-Downtown, DC: GSA Abs vol 23 #1, p110.

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

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., 1989, Geological Exploration of the Southern Rock Creek Valley in DC, Am Geophy Union IGC Guidebook T-208, 12p.

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. ,1987, District of Columbia's Urban Geology: UDC Geoscience Guidebook 15, 34p.

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

O'Connor, J. V., 1985, District of Columbia in Earth Science v. 38 #3, p. I1-15

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

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

Pavich, M. and others, 1989, Investigations of the Characteristics, Origins and Residence Time of the Upland Residual Mantle of the Piedmont of Fairfax Co. VA: USGS PP 1352, 58p.

Pomeroy, J.S., 1987, Landslide Susceptibility and Processes in the MD Coastal Plain: in USGS Cir. 1008- Landslides of Eastern NA, p.4-9.

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

Reed, J. Jr., and Obermeier, S., 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.

Schaffranek, R.W., 1987, A Flow Simulation Model of the Tidal Potomac River: USGS Water Supply Paper 2234-D, 41p.

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

Smith, H. and others, 1976, Soil Survey of the District of Columbia, UDSA-SCS.

Stephenson, R.W., 1981, The Cartography of Northern Virginia: Facsimile Reproductions of Maps Dating From 1608-1915: Fairfax Co., VA. History & Archeology Sec-Office of Planning, 145p.

Sun, R, 1986, RASA Project Summaries, USGS CIR 1002.

University of the District of Columbia, Cooperative extension Service, 1981, A Survey of Pesticide Operators in Washington, D.C., Maryland and Virginia - 1980: Washington, D.C.

US DOD study on the environmental assessment of military facilities in the Chesapeake Region

U.S. EPA, 1987, Office of Ground-Water Protection, EPA Activities Related to Sources of Ground-Water Contamination: WH-550G, Washington, D.C.

U. S. EPA, 1989, Office of Ground-Water Protection, Wellhead Protection Programs: Tools for Local Governments: WH-550G, Washington, D. C.

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

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

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

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

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

US 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.

US 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.

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

US Fish & Wildfile, 1990, Endangered & Threatened Wildlife and Plants, 50 CFR 17.11 & 17.12, 36p. (DC p. 23)
USGS PP 950 Nature to be Commanded...

USGS, 1988, Groundwater Studies in MD: Water Fact Sheet USGS of 88-133

USGS, 1988, Groundwater Studies in VA: Water Fact Sheet **USGS** of 88-135

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

USGS,1990, USGS Water Supply paper 2375: Floods and Droughts- State Summaries Md-DC, p. 319-326.

USGS, Washington West & East, Alexandria and Anacostia Quadrangles 7 1/2 min series. Scale 1:24,000.

USGS, 1987, Spot image- DC-16 Scale 1:50,000.

USGS, Water Resources Data- MD, DC,& Del. for Water Year 19--.(yearly)

U. S. Geological Survey, 1989, Ground-Water Quality Assessment of the Delmarva Peninsula, Delaware, Maryland, and Virginia -- Analysis of Available Water-Quality Data Through 1987: National Water-Quality Assessment Program, Open-File Report 89-34.

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

Wash. Metro Coun. of Gov., 1968, Natural Features of the Washington Metro Area: An Ecological reconnaissance, 49p.

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

Weigmann, and Kohler, C. J., 1984, Threats to Virginia's Groundwater: Virginia Water Resources Research Center, Virginia Polytechnic Institute and State University, Blacksburg.

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

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

Whitington, C.F., 1964, Joints in Clay and their Relation to Slope Failure at Greenbelt, MD (Dec. 28,1962): USGS Open File Report, 7p.

Whitington, C.F., 1967, Geology- Its Role in the Development and Planning of Metropolitan Washington- Jour. Wash Acad Sci. 57, p.189-199, .

York, J.E. & Oliver, J.E., 1976, Cretaceous and Cenozoic Faulting in Eastern North America in GSA Bull. 87 (Aug), p. 1105-1114.

Appendices

A - Glossary of Terms and List of Acronyms

GLOSSARY OF TERMS

A

Abandoned Drinking Water Wells - include those abandoned water wells used for disposal of water.

Aquifer-a 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. If a well taps more than one aquifer, the principal aquifer will be the one that yields the greatest amount of water.

Aquifer Recharge Wells - are used to recharge depleted aquifers and may inject fluids from a variety of sources such as lakes, streams, domestic wastewater treatment plants, and other aquifers.

Aquifer Remediation Related Wells - include wells used to prevent, control, or remediate aquifer pollution, including but not limited to superfuad sites.

Aquitard -an impermeable layer of consolidated or unconsolidated material that restricts the movement of water into or out of a confined aquifer, also called confining bed.

Artesian - means confined and is used to describe swell in which the water level stands above the top of the aquifer tapped by the well. A flowing artesian well is one in which the water level is above the land surface.

Artesian Aquifer -a formation beneath the Earth's surface that is saturated with water and enclosed by less permeable layers; the water is under pressure and will rise above the overlying confining bed if given an opportunity to do so.

Artesian Well - a well tapping an artesian aquifer. Because the water is under pressure, it rises above the top of the aquifer. The height of the water in the well represents the potentiometric surface of the aquifer.

Available Capacity of Sewer -the difference between the design capacity of a sewer and the average daily flow recorded at a point in time.

B

Bedrock - the consolidated rock underlying unconsolidated surface materials such as soil.

Bared Web - a relatively shallow well installed by a mechanically driven auger, commonly 18 to 24 inches in diameter, lined with concrete casing to prevent collapse.

C

Celsius (C) - the measure of temperature most commonly used by scientists. Water freezes at 0 °C (32 °F) and boils at 100 °C (212 °F). To convert Celsius to Fahrenheit, °F - 915 °C + 32. Celsius was formerly termed Centigrade.

Centigrade - see Celsius,

cfs-day - the volume of water represented by flow of 1 cubic foot per second for 24 hours. It is equivalent to 86,400 cubic feet, approximately 1.9835 acre-feet, about 646,000 gallons or 2,447 cubic meters.

Channel (Watercourse) - an open conduit either naturally or artificially created which periodically or continuously contains moving water, or which forms a connecting link between two bodies of water.

Chemical Oxygen Demand (COD)-a measure of the cbemically oxidizable material in the water, and furnishes an approximation of the amount of organic and reducing material present. The determined value may correlate with natural water color or with carbonaceous organic pollution from sewage or industrial wastes.

Chlorination - the application of chlorine to water or wastewater, generally far the purpose of disinfect tion, but frequently in the process of photosynthesis, used as an indicator of plants biomass in water.

Chlorine - a common element, best known as a heavy greenish yellow irritating toxic gas of disagreeable odor used chiefly as a powerful bleaching, oxidizing, and disinfecting agent in water purification and in mating pesticides.

Coastal Plain - a lowland area extending in a gentle dope inland from the shoreline of an ocean.

Combined Sews,¢ - sewage containing both domestic sewage and surface water a stormwater. It includes flow in heavily infiltrated sanitary sewer systems, ad well as flow in combined sewer systems.

Combined Sews Overflow (CSC) - excess flow from an overloaded combined sewer.

Conductivity - the quality or power of conducting or transmitting electrical current; in water, a measure of the dissolved ions. Confined Aquifer -an aquifer bounded above and below by impermeable beds or beds of distinctly lower permeability than that of the aquifer itself; it contains confined ground water.

Confining Had -an impermeable unit that lies over or under an aquifer and prevents or impedes movement of water into or out of the aquifer.

Conservation - a careful preservation and protection of something; esp.: planned management of a natural resource to prevent exploitation, destruction, or neglect.

Contamination - the process of becoming impure; damage to the quality of water sources by sewage, industrial waste, or other matter.

Contents-the volume of water in a reservoir or late. Unless otherwise indicated, volume is computed on the basis of a level pool and does not include bank storage.

Continental Shelf-the submerged edge of a continent extending from the low water line to a region with a distinct change in slope.

Control - designates a feature downstream from the gage that determines the stage-discharge relation at the gage. This feature may be a natural constriction of the channel, an artificial structure, or a uniform cross section over a long reach of the channel.

Corrosion - a dissolving and wearing away of metal caused by a chemical reaction (in this case, between water and the piping that the water contacts or between two different metals}.

Cubic Feet Per Second (FT0/S, ft3/s) - the rate of discharge representing a volume of 1 cubic foot passing a given point during 1 second and id equivalent to approximately 7.48 gallons per second or 448.8 gallons per minute or 0.02832 cubic meters per second.

Cubic Feet Per Second Per Square Mile (CFSM) -the average number of cubic feet of water flowing per second from each square mile of area drained, assuming that the runoff is distributed uniformly in time and area

Curie -a measurement of radioactivity equal to 3.7×10^{10} disintegrations per second.

Datum - any level surface, line, or point use as a reference in measuring elevation.

Design Capacity of Sewer - the hydraulic capacity of any sewer when installed as indicated by the diameter of the pipe.

Diversity - a measure of the complexity of an ecological community that is generally a function of both the number of species present and the relative proportions of their number.

Diversity Index - a numerical expression of evenness of distribution of aquatic organisms.

Domestic Consumption - water used for household purposes such as washing, food preparation, and shower.

Domestic Use - water use in homes and on lawns, including use for laundry, washing cars, cooling, and swimming pools.

Drain - a small artificial water course designed to drain swampy areas or irrigated lands. Theoretically, it is actually a small canal, but it is referred to as a "drain" in many localities.

Drainage area - of a stream at a specified location of a site is that area, measured in a horizontal plane, enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into the stream above the site.

Drainage Basin - a part of the surface of the earth that is occupied try a drainage system which consists of a surface stream or a body of impounded surface water together with all tributary

Dredged Spoil - the sediment removed by man from the bottoms of aquatic habitats.

Drilled Well -a well which penetrates fractured bedrock, drilled with a rotating bit; lined with steel or polyvinylchoride casing.

Driller's Log-description by the driller of the geologic materials penetrated from the land surface to the greatest depth of the well.

Drought - a prolonged period of dryness.

Dug Web -a large diameter well (30 inches or more) excavated by shovel, usually to a depth just below the water table; commonly Wed with brick, stone, or wood to prevent collapse.

E

Ecology - the study of the interrelationships of organisms to one another and to the environment.

Ecosystem - an interactive system which includes the organism of a natural community together with their environment.

Evaporation -the process by which water is changed from the liquid into the vapor state. In hydrology, evaporation is vaporization that takes place at a temperature below the boiling point. It is usually measured with evaporation pans.

Evapotranspiration -the release of water from the earth's surface to the atmosphere by evaporation from soil and surface waters and by transpiration from plants.

Fail line - a line joining the water-falls on numerous rivers that marks the point where each river descends from the upland to the lowland. In Virginia, the fall line passes through Fairfax, Fredericksburg, Richmond, Petersburg, and Emporia. equipment for fishing.

Flood Plain - the lowland that borders a river, usually dry but subject to flooding when the stream overflows its banks.

G

Gauge Height (G-II-) - the water surface elevation referred to some arbitrary gauge datum. Gauge height is often used interchangeably with the more general term "stage", although gauge height is more appropriate when used with a reading on a gauge

Gauging Station - a particular site on a stream, canal, lake, or reservoir where systematic observations of hydrologic data are obtained.

Geomorphology-a science that deals with the land and submarine relief features of the Earth's surface or the comparable relief features of a celestial body and seeks a genetic interpretation of them.

Geophysics - the physics of the Earth including the fields of meteorology, hydrology, oceanography, seismology, volcanology, magnetism, radioactivity, and geodesy.

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, the water that supplies wells and springs.

Ground Water Aquaculture Return Flow Wells- reinject ground water or geothermal fluids used to support aquaculture. Nongeothermal aquaculture disposal wells are also included in this category.

H

Habitat - the sum total of environmental conditions of a specific place that is occupied by an organism, population, or community.

Heavy Metals - metals with a specific gravity of 5.0 or higher, including cadmium, chromium, copper, lead, and zinc.

Herbicide - any compound, usually a synthetic organic chemical, used to control plant growth.

Hydraulically Overloaded - a condition in which the quantity of flow through a treatment plant is greater than that for which it is designed, which often results in the decrease in operational efficiency of the plant.

Hydraulic Conductivity - the rate at which water moves through aquifer material under a unit hydraulic gradient, expressed as volume per unit time per unit crass section ($ft^3/day/ft^2$ or $M^3/day/m^2$) reduced to feet per day or meters per day.

Hydrogen Ion (pH) - the cation H+ of acids consisting of a hydrogen atom whose electron has been transferred to the anion of the acid.

Hydrogeology - the science that deals with subsurface waters and related geologic aspects of surface waters.

Hydrologic Circle -a continuous sequence of processes in which water passes from the atmosphere to the land or oceans and back to the atmosphere.

Hydrologic Unit -a geographic area representing part or all of a surface drainage basin or distinct hydrologic feature a delineated by the Office of Water Data Coordination on the State Hydrologic Unit Maps; each hydrologic unit is identified by an 84git number.

Hydrology-the science dealing with the properties, distribution, and circulation of water on the surface of the land, in the soil and underlying rocks, and in the atmosphere.

Igneous Rock - rock produced through the cooling of molten mineral material.

Impermeable - not permitting passage - impermeable rocks do not allow water to move through

Impoundment - a body of water formed by being confined; a reservoir for liquid wastes.

Incineration - consists of burning the sludge to remove the water and reduce the remaining residues to a safe, non-burnable ash. The ash can be disposed of safely on land, in some water, or into aria or other underground locations.

L

Land Application - the discharge of raw or treated wastewater onto the ground for treatment or reuse. The wastewater penetrates into the ground where the natural filtering and straining action of the soil removes most of the pollutants. Three techniques are used: spray irrigation, rapid infiltration and overland flow.

Land Cover - the vegetation, water, natural surface, and artificial construction of the land surface.

Landfill - a system of trash and garbage disposal in which waste is buried between layers or earth.

Land Use - titan's activities which are directly related to the land.

LC5O - the concentration of a substance that is lethal to fifty percent of the test organisms within a specific time period (96 hours

Leads- to dissolve by the action of a percolation liquid, such as rainwater seeping through soil and carrying pesticides, fertilizers, or chemical wastes with it.

Leachate - a solution formed when water percolates through soluble material, often used in reference to the liquid formed from the percolation of precipitation through landfill wastes.

Leaching - the removal in solution of the more soluble minerals by percolation waters.

Main Stem - the main body of a river or estuary, excluding its tributaries.

Mass Transport -a volume of water transported per unit time across a given plane in a body of water.

Mean -the "average" value for a series of counts. The arithmetic mean (x) is found by dividing the sum of all of the counts by the total number of observations, The geometric (log) mean is found by dividing the sum of the logs of the counts by the total number of observations and then transforming that value back into a natural number. Calculation of log as in the case with bacterial counts.

Mean Low Water (MLW) - the average height of all low tides at a given location.

Median Value - the value of the middle item when items are arrayed according to size.

Meteorology - study of the Earth's atmosphere, including its movements and other phenomena, especially as they relate to weather forecasting.

Milligrams Per Liter (MG/L, mg/L) -a unit expressing the concentration of chemical constituents in solution. Milligrams per liter represent the mar of solute per unit volume (liter) of water. Concentration of suspended sediment also is expressed in mg/L, and is based on the mass of sediment per liter of water4sediment mixture.

Morphology - the physical form or structure of plants or animals.

Most Probable Number (MPN) - a statistical index of the number of coliform bacteria in a given volume of sample as derived by a specific laboratory test. It is used for appraising the sanitary quality of water.

N

Nitrate Nitrogen (NO_3-N)-the predominant form of inorganic nitrogen that supports algal production. Other inorganic nitrogen forms, such as nitrite nitrogen ($N0_2$-N) and ammonia nitrogen (NH3-N) vary in abundance in streams. Sewage treatment plant effluents may contain high ammonia nitrogen concentration if nitrification (conversion of NH_3N to $N0_3$-N) is not a part of the treatment process.

Nitrification - a microbial process in which nitrogenous matter in the form of ammonium ions is converted into nitrates.

Nitrogen - a colorless, tasteless, odorless, gaseous element that constitutes 78 percent of the atmosphere by volume and is a constituent of all living things.

Non-point Source - a discharge which originates over a broad area, such as storm water runoff from forested, agricultural, and urban areas. Distinguished from POINT SOURCE.

Nutrients -an element or compound, primarily nitrogen and phosphorus, that are necessary for the growth, development, and reproduction of plants. An excessive input of nutrients into a water system may lead to algal blooms and eutrophication.

Nutrient hooding - the input of nutrients into a body of water, which leads to increased primary productivity (usually implies excess input of nutrients

O

Organic Compounds - chemical compounds containing carbon, usually of living origin.

P

PCB (Polychlorinated Biphenyls) - a class of industrial compounds that are toxic environmental pollutants and tend to accumulate in animal tissue.

Perched Water - ground water that occurs above the water table "perched" above a layer of unsaturated rock or soil.

Percolation - liquid moving through a permeable substance.

Permeability-the property of soil or rock to pass water through it. This depends not only on the volume of the openings and pores, but also on how these openings are connected one to another.

Pesticides - chemical compounds used to control undesirable plants and animals. Major categories of pesticides include insecticides, miticides, fungicides, herbicides and rodenticides. Insecticides and herbicides, which control insects and plants respectively, arc the two categories reported.

pH - the negative logarithm of the hydrogen ion concentration, part hydrogen is a term used to egress the intensity of the acid or alkaline condition of a solution. This hydrogen ion activity is expressed in moles per liter. The pH scale is "zero" to 14; a pH of 7.0 indicates that the water sample solution is neutral while readings lower than 7.0 denote increasing acidity and higher than 7.0 denote increasing alkalinity. Natural waters have a pH typically between 63-85.

Phosphorus, Total (TP) - all the phosphorus forms in the sample (mg/1 as P) including ortho-phosphate, poly-Phosphate and organic phosphorus. Total phosphorus concentrations greater than .1 mg/l in streams can support algal blooms.

Point Source -a discharge with a definite outlet such ass pipe, tunnel or channel Usually industrial and/or municipal discharges. Distinguished from NON-POINT SOURCE.

Pollutant - something that pollutes (to make physically impure or unclean; to contaminate).

Porosity- the quality of being porous, or full of pores or openings; a measure of the amount of space in a material or of the water storage capacity of a substance.

Pumping - the artificial removal of water from an aquifer.

Sediment - particulate organic and inorganic matter that originates mostly from disintegrated rocks and is transported by, suspended in, or deposited from water, it includes chemical and biochemical precipitates and decomposed organic material, such as humus. The quantity, characteristics, cause of the occurrence of sediment in streams are influenced by environmental factors. Some major factors are degree of slope, length of slope, soil characteristics, land usage, and quantity and intensity of precipitation.

Sedimentary Rat - the part of water-bearing material where voids are filled with water, the zone in which ground water occurs.

Septic System -a wastewater and sewage disposal system in which solids settle to the bottom of a tank and liquids are discharged to the soil through a series of lines in a drain field.

Soil Water - any water that is not "hard". Water is considered to be hard when it contains a large amount of dissolved minerals, such as salts containing calcium or magnesium. You may be familiar with hard water that interferes with the lathering action of snip.

Soil Moisture (Soil Water) -water Mused in the soil immediately below the land surface (zone of aeration), from which water is discharged by transpiration in plants or by evaporation.

Subsidence - the lowering of the elevation of the land surface due to withdrawal of subsurface fluids, resulting from the compaction of sediments composing the aquifer system.

T

Talc Substance - chemicals such as pesticides (bug killers) and mercury that can make people and animals ill or die.

Toxicity Teat - a test which determines the potency of a toxic substance by measuring the intensity of a biological response.

Tract; E - elements of compounds that arc necessary for the operation of living systems, but that are present in the environment only in minute quantities.

Trace Metals- trace metallic elements found in surface waters and sediments; the principal ones in the Potomac Basin: strontium, aluminum, boron, barium, and zinc.

Transmissivity - the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of saturated thickness of an aquifer under a unit hydraulic gradient.

Unconfined Aquifer - an aquifer that has a water table; it contains unconfined ground water.

Unconsolidated - not formed into a compact mesa; loosely associated or soil-like.

Unsaturated Zone- the zone between the land surface and the water table containing water held by capillary water, and containing air or gases generally under atmospheric pressure.

Urban Runoff –storm water from city streets and gutters. It usually contains titter, organic, and bacterial wastes. In the past, urban runoff has gone untreated, but recently it has been recognized as a significant pollutant that needs retention and treatment.

W

Water Quality - the fitness of water for use, being affected by physical, chemical, and biological factors.

Watershed or Drainage Area - an area from which water drains to a single point; in a natural basin, the area contributing flow to a given place or a given point on a stream. A region drained by a stream.

Water Table -that surface in a ground water body at which the water pressure is atmospheric. It is defined by the levels at which water stands in wells that penetrate the water body just far enough to hold standing water. In wells which penetrate to greater depths, the water level will stand above the confining upper bed of the aquifer.

Water Table Well - a vertical excavation that taps a underground source of water in an unconfined aquifer, the level of water in the well reflects the water table of the aquifer.

Water Year - in Geological Survey reports and statistics dealing with surface-water supply, the 12-month period of October 1 through September 30 is known as a water year. The water year is designated by the calendar year in which it ends and which includes 9 of 12 months. For example, the year ending September 30,1959, is called the "1959 water year.

Weathering - decomposition, mechanical and chemical, of rock material used the influence of climatic factors of water, heat, and air.

Well Depth - the greatest depth below land surface at which water can enter the well will be reported. For screened or perforated wells, the depth to the bottom of the screen a to the lowest perforation will be reported. The open-hole or open-end wells, the total depth will be reported.

Transpiration - the process by which water vapor escapes from the surface of the living plant and enters the atmosphere. Transport Processes - mechanisms that result either in displace-went, advection, or mixing (turbulence) of water masses. larval stages with distinct chordate characteristics; commonly called sea squirts.

LIST OF ACRONYMS

AC-FT-acre-foot

ACTMO -Agricultural Chemical Transport Model (USDA)

AGP -Algal Growth Potential

ARS - Agricultural Research Service

ASCE-American Society of Civil Engineers

ASCS - Agriculture Stabilization & Conservation Service

AST-Advanced Secondary Treatment

ATP - Adenosine Triphosphate

AWT-Advanced Wastewater Treatment

AWIP -Advanced Wastewater Treatment Plant

BAWQ - Bureau of Air and Water Quality

AHW&P - Bureau of Hazardous Wastes and Pesticides BMP - Beat Management Practices

BOD - Biological Oxygen Demand

BOD_S - Ewe Day Biological Oxygen Demand BOD_{20} - Ultimate Biological Oxygen Demand BOR - Bureau of Reclamation

BWQMN - Baseline Water Quality Monitoring Network °C - Degree Celsius

CBL - Chesapeake Biological Laboratory

CERCLA- Comprehensive Environmental Response, Compensation and Liability

cfs -cubic feet per second

cfsm - cubic feet per second per square mile

CLENS - Computing Loading Estimates from Non-point Sources (Canter for Environment and Man model)

CO - carbon monoxide

COD -chemical oxygen demand

COE - Corps of Engineers (US Army)

COG - Council of Governments

CO-0P - Cooperative Water Supply Operations on the Potomac (Interstate Commission on the Potomac River Basin)

CREAMS -Chemicals, Runoff and Erosion from Agricultural Management (USDA model)

CRL - Central Regional Laboratory

CSO - Combined Sewer Overflow

CWA - Clean Water Act (revised 1977 as public law 95-217) key sections include:
Section 106 - Water Pollution Control Program
Section 201 - Sewage Treatment Plant Grants Program
Section 205(g) - Construction Grants Management Assistance Grant
Section 208 - Water Quality Management Planning

CWS - Community Water System

DBCP – dibromo-chloropropane

DCRA - Department of Consumer and Regulatory Affairs

DCWRMA-District of Columbia Water Resources Management Administration

DDT -dicbloro-diphenyl-trichloroethane

DEM - Dynamic Estuary Model (EPA)

DES - District of Columbia Department of Environmental Services

DO - dissolved oxygen

DOC - dissolved organic carbon

DOI - US Department of the Interior DPW - Department of Public Works EDB - ethylene dibromide

EEM - (Potomac) Estuary Equilibrium Model

EDF - Environmental Defense Fund

EHA-Environmental Health Administration

EMS - Environmental Impact Statement - complete review of topical concerns (see NEPA)

ENVIS - Environmental Information System

EPA- Environmental Protection Agency

o F Degree Farenheit

FCCSET - Federal Coordination Council for Science, Engineering, and Technology

FCWA-Fairfax County Water Authority

FDA-Federal Drug Administration

FIFRA-Federal Insecticide, Fungicide, and Rodenticide Act

FLSRAC - Federal Interstate State Regional Advisory Committee

FWS - Fish & Wildlife Service

FY - Fiscal Year

GH-Gage Height

GIS - Geographic Information System

GPCPD - gallons per capita per day

GWSI - Ground Water Site Inventory File

HEC - Hydrologic Engineering Center

HSPF- Hydrologic Simulation Program – FORTRAN (EPA model)

HR - House of Representatives

ICPRB - Interstate Commission on the Potomac River Basin

IN - runoff in inches

o K Degree Kelvin

LC_{50} - median lethal concentration

LDsp - median lethal dose

LUST- Leaking Underground Storage Tanks

MBAS - methylene blue active substance

MCI& - maximum contaminant levels

MEAN - mean discharge

mgd - million gallons per day

mg/L-milligram per liter

MIS - Management Information System

MLW - Mean Low Water

MOA - Memorandum of Agreement

MOU - Memorandum of Understanding

MPN - Most Probable Number

MWA - Metropolitan Washington Area

MWCOG - Metropolitan Washington Council of Governments

MWDI - Master Water Data Index

NAAQS - National Atmospheric Air Quality Standards

NAE - National Academy of Engineers

NAS - National Academy of Sciences

NAWDEX - National Water Data Exchange

NCIC - National Cartographic Information Center of the National Map Division, USGS

NCPC - National Capital Planning Commission

NEPA - National Environmental Policy Act - requires federal agency development of environmental impact consideration procedures

NEWS - Northeastern US Water Supply Study (COE)

$N0_2$ - nitrogen dioxide - one of the NAAQS and a major contributor to photochemical SMOG

$N0_3$-N - nitrate nitrogen

NOAA - National Oceanographic and Atmospheric Administration

NOEL - no observable effect level

NPS - non-point source

NURP - Nationwide Urban Runoff Program (EPA)

NVPDC - Northern Virginia Planning District Commission

NWSRFS - National Weather Service River Forecasting System

0_3 - ozone - one of the NAAQS and major component of photochemical SMOG

O&M - Operation and Maintenance

OM - Organic Matter

O-PO_4 -ortho phosphate

OTA - Office of Technology Assessment

OWDC - Office of Water Data Coordination, USGS

PC - picocurie

PCB - polychlorinated biphenyl PM - polychlorinated biphenyls

PEPCO - Potomac Electric Power Company

pH – acidity/alkalinity measurement scale

PI.FAA - Potomac Low Flow Allocation Agreement

POC-Particulate Organic Matter

ppb - one part per billion

ppm - one part per million

ppt - one part per trillion

PRISM-Potomac River Interactive Simulation Model (EPA)

PS - Point Source

PSTC - Potomac Studies Technical Committee

QA - Quality Assurance

QC - Quality Control

RCRA - Resource Conversation & Recovery Act

SCAM - Street Cleaning Analysis Model (EPA)

SCRAM - Simulation of Containment Practices and Movement (EPA model)

SES - Sewer Expansion Simulation

SDWA - Safe Drinking Water Act

SO_Z - sulfur dioxide - key NAAQS and pollutant

as - suspended solids

STORET - a computerized data base utility maintained by EPA for to STOrage and RETrieval of parametric data relating to the quality of the waterways of the United States

STP - Sewage Treatment Plant

SWCB - State Water Control Hoard

SWMM - Storm Water Management Model (Metcalf and Eddy)

'IDS - Total Dissolved Solids

TKN-Total Kjeldahl Nitrogen (the organic nitrogen, as found in cell, plus ammonia nitrogen)

TOC - Total Organic Carbon

TP - Total Phosphorus

T PO_4 - Total Phosphate as P

UDC - University of the District of Columbia

uglg - micrograms per gram

ug/L - micrograms per liter

UOD - Ultimate Oxygen Demand

UOSA-Upper Occoquan Sewage Authority

USDAHL - US Department of Agriculture Hydrograph Laboratory Model

USDA - US Department of Agriculture USGS - United States Geological Survey USNPS -US National Park Service (Department of the Interior)

UST - Underground Storage Tanks

WATWRP - Washington Area Interstate Water Resources Program

WASP - Water Quality Analysis Simulation Program (EPA model)

WASUA - Water tit Sewer Utility Administration

WATDOC - Water Resources Document Reference Center, Canadian Department of the Environment

WATSTORE - National Water Data Storage and Retrieval System

WAWAG - Washington Area Waterfront Action Group

WDSD - Water Data Sources Directory

WHD - Water Hygiene Division

WLA - Waste Load Allocation

WMA- Washington Metropolitan Area

WQC - Water Quality Criteria

WQM - Water Quality Management

WQMP - Water Quality Management Plan

WOS - Water Quality Standards

WRCAC - Water Resources Citizens Advisory

Committee

WRSIC- Water Resources Scientific Information Center

WRPH - Water Resources Planning Hoard

WRRC - Water Resources Research Center

WSEA- Water Supply Emergency Agreement

WSEP - Water Supply Emergency Plan

WSSC - Washington Suburban Sanitary Commission W

WTP - Wastewater Treatment Plan

B - Springs of Old Washington, D.C.

Springs of Old Washington, D.C.

1. Smith (Congressional or Effingham), McMillan Reservoir area
2. City (Ridge) , north side of C. St. between 4 1/2 and 6th Sts., N.W.
3. Caffrey's (Hotel, Burnes', St. Patrick's, Federal), northwest corner of 9th and F Sts., N.W.
4. City Hall, near nothwest corner of 5th and D Sts., N.W.
5. Franklin Square, between 13th and 14th and I and k Sts., N.W.
6. 13th and K Sts., N.W. and vicinity
7. Gibson (Cool, Young's, StoddertIs Federal), 15th and E Sts., N.E.
8. Capitol Hill, foot of Capitol Hill near Pennsylvania Ave., northwest of Capitol
9. Spring Garden, south side of canal just west of 6th St., West
10. Carroll, intersection of New Jersey and Virginia Aves., West
11. Pennsylvania and 2nd St., S.E.
12. Intersection of North Carolina Ave., D. and 3rd Sts., S.E.
13. Gales (Eckington), just northeast of intersection of 1st St. East and Boundary St. (Florida Ave.)
14. Reedbirds hill, North Capitol and M. Sts.
15. Dunlop, just east of present U.S. soldier's Home
16. Along or near right bank of Anacostia River, between about C St. North and C. St. south
17. Post Office, northwest corner of 7th and E Sts. N.W.
18. leech, on New York Ave. between 5th and 6th Sts., NW
19. Blue House, on 10th St. between K St. and Massachusetts Ave.. N.W.
20. Willow (Willow Tree), just north of 1 St. between 4th and 5th Sts., NW
21. Just southeast of intersection of 10th and M. Sts., NW.
22. On Massachusetts Ave. between 15th and 16th Sts., NW
23. South Side of Rhode Island Ave., just east of Connecticut Ave., N.W.
24. Brown's, just north of Boundary St. (Florida Ave.), between 14th and 15th Sts., N.W.
25. On 18th St. near Boundary St., N.W.
26. On 13th St. near Boundary St., NW
27. Moore's vicinity of 11th and boundary Sts., N.W.
28. 11th St. between Florida Ave., and Euclid St., NW
29. Head of Reedy Branch, about 13th and Harvard Sts., NW
30. James White, near northwest corner of Georgia Ave. (16th St.) and Ingraham St.
31. Octagon House, northeast corner of 18th St. and New York Ave., NW.
32. Easby's Point, D and 26th Sts., NW (just east of today's Kennedy Center)
33. On Virginia Ave., between 26th and 27th Sts., NW
34. East bank of Rock Creek near K St.
35. P and 22nd Sts., N.W. near or on the eastern bank of Rock Creek
36. Quarry Road, just east of Rock Creek and opposite the zoo
37. Pierce Mill, in the present Tilden St., a few hundred feet

west of Rock Creek

38. Corner of Wisconsin Ave. and Q Sts., NW., in Georgetown'

Source: USGS Circular # 752

C - Groundwater Levels

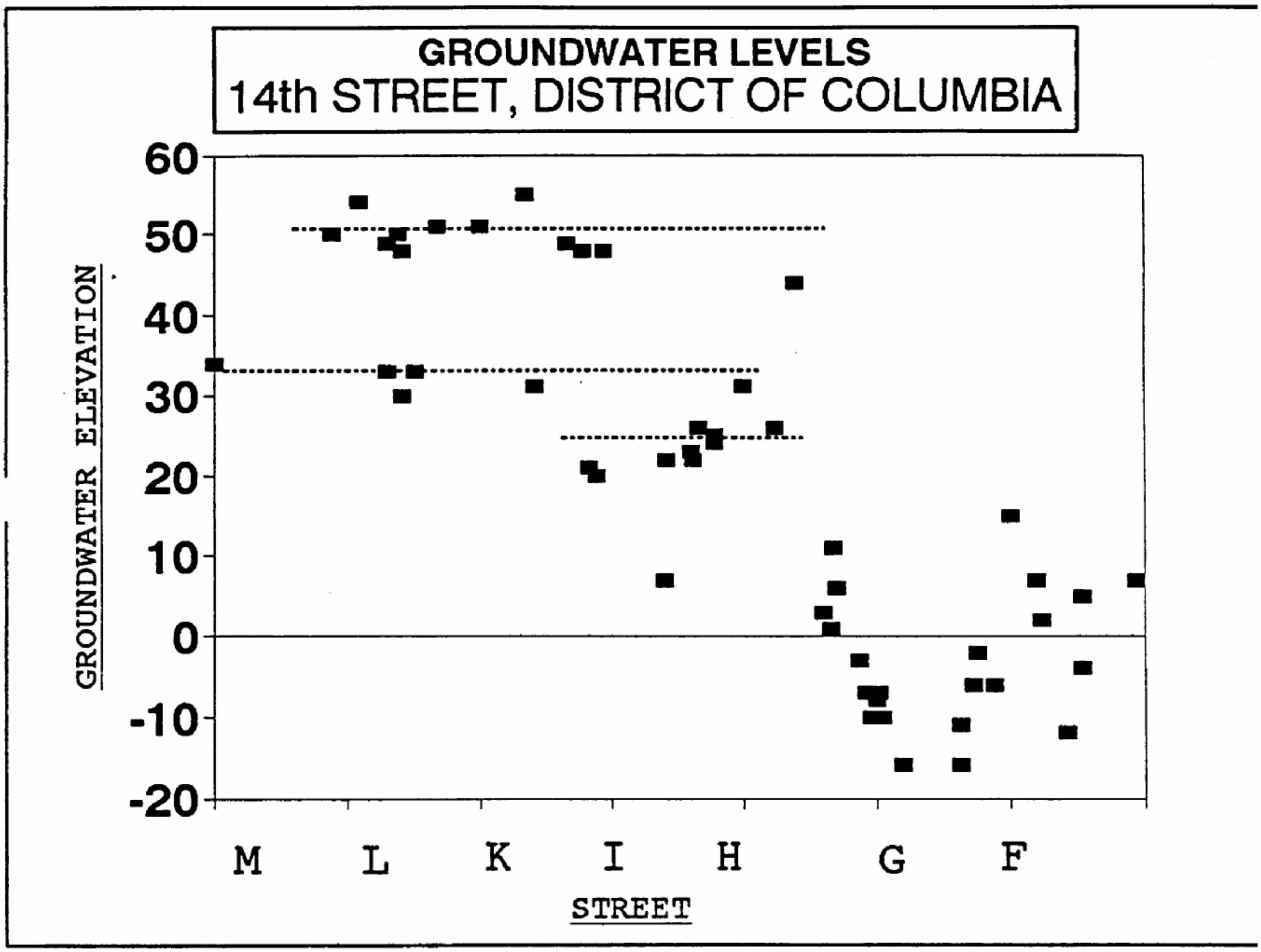
CORRELATIONS BETWEEN GROUNDWATER LEVELS AND PLEISTOCENE TERRACES, MID-DOWNTOWN,

DISTRICT OF COLUMBIA

Groundwater levels taken from observation wells and soil borings drilled for geotechnical purposes in an area bounded by 12th, 15th, H and M Sts, N.W. show two distinct water levels. Measurements taken between 1962 and 1989 appear consistent in **spite of construction and dewatering. The highest water level, El 50 to 55, occurs between M and 1 Sts. It was probably the source for springs that formerly provided drinking water in Franklin Square and corresponds to a 50 ft terrace consisting primarily of overconsolidated silty clay identified during development of the METRO subway. A second level at about El 25 at G St correlates with a 25 ft terrace also encountered during METRO development.**

The recharge area for both levels appears to be large enough that construction and dewatering activities have had little effect on them over time. It is only when the METRO tunnel system with its extensive drainage is encountered that the levels are significantly affected. The 50 ft water level appears to be intercepted by drainage into a METRO tunnel under I St. Likewise, south of the METRO tunnel at G St, ground water drops below sea level.

This study, although limited in extent, points out the need for more extensive research into **urban hydrogeologic systems and the complex interrelations between development, hydrogeology and geomorphology.**



(O'Connor and Kirkland, 1991)

D - Major Developments in Downtown

MAJOR DEVELOPMENTS I.. DOWNTOWN WASHINGTON

NEW BUILDINGS AND MAJOR RENOVATIONS DURING THE BARRY YEARS

This is the downtown area, as defined in the District Elements of the Comprehensive Plan for the National Capital. All the construction shown here has been completed or begun in the last 12 years:

● New buildings
▲ Major renovations
(u/c) Still under construction

FRANKLIN SQUARE
- ● 1. Vista Hotel
- ● 2. One Thomas Circle
- ● 3. 1120 Vermont Avenue
- ● 4. 1110 Vermont Avenue
- ▲ 5. 1025 15th Street (u/c)
- ● 6. 1023 15th Street
- ● 7. 1090 Vermont Avenue
- ● 8. American Medical Assn.
- ● 9. 1400 L Street
- ● 10. 1400 K Street
- ● 11. 1420 K Street
- ▲ 12. 1430 K Street
- ▲ 13. 927 15th Street
- ▲ 14. 915 15th Street
- ● 15. McPherson Building
- ▲ 16. Franklin Tower
- ● 17. UPI Building
- ● 18. 1444 I Street
- ▲● 19. Southern Building
- ● 20. City Center (u/c)
- ● 21. 1401 New York Avenue
- ● 22. 1425 N.Y. Ave. (u/c)
- ▲● 23. Crestar Bank Building
- ▲● 24. 727 15th Street
- ● 25. 1111 14th Street
- ● 26. 1101 14th Street
- ● 27. 1313 L Street
- ● 28. 1300 L Street
- ● 29. Franklin Court (u/c)
- ● 30. One Franklin Square
- ▲ 31. Franklin Square improvements
- ● 32. 1300 I Street
- ● 33. 1350 I Street
- ▲● 34. 1333 H Street
- ▲ 35. 1331 H Street
- ▲ 36. 1321 H Street
- ▲ 37. New York Ave. reconstruction
- ● 38. 1201 L Street
- ● 39. 1220 L Street
- ● 40. 1275 K Street
- ● 41. Franklin Plaza (u/c)
- ▲ 42. Franklin School (u/c)
- ● 43. 1225 I Street
- ● 44. 1201 New York Avenue
- ● 45. 1250 I Street
- ● 46. 1212 New York Avenue
- ▲ 47. National Museum of Women in the Arts

MOUNT VERNON SQUARE
- ● 48. N.F.B. Building
- ▲ 49. American Youth Hostel
- ▲ 50. Henley Park Hotel
- ▲ 51. Carnegie (UDC) Library

CONVENTION CENTER AREA
- ▲ 52. 1108 K Street
- ● 53. 1100 New York Avenue (u/c)
- ● 54. Washington Convention Center
- ● 55. Techworld Plaza Phase I
- ● 56. Techworld Plaza Phase II

RETAIL CORE
- ▲● 57. Washington Building
- ▲● 58. Commercial National Bank Building
- ● 59. Bond Building
- ● 60. Metropolitan Square
- ▲ 61. Garfinckel's
- ▲ 62. Washington Hotel
- ● 63. Willard Office/Retail
- ▲ 64. Willard Inter-Continental Hotel
- ● 65. 1300 New York Avenue
- ● 66. 1350 New York Avenue
- ▲ 67. 717 14th Street
- ▲● 68. Colorado Building
- ● 69. 700 13th Street
- ● 70. 1310 G Street (u/c)
- ▲ 71. Sun Building
- ● 72. 1331 F Street
- ▲ 73. 1333 F Street
- ● 74. 607 14th Street
- ▲ 75. National Press Building
- ● 76. Nat. Place/ J.W. Marriott Hotel
- ● 77. National Place/ The Shops
- ● 78. American City Building
- ▲ 79. National Theatre
- ● 80. Herald Square (u/c)
- ● 81. Hecht's
- ● 82. Homer Building
- ● 83. 1200 G Street (u/c)
- ● 84. Columbia Square
- ▲● 85. Warner Theatre/ 1299 Pa. Ave. (u/c)
- ● 86. Holiday Inn Crowne Plaza
- ● 87. 700 11th Street (u/c)
- ▲ 88. 605 12th Street
- ● 89. Washington Center/ Grand Hyatt Hotel
- ▲● 90. Washington Center/ 1000 G Street
- ▲ 91. Woodward & Lothrop
- ● 92. YWCA
- ▲ 93. 999 E Street
- ● 94. 901 E Street

PENNSYLVANIA AVE. WEST
- ● 95. Pershing Park
- ● 96. Freedom Plaza
- ▲ 97. 1275 Pennsylvania Avenue
- ▲● 98. Evening Star Building
- ● 99. 1001 Pennsylvania Avenue

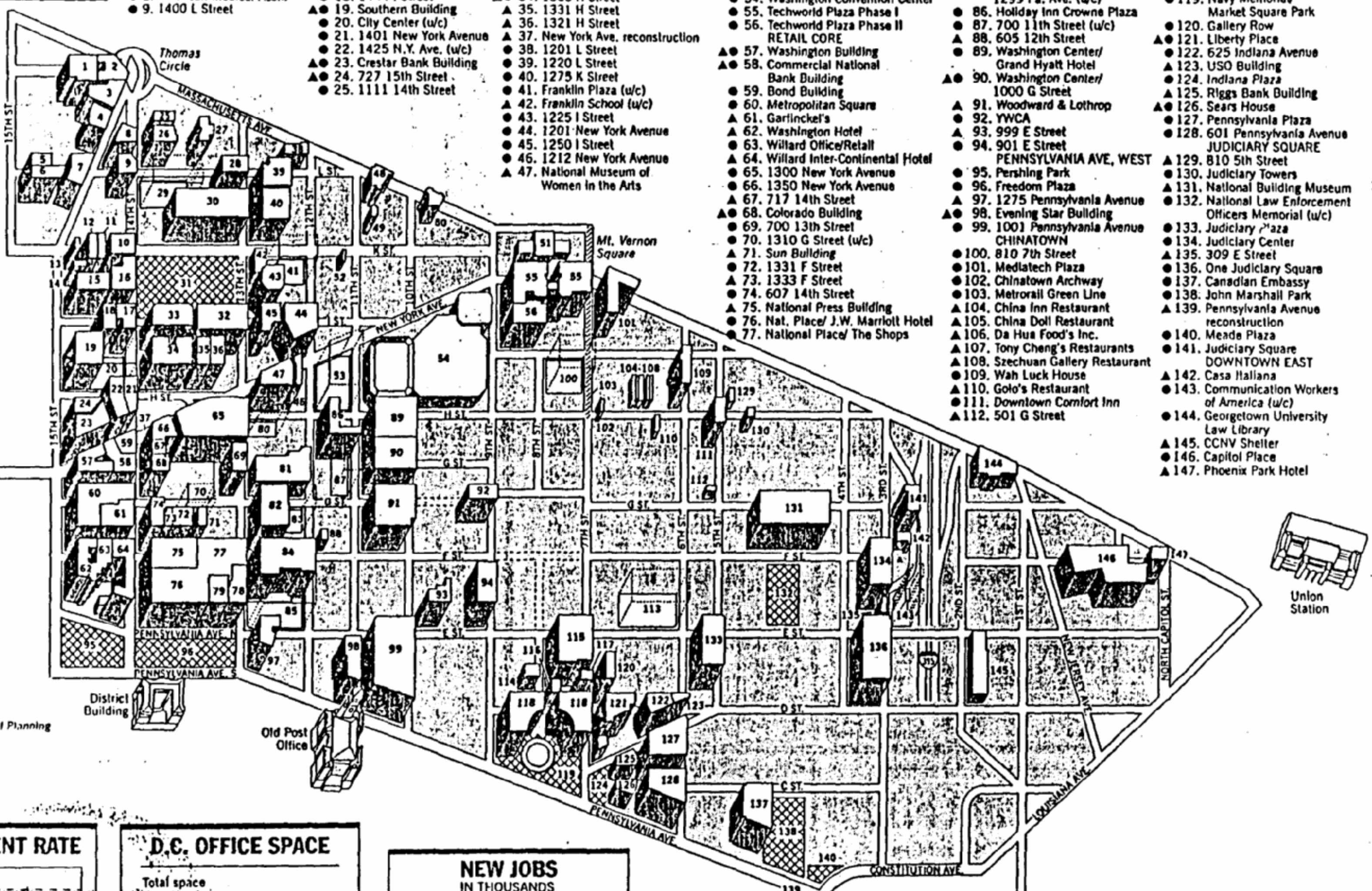
CHINATOWN
- ●100. 810 7th Street
- ●101. Mediatech Plaza
- ●102. Chinatown Archway
- ●103. Metrorail Green Line
- ▲104. China Inn Restaurant
- ▲105. China Doll Restaurant
- ▲106. Da Hua Food's Inc.
- ▲107. Tony Cheng's Restaurants
- ▲108. Szechuan Gallery Restaurant
- ●109. Wah Luck House
- ▲110. Golo's Restaurant
- ●111. Downtown Comfort Inn
- ▲112. 501 G Street

GALLERY PLACE
- ●113. AARP Headquarters Building

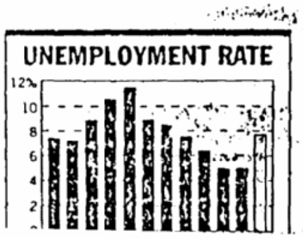
PENNSYLVANIA QUARTER
- ▲114. Stables Art Center
- ▲115. The Lansburgh
- ▲116. 717 D Street
- ▲●117. Jenifer Building
- ●118. Market Square
- ●119. Navy Memorial/ Market Square Park
- ●120. Gallery Row
- ▲●121. Liberty Place
- ●122. 625 Indiana Avenue
- ▲123. USO Building
- ●124. Indiana Plaza
- ▲125. Riggs Bank Building
- ▲●126. Sears House
- ●127. Pennsylvania Plaza
- ●128. 601 Pennsylvania Avenue

JUDICIARY SQUARE
- ▲129. 810 5th Street
- ●130. Judiciary Towers
- ▲131. National Building Museum
- ●132. National Law Enforcement Officers Memorial (u/c)
- ●133. Judiciary Plaza
- ●134. Judiciary Center
- ▲135. 309 E Street
- ●136. One Judiciary Square
- ●137. Canadian Embassy
- ●138. John Marshall Park
- ▲139. Pennsylvania Avenue reconstruction
- ●140. Meade Plaza
- ●141. Judiciary Square

DOWNTOWN EAST
- ▲142. Casa Italiana
- ●143. Communication Workers of America (u/c)
- ●144. Georgetown University Law Library
- ▲145. CCNV Shelter
- ●146. Capitol Place
- ▲147. Phoenix Park Hotel



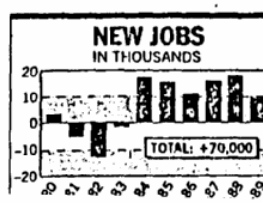
MAP SOURCE: D.C. Office of Planning



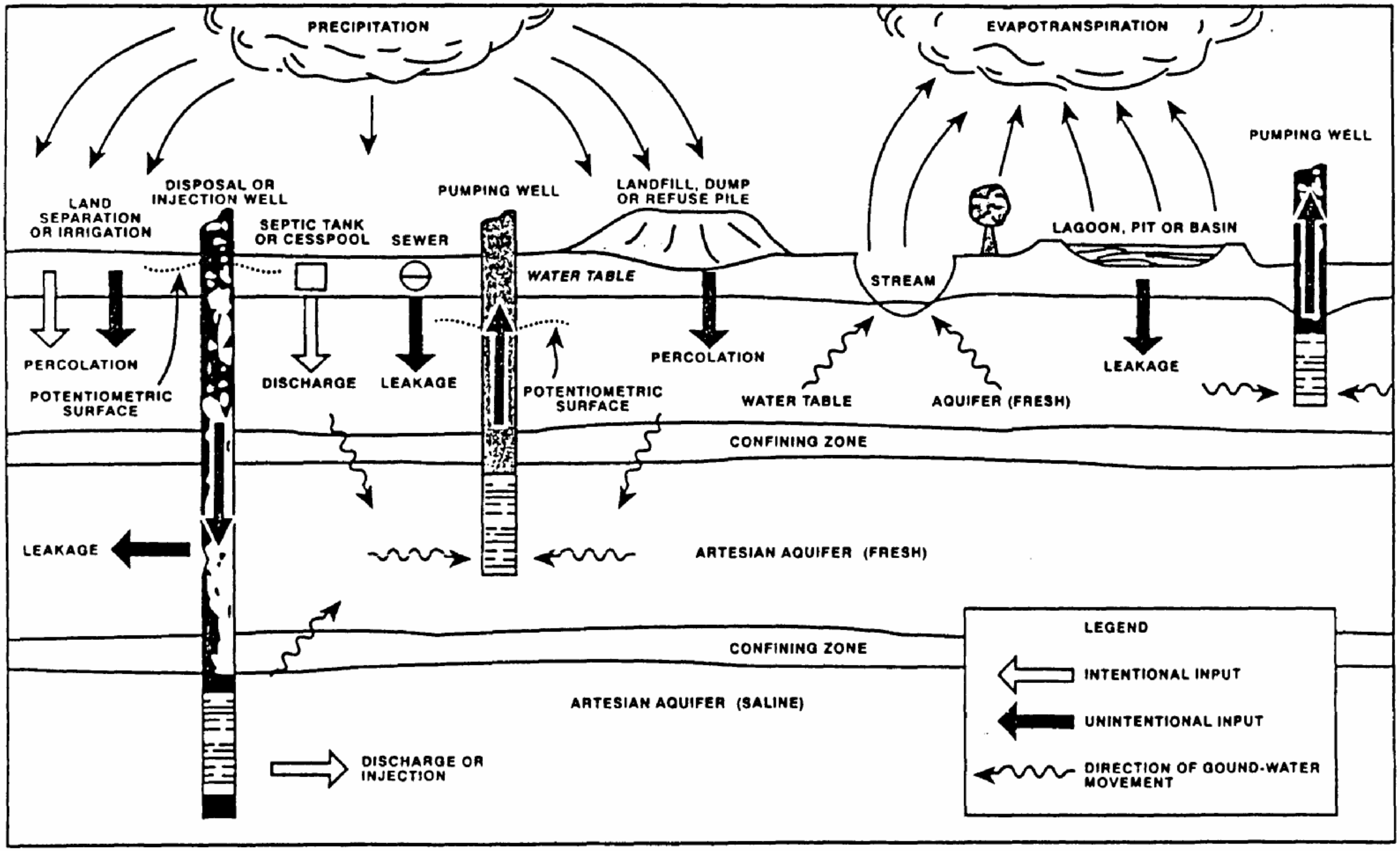
D.C. OFFICE SPACE

Total space
1980 46,752 million square feet
1990 82,099 million square feet

Available space
1980 4.646 million square feet



E. Groundwater Contamination



How waste disposal practices contaminate the ground-water system

F - DC Fire Dept. Hazardous Unit Response Record

DC Fire Department Hazardous Materials Unit Response Record for January 1, 1987 - December 31, 1987

Material Name	Number of Responses	DOT Placard	Health Hazard	Flammability	Reactivity
Asbestos	6	Solid	3	1	1
Acetone	1	Flammable Liquid			
Adehyde	1	Flammable Liquid			
Ammonium Thiosulphate	1	ORM-E Solution			
Calcium Hydroxide	1	Crystals Pellets			
Chlorine	6	Chlorine Gas liquid	3	0	0
Dichlorobenzene	1	Liquid	2	2	0
Diesel Fuel	23	Flammable Liquid	0	2	0
Ether	2	Flammable Gas / Liquid			
Ethylene Oxide	4	Flammable	2	4	3
Etiological Waste	1				
Explosives	7	Explosive			
Ferrous Sulphate	2	Flamm. Solid Crystals			
Formaldehyde	3	Comb. Liquid Solution	2	2	0
Gasoline	42	Flammable	1	3	0

Material Name	Number of Responses	DOT Placard	Health Hazard	Flammability	Reactivity
Hydraulic Oil	3	None			
Hydrochloric Acid	4	Corrosive	3	0	0
Iodine	2	Corrosive	4	0	0
Iodine Potassium	1	Crystals Solution in K			
Isopropyl Alcohol	2	ORM-A	1	3	0
Kerosene	4	Flammable liquid	0	2	0
Lacquer Thinner	1	None			
Liquid Oxygen	1	Oxidizer	3	0	0
Mercury	2	ORM-B			
Methanol Alcohol	1	Flammable	1	3	0
Methyl Ethyl Ketone	1	Flammable Liquid			
Morpholine	1	Flamm. Liquid			
Motor Oil	1	Oil			
Mustard Oil	1	oil			
Nitrocellulose	2	Flamm. Liquid			
Paraldehyde	2	Flammable	2	3	1
Polychlorinated Byphenyls (PCB)	2	ORM-E			
Perchlorethylene	1	ORM-A			

Material Name	Number of Responses	DOT Placard	Health Hazard	Flammability	Reactivity
Pesticides	3	Powder/ Gas			
Hydrochloric Acid	4	Corrosive	3	0	0
Iodine	2	Corrosive	4	0	0
Iodine Potassium	1	Crystals Solution in K			
Isopropyl Alcohol	2	ORM-A	1	3	0
Kerosene	4	Flammable liquid	0	2	0
Lacquer Thinner	1	None			
Liquid oxygen	1	Oxidizer	3	0	0
Mercury	2	ORM-B			
Methanol Alcohol	1	Flammable	1	3	0
Methyl Ethyl Ketone	1	Flammable Liquid			
Morpholine	1	Flamm. Liquid			
Motor Oil	1	Oil			
Mustard Oil	1	Oil			
Nitrocellulose	2	Flamm. Liquid			
Paraldehyde	2	Flammable	2	3	1
Polychlorinated Byphenyls (PCB)	2	ORM-E			
Perchlorethylene	1	ORM-A			

Material Name	EPA	Approx. Used (gal.)	Pest Controlled	Site most Usually Applied
Malathion	2393-280	25	Aphids, beetles caterpillars, whitefly	Trees & Shrubs
Malathion 55	72-PA-1	1.25	Spittlebug	Plant collection
Kelthane	2125-25-AA	0.25	Spidermites	Shrubs
Kelthane	904-150	30	Spidermite	Trees & Shrubs
Dormant Oil (Superior Nu-oil 70)		54	Scales, etc.	Residential
Dormant Oil	--------	1	Scales	Oaks
Cygon	904-179	1	Scales, thrip..	Ornamental trees
Cygon 2E (Pratt)	904-N-J1	2.50	Leafminor,psylid lacewing, aphid	Plant collection
Orthene	239-2436	0.25	Aphids, spider-mites, leafmites	Shrubs & evergreen
Diazinon	100-463	2	Mealybug, bill	Greenhouse, turf
Diazinon (AG 500)		12	Grubs, etc.	Landscape
Dursban (chlopyrifes)	464-524	10	Chinches, sod webworm	Lawn
Diazinon (50WP)	-------	150	Grubs, etc.	Landscape
Diazinon (14G)	1159-195-655	75	Grubs	Lawn
Dursban (2.32 %)	--------	300	Chinches, grubs sod webworm	Turfs
Malathion 25W	---------	4	Alphids, thrips, whitefly	Plant collection

Material EPA Name	Approx. Used (gal.)	Pest Controlled	Site most Usually Applied
Cleary 1001-50	3	Striped Smut	Lawn
Captan 293-533-AA	2	Fungus	Crabapples
Heritage House 7764-36 Lawn Fungicide*	200	Leaf Spots	Turf
Ferbam 279-388	1	Fungus	Rust
Acti-Dione 1023-50-AA	1	Fungus	Turf
Round Up 524-308-AA	11,340	Various	Railroad lines
Round Up 524-308-AA (Mosanto)	3	Weeds	Plant collections
Round Up 524-308-AA (Mosanto)	8	Grass & Weeds	Sidewalks, lots
Round Up ---------	12	All Vegetation	Turf
Round Up 524-308-AA	0.25	Weeds	Paths
Round Up 524-308-AA	2	Weeds	Turfs
Dowpon 464-402-ZA	96,500	Cane grass	Railroad yards & main line
Andon 101 464-306-264	53,030	Various	Railroad yards & main line
Parquat 293-2186-AA	2	Weeds	Turfs
Parquat 239-2186-AA	3	Weeds	Plant collection
Basagran 7969-45	2	Nutsedge	Turf
Basagran ----------	1	Nutsedge	Turf
Super D ,264-2186-AA (Weedone)	1	Lawn needs	Lawn
Betasan ----------	16	Weeds (crabgrass)	Turf

Material Name	EPA	Approx. Used (gal.)	Pest Controlled	Site most Usually Applied
500T (Norkem)	5107-37-AA	55	Grass & Weeds	Sidewalks, parking lots, etc.
400T (Norkem)	5196-46-AA	75	Broadleaf Weed	Lawn
PTH Sun Trimec(2,4-D/ MCPP/Banuel)	2217-517	5	Broadleaf Weed	Lawn
PTH Shade (2,4-D/MCPP/ Banuel)	2217-529-AA	2	Broadleaf Weed	Lawn
Bensulide (Betasan) (Lescosan)	476-1817-10404	37	Crabgrass foxtail	Lawn
Dactal 5G (Diamond-Shamrock)	677-277-AA	275	Annual Grasses	Plant collection
Dactal	----------	384	Crabgrass	Turf
Dactal (D.C.P.A.)	677-262-AA	50	Crabgrass foxtail	Lawn
Karmex	352-247-AA	345,000	Various	Railroad yards & main lines
Krovar	452-352-AA	157,900	Various	Railroad yards & main lines
Balan	1471-62-AC	400	Crabgrass	Turf
Ronstar G	359-659	50	Weeds	Turf, flower beds
Tupersan	----------	96	Crabgrass	Turf
Treflan 5G (Elanco)	1671-66	1,280	*Annual* Weeds	Plant collection
Weed Be Gone (Ortho)	239-1857-AA	12	Broadleaf Weeds	Plant collection
Hyvar	239-1857-AA	80,700	Various	Railroad yards & mine lines
Spike	1471-97-AA	67,600	Various	Railroad yards & main lines

Material Name	EPA	Approx. Used (gal.)	Pest Controlled	Site most Usually Applied
Kelthane	----------	200	Mites	off buildings
Kelthane (ROHM)	707-89-AA	2	Mites	Plant collections
Orthene	239-2427	12	Bugworm (imported willow beetle)	Plant collections
Superior (Nu-oil)	72-70	165	Scale	Plant collections
Algimy cin 400	7364-23-AA	1	Algae	Pool
Daconil 2787	677-229-AA	1	Leaf spot	Lawn
Benlate	----------	72	Fungus	Shrubs, Turf, etc,
Benlate (Dupont)	352-354-AA	2	Black slot mildew	Greenhouse
Benlate (Benomyl)	352-354-AA	1	Fungus	Greenhouse
Tersan (1991) (Dupont)	352-357-AA	2	Fusarium	Turf Areas
Tersan (1991)	352-357-AA	3	Fusarium	Lawn
Tersan LSR	352-343-AA	3	Leaf spot	Lawn
Tersan (1991)	----------	20	---------:	Turf
Daconil 2787 (chlorotalconic)	677-315-2A	1	Fungus	Turf
Daconil 2787	-----------	6	Fusarium	Turf
Methyl Bromide	5785-4-AA	110	Perennial weeds	Bed areas
Maneb	-----------	20	Mildew blackspot	Plant collection
Fore	-----------	6	Fungus	Turf
Chipo 26019	----------	12	Fungus	Turf

Material Name	EPA	Approx. Used (gal.)	Pest Controlled	Site most Usually Applied
Wafarin (D-Con)	3282-4-7-A	20	Rats	Greenhouse or outside areas
Hubstates no. 147	5602-12	200	Rats	Basements & outside
Eatons AC (formula 50)	56-27 56-OH-1	4,200	Rats & mice	Basements, Stora areas, outside i bait station
Bait Blocks	56-42	1,200	Rats	Wet damp areas
Bait Blocks (Eatons)	56-18	600	Rats	Wet damp areas
Bait Pellets (Promar)	876-192-AA	480	Mice & rats	Wet damp areas
Residex Resrattus-Plus	373-93	100	Rats & mice	Commercial
ICI Americas	523-IL-1	2	Rodents	Greenhouse
Chempar	7173-144	25	Rodents	Plant collection
Rat Rack	12455-1-3840	75	Rats & mice	Around buildings outside

G. Wells in D.C.

WELLS IN THE
DISTRICT OF COLUMBIA
(WASHINGTON WEST QUADRANGLE)

WELL #	LOCATION	ALT. ABOVE SEA-LEVEL (FT.)	MAT-ERIAL*	DEPTH OF WELL (FT.)	WATER LEVEL		YIELD		USE
					DEPTH UNDER SUR-FACE (FT.)	DATE	GPM	DATE	
Aa-5	Conn. Ave. & East-West Highway	350	Sch.	340	-	-	-	-	Ind
Ac-1	1701 Kalmia Rd. NW	230	Sch.	178	165	3-56	-	-	Dom
Ac-2	17th & Kalmia Rd.	200	Gran./ Sch.	-	-	-	-	-	-
Ac-6	6101 Blair Rd., NW	245	Gran.	61	-	-	-	-	Pub
Ac-7	6101 Blair Rd., NW	240	Gran.	220	20	12-46	-	-	Pub
Ba-1	5232 Macomb NW	160	Sch.	-	-	-	-	-	-
Ba-2	3000 Univ. Terrace	320	Sch.	125?	-	-	OK	-	Dom
Ba-3	Battery, Kemble Pk NW	290	Sch./ Gran.	-	-	-	-	-	Pub
Ba-4	4530 Klingle, NW	350	Gran.	-	-	-	1.7	6/57	Dom
Ba-5	4401 Cathedral Av. NW	290	Gran.	-	-	-	-	-	Dom
Ba-6	2301 Foxhall Rd. NW	300	Gran.	350	32	1954	11	7/37	Pl
Ba-7	2318 King Pl., NW	250	Sch.	301	56	-	-	-	Dom
Ba-8	2243 49th St., NW	225	Sch.	96	-	-	-	-	Irr
Bb-1	4500 Wisconsin Av. NW	405	Grnstn	500	50?	-	35?	-	Pub
Bb-2	3200 Newark, NW	305	Alluv.	-	-	-	-	-	-
Bc-1	715 Kennedy, NW	230	Gran.?	164	-	-	-	-	Ind
Bc-2	3825 Georgia Av NW	220	Gran.?	159	-	-	-	-	Ind
Bc-3	3128 14th St., NW	195	Sand & Gravel	102	-	-	-	-	Ind
Bc-4	10th St. & Florida Ave. NW	145	-	125	35	-	15	-	Ind
Bc-5	2012 11th St., NW	100	Alluv.	80	-	-	40	1930	Ind
Bc-6	2146 Georgia Av NW	95	-	500	-	-	14	11/37	Ind
Bc-7	2220 6th St., NW	105	Sand	83	25	8/47	30	8/47	Ind

WELLS IN THE
DISTRICT OF COLUMBIA
(WASHINGTON WEST QUADRANGLE)

WELL #	LOCATION	ALT. ABOVE SEA-LEVEL (FT.)	MAT-ERIAL*	DEPTH OF WELL (FT.)	WATER LEVEL		YIELD		USE
					DEPTH UNDER SUR-FACE (FT.)	DATE	GPM	DATE	
Ca-7	4500 Canal Rd., NW	20	Sch.	-	-	-	5	1-56	Dom
Ca-8	4518 Canal Rd., NW	20	Sch.	-	-	-	-	-	Dom
Cb-1	3001 R St., NW	155	Grnstn	55?	20?	-	-	-	Pub
Cc-1	14th & R Sts., NW	100	Sand & Gravel	103	27	12-40	30	-	Ind
Cc-2	1620 1st St., NW	70	Sand	120	15.2	2-40	100	1935	Ind
Cc-3	18 O St., NE	55	Sand	159	-	-	40	-	Ind
Cc-4	Florida & Eckington Pl., NW	70	Sand	128	60	8-55	15	8-55	Ind
Cc-5	Near Florida & 3rd St., NE	70	Sand & Gravel	178	-	-	79	-	Ind
Cc-6	60 M St., NE	50	Sand & Gravel	176	-	-	100	6-30	Ind
Cc-7	1140 N. Capitol St	50	Sand & Gravel	161	-	-	90	-	Pub
Cc-8	N. Capitol & G NW	30	Sand & Gravel	96	-	-	30	1898	Ind
Cc-9	1st St. & G NW	30	Sand	141	-	-	12	-	Pub
Cc-10	S. Capitol & E St. SE	30	Bed-rock	273	48.6	6-40	-	-	Ind
Cc-11	41 L St., SE	30	Sand	120	-	-	70	-	Ind
Cc-12	12th & D St. SW	35	Sand	90	-	-	175	2-40	Ind
Cc-13	434 7th St. NW	30	Sand & Gravel	123	32	1935	120	1935	Ind
Cc-14	425 9th St. NW	25	Sand & Gravel	127.5	-	-	50	1957	Ind
Cc-15	909 Penn. Ave. NW	15	Sand & Gravel	81	-	-	20	1957	Ind
Cc-16	411 10th St. NW	15	Sand & Gravel	45	27.7	9-37	60	1935	Ind
Cc-17	10th & E St. NW	20	Sand	92	34.7	4-41	-	-	Ind
Cc-18	11th & E St. NW	15	Gravel	93	-	-	150	2-36	Ind
Cc-19	14th & F St. NW	35	Gravel & Sand	69	40	1930	30?	1930	Ind
Cc-20	1214 G St. NW	35	Sand	70	-	-	-	-	Ind

WELLS IN THE
DISTRICT OF COLUMBIA
(WASHINGTON WEST QUADRANGLE)

WELL #	LOCATION	ALT. ABOVE SEA-LEVEL (FT.)	MAT-ERIAL*	DEPTH OF WELL (FT.)	WATER LEVEL		YIELD		USE
					DEPTH UNDER SUR-FACE (FT.)	DATE	GPM	DATE	
Cc-21	1214 G St. NW	35	-	103	-	-	-	-	Ind
Cc-22	1101 G St. NW	35	Gravel	96	-	-	80	1935	Ind
Cc-23	11th & G Sts. NW	40	Sand & Gravel	97	-	-	35	-	Ind
Cc-24	NY Ave. & 12th Sts NW	50	Gravel	124	-	-	25	7-39	Ind
Cc-25	NY Ave. & 12th Sts NW	50	Sand & Gravel	100	-	-	70	2-40	Ind
Cc-26	14th & K Sts. NW	65	Sand & Gravel	85	-	-	35	1935	Ind
Cc-27	14th & K Sts. NW	60	Sand	96	62	8-51	65	7-36	Ind
Cc-28	920 14th St. NW	60	Sand & Gravel	102	-	-	75 20	1948 1957	Ind
Cc-29	920 14th St. NW	60	-	64	-	-	-	-	Ind
Cc-30	Lafayette Sq. NW	55	Sand	70	-	-	-	-	Pub
Cc-31	1726 I St. NW	70	Bed-rock	375	22	6-40	1.5	1933	Ind
Cc-32	1140 15th St. NW	70	-	99	20	3-44	50	-	Ind
Cc-33	300 Indiana Ave NW	20	-	179	34	1936	-	-	-
Cc-34	Va. Ave. & 2nd St. SE	40	-	263	38	7-57	225	7-57	Ind
Cc-35	324 B St. SW	10	Gravel	147	-	-	-	-	Ind
Cc-36	1140 15th St. NW	-	-	-	-	-	-	-	-
Cc-37	Pedestal	53	Sand & Gravel	84	53	1-7-63	48	1-7-63	WS
Cc-38	Pedestal	53	Sand & Gravel	83	52	1-15-63	55	1-15-63	WS
Cc-39	Pedestal	45	Sand, Gravel & boul-ders	68	-	1-29-63	-	-	Dif
Cc-40	Fisheries, Haines Pt.	-	-	-	-	-	-	-	-

WELLS IN THE
DISTRICT OF COLUMBIA
(WASHINGTON EAST)

WELL #	LOCATION	ALT. ABOVE SEA-LEVEL (FT.)	MAT-ERIAL*	DEPTH OF WELL (FT.)	WATER LEVEL		YIELD		USI
					DEPTH UNDER SUR-FACE (FT.)	DATE	GPM	DATE	
Ba-1	1400 Rhode Island Ave., NE	170	Sand	298	150	1940	40	1940	Pul
Ba-2	N of Ivy City	100	Sand & Gravel	218	63	5-26	140	5-51	Inc
Ba-3	N of Ivy City	90	Sand	255	102?	6-46	185	6-46	Inc
Ba-4	2301 Bladensburg Rd.	55	-	139.5	55	3-38	50	10-53	Pul
Ba-5	Langdon	40	Sand	210	103	3-48	381	4-35	Inc
Ba-6	Langdon	50	Sand	240.8	46	4-29	230	4-29	Inc
Ba-7	Langdon	70	Sand	245	50	3-43	335	3-43	Inc
Ba-8	N of Ivy City	100	Sand	260	143	4-57	3.5	4-57	Inc
Ca-1	Ivy City, NE	100	Sand & Gravel	226	-	-	125	-	Inc
Ca-2	New York Ave., NE	95	Sand & Gravel	234	-	-	125	-	Inc
Ca-3	1262 5th St. NE	85	Sand	162	60	-	25	1-56	Inc
Ca-4	911 Bladensburg Rd	65	Sand & Gravel	304	50	-	225	4-30	Inc
Ca-5	1515 F St. NE	45	-	-	-	-	50?	5-56	Inc
Ca-6	NW of Lincoln Park	80	Sand	331	122	3-40	150	3-40	Inc
Ca-7	Lincoln Park	80	Sand	181	70	-	10	-	Inc
Ca-8	10th St. & S.C. SE	75	Sand	147	79	-	13	-	Inc
Ca-9	14th & C Sts. SE	75	Sand	149	83	-	12?	-	Inc
Ca-10	1337 D St. SE	75	-	300	-	-	100	1-56	Inc
Ca-11	Naval Gun Factory	32	Sand & Gravel	367	30	10-53	200	10-53	Pul
Ca-12	Ivy City	95	-	223	-	-	75	-	Inc
Cb-2	Kenilworth School, NE	25	-	350?	-	-	-	-	Pul
Cb-3	Benning, NE	55	Sand	229	35	1910	20	1910	Pul

KEY

* Character of material in water-bearing formation

Sch.	-	Schist
Gran.	-	Granite
Gran./Sch.	-	Granite/Schist
Alluv.	-	Alluvium
Grnstn	-	Greenstone

Dif	-	Diffusion
Dom	-	Domestic
Ind	-	Industrial
Irr	-	Irrigation
Pl	-	Pool
Pub	-	Public
WS	-	Water Supply

Adapted from USGS Water Supply Paper #1776 - (i) Data Supplemental Table 13 dated 1964 (unpublished) and (ii) Plate 2 - Well Map of Washington, D.C., and Vicinity.

1896

DEEP WELLS IN THE DISTRICT OF COLUMBIA.

There are quite a number of deep wells in the District, and they have been so satisfactory that plans have been made for sinking many others. The following list is thought to be nearly complete:

List of deep wells in District of Colnmbia.

Location.	Depth.	Capacity per minute.	Remarks.
	Feet.	*Gallons.*	
Reform School	270	60	Low in Potomac.
Eckington power house	159	65	Basal Potomac.
Ice Works, Fifteenth and E streets NE	150	Many.	Low in Potomac.
Do	90	30	In Potomac.
Do	320	15	Basal Potomac.
Metropolitan Railroad power house, Four-and-a-half and O streets SW.	208	20	Do.
St. Elizabeth Asylum:			
Twenty or more small wells	240–350	130 in all.	Low and basal Potomac beds.
Two 6-inch wells	350 and 380	65 each.	Basal Potomac beds. Flowing wells.
Anacostia stables	170	Many.	
Heurich's Brewery, Twentieth and M streets NW.	900	7	In crystalline rocks.
Storage warehouse, Fifteenth and M streets NW.	97	40	Basal Potomac. Rock at 97 feet.
"The Cairo," Q and Sixteenth streets NW.	70	15	70–312 feet, in crystalline rock. Water is at base of Columbia.
"Mount Vernon," Ninth street and New York avenue NW.	183	40	133–183 feet, in crystalline rocks. No water above.
The Shoreham, Fifteenth and H streets			25 gallons per minute were found in gravel on top of crystalline rocks at 110 feet.
312 Pennsylvania avenue	93	Many.	
E, between Twenty-first and Twenty-second streets NW.	132	(?)	In crystalline rocks.
Lafayette Square Opera House	70	16	Basal Potomac.
Riggs House	558	None.	In crystalline rocks.
Fifteenth street, near M street NW	97	Many.	Do.
Palais Royal, Eleventh and G streets NW.	97	35	Basal Potomac beds.
Brightwood	146	20?	In crystalline rocks.
J. P. Clark, Conduit road	100	15	Do.
W. H. Bolton, Somerset Heights	60	20	Do.
Bethesda Park	67	10?	Do.
Good Hope Hill	380		Unfinished.
Hotel at North Takoma	251	20	In crystalline rocks.
National Brewery, Fourteenth and D streets SE.	310	120	Basal Potomac.
Washington Brewery, Fourth and F streets NE.	300	75	Do.
Do	275	100	Do.
Highland Station, 5-inch well	96	Many.	Low in Potomac.
Gas Works, Twelfth street SE	290		Do.

*Note: All wells are gone

(Darton 1896) USGS Bul. 138

H - Soil Properties in D.C.

SOME PHYSICAL PROPERTIES OF SOILS
IN WASHINGTON, D.C.

SOIL NAME & MAP SYMBOL	PERMEABILITY IN/HR	AVAILABLE WATER CAPACITY IN/IN	HIGH WATER TABLE		
			DEPTH (FT)	KIND	MONTHS
Ashe: AsC, AsD	2.0-6.0	0.08-0.18	> 6.0	-	-
Beltsville: BdB, BeB	<0.2-6.0	0.08-0.21	1.5-2.5	Perched	Nov-Apr
Bibb: Bg	0.6-2.0	0.08-0.20	0.15-1.5	Apparent	Dec-Apr
Bourne: BnB, BnC, BpB	<0.2-6.0 *	0.08-0.16 *	1.5-2.5	Perched	Dec-May
Brandywine: BrC BrD, BtB, BtC BtD	2.0-6.0	0.06-0.18	> 6.0	-	-
Chillum: CcB, CcC, CcD, CdB CdC, CdD	0.2-2.0	0.03-0.22	> 6.0	-	-
Christiana: CeB CeC, CeD, CfB CfC, CfD	0.06-2.0	0.14-0.24	> 6.0	-	-
Cordorus: Ck, Cn	0.6-20	0.04-0.20	1.0-2.0	Apparent	Nov-Apr
Croom: CwB, CwC CwD, Cxb, CxC CxD	0.2-20	0.04-0.18	> 6.0	-	-
Dunning: Dn	0.06-2.0 *	0.14-0.22 *	1.5-2.5	Apparent	Dec-May
Fallsington: Fa	0.6-6.0	0.06-0.24	0-1.0	Apparent	Dec-May
Fluvaquents: FB FD, FF, FH					
Galestown: GeB, GfB, GfC	2.0-> 6.0	0.04-0.15	> 6.0	-	-

SOME PHYSICAL PROPERTIES OF SOILS IN WASHINGTON, D.C.

SOIL NAME & MAP SYMBOL	PERMEABILITY IN/HR	AVAILABLE WATER CAPACITY IN/IN	HIGH WATER TABLE		
			DEPTH (FT)	KIND	MONTHS
Glenelg: GgB, GgC, GgD, GhB GhC, GhD, GlB GmB	0.6-2.0	0.10-0.24	2.0-> 6.0*	Apparent*	Feb-Apr*
Inka: Ik, Ip	0.6-2.0	0.10-0.15	1.0-3.0	Apparent	Dec-Apr
Joppa: JtB, JtC JtD, JuB, JnC	2.0-20.0	0.2-0.18	> 6.0	-	-
Keyport: KeB, KeC, KmB, KmC	<0.2-2.0	0.12-0.2	1.5-4.0	Perched	Nov-May
Lindside: Ld, Lp	0.2-2.0	0.17-0.26	1.5-3.0	Apparent	Dec-Apr
Manor: MbC, MbD McC, MdB, MdC MdD	0.6-2.0	0.14-0.20	> 5.0	-	-
Matapeake: MgB, MgC	0.2-6.0	0.08-0.24	> 6.0	-	-
Melvin: Mp	0.6-2.0	0.18-0.23	0.0-1.0	Apparent	Dec-May
Muirkirk Variant: MvB, MvC, MvD	0.06-20	0.06-0.08	> 0.6	-	-
Neshaminy: NeC, NeD, NuC, NuD	0.2-0.6	0.10-0.14	4.0-7.0	Apparent	-
Sassafras: SaB, SaC, ScB, ScC ScD, SgB, SgC SgD	0.6-20	0.04-0.22	> 6.0	-	-
Sunnyside: SmB, Smc, SmD, SpB, SpC, SpD	0.6-6.0	0.05-0.24	> 6.0	-	-

SOME PHYSICAL PROPERTIES OF SOILS
IN WASHINGTON, D.C.

SOIL NAME & MAP SYMBOL	PERMEABILITY IN/HR	AVAILABLE WATER CAPACITY IN/IN	HIGH WATER TABLE		
			DEPTH (FT)	KIND	MONTHS
Udorthents: U1, U2 U3 U4 U5 U6 U7 U8 U9 U10 U11B U11C U11D					
Udifluvents: UA					
Urban land: Ub					
UcB:Beltsville	<0.2-6.0	0.08-0.12	1.5-2.5	Perched	Nov-Apr
UdB:Brandywine	2.0-6.0	0.06-0.08	> 6.0	-	-
UeB, UeC: Chillum	0.2-2.0	0.03-0.12	> 6.0	-	-
UfB, UfC: Christiana	0.06-2.0	0.14-0.20	> 6.0	-	-
UkC:Croom	0.2-20	0.04-0.07	> 6.0	-	-
UmB:Galestown	> 6.0	0.06-0.08	> 6.0	-	-
UoC:Joppa	2.0-20	0.02-0.05	> 6.0	-	-
UpB:Keyport	<0.2-2.0	0.12-0.18	1.5-4.0	Perched	Nov-May
UsB, UsC:Manor	0.6-2.0	0.14-0.20	> 5.0	-	-
UxB,UxC: Sassafras	0.6-20	0.04-0.22	> 6.0	-	-
UyC:Sunnyside	0.6-6.0	0.08-0.24	> 6.0	-	-
UzB:Woodstown	0.6-6.0	0.06-0.21	1.5-2.5	Apparent	Feb-Apr
Woodstown:WoB, WpB	0.6-6.0	0.06-0.21	1.5-2.5	Apparent	Feb-Apr

* KEY

App - Apparent
Per - Perched

Adapted from USDA Soil Survey of the District of Columbia, Tables 12 & 13.

GENERAL ACREAGE, PROPORTIONATE EXTENT AND PERMEABILITY OF D.C. SOILS

MAP SYM-BOL	SOIL NAME & % SLOPE	ACRES SUB	ACRES TOT-AL	PERCENT SUB	PERCENT TOT-AL	PERME-ABILITY (IN/HR)
As	Ashe loam 8-40% slopes	174	174	0.4	0.4	2-6
Bd	Beltsville silt loam 0-8%	52		0.1		
BeB	Beltsville-Urban LC 0-8%	651	703	1.5	1.6	<0.2-6
Bg	Bibb sandy loam	174	174	0.4	0.4	0.6-2
Bn	Bourne fine sandy loam 0-15%	90		0.2		
BpB	Bourne-Urban LC 0-8%	54	144	0.1	0.3	<0.2-6
Br	Brandywine 8-40%	353		0.8		
Bt	Brandywine-Urban LC 0-40%	936	1289	2.2	3.0	2.0-6
Cc	Chillum silt loam 0-40%	321		0.7		
Cd	Chillum-Urban LC 0-40%	1509	1830	3.4	4.1	0.2-2
Ce	Christiana silt loam 0-40%	532		1.3		
Cf	Christiana-Urban LC 0-40%	1825	2357	4.1	5.4	0.06-2
Ck	Codorus silt loam	191		0.4		
Cn	Codorus-Urban LC	108	299	0.2	0.6	0.6-20
Cw	Croom very gravelly sandy loam 0-40%	358		0.9		
Cx	Croom Urban LC 0-25%	484	842	1.1	2.0	0.2-20
Dn	Dunning soils	51	51	0.1	0.1	0.06-2
Fa	Fallsington sandy loam	37	37	0.1	0.1	0.6-6
F	Fluvaquents	183		0.4		
FH	Fluvaquents-Udifluvents-Urban LC	106	289	0.2	0.6	*
GeB	Galestown-Urban LC 0-8%	614		1.4		
Gf	Galestown & Rumford soils 0-15% & Variant silt loam	116	730	0.2	1.6	2.0->6
Gg	Glenelg loam 0-25%	385		0.8		
Gh	Glenelg-Urban LC & Variant LC	1131	1516	2.6	3.4	0.6-2
Ik	Iuka sandy loam	273		0.6		
Ip	Iuka-Urban LC	253	526	0.6	1.2	0.6-2
Jt	Joppa gravelly sandy loam 0-40%	250		0.5		
Ju	Joppa-Urban LC	169	419	0.4	0.9	2.0-20
Ke	Keyport fine sandy loam 0-15%	158		0.4		
Km	Keyport-Urban LC 0-15%	468	626	1.1	1.5	<0.2-2
Ld	Lindside loam	117		0.3		
Lp	Lindside silt loam, bedrock substratum	102	219	0.2	0.5	0.2-2
M	Manor loam & Channery loam 8-40%	1430		3.2		
Md	Manor-Urban LC 0-40%	2461	3891	5.6	8.8	0.6-2

GENERAL ACREAGE, PROPORTIONATE EXTENT AND PERMEABILITY OF D.C. SOILS

MAP SYM-BOL	SOIL NAME & % SLOPE	ACRES SUB	ACRES TOT-AL	PERCENT SUB	PERCENT TOT-AL	PERME-ABILITY (IN/HR)
Mg	Metapeake silt loam 0-15%	42		0.1		
Mh	Metapeake-Urban LC 0-8%	155	197	0.4	0.5	0.2-6
Mp	Melvin silt loam	117	117	0.3	0.3	0.6-2
Mv	Muirkirk Variant complex 0-40%	797	797	1.8	1.8	0.06-2
Ne	Neshaminy silt loam 8-40%	172		0.4		
Nu	Neshaminy-Urban LC 8-40%	99	271	0.2	0.6	0.2-2
Sa, Sc	Sassafras sandy & gravelly sandy loam 0-40%	710		1.6		
Sg	Sassafras-Urban LC 0-40%	2076	2786	4.7	6.3	0.6-20
Sm	Sunnyside fine sandy loam 0-40%	257		0.5		
Sp	Sunnyside-Urban LC 0-25%	612	869	1.4	1.9	0.6-6
U1-11D	Udorthents	5298	5298	12.1	12.1	*
UA	Udifluvents, sandy	52	52	0.1	0.1	*
Ub	Urban land	6121		13.9		*
UcB	Urban land-Beltsville complex 0-8%	294		0.7		
UdB	Urban land-Brandywine complex 0-8%	127		0.3		
UeB, UeC	Urban land-Chillum complex 0-15%	1405		3.2		
UfB, UfC	Urban land-Christiana complex 0-15%	532		1.2		
UkC	Urban land-Croom complex 8-15%	100		0.2		
UmB	Urban land-Galestown complex 0-8%	153		0.3		
UoC	Urban land-Joppa complex 0-15%	211		0.5		
UpB	Urban land-Keyport complex 0-8%	188		0.4		
UsB & UsC	Urban land-Manor complex 0-15%	415		1.0		
UxB & UxC	Urban land-Sassafras complex 0-15%	2150		4.8		
UyC	Urban land-Sunnyside complex 8-15%	138		0.3		
UzB	Urban land-Woodstown complex 0-8%	206	5919	0.5	27.3	0.06-20

GENERAL ACREAGE, PROPORTIONATE EXTENT AND PERMEABILITY OF D.C. SOILS

MAP SYM-BOL	SOIL NAME & % SLOPE	ACRES SUB	ACRES TOT-AL	PERCENT SUB	PERCENT TOT-AL	PERME-ABILITY (IN/HR)
WoB	Woodstown sandy loam 0-8%	174		0.4		
WpB	Woodstown-Urban LC 0-8%	323	497	0.7	1.1	0.6-6
	Water	5120	5120	11.6	11.6	
	Total		44160		100.0	

LC = land complex

*
Data not available or not estimated.

Adapted from USDA Soil Survey of the District of Columbia, Tables 4 & 12.

I - USGS Observation Well Data Surrounding DC

385253077042301. Local number, 54V 3.

LOCATION.--Lat 38°52'53", long 77°04'23", Hydrologic Unit 02070010, at Arlington National Cemetery in Arlington. Owner: NPS National Capitol Parks.

AQUIFER.--Terrace gravels of Eolocene age and sand of early Cretaceous age.

WELL CHARACTERISTICS.--Dug unused water well, diameter 48 in., depth 50 ft.

INSTRUMENTATION.--Monthly measurement with chalked tape by USGS personnel. Prior to Oct. 1, 1989, bimonthly measurement with chalked tape.

DATUM.--Elevation of land-surface datum is 205 ft above National Geodetic Vertical Datum of 1929, from topographic map. Measuring point: Top of brick and stone casing, 3.0 ft above land-surface datum.

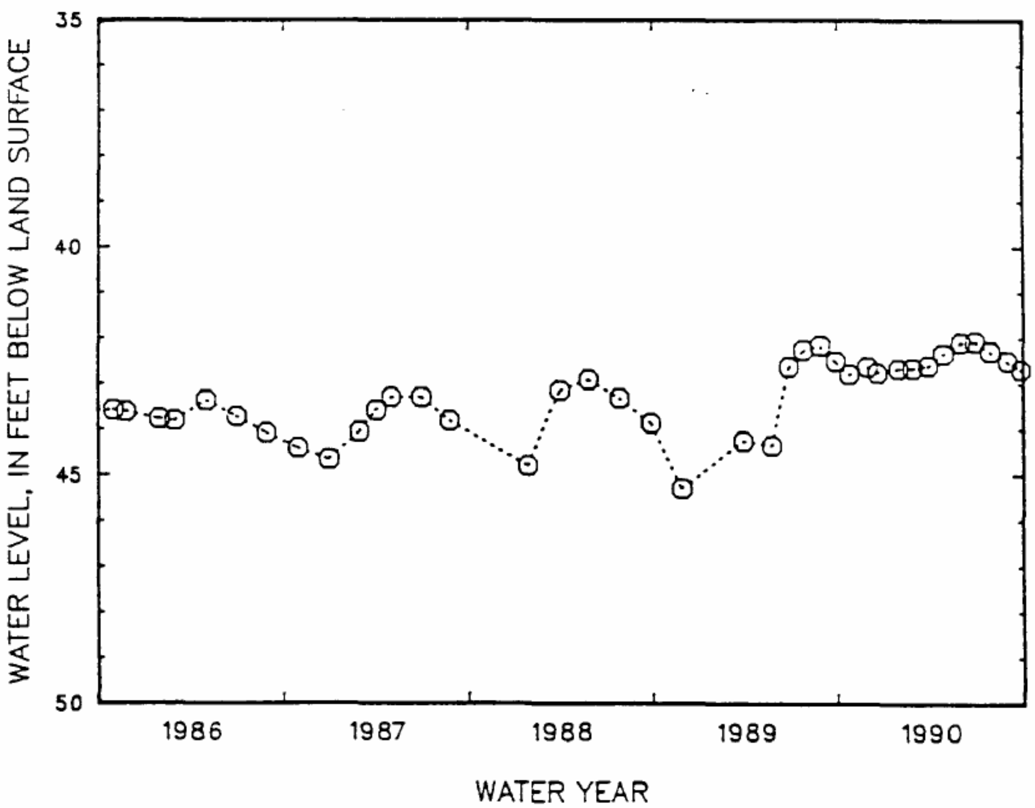
PERIOD OF RECORD.--January 1953 to current year.

EXTREMES FOR PERIOD OF RECORD.--Highest water level measured, 40.34 ft below land-surface datum, June 26, 1978; lowest measured, 45.28 ft below land-surface datum, Nov. 28, 1988.

WATER LEVEL, IN FEET BELOW LAND-SURFACE DATUM, WATER YEAR OCTOBER 1989 TO SEPTEMBER 1990

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
OCT 24	42.78	DEC 18	42.75	FEB 26	42.65	APR 26	42.33	JUN 26	42.06	AUG 29	42.49
NOV 29	42.62	JAN 29	42.66	MAR 28	42.59	MAY 29	42.08	JUL 26	42.27	SEP 25	42.68

WATER YEAR 1990 HIGHEST 42.06 JUN 26, 1990 LOWEST 42.78 OCT 24, 1989

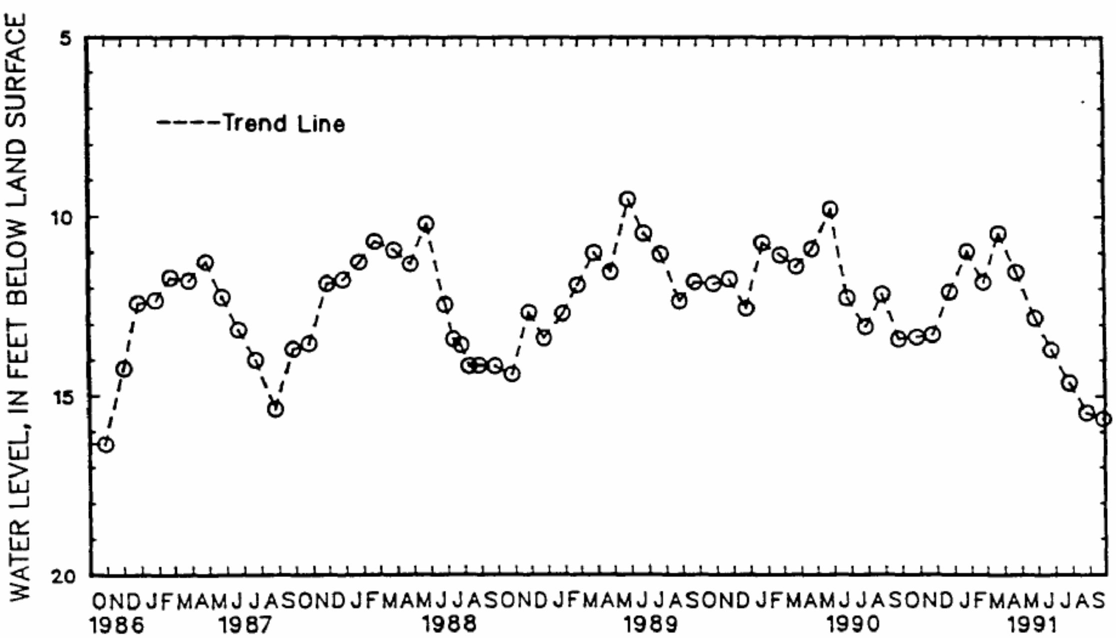


WELL NUMBER.--MO Eh 20. SITE ID.--390434076573002.
LOCATION.--Lat 39°04'34", long 76°57'30", Hydrologic Unit 02070010, at MD Rt. 196 and Fairland Rd., Fairland. Owner: Cities Service Oil Co.
AQUIFER.--Wissahickon Formation (lower pelitic schist) of Paleozoic age. Aquifer code: 300WSCK.
INSTRUMENTATION.--Monthly measurements with chalked steel tape by USGS personnel.
WELL CHARACTERISTICS.--Drilled, unused, water-table well, depth 102.9 ft; casing diameter 6 in., to 50 ft; open hole.
DATUM.--Elevation of land surface is 410 ft above National Geodetic Vertical Datum of 1929, from topographic map. Measuring point: Top of casing at land-surface datum.
REMARKS.--Maryland Water-Level Network observation well.
PERIOD OF RECORD.--March 1955 to current year.
EXTREMES FOR PERIOD OF RECORD.--Highest water level measured, 4.39 ft below land-surface datum, June 25, 1972; lowest measured, 16.36 ft below land-surface datum, Oct. 29, 1986.

WATER LEVEL, IN FEET BELOW LAND SURFACE, WATER YEAR OCTOBER 1990 TO SEPTEMBER 1991

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
OCT 29	13.35	DEC 27	12.08	FEB 26	11.82	APR 25	11.53	JUN 26	13.70	AUG 28	15.48
NOV 26	13.28	JAN 28	10.96	MAR 26	10.46	MAY 28	12.82	JUL 29	14.63	SEP 27	15.65

WATER YEAR 1991 HIGHEST 10.46 MAR 26, 1991 LOWEST 15.65 SEP 27, 1991



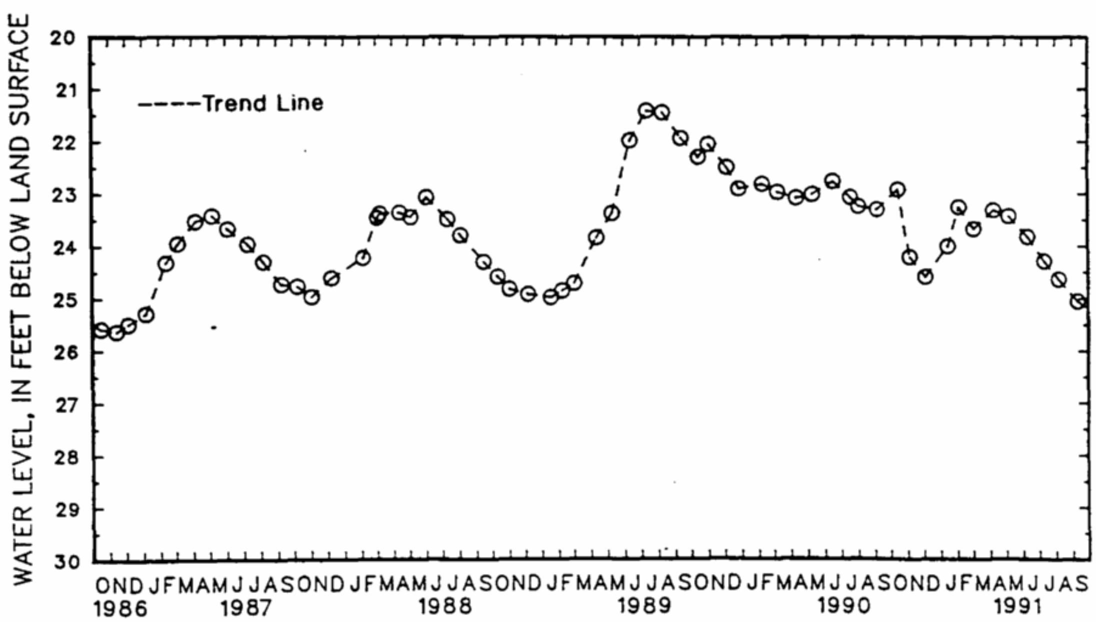
5 YEAR HYDROGRAPH
OCTOBER 1, 1986 THROUGH SEPTEMBER 30, 1991

WELL NUMBER.--PG Bc 16. SITE ID.--390151076561501.
LOCATION.--Lat 39°01'51", long 76°56'15", Hydrologic Unit 02070010, at National Agricultural Research Center, Beltsville.
Owner: U.S. Department of Agriculture.
AQUIFER.--Patuxent Formation of Lower Cretaceous age. Aquifer code: 217PTXN.
WELL CHARACTERISTICS.--Dug brick-lined, unused, water-table well, measured depth 27.4 ft; casing diameter 40 in.
INSTRUMENTATION.-- Monthly measurements with chalked steel tape by USGS personnel. Equipped with water-level recorder from Oct. 31, 1962 to Feb. 9, 1965.
DATUM.--Elevation of land surface is 190 ft above National Geodetic Vertical Datum of 1929, from topographic map. Measuring point: Top of steel cover, 0.10 ft above land surface.
REMARKS.--Maryland Water-Level Network observation well.
PERIOD OF RECORD.--September 1962 to current year.
EXTREMES FOR PERIOD OF RECORD.--Highest water level measured, 17.26 ft below land surface, July 6, 1972; lowest measured, 26.46 ft below land surface, July 8, 1981.

WATER LEVEL, IN FEET BELOW LAND SURFACE, WATER YEAR OCTOBER 1990 TO SEPTEMBER 1991

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
OCT 16	22.93	DEC 5	24.60	FEB 5	23.27	APR 9	23.32	JUN 11	23.84	AUG 7	24.65
NOV 6	24.23	JAN 15	24.02	MAR 4	23.69	MAY 7	23.43	JUL 11	24.31	SEP 11	25.06

WATER YEAR 1991 . HIGHEST 22.93 OCT 16, 199 LOWEST 25.06 SEP 11, 1991

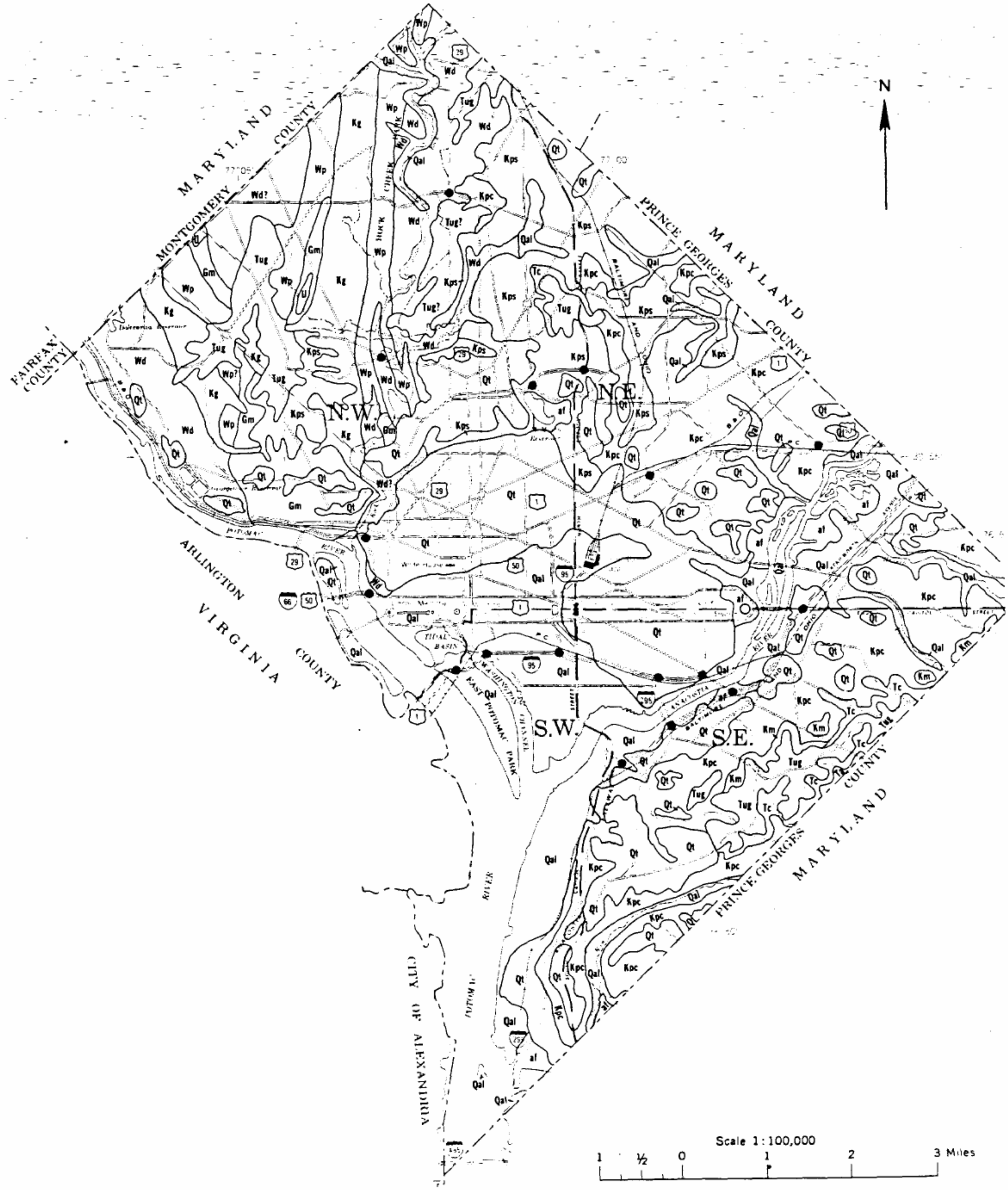


5 YEAR HYDROGRAPH

OCTOBER 1, 1986 THROUGH SEPTEMBER 30, 1991

J. Geology Map for DC (1974)

DISTRICT OF COLUMBIA



Reduced Preliminary Geology Map of the District of Columbia.

LEGEND

UNCONSOLIDATED MATERIALS
(Mainly Coastal Plain sediments)

(Queried where uncertain - ?)

QUATERNARY

RECENT

af

Artificial fill

Local unconsolidated material from nearby cuts and river dredgings; includes sanitary landfill.

Qal

Alluvium and artificial fill

Gravel, sand, silt, and clay of lowest stream terraces and bottoms; only larger deposits shown. Thickness of a few inches to 25 feet or more. Many large areas of fill, especially along Potomac River and Anacostia River.

PLIOCENE (?) & PLEISTOCENE

Unconformity

Qt

River terrace deposits

Gravel, sand, and loam; basal part is generally unsorted boulders, pebbles, and sand; locally contains plant fossils and peat beds. Average thickness of 30 feet; occurs at various levels.

TERTIARY

MIOCENE(?) & PLIOCENE (?)

Unconformity

Tug

Upland gravel and sand

Gravel and sand in orange loam matrix, capping remnants of former plateau. Coarse material at base. Gravel largely quartzite; some vein quartz, crystalline rock fragments, and chert. Average thickness 30 feet. Deposited by ancestral Potomac River.

MIOCENE

Unconformity

Tc

Calvert Formation

Very fine sand mixed with clay. Compact, dark gray to green where fresh; weathered outcrops are soft gray or buff sand. Thickness of 20 to 80 feet. In places contains shells and impressions, bone fragments, shark teeth, fish scales, and remains and impressions of plants.

PALEOCENE

Unconformity

Ta

Aquia Formation

Where fresh, bluish- or greenish-black, moderately fine sand mixed with clay, greensand (glauconite), organic matter, and chalky white marine fossil shells. Weathered material is gray, buff, or reddish-brown sand, with ironstone concretions in places. Thickness less than 50 feet.

MESOZOIC

UPPER CRETACEOUS

Unconformity

Km

Monmouth Formation

Dark micaceous sand with considerable greensand (glauconite). Weathers to brown sand with limonite cemented crusts and concretions. In places contains marine shells or impressions, mostly mollusks. Thickness of as much as 50 feet.

LOWER & UPPER CRETACEOUS

Unconformity

Kpc / Kps

Potomac Group

Kpc- clay and silt facies   Kps - sand and gravel facies

Kpc-beds in eastern part of area are chiefly pink, red, and gray silty clay with interbedded irregular sand and gravel lenses that in places grade into clay. Contains fossil bones, plant remains, and lignite. Kps-basal part in western part of District is gravel, sand, and arkose with occasional sandy clay lenses, generally light gray in color. This unit overlies crystalline rocks. Thickness of total Potomac Group increases to the east, where it exceeds 700 feet.

CONSOLIDATED ROCKS AND WEATHERED RESIDUUM
(Mainly Piedmont crystalline rocks and saprolite)

(Queried where uncertain - ?)

PRECAMBRIAN, LOWER PALEOZOIC, OR BOTH

Kg

Kensington gneiss

Medium to coarse, crystalline, light gray, layered to nearly massive, jointed quartz diorite gneiss consisting of quartz, feldspar, and mica; overlain on valley slopes and uplands by grayish-brown, soft, weathered, sandy and silty, well drained saprolite residuum as much as 120 feet thick.

Gm / U

Georgetown mafic complex

Mixed group of metaigneous and metavolcanic rocks consisting of fine to coarse-crystalline, dark gray green to black, foliated to massive, jointed gabbro, tonalite, diorite, amphibolite, and chloritic schist. The predominant minerals are amphibole, chlorite, plagioclase feldspars, and mica; overlain by 10 to 50 feet of red brown, ferruginous, poorly drained, clay-rich saprolite.

U - Ultramafic rocks, chiefly serpentinite, talc schist, and chlorite schist with little or no saprolite on weathered, dark green rock.

GLENARM SERIES

Wp **Wd**

Wissahickon Formation

Wp - pelitic schist facies   Wd - diamictite gneiss facies.

Wp - Fine to coarse crystalline, foliated quartz-mica schist and chlorite quartz schist with fine garnets; overlain on uplands by reddish brown, soft, micaceous, silty, well drained saprolite residuum as much as 160 feet thick.

Wd - Medium to coarse crystalline, layered to massive, jointed quartz-feldspar-biotite gneiss with scattered quartz pods and schist and amphibolite cobbles; overlain by sandy, reddish-brown, well drained saprolite as much as 120 feet thick on uplands but less than 25 feet thick where overlain by Coastal Plain