ROCK CREEK WATERSHED CONSERVATION STUDY

ROCK CREEK PARK
WASHINGTON D.C.

ROCK CREEK
WATERSHED CONSERVATION STUDY

prepared for

UNITED STATES DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE
NATIONAL CAPITAL REGION
ROCK CREEK PARK

1979

prepared by

CH2M HILL
W12124.A0

ACKNOWLEDGEMENTS

The magnitude of this study and the great amount of data that had to be acquired, reviewed and reduced into report format required the aid of many for which acknowledgement is gratefully extended.

Considerable information was provided by the staff of the National Park Service in the form of topographic maps, zoning maps, inventories, reports, flooding information, and field assistance.

The District of Columbia provided extensive water quality data, sewer maps, reports, and field assistance that was of invaluable aid. The U.S. Geological Survey provided extensive streamflow data and stream channel cross sections.

Special thanks and appreciation are extended to all who participated in the execution of the study:

NATIONAL PARK SERVICE STAFF

Bob Ford, Project Manager
Jim Redmond, Park Superintendent
Jack Longworth
Dick Hammerschlag
Lee Purkerson
Russ Davis
Charlie Gordon
Peggy Fleming
Norbert Erickson
Mark Burchick

M-NCPPC STAFF

Nazir Baig, Project Administrator

D.C. DEPARTMENT OF ENVIRONMENTAL SERVICES

Abe Strealy
John Brink
Noranda Mathur
Tracy Manhoff

U.S. GEOLOGICAL SURVEY

Ed Knuckles
Myra Lys
Jim Bailey

ACKNOWLEDGEMENTS (CONTINUED)

CONSULTANTS

MAPS Incorporated
Hydrocomp International
Boeing Computer Service
Biospherics, Incorporated
Jerry Smrchek
Tom Grizzard

SPECIAL ACKNOWLEDGEMENTS

Jack Hartigan, NVPDC
Nancy Willis, D.C. Metropolitan COG
Jeff Heath, Stearns & Wheler, Engineers
Greg Welter, O'Brien & Gere, Engineers
Ron Parise, Maryland Department of Health and Environmental Control
Bob Pease, U.S. EPA

CH2M HILL STAFF

Wes Blood, Project Director
Mike Taylor, Project Manager
Steve King
Skip Ellis
Ed Dorris
Marian Rodenhizer

CONTENTS

CONTENTS (CONTINUED)

TABLES

TABLES (CONTINUED)

TABLES (CONTINUED)

TABLES (CONTINUED)

TABLES (CONTINUED)

FIGURES

FIGURES (CONTINUED)

FIGURES (CONTINUED)

FIGURES (CONTINUED)

CHAPTER 1
INTRODUCTION

STUDY AREA

The Rock Creek Watershed Conservation Study area incorporates the 18.1-square mile drainage basin of that portion of Rock Creek between the Maryland-District of Columbia boundary at the upstream end to its confluence with the Potomac River. This drainage basin, depicted in Figure 1-1, is located almost entirely within the District of Columbia with small areas of Montgomery County, Maryland also contributing. To the north of the Maryland-D.C. line, approximately 58 square miles of drainage area in Montgomery County serves as the origin of flow to the District.

Rock Creek is a stream of approximately 33 miles of winding channel flowing from its source near Laytonsville, Maryland to the Potomac. Virtually the entire length of its course except for the uppermost reaches is lined with publicly owned park land; 21 miles of stream valley park in Maryland under the jurisdiction of the Maryland National Capital Parks and Planning Commission (M-NCPPC) and 9.3 miles in the District of Columbia under the National Park Service. In terms of area, M-NCPPC manages approximately 4300 acres in the total drainage basin, while the Park Service manages the approximate 2118 acres which are depicted in Figure 1-1.

The National Park Service manages several park areas within the study area. Rock Creek Park was one of the first national park areas, with specific legislation enacted by the United States Congress on 27 September 1890. In addition to authorization of both funds and a procedure for purchase of land, the congressional action stipulated that the area be "perpetually dedicated and set apart as a public park or pleasure ground for the benefit and enjoyment of the people of the United States." Specific provisions for use of the park include trails and roads for hiking, horseback riding, and pleasure driving. Further provisions for "preservation from injury or spoliation of all timber, animals or curiosities within said park and their retention in their natural condition, as nearly as possible" were defined. The park thus established is now approximately 1754 acres and extends from the National Zoological Park, authorized just a few years earlier, to the Maryland-D.C. boundary.

The Rock Creek and Potomac Parkway was authorized in 1913 "for the purpose of preventing pollution and obstruction of Rock Creek and of connecting Potomac Park with the Zoological Park and Rock Creek Park." Land has been added to the parkway in ensuing years "to preserve forests and natural beauty in and about Washington." Located mainly along tributaries, Fenwick, Portal, Dumbarton, Klingle Valley, Melvin Hazen, Normanstone, Pinehurst, and Soapstone Valley Parks add 190 acres to the NPS acreage.

Rock Creek Park in Maryland stems largely from the Capper-Crampton Act of 1930 which provided matching funds and loans "for the extension of Rock Creek Park into Maryland for the preservation of the flow of water in Rock Creek."

The significance and influences of Rock Creek Park in the District of Columbia can perhaps be best presented with quotations from the "Statement for Management, Rock Creek Park, National Capital Region."

> "Rock Creek Park's significance lies in being a picturesque, forested valley preserved in sizeable proportion within the Nation's Capital City. The early legislators recognized the ruggedly attractive aspects of the Rock Creek Valley and deemed it a special place for the inhabitants and visitors to the capital city and, in its grand scale, appropriate to this city of national stature. Significantly, today it remains as one of the largest natural parks (1754 acres) within the boundaries of a major urban center in the United States.
>
> The most pervasive single regional influence upon Rock Creek is human settlement and development within the watershed. As part of the Greater Washington Metropolitan Area, the watershed is approximately 70% developed with man-made structures and surfaces. While a majority of the area's 3,000,000 population probably utilize the valley in some manner, an estimated 500,000 humans actually reside within its 77 square mile area. Rock Creek Park is located at the lower end, rather than at the headwaters, of this drainage system. Problems including flooding, stream sedimentation, bank erosion, organic and chemical pollution, and littering are among the worst that occur in the watershed.
>
> Development has surrounded the park on most borders, making it a virtual island in some

important biological ways. Wildlife and plant migrations are barely possible through a connecting thread of park land in the bordering state of Maryland. Existence of this sister park further serves to increase equestrian and bicycle use of trails in the park's northern end, raises a need for coordinated planning efforts, and slightly reduces the severe hydrologic effects noted. Its parent agency, the Maryland National Capital Park and Planning Commission, has initiated a watershed study that will focus on stormwater management for the entirety of Rock Creek. Park Management will participate in and directly benefit from this study. Some stormwater and silt control devices already in the Maryland portion of the watershed, including Lake Frank and Lake Needwood, have a beneficial, if slight, effect on downstream water quality and volume.

Numerous storm sewers throughout the Rock Creek Valley contribute pollution from street wash to park waters. This is probably the major overall source of pollution. A unique source of pollution exists within Washington, D.C., where combined sanitary-storm sewers, during storms, flush raw sewage and rainwater into Rock Creek from Piney Branch downstream to the Potomac River. At no times do park waters meet quality standards for human contact, thus limiting water-oriented recreation.

In a larger sense, the proximity of the metropolitan areas as a whole exerts a variety of effects. Great surges of commuter traffic utilize park roads, notably during morning and evening rush hours, creating visible, audible, and safety intrusions on the true visitor's park experience and impacts on the park's ecosystem.

A well developed net of secondary roads, mass transit bus lines through the park or near its border, and a developing regional subway system enhance park access and visitation from all surrounding communities. The proximity of a large heterogeneous metropolitan population also places an exceptional demand on park resources for varied interpretive and recreational experiences. Facilities for biking, jogging, tennis, basketball, soccer, and volleyball, among others, are experiencing increased public demand. Picnicking remains in everpresent popularity to the limit of resource capability, with a trend for more large group picnics.

The Rock Creek Valley provides one of the few relatively level bicycle routes to downtown Washington. This creates a demand for recreational and commuter cycling. Currently within the park system there are approximately eight miles of maintained hard surface bike trails. Considerable fishing by area residents is evident on Rock Creek, particularly along the parkway during the spring.

Interpretive facilities including the Rock Creek Nature Center and Peirce Mill serve as focal points of park visitation and as primary sources of visitor information. Cultural resources including abandoned mill sites, homesites, roads, quarries, and Civil War facilities occur throughout established park areas. Some few resources remain to be discovered. Their contents, historical importance, and requirements for protection await needed research. Weathering, vegetative growth, and development within the park have combined in varying degrees to cause some deterioration of these resources.

A full knowledge of archaeological sites in the Rock Creek Park Area is not presently available in park files. Surveys and reports produced by the Smithsonian Institution late in the 19th Century focused on the Piney Branch Quartzite Quarry as a significant area. Sites other than this known location are not currently receiving consideration for protection. The presence and significance of additional archaeological sites requires both literature and field research."

A compilation of statistical facts of facilities and visitation of Rock Creek Park (Table 1-1) attests to its significance as a recreational asset of the Washington metropolitan area. The inventory of park resources, performed as a part of this conservation study, will further attest to the importance of natural geological, ecological, historical, cultural and archeological features to be found within its bounds.

TABLE 1-1
ROCK CREEK PARK FACT SHEET

	Acreage	Mileage: Roads	Mileage: Foot Trails	Mileage: Bike Trails	Mileage: Horse Trails
Rock Creek Park	1754	15.2	8	4.5	11
Rock Creek and Potomac Parkway	174	3.4	0.8	4	-
Other Parks	190	-	0.7	-	-
TOTAL	2118	18.6	9.5	8.5	11

Parking Areas:		- 34
Facilities:		- 30 buildings
Community Gardens:		- 5 gardens (250 plots)
Recreation Fields:	Tennis Courts	- 28
	Basketball Courts	- 4
	Golf Course	- 18 holes
	Athletic Fields	- 5
	Others	- 2
Picnic Areas:	Reserved Groves	- 12
	Non-Reserved Groves	- 21
Traffic Count:	Beach Drive	- 11,200 cars per day - 5,850 cars during rush hours
	Rock Creek Parkway	- 40,000 cars per day
Visitation:	Rock Creek Park Headquarters	- 9,600 visitors (1975)
	Rock Creek Nature Center	- 65,350
	Peirce Mill	- 45,500
	Art Barn	- 11,900
	Special Events	- 32,900
	Rock Creek Horse Centre	- 43,400
	Rock Creek Golf Course	- 57,000
	Carter Barron Amphitheatre	- 100,000
	Brightwood Recreation Area Fields	- 42,000
	Tennis Courts	- 35,500
	Picnic Areas; Reserved	- 240,800
	Non-Reserved	- 120,000
	Trails (Hiking, Biking, Jogging)	- 225,000
		1,046,950

PURPOSE OF STUDY

The purpose of this watershed conservation study is to develop a set of action-oriented recommendations that the National Park Service can implement in order to mitigate the deleterious impacts of flooding, channel erosion, water pollution, and sedimentation that have been historically imposed upon Rock Creek. In addition, this study will provide a technical basis of information by which the Park Service may evaluate planning activities of neighboring jurisdictional entities and issue policy statements and/or recommendations.

Specific items to be addressed within the scope of work of this study are:

- Determination of 2.33-, 10-, 25-, 50-, and 100-year peak flood discharges at key locations on Rock Creek for the existing and ultimate land use conditions.
- Develop water surface profiles and delineate the flood plain for each of these discharge frequencies.
- Compile an inventory of all sewer outfalls to Rock Creek and identify and evaluate pollution sources discharged therefrom.
- Develop a computerized hydrologic and water quality model of Rock Creek to evaluate existing and future water quality conditions.
- Compile an environmental inventory and evaluate ecological impacts of flooding, channel erosion, water pollution and sedimentation thereon.
- Identify present and potential water quality, flooding, channel erosion and sedimentation problems and impacts within the study area.
- Develop, analyze, and recommend alternative control strategies for solution of identifiable problems in the Rock Creek watershed.
- Prepare and submit a final report, complete with appropriate maps and graphic illustrations, for printing.

A major product of the study is a set of detailed mapping of 2.33-, 10-, and 100-year flood plains in the Rock Creek watershed. In addition, mapping of sewer outfall locations and channel erosion problem areas have been provided to the National Park Service, National Capital Region, Rock Creek Park. Supporting technical data is also on file with the NPS.

CHAPTER 2
SUMMARY

A brief summary of the results of analysis of flooding, channel erosion, ecological, and water quality problems and conditions of the Rock Creek Park watershed within the District of Columbia is presented. For further detail and supporting data, the reader is referred to subsequent chapters.

Recommendations for four major areas are given. These are in their order of importance: water quality enhancement, ecological enhancement, flooding and channel erosion damage mitigation, and park management. The primary recommendations relating to these four subject areas are briefly stated below. More detailed recommendations are summarized under the sections describing the problem areas.

Summary of the most important recommendations:

- Inspection, maintenance, and monitoring programs need to be undertaken or expanded.
- Consideration should be given to an instream sediment trap near the Maryland - D.C. border.
- Fisheries management should be considered.
- Stream channels, roads, bridges, and buildings need protection from flood waters.
- The Park Service needs to work in a close, cooperative effort with other agencies and jurisdictions to meet the goals of improving Rock Creek.
- Automobile traffic on certain roads through the Park should be reduced or stopped.

WATER QUALITY ENHANCEMENT

The enhancement of water quality conditions in Rock Creek will require an intensive program of inspection and monitoring to further identify and mitigate the numerous sources of pollution to Rock Creek. Results of the dry weather survey and monitoring of discharges show several major sources of sewage discharge from past and present combined sewer areas that result in a nearly constant violation of the water quality criteria for body contact recreational usage of Rock Creek. District of Columbia Department of Environmental Services (DES) monitoring data also provides evidence of similar bacterial contamination at the Maryland-District of Columbia boundary that must be eliminated to achieve water quality goals.

Other illegal point source discharges were evidenced by survey and monitoring data. Instream ammonia nitrogen concentrations indicate the presence of a significant source of discharge on Fenwick and/or Portal Branch and the excessively high levels at the Maryland-D.C. line evidence the possibility of a similar industrial/commercial discharge source.

Evaluation of the Rock Creek Interim Advanced Wastewater Treatment Plant by model simulation indicates a resultant dissolved oxygen deficit of 0.2 mg/l during low flow in Rock Creek when the plant is operating. Critical levels of dissolved oxygen concentrations are not realized in the District as a result of this discharge. The primary impact is that of high nutrient concentrations of nitrate nitrogen and orthophosphate phosphorus such that they provide little if any limitation to the potential aquatic plant growth in the creek.

Nonpoint sources of pollution to Rock Creek exert a significant impact and cause adverse water quality conditions both during and subsequent to storm events. Excessive BOD concentrations from impervious urban runoff sources result in occasional excursions of minimum dissolved oxygen criteria for brief time spans. Primary impacts of nonpoint pollution are that of prolonged and excessive periods of high suspended solids concentrations, turbidity, and bacterial contamination. The great majority of the loads of these pollutants originate outside park bounds from the urbanizing areas of Montgomery County and the District of Columbia and as such, are not within the Park's jurisdictional control. The identification and quantification of individual nonpoint sources outside Park bounds are not a part of this study. Literature investigation, however, points to construction site, agricultural, and urban sources of sediment in Montgomery County to be the primary source of large suspended sediment loads and resultant turbidity. Separate sewer system surcharge and overflow as well as failed septic systems in the Maryland portion of the watershed are suspected of contributing high coliform bacteria concentrations in stormwater flows to the upper D.C. reaches of Rock Creek.

As a result of hydraulic analysis and model simulation, combined sewer overflows in the District of Columbia were determined to exert a far less significant impact on Rock Creek than historical literature has documented. The combined sewer system within the Rock Creek watershed provides sufficiently high dilution of sewage and low volume and frequency of overflow such that instream water quality is not adversely impacted. The primary impact of combined sewers in Rock Creek is realized during dry weather due to gross lack of inspection and maintenance, incomplete sewer separation programs of the past, and antiquated overflow regulators that do not provide optimal and efficient hydraulic operation of the existing system.

Maintenance activities within the Park bounds are found to be deficient in practices to control nonpoint source pollution. It is concluded that a great deal of this inadequacy is a result of overuse and abuse of Park facilities to the extent that maintenance and Park natural resources are taxed beyond their limits. Park aesthetics, natural environmental resources, and water quality suffer as a result.

Recommendations

A series of inspection, maintenance, and monitoring programs are recommended. These include:

- Site-specific recommendations for control of point source discharges within the District identified during this study are offered to control bacterial contamination during dry weather conditions. The source of these discharges emanate from malfunction of combined sewer regulators and incomplete combined sewer separation programs of the past. A regular inspection and monitoring program is required to further identify these pollution sources for mitigation by the D.C. DES. Dry weather surveys should become a regular part of Park maintenance activities. Other illegal discharges to storm sewers should be traced to the source and legal action undertaken for cessation and punishment of offenders. A stringent application of enforcement and penalty powers is recommended if the Park Service is to demonstrate a dedication and commitment to attainment of its objective.

- Water quality objectives cannot be met without control of dry weather pollution sources in Montgomery County. It is recommended that the

Park Service offer their services to aid in the performance of a similar dry weather survey, inspection, and/or monitoring program of the entire Maryland watershed to identify and correct the sources of contamination. Again, once such sources are identified, all legal powers should be immediately insituted to correct the problem and punish the offenders. It is within the rights of the Park Service to mount a campaign against all such transgressions and petition immediate action by the responsible jurisdictional agencies.

- A special monitoring program of ammonia nitrogen is endorsed to define the true regime of concentrations in Rock Creek and identify suspected illegal dischargers. DES monitoring has recorded several possibly toxic levels that should be investigated.

- Regular monitoring and quantification of the biomass of aquatic plant life are recommended in Rock Creek to establish the impact of nutrient availability as a result of Rock Creek Interim Advanced Wastewater Treatment Plant effluent. Late spring and summer surveys of diurnal dissolved oxygen, chlorophyll *a*, and bottom substrate examination of aquatic macrophyte community populations should be conducted and documented.

- A comprehensive inspection program is needed of all activities within the park. This should incorporate visual inspection of flows at all sewer outfalls, erosion problems, construction site practices, instream debris, and other park abuses. Such a program is necessary to mitigate the large yet pervasive sources and influences of these pollution problems. The Park Service must be quick, decisive, and stringent in enforcement and punishment of offenses. Effectiveness of pollution control programs hinges entirely upon the willingness to execute penalties for noncompliance.

- An instream monitoring program is recommended. The detailed design of this program must be done by the Park Service; however, some general guidelines are offered. The program should be flexible and geared towards identifying problems and their causes. To this end, a mixture of intensive synoptic surveys and periodic trend monitoring is encouraged. The synoptic surveys could be done every third or fifth year with trend samples done in the intervening years. A mixture of physical, chemical, and biological analyses should be made. The most important physical/chemical parameters are water temperature, dissolved oxygen, pH, fecal coliform bacteria, ammonia-nitrogen, suspended solids, phosphorus, nitrite and nitrate nitrogen, BOD, and chlorophyll a. It may be desirable to consider testing for some metals, pesticides or toxins.

Based on initial assessment of sampling sites, it is suggested that as a minimum samples should be taken at the Maryland-D.C. boundary, near the Sherrill Drive gage, around Calvert Street, and at the mouth of Rock Creek. If budget and manpower constraints allow, additional sampling sites such as Missouri Avenue and Peirce Mill Road should be considered. The number and location of the sampling sites, especially for the synoptic studies, need to be flexible to allow for the identification of pollution sources. A possible result of the monitoring program may be the need for special studies to analyze the origin and impacts of various pollutants. Biological monitoring can prove very useful in determining the ecological impact of pollutants.

This program would serve to monitor the water quality of Rock Creek on a continuing basis and could document improvement and deterioration in water quality. Macro invertebrates and fish could be sampled in this program at stations established in the District's portion of Rock Creek. Reference or control stations could be established in "healthier" portions of upper Rock Creek in Maryland. Organisms collected at these reference stations would serve as a baseline upon which to document changes, such as presence/absence and quantitative increases in abundances of the same organisms, in assessing water quality at the lower stations. Groups which might be monitored, and which would be indicative of improving or deteriorating conditions are many types of aquatic insects (orders Plecoptera, Ephemeroptera, Trichoptera, Odmata, and Hemiptera), crustaceans (orders Ostracoda, Amphipoda, Isopoda, and some Decapoda), and clams (Family Unimidae). Also, as the water quality of lower Rock Creek improves, propagation of desirable species of fish, for example, trout and bass, and wildlife may be established on a large scale.

As much as possible, the instream monitoring program of the Park Service needs to be coordinated with Montgomery County and DES so that the water quality of Rock Creek as a whole can be studied. Regular monitoring of Lakes Needwood and Frank should be encouraged to define their role in determining downstream water quality conditions.

- The inspection and monitoring program of the Washington Surburban Sanitary Commission sewer system in Montgomery County should be modified to determine the frequency and magnitude of surcharge overflow during wet weather and its impact on water quality in Rock Creek.

Other recommendations include:

- The construction of an instream sediment and debris trap at the B&O Railroad Bridge is strongly recommended not only for the purpose of ecological habitat suitability. Significant reduction of water quality constituent concentrations will also be realized. Reduced stormwater loads of suspended sediment, turbidity, and BOD are the primary water quality benefits of the proposal. Dissolved oxygen deficits may subsequently be reduced. Estimates of pollutant load reductions can only be approximated without further stormwater monitoring information.

- Specific recommendations for Park maintenance activities are presented. Litter control ordinances must be stringently enforced and it is suggested that the Park Service curtail overuse of facilities and allow its limited manpower resources to provide the needed management, inspection, and maintenance of Park resources and facilities. Instream control of litter and debris is required as a regular maintenance activity. Mitigation of horse manure contamination by diapers and control of manure pit drainage and seepage is proposed. Vegetation managment as a nonpoint pollution source control measure is endorsed. Mowing and clearing of park and streamside areas should be curtailed to a minimum and the forest should be allowed to revert to a more natural composition with little of man's interference. Street and parking lot cleaning practicies should be changed to utilize a vacuum sweeper on a weekly schedule.

- Control of nonpoint sources in Montgomery County and the District of Columbia cannot be implemented by the Park Service. It is recommended that active involvement in plans, policies, and programs of the appropriate planning agencies be a major element of Park management activities. Recommendations for nonpoint source controls specified in the Functional Master Plan for Conservation and Management in the Rock Creek Basin should be implemented. Additional recommendations offered in this study should be considered for amendment to the plan. Recommendations for amendments to the Metropolitan Washington Water Quality Management Plan of the Metropolitan Washington Council of Governments are also proposed.

- Completion of unfinished sewer separation programs in the partially separated sewer districts of Connecticut Avenue, Normanstone, 28th Street-Cleveland Avenue, Massachusetts Avenue, and Whitehaven Street is recommended to provide additional stormwater-carrying capacity in the major interceptors of the Rock Creek watershed. Additionally, investigation of sewage sources in other supposedly completely separated districts of Klingle Road, Luzon Valley, and Soapstone Valley is required.

- The hydraulic operation of the combined sewer system was found to be inefficiently utilizing the available carrying capacity of the major sewage interceptors. The replacement of antiquated, statically-set overflow regulators with fluidic regulators is recommended as a relatively inexpensive measure to provide optimal dynamic hydraulic operation of the combined sewer system. Frequency and volume of overflow will thus be reduced and mitigation of chronic problems of sedimentation, blockage, and seepage can be conjunctively facilitated.

ECOLOGICAL ENHANCEMENT

Quantitative analysis of the ecological impact of flooding, channel erosion, sedimentation, and water pollution is arduous, and isolation of any one or more causal factors is even more difficult. Review of past studies and analysis results of key biological indicators shows Rock Creek Park to be suppressed in aquatic ecological diversity and abundance compared to upstream reaches. Results indicate the major limiting factor to be habitat suitability.

Sedimentation within the channel results in smothering of microhabitat with deposits of sand and silt believed to be of urban origin. The physical and chemical integrity of these deposits directly limits the population and diversity of macroinvertebrate and macrophyte species. Fish populations and species are both directly and indirectly affected by sedimentation and turbidity effects. Spawning and habitat are spoiled and suppression of macroinvertebrate population depletes food sources. The fish population is also adversely impacted by the lack of adequate fisheries management in Rock Creek Park.

Recommendations

- Source control practices of sediment and stormwater control within Montgomery County, even though very good, have not proved entirely effective in eliminating sediment delivery to the District of Columbia reach of Rock Creek. It is recommended that consideration be given to an instream sediment and debris trap to be constructed on the main stem of Rock Creek near the Maryland-D.C. boundary. An initial survey indicates the Baltimore & Ohio Railroad bridge crossing to be an ideal location for such a facility. Much further investigation and analysis will be required to determine the feasibility of this or other locations.

  It is estimated that, with a flood water detention time of 10 hours, a trap efficiency of 65 to 85 percent could be realized at this site, depending on the size of storm event. The volume of required storage would be approximately 1200 acre-feet, or an elevation of 200 feet National Geodetic Vertical Datum (NGVD), at the bridge. Additional benefits of mean annual flood peak attenuation from 3760 cubic feet per second (cfs) to

1470 cfs would be realized along with possible recreational benefits and stormwater pollutant load reduction.

The analysis of this site presented in Chapter 10 is of a preliminary and basic nature. Extensive monitoring and testing of sediment loads and particle size distribution, along with associated water quality characteristics, are recommended for design considerations.

- The improvement of aquatic habitat will greatly benefit the fisheries potential of Rock Creek. Management of the fish resources and a set of regulations of fishing permits, limits, suitable fishing locations, and allowable fishing practices are required. Strict enforcement of these regulations should be the responsibility of the Park Police.

- Upstream mobility of fish is greatly impeded by impassable barriers at the Q Street dam site and the Peirce Mill dam. It is recommended that fish ladders be constructed at these sites to facilitate spawning runs of anadromous fish species and to allow upstream movement of indigenous species to select desirable habitat.

- Reestablishment of native fish species in the District reach of Rock Creek can be attempted by a regular program of fish stocking and monitoring. Such programs have been accomplished in the upper watershed with moderate success. A 'put and take' program whereby unrestricted fishing totally depletes the yearly stocking is not recommended. Rather, a stable and self-sufficient population should be the objective of such a program. Therefore, careful and stringent enforcement of fishing regulations is an imperative element of any stocking program.

FLOODING AND CHANNEL EROSION DAMAGE MITIGATION

The regime of peak flood flows has significantly increased in the Rock Creek main stem due to extensive development of the watershed in Montgomery County, Maryland, which comprises approximately 80 percent of the total drainage area. Prior to development, a mean annual flood peak of 1620 cfs was estimated at the Montgomery County boundary. Ultimate land use conditions will increase the peak to 3760 cfs for the same return frequency. This change in flow regime can be expected to produce up to a 40 percent widening of the channel by erosion of stream banks.

Policies and plans of the Maryland-National Capital Park and Planning Commission and Montgomery County are designed to mitigate the increased peak flows due to future development in the upper watershed by required onsite or instream detention of floodwaters. Such controls can do much to prevent future increases in the flooding regime, but little to mitigate the existing problems resulting from past development.

Actual flooding damage (that caused by inundation by floodwaters) is limited due to the wise use of the flood plain in Rock Creek Park and flood detention reservoirs constructed in the upstream Montgomery County reaches. Danger to human life is minimal and potential damage to structures is small since only six buildings are located with the 100-year flood plain. The principal problems due to floodwaters are the destruction of roads and bridges and damage to recreational and undisturbed park areas. Ecological damage as a result of flooding and channel erosion is pervasive and not quantifiable. There is no evidence of harm to environmentally sensitive areas.

Recommendations

- Source control measures for flood peak attenuation are the most desirable strategy for flooding and channel erosion mitigation. Retroactive measures (post-development) are extremely difficult to implement, but are necessary to effectively manage existing problems.

  The Park Service has limited means by which it can bring about any significant control of floodwaters in the District. The recommendations of Chapter 7 include policies and measures that may be adopted; some within Park bounds, but most outside. Much involvement and cooperation in programs of outside governmental agencies will be required to implement most of these policies and strategies.

- Although several suitable sites may be available, construction of a large impoundment solely for the purpose of flooding and channel erosion control is not recommended. Possible instream flood storage reservoir sites have been identified and sized, tentatively, to control the increased mean annual flood peak to its predevelopment condition. This would mitigate the streambank erosion and associated problems in the District reach. However, the major damage of floodwaters, that of roadway and bridge destruction by the larger events (greater than the 5-year flood), would still occur. The damages observed as a result of the lesser events do not warrant recommendation of a large impoundment.

- Floodproofing measures are recommended for minimizing flood damages to the six buildings within the 100-year flood plain. Such measures may simply involve an evacuation plan and safeguarding of valuable items within these structures.

- Site-specific recommendations of channel, road, and bridge protection are offered in Chapter 7 Only where existing or potential structural damage is envisioned is it recommended that measures be taken. The anticipated continuance of channel bank erosion should, despite the distasteful aesthetic appeal and sediment pollution of the water body, be allowed to take its own course as long as it does not pose a threat to some structure. Eventually, a more stable channel configuration will be reached.

  Channel bank armoring by a flexible lining of riprap is the preferred method where a suitable grade can be achieved. Steep bank slopes will require gabions for adequate protection. Extensive use of vegetation to further stabilize banks and provide a natural appearance is heartily recommended.

- Proper grading, draining, and vegetating of picnic groves is recommended to mitigate flood damage to these areas.

- Localized flooding of roadways occurs as a result of insufficient local drainage facilities rather than overbank flooding of Rock Creek. A regular program of inspection and maintenance of drainage culverts, with enlargement of undersized pipes, will alleviate this problem.

- A regular program of selective snagging and clearing of large debris from the stream channel and bank areas to minimize damage, blockage, and sedimentation problems is endorsed.

- Damage to stormwater drainage outlets is prevalent throughout the Rock Creek watershed. Discharges at the outlets can, in turn, create serious erosion scars along the channel banks. Inadequate design considerations and lack of maintenance allow for undercutting and large scale destruction of outlet structures. Improper design of spillways and/or energy dissipating structures results in gully erosion of valley walls and stream banks.

  It is recommended that the Park Service appeal to the appropriate responsible agencies for rehabilitation of these drainage outfalls with all the legal power that is granted under the original construction permits for such. In addition, all new permits should be carefully reviewed for design considerations and the Park Service should avail themselves of this power to effect implementation of source control strategies of flooding and erosion control.

PART MANAGEMENT RECOMMENDATIONS

In the original Act of 1890, the National Park Service was mandated by Congress to "preserve from injury or spoilation all timber, animals, or curiosities and retain them in their natural conditions, as nearly as possible." It is obvious that by no means could the Rock Creek Park watershed now be termed 'natural'. Urban development outside the park bounds could not be prevented from exacting a large and pervasive influence on park resources simply by proximity. Also, considering the fact that Rock Creek Park receives essentially all its streamflow from urban environs, achievement of the natural status of the creek is long past feasibility.

Previous conclusions and recommendations have dealt with direct strategies and measures to improve the flooding, erosion, water quality, and ecological conditions within the watershed. Where possible, quantitative analysis of the problems and control measures was offered.

Not within the scope of this study, but evident as a result of field reconnaissance and research, is the pervasive impact of overuse of Rock Creek Park. At one time in the past, the park provided a quiet and scenic setting for strolls and horse-carriage rides. What has evolved since then is a major commuter path and recreation center. Most of the damage to the physical, ecological, and aesthetic quality of Rock Creek Park can be attributed to the overuse and abuse of the facilities. Picnic groves cannot be sustained with any permanent vegetation because of overuse. Trash and debris is evident throughout the park and maintenance resources cannot keep up with the load.

The easy access to virtually all park areas encourages improper and unauthorized use and abuse of park grounds and limits proliferation of a natural ecological balance. Commuter traffic along the length of Beach Drive and the Rock Creek and Potomac Parkway, in addition to several major crosstown arterial routes, virtually dissects the park and limits the range of terrestrial wildlife. The continual traffic results in pervasive noise and air pollution throughout the heart of Rock Creek Park; a condition one could hardly term 'natural'.

It is therefore recommended that one of the most aesthetic and ecologically beneficial measures the National Park Service can undertake to conserve the natural resources of Rock Creek Park is to close the park transportation system to motorized vehicles. The benefits of such an act would be multifold. Isolation of the park from its urban environment would help to provide a haven for wildlife and extension of migration limits. Adverse impacts of noise and air pollution to biota would be reduced. Park recreational resources would not be overtaxed and/or abused by the undesirable elements of park visitation since access would be limited. The park resources would regain a 'natural' setting and management and maintenance activities will not be as overburdened. Roads could be turned into safe bicycle paths; much needed facilities in metropolitan Washington for both recreation and commuting purposes. Additional recreational benefits could be realized as regular tours (perhaps by horse-drawn carriages) directly along the creek, the most appealing aspect of the Park, would be possible.

Perhaps the most significant adverse impact of such an action will be the disruption of traffic patterns in metropolitan Washington. However, with the anticipated completion of the Washington Metropolitan Area Transit Authority subway line to Rockville, Maryland, commuter transportation from Montgomery County would not require the Beach Drive commuter route. In fact, such an act will be in concert and actively promote the countrywide energy conservation principle of mass transit.

The closing of the Rock Creek and Potomac Parkway may seriously impact downtown D.C. traffic and further study by transportation authorities is necessary. It is initially recommended that only the Beach Drive corridor from the Maryland-D.C. line to the National Zoological Park be isolated. Crosstown traffic along the Tilden Street-Park Road, Porter Street, West Beach Drive, Wise Road, and Military Road corridors in this sector ideally should also be suspended by closure, but further study of adverse impact is required.

The benefits of this recommendation are not easily quantifiable. The Park Service finds itself at the mercy of planning and development decisions of its urban environment that it has very little or no means of control. The complete isolation of Rock Creek from this environment is probably one of the most visibly beneficial endorsements that can be offered as a tool that the Park Service may wield in its defense of urban pressures.

The Park Service should realize that problems in Rock Creek Park are a watershed concern and no lasting degree of conservation of resources can be achieved by any one entity within the watershed. The concept of "watershed planning" must transcend the jurisdictional limits that have dissected Rock Creek basin.

At one time in the late 1960s, at the peak of the U.S. era of environmental awareness, an organization entitled the Rock Creek Watershed Association was formed and the problems of the creek were brought to focus. Interestingly enough, the documentation of conditions at that time mirror those of this study. The organization no longer exists and Rock Creek remains much the same. Obviously, the programs of the jurisdictional entitites could not be melded into a common purpose.

Despite previous failures, it is recommended that the Rock Creek Watershed Association be revived at the initiation of the Park Service. Only with the cooperation of several organizations can many of the proposals of this study be implemented. Representation of the association should include the Park Service, M-NCPPC, Metropolitan Washington Council of Governments, D.C. Department of Environmental Services, Montgomery County Health Department and Department of Environment Protection, Washington Suburban Sanitary Commission, U.S. Soil Conservation Service, Maryland Department of Natural Resources, Maryland Water Resources Administration, and concerned citizens' groups. The organization should be utilized as a forum to organize, coordinate, and implement programs designed specifically to preserve the natural value and aspect of Rock Creek. This organization and the Park Service should begin a public awareness/education program of the attributes of Rock Creek, its problems, possible solutions to the problem, and what the public can do to help preserve and improve Rock Creek.

CHAPTER 3
WATERSHED RESOURCE INVENTORY

A conservation study must take into account the existing natural and man-made resources that are prevalent within the watershed. A resource inventory is presented to describe the Rock Creek Park watershed in terms of natural physical, meteorological, hydrological, and biological features. In addition, those aspects that man has historically imposed on the basin are discussed.

HISTORICAL HERITAGE OF ROCK CREEK PARK

The foresight of our ancestors in establishment of the Rock Creek Park has managed to preserve many vestiges of our past within its bounds. Much of this heritage has been lost, however, and the presence of man has brought about profound changes in the appearance of the watershed in the past two hundred years. Locations of historically or archaeologically significant areas in the Rock Creek Watershed are portrayed in Figure 3-1. An index to the sites is provided in Table 3-1 (Reference 7).

For centuries before colonial settlement, the Rock Creek valley was a hunting and camping ground of the Algonkian Indians. They hunted buffalo, elk, beaver, fox and smaller game animals, most of which have long since disappeared from the urbanized area. These Indians left little evidence of their presence and long occupancy, except for the remmants of a workshop near Piney Branch. Here they laboriously fashioned arrowheads and other stone implements from quartzite boulders and from quartz rock found abundantly in the vicinity. An area littered with stone chips and discards is mute evidence of this aboriginal activity. The Indians also carved bowls and other utensils from exposed soapstone in Soapstone Valley which parallels Albermarle Street on the south. Building construction eliminated this site long ago (Reference 2).

When the first European settlers came into this area in the early 18th Century, they established the tiny post of Georgetown near the head of navigation on the Potomac River. Land in the surrounding area was slowly cleared, and tobacco plantations established. This crop was grown for export to the large and growing European market, chiefly Britain, the mother country. The fate of the crop each year spelled the fate of the local economy. Ships plied the Atlantic regularly, bringing manufactured goods to Georgetown and returning with a load of tobacco.

In those days, Saw Pit Landing was located on the west bank of Rock Creek Park at the southern tip of Georgetown. Ocean-going sailing vessels came a short distance up the creek to unload at this trading post. Rock Creek formed the border between the original District of Columbia and the Maryland town of Georgetown. The mouth of Rock Creek 200 years ago formed a broad bay about one-fourth mile wide at the outlet. This bay narrowed upstream, so that the channel in the vicinity of M Street probably was about the same width then as now. The land that has been filled in during the intervening years has been contributed in part by the creek and in part by man (Reference 6).

TABLE 3-1
HISTORIC AND ARCHAEOLOGICAL SITES OF ROCK CREEK PARK

IDENTIFICATION NUMBER	DESCRIPTION
1*	Wooden Floodgates Remains - Mouth of Rock Creek
2	C&O Canal
3	Godey Lime Kilns
4	P Street Paper Mill Site
5	Lyons Mill Site
6	Cabin at Montrose Park
7	Waterwheel Pump - Dumbarton Oaks Park Springhouse
8	Massachussetts Avenue Quarry
9	Taft Quarry
10	Old Trolley Bridge Foundation
11	Woodley Road Bridge Foundation
12	Klingle Ford
13	Klingle-Peirce Mansion
14	Jusserand Memorial
15	Peirce Mill Barn and Springhouse
16	Hazen Quarry
17*	Piney Branch Quarry
18	Blagden Mill Bridge Foundation
19	Blagden Homesite

*Not shown on map

TABLE 3-1
HISTORIC AND ARCHAEOLOGICAL SITES OF ROCK CREEK PARK
(CONTINUED)

IDENTIFICATION NUMBER	DESCRIPTION
20	Blagden Millsite
21	Broad Branch Quarry
22	Boulder Bridge
23	Historical Gullies
24	Ross Road Battery
25	Battery Sill
26	Nature Center Quarry
27	Battery Kingsbury
28	Old Barn at Golf Course
29	Milkhouse Ford & Cross Valley Road
30	Milkhouse Ford Structures
31	White Residence
32	Fort DeRussey
33	C.C.C. Camp Good Will
34	Bingham Springhouse
35	Clagett Structure

The Rock Creek bay was a key part of the thriving foreign shipping trade in early Georgetown. Wharves and docks lined the bay's shores. Along the eastern bank these wharves began about 200 to 300 feet from the Potomac and extended up the creek to within 100 feet of K Street. The wharves were in constant use until about 1831. In early days, sailing vessels drawing as much as 20 feet of water frequented the Rock Creek harbor.

A great change in the area's economy took place about the middle of the 18th Century. Soil exhaustion and the settlement of the Piedmont region to the north and west by European immigrants caused a shift away from tobacco to grain production. This soil depletion resulted from rapid erosion and poor farming practice, especially the continued planting of tobacco year after year.

The new staples, primarily wheat, rye and corn, posed a problem of marketing. These crops had to be made compact and durable for transport. It was necessary to convert them into flour and meal. This led to the construction of community grist mills along streams which had a potential for water power and which were located within a distance of about ten miles from the grain producers. Small "custom" mills sprang up, grinding grain on demand for individual farmers. A typical mill had a capacity of 100-200 bushels of wheat a day.

Mills were an important feature of the Rock Creek stream valley for more than a century, from the late 18th century to the beginning of the 20th century. Each was connected with a farming operation. None of the grist mills was large enough or had sufficient year-round business to provide a livelihood for the mill operator. Some mill owners also engaged in small-scale artisan or commercial activity to supplement income.

During the late 18th and early 19th Centuries, at least eight mills were built along Rock Creek within the area of the present park and in Maryland. These mills processed not only grains, but also produced plaster, lime, lumber, bone meal and woolen goods. Their raw materials came largely from nearby woodlands and from farms carved out of the upland forests in the early days of settlement.

Of the mills which once operated in the present park area, only Peirce Mill has been restored and vestiges of Blagden's Mill still exist. Hardly a trace exists of the others which once flourished here. Peirce Mill was established about 1820 by Isaac Peirce. Near the site of present-day Peirce Mill he built a home, barns, sawmill, springhouse and gristmill. Business flourished from the beginning until the 1870's, though the mill continued to operate until 1897. The waterwheel provided the power to turn three millstones which ground wheat, rye, buckwheat and corn into flour and meal.

The original dam was above the site of the present one. It raised the water level sufficiently to let the water into the millrace and turn the waterwheel. The dam was washed away by floods and rebuilt several times, the last in 1904. The mill was restored by the National Park Service in 1936 and operates on an intermittent basis.

At Thomas Blagden's Argyle Mills was located a grist and a bone mill, close to each other, served by a common mill race which passed between the two structures. The mill ceased operating in 1889. A merchant mill, known as Lyon's or Federal Mills, was located east of Oak Hill Cemetary and operated from 1780 to 1875. Other mills of which little information is known include: Patterson's Paper Mill built in 1800 just north of P Street; John Quincy Adams Mill operated until 1867 within present zoo bounds; Parrott's Mill, located just below Lyon's Mill, utilized water power to card wool and spin cotton; White's Mill Seat located north of Peirce Mill; Jones Mill was built in Montgomery County just above the District line (Reference 2).

Other reminders of 19th Century commerce on Rock Creek are the remains of Godey's Lime Kilns on the east side of Rock Creek, opposite the terminus of the C&O Canal. Built in 1854, the kilns manufactured lime, cement and plaster from limestone barged via canal from upper Maryland until 1907. Slaughterhouses were numerous along Slash Run's banks, especially before the Civil War, and some of these establishments were still in operation along the upper reaches at the beginning of the present century.

Sparkling springs were the best source of drinking water in Washington's earliest days. After about 1800, for the convenience of having water closer to home and readily available in congested areas, pumps gradually became more and more popular, drawing water from wells. The springs and wells furnished most of the city's drinking and fire-fighting water until 1859, by which time the demand was greater than the supply and river water was introduced. Even after this date the people were reluctant to discontinue using the spring water for drinking purposes. However, by the early 1880's, most residents no longer used spring water. Soon after the beginning of the 20th century, the city water system completely replaced the old springs in the District.

Although a few springs still flow in the vicinity of Rock Creek, nearly all of the District's original springs have disappeared. Some dried up, possibly because rain water began to be diverted into sewers instead of filtering into the ground. In a number of cases, spring waters were piped to sewers. Other springs have been filled in and paved over in the development of the city. Remnants of this element of colonial heritage are visible at springhouse sites in Dumbarton Oaks Park, Peirce Mill, and along Bingham Drive (see Figure 3-1).

From colonial times, the growth of Washington, agricultural activities in Maryland, and the construction of the C&O Canal gradually altered the physical aspect and commercial activities of the Rock Creek watershed. Many of the springs helped produce creeks of varying sizes. The channels of these creeks originally wound through the District's forests and swamps and eventually into Rock Creek. Over the years, however, man has filled in or converted to underground sewers nearly all of the area's original streams, thereby relegating them to extinction or entombment together with the springs. The only surviving reaches of original streams, in nearly all cases, are in those few areas that have been made into parks by legislation. Thus Piney Branch and Broad Branch, each of which began near what is now the District line, are today represented only by the lower mile or so of their originally much more extensive routes. Even these few vestiges remain only by virtue of being included in Rock Creek Park (Reference 6).

Erosion of sediment in the upstream reaches, probably associated with the agricultural and construction activities of the settlers, provided Rock Creek with extra tons of sand and silt to transport. This was mostly dumped in the harbor where the stream's mean velocity was suddenly lowered due to the considerable widening of the channel and to the impeding influence of the tide. A bridge--Rock Creek's first--was erected at M Street in 1788. A second was built at K Street in 1792. Some land was reclaimed to the north and south of the causeway, thus decreasing the size of the harbor. More area was reclaimed by 1830, by which time a quay across the mouth of the bay was finished, in connection with the Chesapeake and Ohio Canal. With this development, Rock Creek's harbor, from the mouth to the K Street bridge, was reduced to 8-1/4 acres and the outlet to the Potomac was only about 200 feet wide. Additional reclaiming in the basin was done as time went by, so that today Rock Creek's once-bustling harbor has completely disappeared, and the outlet in the Potomac is virtually the same width as the creek for miles upstream (Reference 6).

The Chesapeake and Ohio (C&O) Canal, completed in 1850, traversed 184 miles from the west bank of Rock Creek to Cumberland, Maryland. From the time of its completion, it fought a losing battle against railroads, highways, eastern seaports, and floods. It finally ceased commercial operation in 1924 after another damaging flood. In 1938, the U.S. Department of the Interior purchased the waterway, restored much of the lower section, and has since maintained it as a recreational and scenic asset. The District portion of the Canal was connected to the Washington City Canal in 1833 which was operational until sediment problems forced abandonment in the 1850's. The canals were intended to be a major transportation artery in the scheme to build Washington into an important port and trade center. All that remains now is the preserved C&O Canal and the remnants of wooden floodgates at the mouth of Rock Creek.

The remains of several forts and batteries are still another historical landmark within Rock Creek Park. Notable is Fort DeRussey, one of 68 forts and batteries which were built around Washington during the Civil War to protect the Nation's Capital from Confederate attacks. Vestiges of the parapet, gun mounts, moat, and trenches are still evident at the site just north of Military Road and Oregon Avenue.

The Klingle-Peirce mansion, located just north of Porter Street and Klingle Road, is another historical landmark. The 19th century estate of Joshua Peirce and his nephew J. Peirce Klingle is preserved, along with the beautiful horticultural gardens, for public display. The Jusserand Memorial, a momento to the friendship nurtured in Rock Creek Park between President Theodore Roosevelt and French Ambassador Jean Jules Jusserand, is located just north of the mansion.

The idea of establishment of Rock Creek as a park began to evolve at the close of the Civil War. Charles C. Glover, banker, financier and civic leader, played a significant role in the creation and development of Rock Creek Park. He, with other prominent leaders in the city, recognized the valley as a haven of natural beauty that afforded relaxation and enjoyment to both residents and visitors. Urban growth was beginning to threaten the existence of this valley and Federal aid was needed to preserve Rock Creek Valley for the perpetual use and benefit of the people.

Repeated attempts to establish a national park here met with failure for one reason or another. Under Glover's leadership, a small group of dedicated men banded together to achieve their goal of a major park in the Nation's Capital. Bills were introduced in Congress in 1889 and in 1890. An act providing for creation of Rock Creek Park was finally passed by Congress and signed into law on September 27, 1890.

The purchase of lands for the park was largely completed by 1892 when some 1600 acres, located north of the Zoo and adjoining Rock Creek, was acquired. After the turn of the century, more land was acquired south of Klingle Road for the Rock Creek and Potomac Parkway.

In the early days, a winding drive crossed Rock Creek at several fords. Several presidents enjoyed frequent excursions in the wooded valley of Rock Creek. Andrew Jackson, Martin Van Buren, and Abraham Lincoln all took carriage rides along the creek. At the turn of the century, Theodore Roosevelt, with friends and family, frequently visited the park. Many of the fords and bridges of this drive, although decimated, retain much historical, geological, and engineering significance. Of particular note is the unique stone arch structure at Boulder Bridge.

Today, Rock Creek Park is the Nation's largest natural park in an urban setting. This 1754-acre park includes approximately 18 miles of the rugged Rock Creek watercourse, and it is up to 1.25 miles wide. In Maryland, the park continues for almost 18 miles to the vicinity of Laytonsville, and includes 4,500 acres under bi-county agency jurisdiction.

SLOPE AND TOPOGRAPHY

The slope and topography of the Rock Creek Watershed exhibits a large variability. Upland elevations near the Maryland-D.C. line reach up to 390 feet above mean sea level and drop to the stream channel at 160 feet msl. Near the mouth at the Potomac River, upland elevations of under 100 feet msl are typical and the channel bottom reaches 7 feet below mean sea level.

Overland slope is a natural topographic feature that controls the pattern and rate of drainage within the watershed. The percentage of slope is a mathematical relationship and defined as the quotient obtained after dividing the difference in vertical elevation by the corresponding horizontal distance. The percentage of slope, to a great degree, will dictate the land use suitability of a given area. In general, the following list shows various slopes categorized as to what limitations they may impose on particular types of developments:

Percent Slope	Land Use Limitation
0 - 8	Little limitation
8 - 15	Impractical extensive commercial and industrial development; restricted agriculture and intensive recreation; restricted residential development
15 and over	Special purpose recreation (hiking, nature study, scenic areas); should remain forested and undeveloped

The limitations placed by slope and topography have resulted in extensive land disturbance in the development of the Washington, D.C. urban area. Figure 3-2 displays a generalized slope map of the watershed. A generalized trend can be seen in the pattern of slopes within the basin. In the upland, urbanized areas, relatively mild slopes of 2 to 6 percent are typical. The areas immediately adjacent to the natural stream channels steepen dramatically in excess of 15 percent, sometimes reaching over 25 percent. The flatest areas are observed in the southeast portion of the watershed in the D.C. central business district (CBD). Consequently, drainage of stormwater in these areas is relatively slow.

The storm sewer system and extensive impervious areas deliver large and flashy flood flows to the Rock Creek tributaries. Channel bank erosion by these high velocities is evident as the steep channel slopes (1.5 to 2.5 percent) do little to impede the flow.

Within the District of Columbia, the main stem of Rock Creek is defined by three distinct hydraulic segments. From the Maryland-D.C. line to Sherrill Drive, the stream is very sluggish and deep. The bottom material consists of silt and sand deposits. A transition to sand, gravel and cobble occurs from Sherrill Drive to Military Road. Flow is faster and shallower despite a rather constant channel slope of 0.18 percent.

An abrupt transition occurs at Military Road at what is referred to as the 'Fall Line'. This reach designates a geologic province boundary and is marked by large boulders and a steep (1.6 percent) channel drop. The lower end of this segment occurs between Boulder Bridge and Peirce Mill where a cobble bottom takes over. Channel slope is relatively constant below the Peirce Mill Dam, an 8-foot high structure, to the Potomac. However, from the National Zoological Park, the bottom material changes to a more silty composition and turns into a soft mud nearer the mouth. Much slower velocities are noted here where backwater from the Potomac River is a major hydraulic factor. Flow reversal can be observed near the mouth during high tide.

There are several other small dams along the D.C. reach of Rock Creek but none are more than a few feet high or have a significant hydraulic effect. The main stem follows a meandering path through a generally narrow, constricted flood plain. A channel length of 9.7 miles winds through a linear path of 6.1 miles from Maryland to the Potomac.

HYDROLOGY AND HYDRAULICS

The hydrologic characteristics of the Rock Creek basin are defined in terms of flow regimes. The flood hydrology within the basin is the subject of Chapter 4 which deals with extreme flooding events.

The amount of flow within a natural stream is the product of numerous meterological, biological, and physical processes that define the hydrologic cycle (see Figure 4-1). A streamflow gaging station maintained by the U.S. Geological Survey since 1929 has continuous flow records of Rock Creek at Sherrill Drive. Average flow over the 49-year period of record is 61 cubic feet per second (cfs) or 13.32 inches of runoff per year. Extreme flows recorded over this period are a maximum of 12,500 cfs and a minimum of 0.5 cfs. The seasonal distribution of flow will fluctuate from year to year. A general pattern is exhibited of lowest flow during late summer to early fall and highest flow during late winter to early spring.

The urbanization of the upper basin in Maryland and the construction of Lakes Needwood and Frank in the 1960's have greatly altered the hydrologic regime. The lakes serve to reduce peak flows attributable to storm events and augment low flow periods. In contrast, urbanization results in large expanses of impervious surface that increase storm runoff rates and reduce groundwater recharge. This eventually decreases the low flow regime in Rock Creek.

The hydraulic characteristics of the watershed are defined as the water conveyance systems, both overland and instream. In its original state, the Rock Creek Watershed was a forested basin with a very dendritic stream channel system. Old maps of colonial Washington display second and third level tributary branches to the creek. Urbanization has reduced this pattern to a basic one level tributary system. The rest of the sublevels have been forced underground into a vast storm sewer network. The entire length of Slash Run has been covered and converted to a sewer. The only natural channels that are left are those within parkland. The main tributaries to the Rock Creek are displayed in Figure 1-1 to the limit of their extent. Virtually all these branches originate at storm sewer outfalls and are heavily wooded in very steep-sided valleys. The channels generally vary in material from bedrock outcrops in the middle and lower reaches to sand, gravel, and cobble in the upper lengths. Some of the tributaries, such as Broad Branch, extend far enough up to their original headwaters to reach a relatively flat, marshy fountainhead.

CLIMATE

The climate of the Rock Creek basin can be expressed in terms of the meteorologic conditions observed at the Washington National Airport weather station since 1941. The area is characterized by a moderate climate. Summers are warm and humid and winters mild; generally pleasant weather prevails in the spring and autumn. The coldest weather occurs in late January and early February. The warmest weather occurs late in July. There are no well-pronounced wet and dry seasons. Thunderstorms, during the summer months, often bring sudden and heavy rain showers and may be attended by damaging winds, hail, or lightning. Tropical disturbances occasionally, during their northward passage, influence Washington's weather mainly with high winds and heavy rainfall. Tornadoes rarely occur, but some rather destructive ones have been recorded.

Records of the past 20 years show the average date of the last freezing temperature in the spring to be March 29 and the latest April 16. The average date of the first freezing temperature in the fall is November 10 and the earliest October 20. An average growing season of 225 days is evidenced.

Snow accumulations of more than 10 inches are relatively rare. Usually the melt-off is rapid, but snow depths of 3 or more inches make driving hazardous, and slows or halts traffic. The greatest recorded snowfall from a single storm was 28 inches. A summary of pertinent meteorologic statistics and seasonal variation is presented in Table 3-2.

TABLE 3-2
SUMMARY OF SEASONAL CLIMATOLOGICAL DATA (REFERENCE 1)
1959 - 1979

	Temperature, °F			Precipitation, Inches				Snowfall, Inches	
Month	Daily Max.	Daily Min.	Avg.	Max. Monthly	Min. Monthly	Avg.	Max. 24-Hour	Max. Monthly	Avg.
JAN	43.3	28.0	35.7	7.11	0.31	2.62	2.13	21.3	4.9
FEB	46.3	29.3	37.8	5.71	0.42	2.45	1.77	19.0	4.8
MAR	55.1	36.8	46.0	7.43	0.24	3.33	3.43	17.1	2.5
APR	66.8	45.8	56.3	5.97	0.26	2.86	3.08	0.6	0.0
MAY	75.7	55.9	65.8	10.69	1.06	3.68	4.32	0.0	0.0
JUN	83.8	65.1	74.5	11.53	1.21	3.48	7.19	0.0	0.0
JUL	87.5	69.5	78.5	11.06	0.93	4.12	4.69	0.0	0.0
AUG	85.8	68.3	77.1	14.31	0.55	4.67	6.39	0.0	0.0
SEP	79.4	61.5	70.5	12.36	0.20	3.08	5.31	0.0	0.0
OCT	69.0	49.9	59.5	8.18	0.00	2.66	4.98	0.0	0.0
NOV	57.2	39.8	48.5	6.70	0.37	2.90	2.63	6.9	0.8
DEC	45.9	30.8	38.4	6.54	0.22	3.04	2.86	16.2	3.6
YEAR	66.3	48.4	57.4	14.31	0.00	38.89	7.19	21.3	16.6

GEOLOGY

The geology of the Rock Creek Park Watershed demonstrates some of the more spectacular natural features to be found in the area. Along the length of the stream a boundary is marked between two general physiographic provinces; the Piedmont Province and the Coastal Plain Province. The boundary, known as the Fall Line, marks a north-northeast trending zone that is readily visible along a steep segment of Rock Creek between Military Road and Tilden Street; an area in which the creek is beset with a succession of cataracts. The Piedmont Plateau is north and west of this area with its exposed metamorphic rocks, hilly to rolling terrain, and fast flowing streams. The Coastal Plain, east and south is noted for its flatter terrain, absence of rocky outcrops, presence of sandy, gravelly and clayey soils, and quiet, meandering streams.

The crystalline rocks of the Piedmont Plateau are exposed throughout most of Rock Creek Valley, and in the ravines of its major tributaries. There are four major rock types; schist, medium-grained gneiss, biotite gneiss, and diorite. Since the Fall Line, which separates the Piedmont Plateau from the Coastal Plain, cuts across the park, one can also find gravels that were laid down on the Coastal Plain areas. Numerous quarry sites are located within the park and are depicted in Figure 3-1 (References 2 and 7). The major geologic formations of the Rock Creek Park watershed are portrayed in Figure 3-3. The Piedmont section of the watershed is underlain by ancient metamorphosed igneous and sedimentary rocks and the Coastal Plain portion is underlain by much younger, poorly consolidated sediments. Limited areas of both provinces are covered by unconsolidated terrace and alluvial deposits consisting of gravel, sand, and some silt and clay.

The metamorphic rocks of the Wissahickon Formation are the predominant rocks which crop out in the Piedmont. They include boulder gneiss (Laurel gneiss of Chapman), mica schist (oligoclase-mica facies), and quartzite (Sunderland Formation). The schists and gneisses are intimately associated with mafic igneous rocks of the Georgetown complex and with ultramafic rocks (soapstone, serpentinite, etc.). These metamorphic and mafic rocks are also intruded by younger igneous rocks such as Kensington granite gneisses (Reference 3).

All of the crystalline rocks are jointed and have been quarried for building stone, rip-rap, and fill. These quarries include: the Piney Branch Indian quarry where the Algonkian tribes fashioned stone implements out of quartzite boulders; the Broad Branch quarry where Kensington granite gneiss was mined for building stone; a mica schist quarry at the mouth of Soapstone Branch, used to supply flagstone; and two mafic (gabbro rock) quarries at the Massachusetts Avenue and Taft Bridges (Reference 4).

Poorly consolidated Coastal Plain sediments overlie the crystalline rocks east of Rock Creek. The strata thicken to the southeast from a feather edge at the fall line zone to more than 1,000 feet at the southeast District edge. The Patuxent Formation consists mostly of fluviatile, channel-fill, sand and gravel facies, and some lens of silt and clay. Hard concretionary iron oxide layers are common in this formation (Reference 3). The sand and gravel facies crop out chiefly on hillsides in a belt between Rock Creek and the B&O Railroad.

Localized gravel and sand strata of various origin abound in the Rock Creek Park watershed. These include recent alluvial deposits, river terrace deposits, ancient Potomac River alluvium (Brandywine Formation), and artificial fill in man-made or man-modified areas of the Washington urban district.

SOILS

The soils within the Rock Creek Park Watershed exhibit a variety of characteristics that are in keeping with the diversity of land use and geologic formations found within the District. Figure 3-4 displays the general soil associations that are to be found within the park (Reference 5). The majority of soils are those that have been altered through grading, cutting, fill, and other disturbances of urbanization. The net impact of these processes of urbanization and disruption of soils is to decrease soil moisture holding capacity, increase runoff rates, and increase the hazards of erosion. Those that have not been thus affected are generally located within the bounds of the park itself.

By comparing the soil map with the geological formation map (Figure 3-3), one can see a general correlation. The upper, Piedmont portion of the watershed is dominated by soils of Manor-Glenelg association origin. These are well drained to somewhat excessively drained soils that are found in the upland areas. They are deep and overlie micaceous saprolite at a depth of about 15 to 30 inches. This is underlain by the acid crystalline rocks of the Piedmont Plateau. Properties of these soils include moderate permeability, slow to rapid runoff (dependent on slope), moderate to severe erodibility, and moderate to high available water capacity. The general soil profile is a surface layer 2-4 inches thick of dark brown loam, 4-7 inches of yellowish brown loam, and a 15-19 inch subsoil of strong dark brown silt loam.

The wide north-south oriented band of soil to the west of Rock Creek is of the Urban land-Brandywine association and generally overlies the Kensington granite gneiss (see Figure 3-3). This soil is somewhat more permeable than the Manor-Glenelg soils with low available water capacity. This is because it is a more gravelly loam of similar thickness and underlain by a very acidic sandy saprolite.

The channel and flood plain of Rock Creek is marked by a band of soil of the Iuka-Lindside-Cordorus association. These soils are deep, loamy, and only moderately well drained. They overlie stratified alluvial sediments, have moderate permeability, slow runoff (due to flat slope) and are strongly acid.

Below the fall line, soils of the Coastal Plain are dominated by those of the Sassafras-Chillum association. Underlying materials are those sandy and gravelly sediments related to the Coastal Plain geological formations. Characteristics of these soils include; deep, well drained, on uplands, moderate permeability, slow to medium runoff, moderate to high water capacity, and very strongly acid. The Chillum soils are a silt loam while the Sassafras soils are of a sandy or gravelly sandy loam nature. Depth to bedrock is generally greater than 5 feet and depth to seasonal high water table is generally over 6 feet.

The remainder of the Coastal Plain soils are those of the Udorthents and Urban land associations. These soils comprise either areas of cuts, fills or otherwise disturbed land, or areas occupied by structures and works. The Washington commercial/industrial area at the mouth of Rock Creek is composed of these soils.

ECOLOGICAL RESOURCES

The following is an inventory of the existing widespread biological literature pertaining to species of plants and animals previously reported or known to occur in Rock Creek Park, or ones which would probably be found to occur here if additional collecting were undertaken. A biological inventory of Rock Creek Park resources was greatly facilitated when it became apparent that a great deal of biological information, some published, some not, was available which concerned the Rock Creek watershed in the District of Columbia and Montgomery County. This inventory also serves as an aid in identifying environmentally sensitive areas, analyzing all existing water quality studies, and characterizing the current state of biological knowledge of the watershed. Lists of both aquatic and terrestrial plants and animals were prepared from available references and are compiled in a separate appendix of tables to this report. A list of references for these tables and the ensuing discussion is also included therein.

Appendix Table 1 lists those fungi, lichens and related groups which have been collected from Rock Creek. Several different groups of fungi are found here, including mushrooms or toad stools, bracket fungi, mildews, and rusts. Lichens, closely related to fungi, are found throughout the Park growing on boulders, rocks, and on tree bark. Mosses, liverworts, and hornworts found in Rock Creek Park are listed in Appendix Table 2. Mosses are probably the most abundant plant group in the park (Reference 35). Members of these groups may be found in a variety of habitats from dry, arid conditions, to moist situations, and even in true aquatic habitats.

A variety of ferns and fern allies (horsetails and clubmosses) are found in Rock Creek Park (Appendix Table 3). Most ferns are found in shaded, moist habitats, and are associated with a mature, climax forest. If trees in the forest are removed by cutting, disease, fire, or other habitat modifications, the ferns will also disappear until conditions for their existence again become suitable.

Shosteck (Reference 35) suggests that the number of ferns and their distribution in Rock Creek watershed may have been decreased and contracted to some extent because of continual flooding of Rock Creek tributaries after storm events and the introduction of *Lonicera japonica*, the Japanese honeysuckle, to the park area. Also, erosion of topsoil in the stream valleys and along the stream banks due to heavy runoff and flooding has limited the ferns. Were these situations to be corrected or lessened, then the ferns would be benefited accordingly.

Scores of wild flowers are found in Rock Creek Park (Appendix Table 4). Many of the species which flower in the spring occur in the flood plain. Lonicera japonica has limited the occurrence of many herbaceous plants where it has been introduced. Also, this exotic vine inhibits growth of tree seedlings (Reference 35), and thus may pose serious problems for tree replacement in the future. Plant species which form colonies and carpet the forest floor are important in helping to control and prevent erosion by stabilizing stream banks and flood plains.

Trees and shrubs found in Rock Creek Park are listed in Appendix Table 5. According to Jorling (Reference 23), the park vegetation is undergoing secondary succession toward a mature climax community. The later stages of this succession are characterized by an upland community of mixed hardwoods dominated by several species of Quercus (oaks) and Carya (hickories), as well as by Liriodendron tulipifera (tulip tree) and Fagus grandifolia (beech). The shrub and understory layers are dominated by Acer rubrum (red maple), Cornus floridana (dogwood), Carpinus caroliniana (hornbeam), Nyssa sylvatica (Blackgum), Viburnum acerifolium (mapleleaf viburnum), V. dentatum (arrow-wood), and Vitas aestivalis (wild grape). The Rock Creek watershed is within the oak-chestnut forest association of the Piedmont section (References 26 and 27). Red, white, and black oak, along with the chestnut, are the dominant canopy species of this community. Due to the chestnut blight disease, tulip trees have replaced chestnuts as a co-dominant with the oaks.

The oak-tulip tree association borders the oak-pine association on the coastal plain to the east. Flood plain habitats feature the above mixed hardwood dominants plus Tilia americana (basswood), and Platanus occidentalis (American sycamore). However, here the shrub and understory layers are dominated by Acer negundo (box elder), Staphylea trifolia (American bladdernut), and Sambucus canadensis (elderberry). Few or no shrub and understory representatives of the upland habitat type are present.

Various species of trees and shrubs are associated with different amounts of soil moisture (Reference 46). Classifications include dry, well drained, bottomland, and wet (most tolerant to flooding). These species are indicated in Table 3-3. Some species are associated with several amounts of soil moisture; others are restricted to only one category.

TABLE 3-3
SPECIES OF TREES AND SHRUBS FOUND IN ROCK CREEK PARK ASSOCIATED WITH DIFFERENT AMOUNTS OF SOIL MOISTURE

Dry Sites:

- Acer rubrum
- Carya spp.
- Nyssa sylvatica
- Pinus virginiana
- Quercus alba
- Q. falcata
- Q. marilandica
- Q. stellata

Well Drained Sites:

- Acer rubrum
- A. saccharinum
- A. saccharum
- Diospyros virginiana
- Gleditsia tricanthos
- Juglans nigra
- Nyssa sylvatica
- Platanus occidentalis
- Prunus serotina
- Quercus falcata
- Q. marilandica
- Q. velutina
- Robinia pseudoacacia
- Ulmus alatus
- U. americana

Bottom Lands (seldom covered by standing water):

- Fagus grandifolia
- Fraxinus americana
- Liriodendron tulipifera
- Quercus falcata
- Q. phellos
- Q. primus
- Q. stellata
- Q. velutina
- Ulmus alatus
- U. americana

Wet Sites (excessive moisture most of the year):

- Acer rubrum
- Fraxinus americana
- Liriodendron tulipifera
- Magnolia virginiana
- Nyssa sylvatica
- Quercus phellos
- Ulmus americana
- Tsuga canadensis

Appendix Tables 6, 7, and 8 list the mollusca of the District of Columbia and vicinity based on the work of Richards (Reference 1). He collected species within a 20-mile radius of the capital in all directions. Unfortunately, specific locations of collecting sites were not listed. The region has more mollusk faunal similarities with the Coastal Plain than with the Piedmont even though the boundary (fall line) between those physiographic provinces passes through Rock Creek Park. The nomenclature of species names for the mollusca has changed greatly since Richards' study. Additional collecting should be undertaken to verify the occurrence and current status of these species and bring the nomenclature up to date by consulting current taxonomic references. Twelve species of pelecypods (clams) were reported from the Potomac River in the vincinity of Great Falls (Fairfax, Virginia and Montgomery, Maryland Counties), the C&O Canal, and with the District of Columbia (Reference 8). These would be the species which would presumably occur in Rock Creek (see Table 3-4).

TABLE 3-4
PELECYPODS (UNIONACEA) REPORTED FROM THE POTOMAC RIVER IN THE VICINITY OF ROCK CREEK

Scientific Name	Location
Elliptio complanata	Great Falls, Fairfax County, VA
E. lanceolata	Great Falls, Fairfax County, VA
Lasmigina subviridis	Great Falls, Fairfax County, VA
Alasmidonta undulata	Great Falls, Fairfax County, FA
Anodonta cataracta cataracta	Great Falls; District of Columbia: Aqueduct Lake
A. implicata	Potomac River, District of Columbia
Strophitus undulatus	District of Columbia: Aqueduct Lake
Ligumia nasuta	Potomac River, District of Columbia
Lampsilis cariosa	Potomac River, Great Falls; Cabin John, Montgomery County, MD
L. ovata	Potomac River, Great Falls; District of Columbia: C&O Canal; Great Falls, Montgomery County, MD
L. ochracea	Great Falls, Fairfax County, VA; Potomac River, District of Columbia
L. radiata radiata	Potomac River, Great Falls; District of Columbia; Anacostia River, District of Columbia

Fish form a necessary link in the completion of a pelecypod's life cycle. Glochidia are small immature clams which are temporarily parasitic on certain species of fish. These glochidial hosts serve to disperse the clams to suitable habitats. The disruption of this fish-clam relationship generally depends upon destruction of clam habitat, elimination of the fish host, or both (Reference 47). Thus, if one has an idea of which fish species occur in a watershed, he can predict which clams are present there and which ones will be threatened when their fish hosts are disturbed or eliminated by disruptions and alterations. Table 3-5 lists the clams which occur in the Potomac River near Rock Creek and their associated glochidial fish hosts. All these fish species occur in the lower Potomac (Reference 48).

Appendix Table 9 lists those crustaceans which are found in Rock Creek or probably would be found there if additional collecting was undertaken. The rarer crustaceans are discussed in the Rare and Endangered Species section of this report. Distributional and ecological information of the amphipods is given by Holsinger (References 3, 4 and 10). Gammarus fasciatus is found in lakes, rivers, small streams, and sometimes in springs along the Atlantic Coastal Plain. G. minus is a Piedmont species found in springs, while Crangonyx serratus is present in small permanent ponds, streams and ditches from the Washington, D.C. area south. C. shoemakeri occurs in temporary pools and ponds, springs, and small streams along the Piedmont and western portion of the Coastal Plain. Synurella chamberlaini is found from Maryland southward along the Coastal Plain in small streams, ponds, and ditches. Often it is associated with species of Crangonyx. In addition to Stygobromus kenki and S. hayi (discussed in another section), S. pizzinii occurs in Wetzel's Spring in Glover Archbold Park and probably in Rock Creek Park. It inhabits seeps, small springs, wells, and caves. S. tenuis potomacus is found in small springs southeast of the park headquarters and on the south side of the Zoological Park, and is a common species of shallow groundwater habitats in the Piedmont and Coastal Plain areas of the middle Atlantic States (Reference 3). Occasionally, this species is collected in association with S. pizzinii, S. hayi and S. kenki in Maryland and the District of Columbia. Also, it sometimes occurs with Crangonyx shoemakeri, an epigean form, and Asellus kenki, a semi-epigean isopod. S. tenuis potamacus competes successfully with S. hayi when both occur together.

Isopods which possibly would occur in Rock Creek Park are indicated in Appendix Table 9. Asellus communis has been reported in Maryland from creeks, rivers, ponds, and lakes, while A. kenki is discussed in another section of

TABLE 3-5
PELECYPODS (UNIONACEA) REPORTED FROM THE POTOMAC RIVER IN THE VICINITY OF ROCK CREEK AND THEIR ASSOCIATED GLOCHIDIAL FISH HOSTS (REFERENCE 47)

Clam Species	Fish Species (Common Name)
Elliptio complanata	Perca flavescens (Yellow Perch)
E. lanceolata	Not identified
Lasmigina subviridis	Prob. Cyprinus carpio (Carp)
Alasmidonta undulata	Possibly Catostomus commersoni (White Sucker) and Hypentelium nigricans (Hog sucker)
Anodonta cataracta cataracta	Cyprinus carpio
A. implicata	Alosa pseudoharengus (Alewife), Catostomus commersoni, Morone americana (White Perch), Lepomis gibbosus (Pumpkinseed)
Strophitus undulatus	Semotilus atromaculatus (Fallfish), Lepomis cyanellus (Green Sunfish), Micropterus salmoides (Largemouth Bass)
Ligumia nasuta	Possibly Anguilla rostrata (American Eel), Lepomis macrochirus (Bluegill), Pomoxis annularis (White Crappie)
Lampsilis cariosa	Not identified
L. ovata	Lepomis macrochirus, Micropterus salmoides (Largemouth Bass), M. dolomieui (Smallmouth Bass), Pomoxis annularis, Perca flavescens
L. ochracea	Not identified
L. radiata radiata	Ambloplites rupestris (Rock Bass), Lepomis macrochirus, Micropterus salmoides, M. dolomieui, Perca flavescens

this report. A. forbesi has been reported from Piney Branch (Rock Creek), Great Falls, and the Georgetown area. It occurs in temporary ponds, flood pools, sloughs, small creeks, and marshes (References 11 and 12). A. racovitzai racovitzai occurs in creeks, rivers, ponds, swamps and small lakes, and has been noted in the District and Maryland (Chain Bridge area). Lirceus brachyurus is a species found in springs and small streams of Northern Virginia and the Atlantic coast. L. lineatus occurs in rivers, creeks, sloughs, swamps, and lakes in Virginia.

Crayfish are important components of the stream fauna and those likely to occur in Rock Creek are indicated in Appendix Table 9. Orconectes limosus is the most abundant species in Maryland and is found in slow-moving, turbid streams of the Coastal Plain and Piedmont (Reference 2). Cambarus bartoni is most common in cold, small streams, with well-oxygenated water and a bottom of stones, sand, gravel and rubble from the mountains to the coastal plain. C. diogenes is a burrowing coastal plain species, while C. montanus acuminatus is found along the fall line between the Coastal Plain and Piedmont physiographic provinces.

Appendix Table 10 lists the butterflies that may occur in Rock Creek Park, based on the work of J.H. Fales. Extensive collecting of this and other insect groups in the park would probably add substantially to knowledge of the watershed fauna.

Fourteen species of fish have been reported from lower Rock Creek, from a short distance upstream of the Maryland-D.C. line to the mouth of the creek (Appendix Table 11). This is much lower than the thirty species of fish recorded for the whole length of Rock Creek (References 35 and 41). This decrease is undoubtedly related to the deterioration in water quality which has occurred over the years. A more complete discussion of this problem as related to fish will be presented in Chapter 8.

Rock Creek is used as a spawning area by several anadromous fish species (Gabor, personal communication). Fish eggs of Alosa sp. and Morone americana (White Perch) were found at Peirce Mill in 1974. Eggs and larvae of Alosa sp. were collected along Rock Creek Parkway and at a station below Massachusetts Avenue during this time. Dorosoma cepedianum (Gizzard Shad) and Alosa pseudoharengus (Alewife) have been reported to migrate upstream as far as Peirce Mill where they spawn (Reference 37). Van Huizen (Reference 59) found that Alosa pseudoharengus, A. sapidissima (Shad), Osmerus esperlantus (smelt), and Morone saxatilis (Rockfish) were caught by fishermen in Rock Creek. Also, the non-anadromous fish Micropterus dolomieui (Smallmouth Bass), M. salmoides (Largemouth Bass), Ictalurus punctatus (Channel Catfish), Perca flavescens (Yellow Perch), and Pomoxis annularis (White Crappie) were also reported as caught in Rock Creek even though Dietemann did not collect them in his 1974 survey (Reference 41). It is also possible that the anadromous species Alosa mediocris (Hickory Shad), A. aestivalis (Blueback Herring) and Ictalurus catus (White Catfish) may occur in the lower reaches of Rock Creek near its mouth since they have been previously collected in the lower Anacostia River (Reference 42).

Amphibians and reptiles reported from Rock Creek Park are listed in Appendix Table 12. The number of species and population numbers seems to have declined over the past 50 years (Reference 35 and Bob Ford, personal communication). This trend is especially evident in lower Rock Creek Park. Several reasons may account for this decrease in species numbers and in numbers of surviving species populations. Urbanization and its effects appear to be the major cause. Habitat modification by clearing of underbrush, planting grass, and mowing are also probable causes. Removal of turtles, frogs, and snakes as pets by humans, and the tendency to kill snakes have resulted in decreases. Automobile traffic also has caused mortality in populations. Pollution of habitats by auto emissions or spraying for mosquito control also add stresses to amphibians and reptiles. Water pollution and sedimentation also affect these animals by making their aquatic habitat less desirable (elimination of food sources, smothering of stream substrates, etc.). Flooding in the spring would wash away eggs of many amphibians since this is the time of the year when they breed. Thus, today most of the amphibians and reptiles in Rock Creek Park are found in secluded, marshy or rocky areas visited by few people.

Appendix Table 13 lists the birds of Rock Creek Park. The bird life of the area is diverse, due in part to many of the changes in land use which have occurred over the past half-century. Where once there was a uniform cover of forest, now there are fields, strips of woodlands, weed-bordered gullies, golf courses, picnic areas, and areas reverting back to forest. These support a variety of bird species.

Thirty-two species of mammals are found in Rock Creek today, a moderate decrease in the 44 species found there 250 years earlier (References 14 and 35). Among these were large mammals such as bear, bison, bobcat, elk, marten, mink, otter, porcupine, puma, and wolf. The beaver, once absent from the area, evidently is now again found in several areas of Rock Creek Park. The abundance of many species that remain in the park has decreased due to many of the same factors which have affected the herpetological populations. Some of these are water and air pollution, habitat modifications with less cover and food, human interferences, increased vehicular traffic and depredation by domestic dogs and cats.

Some species such as opossums and racoons have increased in numbers in recent years due to increased supplies of food in the form of refuse in trash cans and litter and to other animals killed by vehicles. Squirrels and various species of mice have benefited by urbanization because their predators have been reduced or eliminated. Also, the food supply and shelter for animals of this type have remained unaffected by urbanization. The black and Norway rats, house mice, and stray dogs and cats have been accidently introduced into the parks in the past and remain there in small numbers.

Flooding in Rock Creek caused by heavy rains and urbanization changes in the watershed have indirectly affected the non-herbivorous mammals by reducing their food supply. Birds, amphibians, reptiles, insects and other invertebrates have decreased in abundance and this, in turn, has affected mammals which feed on these sources. Deer and foxes are severely limited in Rock Creek since they need a large area which is free of harassment by people and stray domestic animals (Reference 35). The bat population of the area has probably decreased somewhat, probably because of toxic insect sprays used on farms and in gardens. Mice and other small rodents are usually not affected by urbanization activities.

ENVIRONMENTALLY SENSITIVE AREAS

When Rock Creek Park is viewed in the context of making up a portion of the greater Washington Metropolitan area, the park as a whole can be classified as environmentally sensitive. It is one of the largest natural parks within the boundaries of a major urban area in the United States. The park is noted for its picturesque and rugged beauty and is viewed by residents and visitors as an important asset and a place to relax, participate in recreational activities, and enjoy the park's natural attractiveness. The fate of Rock Creek is closely related to activities that occur in the upper watershed areas in Montgomery County. If flooding and overall water quality were to deteriorate, for example, due to increased urbanization in the county, this would in turn be reflected downstream in Rock Creek in the District.

Specific areas within Rock Creek and the low areas in the flood plain are environmentally sensitive. Many of the park picnic groves are located in these areas, and are susceptible to flooding. Flood plains are an important element in the ecological balance of a natural watershed as they support a whole regime of species of flora and fauna.

Springs are environmentally sensitive and are important to Rock Creek Park because they provide a continuing supply of fresh groundwater to the creek. In the past, many more springs were in evidence than now and they supplied water to the stream so that it remained at a more constant level throughout the year. With increased urbanization, many of the springs have been sealed or supply only a small amount of their former discharge to Rock Creek due to changes in drainage patterns to Rock Creek and a lower water table. Increases in water level due to flooding may cause problems near the springs including sedimentation, alteration of the spring habitat, and contamination due to wastes in the flood waters. Flash flooding may "wash-out" part of the fauna from the springs.

From a biological standpoint, there are reaches of the stream which are environmentally sensitive and valuable. Riffle habitats located at the National Zoological Park, Peirce Mill, Park Police Headquarters, and in several of the tributaries are potentially very productive both in terms of numbers and diversity of aquatic invertebrates and should be protected. Other environmentally sensitive riffles which should be protected include those at station 1, 3 and 4 and downstream of station 2 and 6.

The National Capital Region was surveyed by Thomas (Reference 22) for significant natural values such as unique plants, animals, and minerals. Several plants were present in Rock Creek Park which are uncommon or at the limit of their distribution. These are listed in Table 3-6.

Terrell (Reference 9) studied the plants along the Chesapeake and Ohio Canal, from Washington, D.C. to Seneca, Maryland, and found several species of plants to be rare, some of which occur in Rock Creek Park or may occur there based on the nearness and habitat similarities of both areas. They are, Ceanothus ovatus, Crepis japonica, Ellisia nyctelea, Erythronium albidum, Hybanthus concolor, Jeffersonia diphylla*, Lathyrus venosus, Liparis liliifolia*, Ophioglossum vulgatum, Ornithogalum nutans, Phacelia dubia, P. ranunculacea, Rubus phoenicolasius*, Scutellaria saxatilis, S. serrata*, Silene caroliniana, Smilacina stellata, Thalictrum steeleanum, and Tilia heterophylla. The species designated by an asterisk are areas which actually have been observed in Rock Creek Park.

TABLE 3-6
SIGNIFICANT PLANTS AND THEIR LOCATIONS IN ROCK CREEK PARK, WASHINGTON, D.C. (Reference 22)

Species Name	Common Name	Location	Comments
Adiantum pedatum	Northern Maidenhair Fern	Pinehurst Branch	Edge of species distribution
Osmunda claytonia	Interrupted Fern	Between Bingham Dr. and Wise Rd.	Edge of species distribution
Polypodium virginianum	Rock-polypody	Downstream of Sherrill Dr. - east side of Rock Creek	Edge of species distribution
Lycopodium obscurum	Ground Pine	Downstream of Sherrill Dr. - east side of Rock Creek	Uncommon
Gaultheria procumbens	Teaberry	Near picnic site No. 21	Uncommon

Significant and rare aquatic animals are found in the springs which drain into Rock Creek. The isopod Asellus kenki was originally described from a spring located near the Park Nature Center by Bowman (Reference 6). The species is an indigenous inhabitant of springs and spring-fed streams. Interestingly, in at least one anatomical feature, A. kenki is intermediate between an epigean (above-ground) species and a troglobitic (subterranean) species. Evidently, this species is adapted to a temporary subterranean existence. It is distributed in Northern Virginia (Fauquier, Fairfax, Arlington Counties), the District of Columbia (Rock Creek Park, Wetzel's Spring, Burleith Woods), and in Maryland (spring flowing into Rock Creek near Kensington, Maryland, Montgomery County and in Prince Georges County).

The ostracod, Potamocypris bowmani was described by Ferguson (Reference 5) from the same spring as Asellus kenki and is confined to the spring area. However, additional collecting should increase its distribution to other nearby connected springs. Also, there is always the possibility that additional undescribed species may be found in the area. In addition, there is an undescribed gastropod of the Family Hydrobiidae found at this spring.

Several rare and significant amphipods are found in the Park area. Stygobromus kenki, a troglobitic form, was described by Holsinger (Reference 3) from a spring southeast of the Park Headquarters. The species is confined to this spring. Stygobromus hayi was described by Hubricht and Mackin (Reference 42) from a small spring at the south end of the National Zoological Park and is also known only from this spring, the species type locality. Holsinger (Reference 14) feels its rarity may be due to its inability to compete successfully with another troglobitic amphipod S. tenuis potomacus, which also occurs in the same spring. S. hayi may be a select species on the path to extinction. S. hayi has been proposed as an endangered species (Federal Register, Vol. 42, p. 2507, January 12, 1977) but has not been placed on the most recent list of endangered and threatened wildlife and plants (Federal Register, Vol. 44, pp. 3636-3654, January 17, 1979).

The planarian Phagocata morgani morgani also occurs in the same spring as Asellus kenki and Potamocypris bowmani. This uncommon species is an inhabitant of springs, the upper parts of brooks, and cold creeks of eastern North America (References 44 and 45). No plants or animals were found which are on the current list of endangered and threatened wildlife and plants. If eligible for nomination, though, as with S. hayi, they should be treated as if they are on the list.

LAND USE, POPULATION, AND TRANSPORTATION SYSTEMS

The evolution of the metropolitan Washington, D.C. area has enveloped the Rock Creek Park on all sides, making it a virtual island in the midst of a mass of concrete, asphalt, and other man-made structures and surfaces. The only open land of any appreciable extent is that of parkland, recreational areas, cemetaries, or institutional grounds.

The pattern of land use and demographic distribution can be readily discerned in Figure 3-5. Construction of this map was coordinated with previous zoning and land use mapping (References 11, 12, and 13). The corridor of open land, the park itself, is apparent with the bulk, the original parkland acquisition, located north of Peirce Mill at Tilden Street-Park Road. Commercial and industrial corridors can be seen along several of the main arterial routes of the metropolitan area including; Georgia Avenue, Connecticut Avenue, Wisconsin Avenue, Massachusetts Avenue, 16th Street, and 13th Street. The lower, southeast end of the watershed comprises a portion of the Washington Central Business District that is almost entirely of commercial nature. A large industrial area of Silver Spring, Maryland is located on the B&O Railroad at the northeastern tip of the basin.

Grouped with the commercial/industrial areas in Figure 3-5 is the institutional land use category. Major elements of this use within the watershed are various public high schools, libraries, churches, the Walter Reed Army Medical Center, Dunbarton College, the U.S. Naval Observatory, the National Zoological Park, Washington Cathedral, and the University of the District of Columbia.

The rest of the watershed comprises residential housing of one form or another. Figure 3-5 shows four levels of density by which the residential land uses are classified. The high density or multiple family residential category includes high-rise buildings, apartment housing, and some dense row dwellings with more than 10 dwelling units per acre. Concentrated areas of this kind of development are found on the east side of the basin south of Missouri Avenue. A transition is observed in this area from row housing in the north to apartment and high-rise buildings in the CBD in the south. Other concentrations of high density development occur along Connecticut Avenue and in Georgetown on the west side of Rock Creek and in areas of Silver Spring in Maryland.

The next level of residential development is composed of row housing and semi-detached dwellings with densities from 5 to 10 dwelling units per acre. The vast majority of this type housing is found north of Missouri Avenue on the east side of the creek. Detached housing of densities of 2 to 5 dwelling units per acre predominate in the west side portion of the basin and the edges of the park itself. Low density residential areas within the area consist primarily of large estates and foreign embassies that generally are found on the western border of the park or in high income neighborhoods.

Although the metropolitan area of the District of Columbia has shown rapid growth since 1950, the District itself has had a slow but steady decrease in population from 802,000 to an estimated 707,900 in 1976. Within the entire Rock Creek Watershed, there are approximately 211,000 residents within the District and 199,400 in the upper, Montgomery County portion. The large majority of the Maryland population (approximately 178,000) is residing in the 30 square miles of the basin below Norbeck Road. The population forecast for the Montgomery County watershed by the Maryland National Capital Parks and Planning Commission projects a 42 percent increase by the year 2000. Hence, a shift of demographic distribution can be seen whereby the District population is slowly dwindling and the Montgomery County population is sky-rocketing.

The transportation system of the District of Columbia is a very obvious element within the Rock Creek Park Watershed as several major arterial routes dissect the area. As the Maryland suburbs evolved into the D.C. metropolitan area and the park become a recreational haven, the park roads were paved and widened, curves were eliminated, and tunnels were built. The scenic drive along the quiet and peaceful creek, once a retreat of several past presidents, is now a major route for commuter traffic. Beach Drive is now utilized by over 11,000 cars per day and the Rock Creek and Potomac Parkway has a traffic count of approximately 40,000 cars during a 24-hour weekday period. Major traffic corridors provide crosstown avenues that further divide the park at Military Road, Porter Street, West Beach Drive-Wise Road, and Tilden Street-Park Road. A well-developed net of secondary roads, mass transit bus lines through or near the park, and a developing regional subway system further enhance park access. Other major arteries within the watershed include Connecticut Avenue, Massachusetts Avenue, 16th Street, and Georgia Avenue-13th Street. In addition, at the mouth of the creek, vast amounts of cross-park traffic utilize the bridges at Q Street, P Street, M Street, Pennsylvania Avenue, and the Whitehurst Freeway.

SEWER SYSTEMS

Within the Rock Creek Park watershed there are three distinct types of sewer systems that convey stormwater and/or sanitary sewage; a) separate sanitary sewers convey only sanitary and industrial wastes with limited infiltration/inflow sources of surface and groundwater, b) storm sewers convey only stormwater runoff, c) combined sewers convey both sanitary waste and stormwater. The development of these networks to collect and dispose of sewage and stormwater runoff in the District of Columbia part of the Rock Creek basin originated in 1810 as a system of disjointed culverts and sewers that were constructed as a means of draining streets. These sewers normally discharged to the nearest natural waterway. With the development of water-flushed plumbing in the early 1800's, sanitary wastes were introduced into this network and it thus became a combined sewer system; one in which both stormwater and sanitary sewage are transported together. These sewers discharged to the now defunct Washington City Canal.

It was not until 1871, however, as a result of dramatic growth, that the first real sewer construction efforts began. The central and older portions of the District's sewers were originally designed as a combined sewer system, but, since the 1890's, it has been the policy of the District that all new sewer systems be separated. With the formation of the Washington Suburban Sanitary District (WSSD) in 1918, interceptor sewers in the surrounding Maryland suburbs were integrated with the Washington interceptors where possible. In the 1930's, a program of gradual sewer separation was initiated in selected combined sewer areas and in 1938 the construction of a primary wastewater treatment plant at Blue Plains was completed. The sewer separation program was intensified during the 1960's but was halted in 1970 due to escalating costs and the uncertain effectiveness of sewer separation as a pollution reduction alternative.

The present sewer system of the Rock Creek Park watershed in the District of Columbia comprises approximately 4,440 acres of combined sewer drainage and 6,030 acres of separate sanitary sewer drainage area. For a discussion of the storm sewer system of the watershed, refer to the section dealing with hydrology and hydraulics. The District of Columbia Department of Environmental Services is presently administrating a series of regionalized infiltration/inflow analyses of the D.C. sewer system. There are three of these drainage area reports, recently completed, that cover the Rock Creek Park watershed within District lines. The areas that these studies cover within the Rock Creek Park watershed as well as locations of combined sewer overflows are depicted in Figure 3-6.

A summary of statistical information from these reports is listed in Table 3-7 for sewer district areas within Rock Creek Park. In addition, descriptions of all combined sewer overflow structures that discharge to Rock Creek are included later in Chapter 9.

ROCK CREEK SEWER SYSTEM DRAINAGE BASIN

Drainage Area No. 1, in the report by Stearns & Wheler (Reference 8) covers the northern part of the basin and is referred to as the Rock Creek Sewer System Drainage Basin. It is served by the Rock Creek Main and Relief Interceptor Sewers which convey wastewater flows from 5,803 acres within the District basin as well as flows generated from the Rock Creek Drainage Basin in Maryland. Approximately 3,700 acres of this area (64 percent) is sewered (inhabited and sewered at the time of the study) and the remainder is predominantly parkland.

The D.C. study area is comprised mostly of residential areas with some neighborhood commercial establishments, public schools and small colleges and large areas of undeveloped park, primarily Rock Creek Park. Several large Federal government facilities are located in the study area, including Walter Reed Army Medical Center and the National Zoological Park. In general, the most densely populated portions of the study area are the southern portion and the Luzon Valley area on the east side of Rock Creek. These areas have numerous multi-family dwellings while the remainder of the study area consists mainly of single-family dwellings.

The Rock Creek Sewer System Drainage Basin in the District contains approximately 139 miles of public sanitary sewers ranging in diameter from 6 inches to 66 inches. The majority of the study area has separate or modified separate sewers (designed to carry a certain amount of stormwater from area drains and depressed driveway drains). Three sewer districts, Connecticut Avenue, Klingle Road, and Luzon Valley, were originally designed with combined sewers. However, most of the sewers in these three districts have been separated. This was accomplished by constructing a new sanitary sewer system that goes directly into the main interceptors and disconnecting all sanitary connections to the storm sewer system. Separation was not complete, however, due to homeowner refusal and there still remain approximately 35 buildings connected to the combined system in the Luzon Valley district and 110 in the Connecticut Avenue district.

TABLE 3-7
SANITARY SEWER SYSTEM DRAINAGE AREAS

Area Designation	Description of Sewer District	I/I Study Area	Total Area (acres)	Combined Area (acres)	Average Sewage Production Rate (mgd)	Population
C1	Greenvale St.	(1)	42	0	0.036	306
C2	Daniel Lane	(1)	55	0	0.014	122
C3	Parkside Drive	(1)	7	0	0.005	45
C4	Yorktown Rd.	(1)	64	0	0.043	364
C5	Portal Drive	(1)	266	0	0.295	2,503
C6	Juniper St.	(1)	98	0	0.113	961
C7	Whittier Pl.	(1)	50	0	0.052	442
C8	Pinehurst	(1)	456	0	0.374	3,178
C9	Rittenhouse St.	(1)	134	0	0.089	742
C10	Oregon Ave.	(1)	83	0	0.015	128
C11	Luzon Valley	(1)	627	(mixed)	2.206	16,216
C12	Montague St.	(1)	14	0	0.018	156
C13	Broad Branch Rd.	(1)	1711	0	2.389	20,279
C14	Blagden Ave.	(1)	212	0	0.139	1,177
C15	Tilden St.	(1)	62	0	0.038	319
C16	Melvin Hazen Park	(1)	45	0	0.043	360
C17	Porter St.	(1)	297	0	0.534	4,534
C18	Klingle Rd.	(1)	275	0	0.466	3,963
C20	Connecticut Ave.	(1)	123	123 (mixed)	0.637	5,409
Zoo	National Zoo	(1)	27	0	0.102	0
RCMI	Rock Creek Main Interceptor	(1)	1155	0	16.1[a]	0
G3	Normanstone & 28th St Cleveland Ave.	(3)	279	279 (mixed)	1.175	2,454
G4	Massachusetts Ave. - Whitehaven St.	(3)	58	58 (mixed)	0.028	44
G5	Montrose	(3)	122	122 (mixed)	0.088	173
G6	Q St.-31st St.	(3)	94	94	0.270	2,550
G7	M St.-27th St.	(3)	35	35	0.132	832

[a] Sewage production rate from Maryland connection to Rock Creek main interceptor.

TABLE 3-7
SANITARY SEWER SYSTEM DRAINAGE AREAS
(CONTINUED)

Area Designation	Description of Sewer District	I/I Study Area	Total Area (acres)	Combined Area (acres)	Average Sewage Production Rate (mgd)	Population
WRCDS I	Q St. and Olive St.-29th St.	(3)	100	100	0.116	1,131
WRCDS II	West Rock Creek Diversion Sewer	(3)	43	43	0.015	150
A	Piney Branch	(5)	480	480	0.809	8,259
B	"	(5)	316	316	0.850	9,336
C	"	(5)	250	250	0.607	6,767
D	"	(5)	186	186	0.543	5,996
E	"	(5)	127	127	0.608	6,821
F	"	(5)	91	91	0.395	4,300
G	"	(5)	66	66	0.170	1,925
H	"	(5)	70	70	0.293	3,346
I	"	(5)	410	410	1.201	12,525
J	"	(5)	69	69	0.070	807
L	"	(5)	189	189	0.907	10,194
M	"	(5)	119	119	0.805	8,883
K	National Zoo	(5)	117	0 (mixed)	-	0
N	Park Rd.-Irving St.-Ontario Rd.	(5)	280	280	1.206	13,542
O	Belmont Rd.-Mass. Ave.-24th St.	(5)	218	218	0.428	4,925
P	Northwest Boundary	(5)	293	293	1.572	15,187
Q	"	(5)	39	39	0.225	2,541
R	"	(5)	200	200	1.286	14,531
S	Slash Run	(5)	360	360	3.494	9,523
T	"	(5)	23	23	0.175	1,948
U	"	(5)	32	32	0.171	1,698
V	"	(5)	9	9	0.100	9
WX	Rock Creek Interceptor and ERCDS	(5)	29	0	0	0
			10,477	4,443	41.447	211,600

These two districts are still served by combined sewer overflow structures #80 and #79, respectively (see Figure 3-6). These structures are of the fixed orifice type, similar to that shown in Figure 3-7. As shown, a low dam or sump is built in the combined sewer and a diversion pipe conveys wastewater from the upstream side of the dam to the trunk or interceptor sewer. Generally, all the dry weather flow and a portion of the wet weather flow is diverted to the trunk or interceptor sewer. Flows in excess of the diversion pipe's capacity spill over the dam and discharge to Rock Creek. In some instances, if the interceptor flows under pressure, the direction of flow in the diversion might be reversed, thereby relieving the interceptor sewer, as well as discharging the entire flow of the combined sewer into Rock Creek.

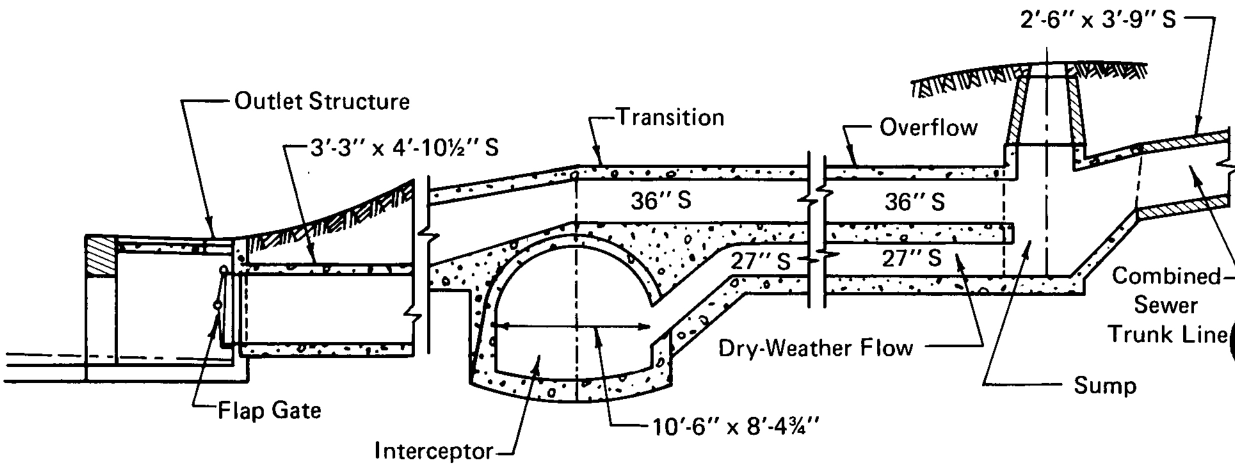


FIGURE 3-7. TYPICAL COMBINED SEWER OVERFLOW STRUCTURE

WEST ROCK CREEK SEWER SYSTEM DRAINAGE BASIN

Drainage Area No. 3 of the D.C. Department Environmental Services series of infiltration/inflow analyses was performed by EcolSciences, Inc. (Reference 9) and includes the West Rock Creek Sewer System Drainage Basin within its boundary. Approximately 731 acres of the drainage area are tributary to interceptors or diversion sewers along Rock Creek. All of this service area is either combined or incompletely separated sanitary sewers with points of combined sewer overflow to Rock Creek and the Potomac River. The drainage basin is characterized by concentrations of commercial development (shops, offices, restaurants) along Wisconsin Avenue and M Street, dense concentrations of residential townhouses

The Rock Creek Main Interceptor, as previously mentioned, conveys all flow from the Rock Creek Sewer System Drainage Basin (No. 1) plus all dry-weather flow from the east side partition of the West Rock Creek Diversion Sewer contributed by the Normanstone, 28th St.-Cleveland Avenue, and Massachusetts Avenue-Whitehaven Street Districts.

The West Rock Creek Sewer System Drainage Area comprises several districts where partial sewer separation work has been performed. The Normanstone District, 28th Street-Cleveland Avenue District, Massachusetts Avenue District, Whitehaven Street District, and Montrose District were all originally served by a system of combined sewers. During the separation project (beginning in 1966), separate sanitary and storm sewers were constructed in the districts with reconnection of catch basins and house laterals where necessary. The intention of the project was the conversion of existing combined interceptors to storm interceptors, where possible, to achieve total separation. As was the case in other areas, separation was not completed because of escalating costs and implementation difficulties. Consequently, the districts are now served by a mixture of partially separated sanitary sewers and combined sewers, which all discharge to sanitary interceptors. It is estimated that 111 residences and other buildings remain connected to the combined sewer trunks in these districts.

There are presently 8 combined sewer overflow structures within the West Rock Creek Sewer System Drainage Basin that discharge to Rock Creek. All but one of these overflow points occur at combined sewer trunk line connections to the main interceptors. Dry-weather flow connections convey all dry-weather and some storm flow to the interceptors and the excess discharges into Rock Creek. There is also a side-weir overflow point on the West Rock Creek Diversion Sewer (overflow #75) which relieves the WRCDS of excessive surcharge conditions.

PINEY BRANCH SEWER SYSTEM DRAINAGE BASIN

Drainage Area No. 3 of the DES infiltration/inflow analyses was completed by Corddry Carpenter Dietz and Zack (Reference 10) and comprises the Piney Branch Sewer System Drainage Basin. The entire basin except the areas of Rock Creek Park and the National Zoo are served by a combined sewer network draining a total of approximately 4,171 acres. Of this, 3,973 acres are tributary to Rock Creek and Piney Branch by a total of 22 combined sewer overflow structures (see Figure 3-6).

and high apartment buildings, and some single-family residential areas. There are several foreign embassies located within the area as well as the National Episcopal Cathedral and the U.S. Naval Observatory.

The drainage basin is served by three main interceptors; the West Rock Creek Diversion Sewer (WRCDS), the Upper Potomac Interceptors (UPI), and the Rock Creek Main Interceptor (RCMI). The West Rock Creek Diversion Sewer serves as a continuation of the Rock Creek Relief Interceptor beginning at Normanstone Drive for 1.5 miles to K Street. The sewer was constructed parallel to Rock Creek, with diversion connections from the sewer districts adjacent to Rock Creek. These connections permit all of the dry weather flow, as well as a comparatively large amount of stormwater flow, from these combined-sewer areas to enter the WRCDS. The discharges are conveyed to a regulator at K Street, where the dry weather flow plus a portion of the rain-related inflow is allowed to discharge to the Upper Potomac Interceptor and thence to the Rock Creek Pumping Station. Flows in excess of the receiving capacity of the UPI are discharged to the Potomac River near the mouth of Rock Creek.

A midline partition was constructed in a 3,400-foot segment of the WRCDS between the Q Street District connection near the P Street Bridge, and the Montrose District connection. The division of the WRCDS resulted in two separate sewage routing patterns. Discharges from sewer connections north of the partition, including the Normanstone sanitary and combined trunks and the Massachusetts Avenue-Whitehaven Street District, as well as the upstream reaches of the WRCDS, are conveyed on the east side of the partition to a control chamber at the downstream end. At this point, the flow is normally routed, by way of an inverted syphon under Rock Creek, to a connection with the Rock Creek Main Interceptor on the east bank of the creek. Discharges originating at the Montrose District connection and all those southward connected to the WRCDS are conveyed on the west side of the partition and downstream in the unpartitioned segment to the regulator at K Street.

The Upper Potomac Interceptor conveys the dry-weather discharges from several Georgetown districts west of the West Rock Creek Sewer System Drainage Basin plus that of the West Rock Creek Diversion Sewer to the Rock Creek Sewage Pumping Station at the intersection of K Street and 27th Street, N.W. on the east side of Rock Creek. The pumping station discharges to either the East Rock Creek Diversion Sewer, the Potomac Interceptor or the Rock Creek Main Interceptor, by which flows are ultimately conveyed to the Potomac River Interceptor Sewer.

The study area north of M Street is comprised mostly of residential areas of medium value with some neighborhood commercial establishments, public schools, hospitals, and a few hotels. In the study area south of M Street, a primarily mercantile tract exists, comprised of major office buildings, institutions, hotels and luxury apartments. Included in this area is the George Washington University, the Watergate Complex and the Kennedy Center. In general, population density increases in a southerly direction through the study area.

The Piney Branch sewer system drainage basin is predominantly of combined type. At present, the sewer system consists of sewers ranging in size from 4 inches in diameter to a concrete rectangular structure 18'-0" x 10'-0". With the exception of service connections there are approximately 213 miles of sewers. The sewers are owned and maintained by the District except for those located in the National Zoological Park.

There are two main interceptors that convey flow from the drainage basin and several large combined trunk sewers. The entire upper half of the system, comprising approximately 2,373 acres, drains to a large overflow structure at the head of Piney Branch (overflow #70) which eventually discharges to Rock Creek. Dry weather flow which is not diverted by this overflow structure discharges into and becomes the origin of the East Rock Creek Diversion Sewer (ERCDS). The ERCDS also picks up flow from several other large trunk sewers including the Northwest Boundary Trunk Sewer at 22nd and Q Streets, N.W. and the Slash Run Branch Sewer at 22nd and M Streets, N.W.

Drainage Area Nos. 1 and 3 (Rock Creek and West Rock Creek Drainage Basins) discharge flow into the study area just south of the Rock Creek Potomac Parkway in the vicinity of Belmont Road. At this point, flow is discharged directly into the Rock Creek Main Interceptor. The Piney Branch Interceptor conveys flow from the National Zoological Park and some small sewer districts and discharges to the Rock Creek Main Interceptor just south of Massachusetts Avenue.

Besides the Piney Branch combined sewer overflow (#70), there are 14 overflow structures on the East Rock Creek Diversion Sewer, 2 on the Piney Branch Interceptor, and 5 on the Rock Creek Main Interceptor within the drainage basin. All occur at combined sewer trunk line connections to the interceptors. In addition, there is an overflow point (overflow #55) on the ERCDS at the junction of the Northwest Boundary Trunk Sewer that prevents surcharge conditions in the ERCDS.

INSPECTION, MAINTENANCE AND REPAIR OF SEWER SYSTEM

Sewer maintenance within the District of Columbia is the responsibility of the Sewer Services Division of the Department of Environmental Services (DES). Approximately 70 employees are directly involved in sewer inspection and maintenance activities, 46 of whom are on field crews. These personnel are responsible for maintaining approximately 1,850 miles of sewers in the District of Columbia sewerage system. Because of the limited manpower in the division, no routine preventive maintenance program has been adopted and there has been no complete inspection of the system since the 1960's. Instead, maintenance is performed on a "complaint" basis to correct problems as they develop. Generally, the steps taken in answering a complaint are a follows:

- Answer complaint and attempt to identify problem
- Investigate problem and alleviate as best possible
- Evaluate extent of problem and means of total relief, where possible

The division has sewer cleaning equipment to reduce clogging where necessary; however, only persistent problems receive attention. It was the general feeling of Division personnel that a definite routine program for preventive maintenance is needed. Such a program could better define the causes of persistent problems and identify the means best suited for total relief, rather than the existing approach of "putting out fires" and shifting problems from one place to another.

Some of the main problems identified during sewer maintenance have included root intrusion and sewer surcharging, resulting in backups and flooding. Root intrusion was considered a frequent and widely-distributed problem, resulting in the sewer leaking and indicating that cracks and holes may exist throughout the system. Surcharging and backups are often caused both by clogging of pipes and by hydraulic deficiencies in sewers. These are most commonly associated with combined sewers, or sanitary sewers with storm connections, where storm inflow exceeds sewer capacity. These kinds of problems are prevalent under the present operational program mainly because they directly affect the service population and thus receive the most complaints. Under surcharge conditions, deteriorated sewer joints and manholes can, and have been observed to, result in exfiltration from the system. Other problems, which have been observed less frequently by the Sewer Services Division, include leaking manholes, grit in sanitary sewers, and inundated manhole covers.

Leaking manholes due to groundwater infiltration are generally observed only in the low-lying areas of the District, adjacent to creeks and rivers. A large portion of the Rock Creek watershed sewer system (mostly the main interceptors) are within the flood plain of Rock Creek and cross the creek in numerous locations (18 places on the main stem itself). Grit (sediment) was not considered a frequent problem in sanitary sewers. On the other hand, combined sewers which receive street washings and runoff are more likely to contain quantities of grit. The West Rock Creek Diversion Sewer was observed to contain sediment deposits up to 2 feet thick. Since manhole covers generally contain two lift holes, they may be susceptible to inflow from surface runoff during intense rain, or inundation if located on stream banks or near curbing. Vandalism and surcharging sometimes result in removal of manhole covers. In addition, shifting of the stream channel in the Rock Creek watershed due to erosion has exposed and damaged many sewer lines and outfalls and some manholes have been observed to be within the stream channel itself. This problem was considered to be small in magnitude by the Division, when compared to the direct sources of storm discharge both in combined and sanitary areas. In addition to the allowable sources of inflow in the sanitary system from area drains and depressed driveway drains, the Division suspects that some roof drains in older separate sanitary areas may be connected to sanitary sewers.

REFERENCES

1. National Oceanic and Atmospheric Administration, 'Local Climatological Data, Annual Summary with Comparative Data, 1978, Washington, D.C. National Airport', U.S. Department of Commerce.

2. Shosteck, Robert, 'Field Guide to Rock Creek Park', unpublished report, 1976.

3. Froelich, A.J. and Hack, J.T., 'Preliminary Geologic Map, District of Columbia', Open File Report 75-537, USGS, 1975.

4. O'Connor, J.V., Personal Memorandum, Geologically significant areas that should be included in Rock Creek Statement for Management, 1976.

5. U.S. Department of Agriculture, Soil Conservation Service, Soil Survey of District of Columbia, 1976.

6. Williams, Garrett P., Washington, D.C.'s Vanishing Springs and Waterways, Geological Survey Circular 752, 1977.

7. ____________, 'Some Historical Sites in the Rock Creek Parklands Needing Evaluation', memo and map supplied by National Park Service, Rock Creek Park.

8. Stearns and Wheler, Infiltration/Inflow Analysis Rock Creek Sewer System Drainage Basin, District of Columbia Department of Environmental Services, 1976.

9. EcolSciences, Inc., Infiltration/Inflow Analysis Drainage Area No. 3 Washington, D.C., District of Columbia Department of Environmental Services, 1978.

10. Corddry Carpenter Dietz and Zack, Infiltration Analysis Report Piney Branch Sewer System Drainage Basin, District of Columbia Department of Environmental Services, 1978.

11. Municipal Planning Office, District of Columbia, Zoning Atlas, District of Columbia, 1975.

12. U.S. Geological Survey, 'Land Cover Map from Landsat, 1973, with Census Tracts', Washington Urban Area, D.C., Maryland, and Virginia', Map I-858-F, 1978.

13. U.S. Geological Survey, 'Land Use Map, 1970, Washington Urban Area, D.C., Maryland, and Virginia', Map I-858-A, 1974.

CHAPTER 4
FLOOD HYDROLOGY AND HYDRAULICS

HYDROLOGIC ANALYSIS

Water moves through our environment in an orderly cycle of precipitation and evaporation. What happens to the precipitation between the time it falls and the time it evaporates back to the atmosphere is a complex process. This process, known as the hydrologic cycle, is illustrated in Figure 4-1.

In the hydrologic analysis for this study, the component of the hydrologic cycle of primary importance is surface runoff. During extreme rainfall events, surface runoff increases to unusual amounts, resulting in floods. Understanding the characteristics of these floods can help reduce damages from flooding.

The amount of precipitation which becomes surface runoff is determined by many factors. In a natural watershed, soils, vegetation type, size and shape of basin, and basin slope are important considerations. In watersheds whose characteristics have been changed by man, additional factors influencing runoff include land use (imperviousness), presence of reservoirs, and storm sewers. The urban development in the Rock Creek watershed is substantial, making the effects of manmade changes very significant.

A stream gage operated by the United States Geological Survey (USGS) has monitored the flow in Rock Creek at Sherrill Drive since 1929. Normally, past flooding records are the best indication of what to expect in the future. However, due to the changes in the Rock Creek basin in past years, the gage records cannot be used to extrapolate into the future. There are two significant factors in the watershed which have changed the runoff characteristics of Rock Creek. The first is the presence of two man-made lakes, Lake Needwood and Lake Frank, which were built in the upper Rock Creek basin in 1966 and 1968, respectively. These lakes decrease peak flows from the upper basin by temporarily storing the flood waters and releasing them at a rate slower than would have occurred naturally. The second factor is the urbanization of the area. Urban areas allow less infiltration into the ground and usually provide an easier path for water to reach the channels. Urbanization greatly increases peak floods over those of natural basins. The effect of urbanization is more pronounced on the more frequently occurring floods such as the 2.33-year mean annual flood and is illustrated in Figure 4-2.

For purposes of computing peak flows in this study, the Rock Creek watershed was separated into two distinct parts. One part is the area drained by Lake Needwood and Lake Frank. The remainder of the basin constitutes the other part. Peak flows from each part were determined independently and added together to give the total flow at points of interest downstream of the lakes. Even though the two parts of the watershed do not experience flood peaks simultaneously, the peak discharges from each area were simply added together because the flow from the lakes was a very small part (4-7 percent) of the total flow in the study area. The results are conservative in that any further refinement would produce smaller flood discharges.

The peak flows at the lake outlets were determined previously and published in the Stormwater and Water Quality Management Study - Rock Creek (Reference 2). The peak flows from the earlier report were adopted for use in this study and are shown in Table 4-1.

Anderson's Method was applied to the portion of the Rock Creek watershed not drained by the lakes. Anderson's Method is a statistical regression procedure developed by using recorded peak runoff rates from many gaging stations in the Northern Virginia-Washington, D.C. metropolitan area. The procedure computes the expected mean annual flood (recurrence interval of 2.33 years) for a watershed, and by applying factors to this mean annual flood, determines peak flows for various recurrence intervals. The important parameters required in the application of the methodology are:

1. The length of the main watercourse draining the area;

2. The average slope of the main watercourse;

3. The degree of development of the watershed; i.e., the percentage of the area sewered or with lined channels;

4. The percent of impervious surface in the drainage area; and

5. Size of the drainage area.

Anderson's Method was applied at twelve locations along Rock Creek in the District of Columbia. These locations and the subbasins which drain the area between them are shown in Figure 4-3. The twelve locations of interest were chosen at points of significant change in drainage

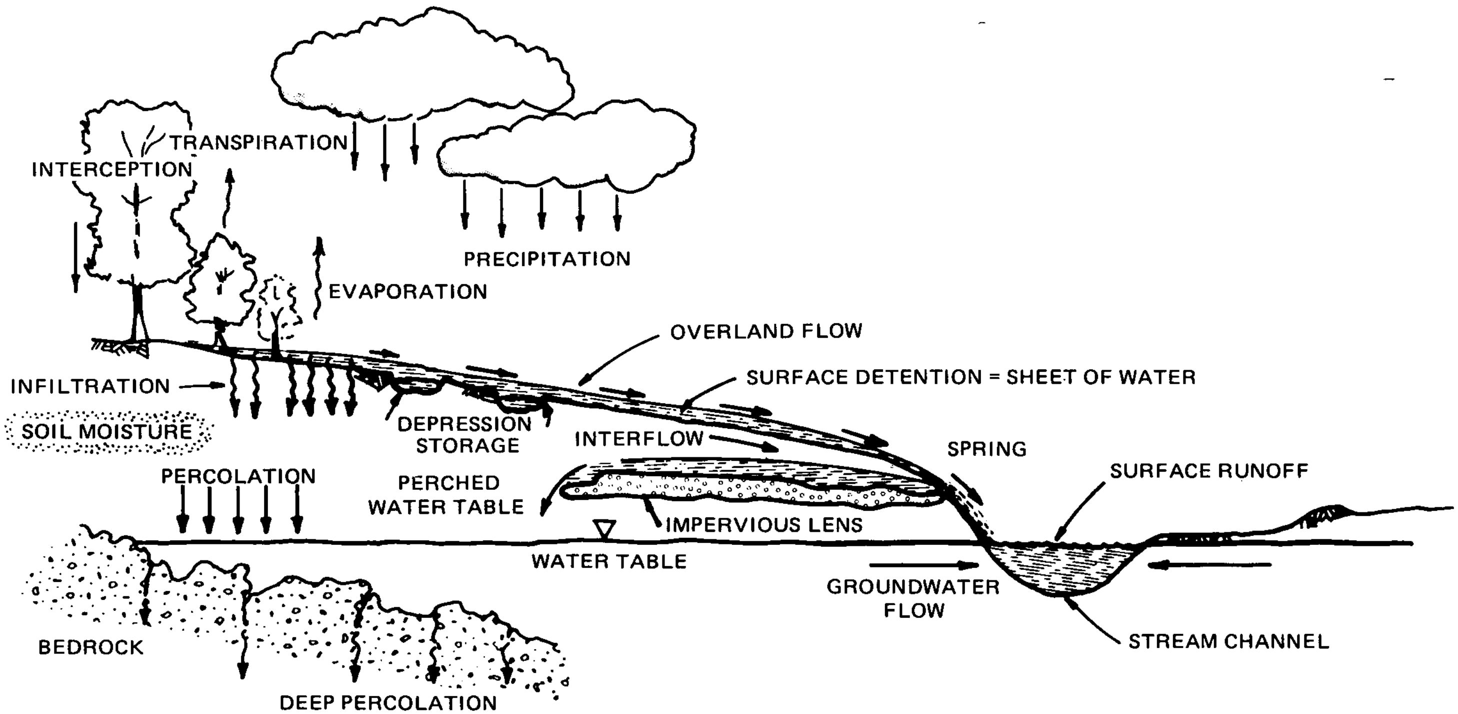


FIGURE 4-1: Hydrologic Cycle

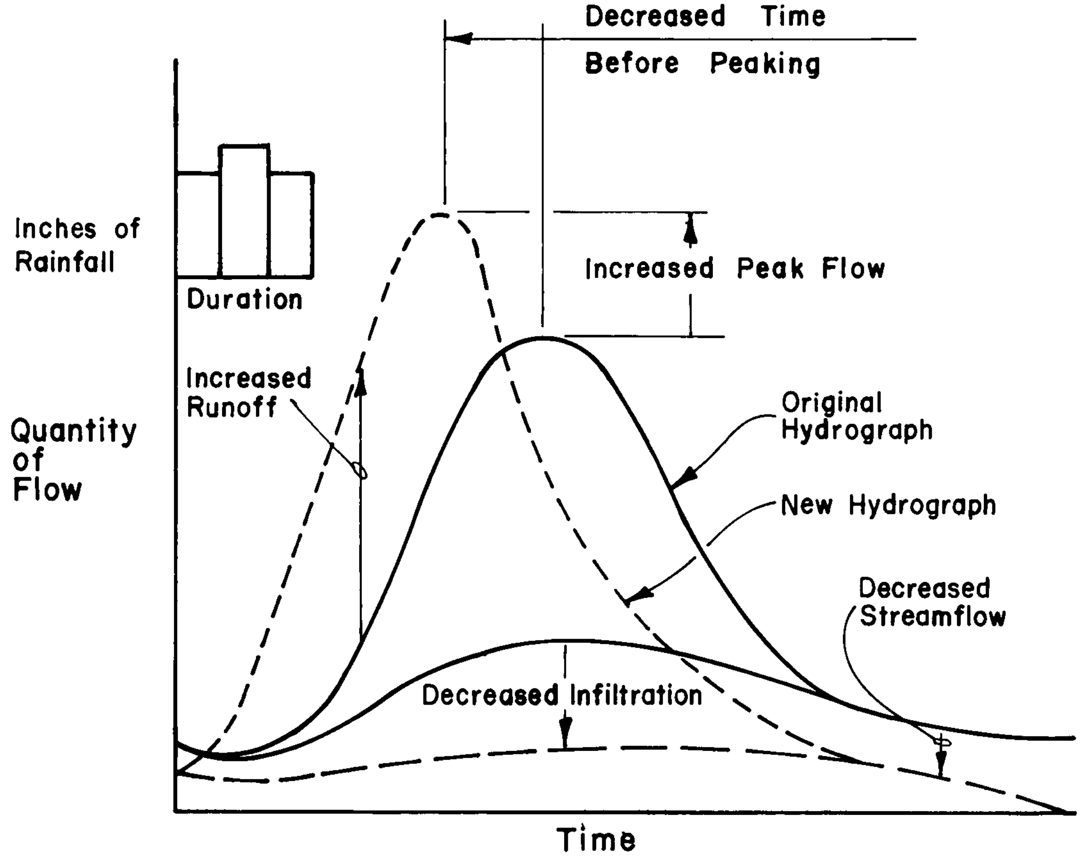


FIGURE 4-2: Impact of Urbanization as Reflected in Changes of Hydrograph

TABLE 4-1
PEAK FLOOD DISCHARGES FROM LAKE NEEDWOOD AND LAKE FRANK

Location	Land Use Condition[1]	Peak Discharge (cfs)				
		2-Year	10-Year	25-Year	50-Year	100-Year
Lake Needwood Outlet	E	75	230	240	250	255
	U	75	235	250	260	265
Lake Frank Outlet	E	60	190	245	265	270
	U	80	210	260	275	280

[1] E = Existing
U = Ultimate

area. The drainage areas of each subbasin were determined using storm sewer maps and topographic maps of the watershed. It should be noted that Subbasin 1 is the entire basin upstream of the Maryland-D.C. boundary. All information for this subbasin was taken from Reference 2.

The hydrologic parameters necessary for Anderson's Method were developed for each of the eleven remaining subbasins. Channel length, channel slope, and drainage area were determined from topographic maps and published streambed profiles (References 3 and 4). The percentage of impervious surface in each subbasin was determined using a weighted average of the imperviousness. This was accomplished by assigning a typical percentage imperviousness to each type of land use (see Chapter 9). The acreage of each land use type was determined for the total drainage area above each of the twelve subbasins. The acreages were multiplied by the appropriate percentage imperviousness and added to obtain a cumulative impervious area. The "weighted" impervious percentage was calculated by dividing this total impervious area by the total drainage area of the subbasin. Existing land use in the District of Columbia was determined by analysis of detailed topographic maps and land use maps (References 5 and 6). Ultimate land use in an area is the anticipated land use after development has stabilized such that no significant changes are expected in the future. As far as the hydrologic response is concerned, ultimate land use in D.C. was considered to be the same as existing land use, since no significant development or changes are expected in the watershed below the Maryland-D.C. boundary.

Anderson's Method develops a basin peak flow lag time as a function of length and slope for three classes of watershed;

1. Class U, a fully developed watershed,
2. Class N, a natural watershed, and
3. Class B, a partially developed watershed.

The degree of development for existing and ultimate land use conditions could not, in all cases, be adequately described by one of the above classes. Therefore, two additional classes of watershed development were approximated by interpolating between the curves developed by Anderson as depicted in Figure 4-4. Curve 4 corresponds to Anderson's curve for a Class B watershed. Curves 2 and 3 were obtained by interpolating between curves 1 and 4.

The assumptions of the degree of development pertaining to the curves are as follows:

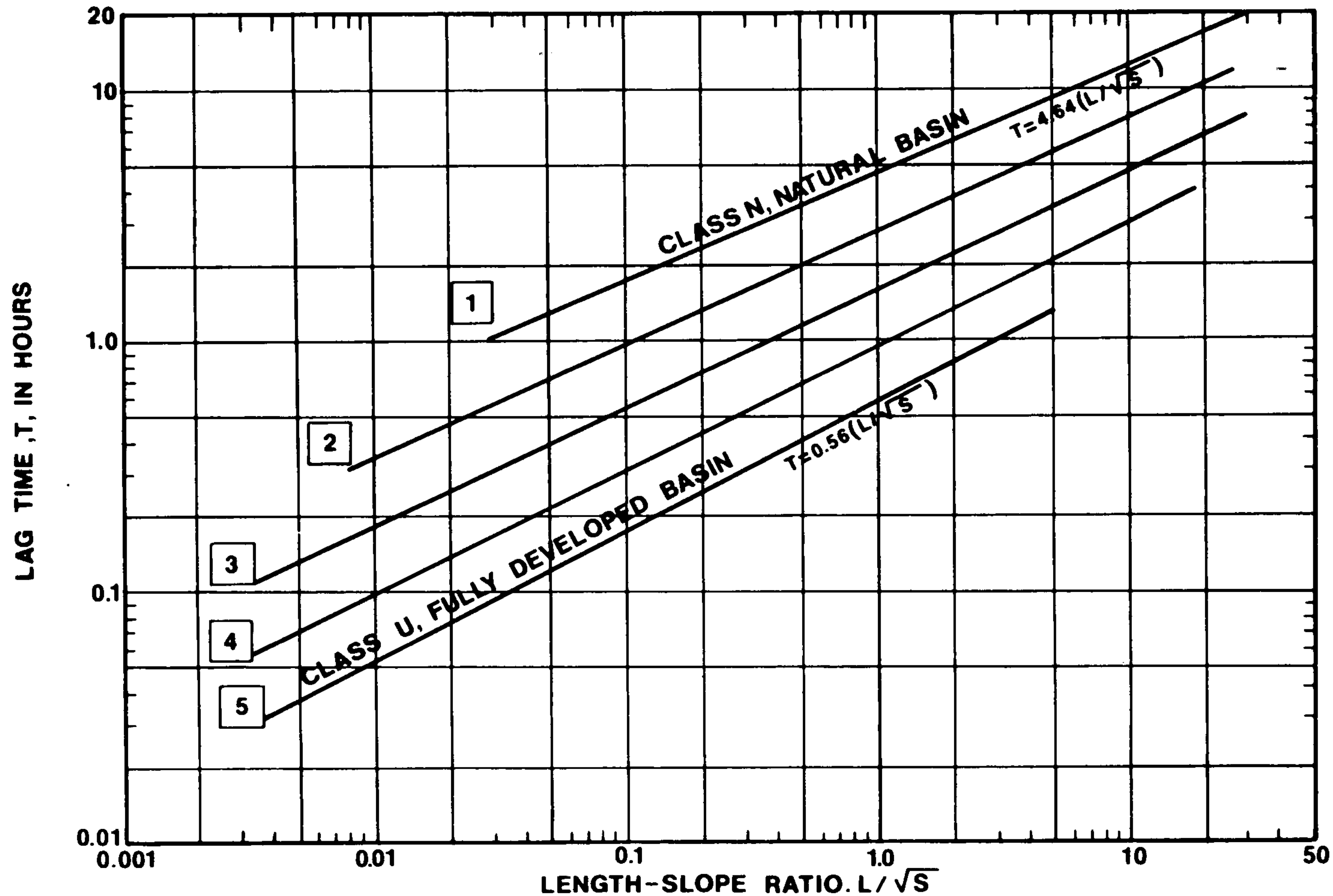


FIGURE 4-4: Relation Between Lag Time And Basin Length-Slope Ratio

Curve No.	Percentage of Area Sewered or with Lined Channels
1	0-5
2	6-35
3	36-65
4	66-90
5	91-100

Curve number 3 was used to represent the degree of development in the Rock Creek Basin. After the basin lag time is determined from Figure 4-4, Anderson's generalized equation is used to compute the "average flood". This average flood is the 2.33-year recurrence interval flood. Anderson's equation is as follows:

$$Q = 230\ KA^{0.82}\ T^{-0.48}$$

where Q = Magnitude of average flood (cfs)
K = Coefficient of imperviousness = 1.00 +.015 I
I = Basin imperviousness, (percent)
A = Drainage area (square miles)
T = Lag time (hours)

This relation has a standard error of -23.3 and +29.9 percent. A listing of input parameters to Anderson's Method for Rock Creek is shown in Table 4-2.

In addition to the magnitude of the average or mean annual flood for each point of interest, Anderson's Method gives ratios for computing floods of other recurrence intervals. Table 4-3 shows the total peak flows of various recurrence intervals at each point of interest under existing and ultimate land use conditions. These flows include both the results from Anderson's Method and the contributions from Lake Needwood and Lake Frank.

The peak flood flows estimated by Anderson's Method cannot be directly compared to the historic floods at the Sherrill Drive gage. The five greatest floods recorded at the Sherrill Drive gage since 1929 are listed below:

Rank	Date	Peak Flow* (cfs)
1	June 22, 1972	12,500
2	July 21, 1956	7,220
3	September 26, 1975	7,050
4	November 22, 1952	5,420
5	September 14, 1966	5,060

* From U.S. Geological Survey Records

TABLE 4-2
INPUT PARAMETERS FOR ANDERSON'S METHOD

Location*	Subbasin Drainage Area (sq. mi)	Total Drainage Area (sq. mi)	Length of Main Watercourse (mi)	Channel Slope (ft/mi)	Subbasin Imperviousness Existing (%)	Subbasin Imperviousness Ultimate (%)	Total Weighted Imperviousness Existing (%)	Total Weighted Imperviousness Ultimate (%)	Degree of Development Existing (Curve No.)	Degree of Development Ultimate (Curve No.)
1. Maryland - D.C. Boundary	33.89	33.89	18.7	15.67	28.0	34.0	28.0	34.0	3	3
2. 1000 feet D/S of Sherrill Drive	2.56	36.45	20.8	11.04	34.6	34.6	28.5	34.0	3	3
3. D/S of Military Road	1.65	38.10	21.7	9.82	21.0	21.0	28.1	33.5	3	3
4. U/S of Broad Branch	1.67	39.77	23.3	8.65	28.7	28.7	28.2	33.3	3	3
5. D/S of Broad Branch	2.61	42.38	23.3	8.65	39.6	39.6	28.9	33.7	3	3
6. U/S of Piney Branch	0.89	43.27	24.1	8.56	28.6	28.6	28.9	33.6	3	3
7. Porter Street	4.05	47.32	24.3	9.24	51.6	51.6	30.8	35.1	3	3
8. Connecticut Avenue	1.21	48.53	25.7	11.63	43.6	43.6	31.2	35.3	3	3
9. Massachusetts Avenue	0.86	49.39	26.2	11.71	41.4	41.4	31.3	35.5	3	3
10. Q Street	0.58	49.97	27.1	11.75	32.1	32.1	31.3	35.4	3	3
11. 1300 feet U/S of M Street	1.52	51.49	27.4	11.82	80.4	80.4	32.7	36.8	3	3
12. Mouth of Rock Creek	0.51	52.00	28.0	11.65	77.7	77.7	33.1	37.2	3	3

*D/S = Downstream; U/S = Upstream

TABLE 4-3
ROCK CREEK PREDICTED PEAK FLOODS

Basin No.	Location*	Land Use Condition	Peak Discharge (cfs) 2-Year	10-Year	25-Year	50-Year	100-Year
1	Maryland - D.C. Boundary	E	3,540	6,650	9,200	11,466	13,710
		U	3,780	6,880	9,400	11,570	13,730
2	1000 feet D/S of Sherrill Drive	E	3,530	6,630	9,170	11,420	13,660
		U	3,760	6,860	9,370	11,500	13,680
3	D/S of Military Road	E	3,570	6,720	9,290	11,570	13,840
		U	3,770	6,910	9,460	11,670	13,860
4	U/S of Broad Branch	E	3,590	6,750	9,330	11,630	13,900
		U	3,970	6,940	9,500	11,720	13,920
5	D/S of Broad Branch	E	3,810	7,120	9,840	12,240	14,620
		U	4,020	7,330	10,010	12,340	14,640
6	U/S of Piney Branch	E	3,840	7,180	9,910	12,340	14,740
		U	4,060	7,390	10,090	12,430	14,760
7	Porter Street	E	4,240	7,820	10,770	13,360	15,920
		U	4,420	8,010	10,930	13,440	15,940
8	Connecticut Avenue	E	4,380	8,080	11,120	13,800	16,460
		U	4,570	8,270	11,290	13,890	16,480
9	Massachusetts Avenue	E	4,420	8,160	11,240	13,940	16,630
		U	4,620	8,350	11,404	14,040	16,650
10	Q Street	E	4,440	8,180	11,260	13,980	16,670
		U	4,630	8,370	11,429	14,070	16,690
11	1300 feet U/S of M Street	E	4,620	8,440	11,580	14,320	17,040
		U	4,820	8,640	11,752	14,410	17,060
12	Mouth of Rock Creek	E	4,630	8,450	11,600	14,340	17,060
		U	4,830	8,650	11,768	14,430	17,080

*D/S = Downstream; U/S = Upstream
E = Existing Land Use
U = Ultimate Land Use

The peak flood flow estimated by Anderson's method for each return period of interest at the Sherrill Drive gage site is listed below:

Recurrence Interval (years)	Predicted Peak Flow (cfs)
2.33	3,530
10	6,630
25	9,170
50	11,420
100	13,660

Recurrence intervals cannot be assigned to the historic floods due to the changes that have taken place in the Rock Creek watershed. In 1972 Tropical Storm "Agnes" produced the largest flood recorded at the Sherrill Drive gage. Based on previous flood records in the region, that flood was estimated to have a recurrence interval of approximately 100 years. As shown in the tables, the estimated "Agnes" flood is slightly less than the 100-year flood peak determined by Anderson's Method. The difference in the two methods of estimating recurrence intervals can be attributed to the changing hydrologic characteristics of the watershed. If the gage records are used alone, the land use conditions are some average of the conditions over the period from 1929 to 1978. If Anderson's Method is used, the hydrologic response of present or even future conditions in the watershed is simulated. The recent development in the watershed is more accurately represented by Anderson's Method.

HYDRAULIC ANALYSIS

The flood hydraulics for this study consisted of computing water surface profiles for floods along the main stem of Rock Creek. Water surface profiles were computed for floods with recurrence intervals of 2.33, 10, 25, 50, and 100 years. The peak discharges used in the computations were determined as described in the previous section, Hydrologic Analysis.

Method of Analysis

Calculations and data organization for backwater computation are well suited for processing by computer. The computer program developed by the U.S. Army Corps of Engineers, HEC-2, was utilized for all flood profile computations in this study (Reference 7). This program was selected because of its wide use in flood studies, its general acceptability, and CH2M HILL familiarity and experience with its use. The same hydraulic model was used to study the Montgomery County portion of the Rock Creek Watershed.

The basic principle of the HEC-2 computations is a determination of total energy at each cross section, using Bernoulli's Theorem. Friction head losses between cross sections are computed by using Manning's formula. Although HEC-2 is a one-dimensional representation of the stream hydraulics, it contains other computational sequences to deal with the complex flow patterns around bridges and other situations. It can handle pressure and weir flow at bridges or culverts, levees in the flood plain, encroachment in the flood plain, channel improvements, and minor energy losses between cross sections, such as expansion or contraction.

There are several limitations of the HEC-2 program which can sometimes affect the accuracy of the results. Since the program is one-dimensional, it does not consider any flow other than parallel to the channel. If two- or three-dimensional flow is experienced in a certain area, approximations must be made to model the energy losses which accompany this type of flow. These approximations are in the form of Manning's "n", expansion and contraction coefficients, and bridge coefficients. Each of these will be discussed later. The HEC-2 program represents steady-state conditions only. This means the flood discharge is considered constant over time. In reality, the flow is continually changing, resulting in a somewhat lower peak elevation than predicted. Finally, the program does not model the effects of debris or unexpected obstructions. Downed trees or other large objects may block off portions of the flood plain or channel. These obstructions, particularly near constricted sections and bridges, increase flood elevations due to backwater and decrease velocities in the local area.

The HEC-2 computer program is flexible in the manner in which structures can be treated. Bridges with piers or special culverts can be specified with relative ease. Losses can be computed through a structure for low flow conditions, weir flow and pressure flow, or combinations of these.

HEC-2 Data Development

In computing water surface profiles for a stream, numerous characteristics of the channel and flood plain must be investigated. Before computations can begin, the following information is necessary:

1. Channel and flood plain geometry in the form of cross sections at various places along the longitudinal reach of the stream.

2. Channel and flood plain roughness estimations in the form of Manning's "n."

3. Information defining bridges, culverts, and weirs.

4. Energy loss coefficients for expansion and contraction of the stream channel.

Channel Geometry. The necessary channel geometry at each cross section is a two-dimensional depiction of the channel, using grid points in a plane perpendicular to the flow. A set of ground elevations and stations (distance along the section from an arbitrary point) was obtained for each cross section. This information was developed by the U.S. Geological Survey (USGS) in 1975 for a flood study performed for the Department of Transportation (Reference 8). The data collected by the USGS were adopted for this study.

A total of 151 cross sections on the main channel of Rock Creek between the D.C.-Maryland boundary and Potomac River were included. The distance between these cross sections ranged from 100 to 750 feet.

Channel and Flood Plain Roughness. Hydraulic roughness is a measure of the resistance to flow over a particular surface. A smooth surface, such as a concrete channel, offers little resistance and carries floodwaters relatively easily. A rough surface, such as a stream channel clogged with debris or overgrown with bushes, impedes the progress of the water. Flows in a "rough" channel will be slower and deeper than corresponding flows in a "smooth" channel.

The relative roughness of a surface is quantified in a term called Manning's "n." Manning's "n" values for surfaces are a function of the depth of flow. For example, the large rocks in some areas of the channel of Rock Creek represent a very rough surface to low flows and mild floods. During a more extreme event, such as the 100-year flood, these rocks are several feet under water. Floodwaters at this higher stage flow relatively unimpeded over the submerged obstructions. The larger floods will experience "n" values somewhat less than "n" values for the same reach under a lower submergence.

Another factor affecting hydraulic roughness is the degree of meander. A highly meandering stream possesses a high hydraulic roughness because of the dissipation of energy on banks from frequent changes in direction of flow. This effect would be most pronounced in the bank full condition and assume less importance with increasing overbank flow. For large floods, the water flow will generally follow the direction of the stream valley and shortcut meanders. This will reduce both travel time and meander roughness factors.

The analysis for this report required three roughness values at each cross section, a channel value and a value for each side of the flood plain. The "n" values estimated by the USGS for the earlier report were adopted for this study. Representative values of Manning's "n" for natural streams are shown in Table 4-4 (Reference 9).

<u>Bridge, Culvert and Weir Data</u>. Structures in the stream channel or flood plain are important considerations in computing water surface profiles. Constrictions in the channel or flood plain can produce a backwater effect that could conceivably cause flooding upstream of the constriction. This effect is planned in a dam or weir, but is not so obvious at bridge crossings. If the opening below a bridge is insufficient to carry the flow, water will back up until it finally flows freely over the roadway. In this situation, flood elevations upstream of the bridge will be higher than they would be under natural conditions. The HEC-2 computer program is designed to handle the special types of flow which occur at structures. Bridge routines covering low flow pressure flow and weir flow are available to handle the special situations.

The physical properties of the structures were taken from the USGS information. The required coefficients for the various types of flow were determined as recommended in the HEC-2 User's Manual (Reference 4).

TABLE 4-4
VALUES OF MANNING'S ROUGHNESS COEFFICIENT "n"(9)

Type of Channel and Description	Minimum	Normal	Maximum
I. Minor streams (top width at flood stage < 100 ft)			
a. Streams on plain			
1. Clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
2. Same as above, but more stones and weeds	0.030	0.035	0.040

Type of Channel and Description	Minimum	Normal	Maximum
3. Clean, winding, some pools and shoals	0.033	0.040	0.045
4. Same as above, but some weeds and stones	0.035	0.045	0.050
5. Same as above, lower stages, more ineffective slopes and 0 sections	0.040	0.048	0.055
6. Same as 4, but more stones	0.045	0.050	0.060
7. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
8. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
b. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
1. Bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
2. Bottom: cobbles with large boulders	0.040	0.050	0.070
II. Flood plains			
a. Pasture, no brush			
1. Short grass	0.025	0.030	0.035
2. High grass	0.030	0.035	0.050

TABLE 4-4
VALUES OF MANNING'S ROUGHNESS COEFFICIENT "n"[9]
(CONTINUED)

Type of Channel and Description	Minimum	Normal	Maximum
b. Cultivated areas			
1. No crop	0.020	0.030	0.040
2. Mature row crops	0.025	0.035	0.045
3. Mature field crops	0.030	0.040	0.050
c. Brush			
1. Scattered brush, heavy weeds	0.035	0.050	0.070
2. Light brush and trees, winter	0.035	0.050	0.060
3. Light brush and trees, summer	0.040	0.060	0.080
4. Medium to dense brush, winter	0.045	0.070	0.110
5. Medium to dense brush, summer	0.070	0.100	0.160

Type of Channel and Description	Minimum	Normal	Maximum
d. Trees			
1. Dense willows, summer, straight	0.110	0.150	0.200
2. Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
3. Same as above, but with heavy growth of sprouts	0.050	0.060	0.080
4. Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120
5. Same as above, but with flood stage reaching branches	0.100	0.120	0.160
III. Major streams (top width at flood stage > 100 ft). The n value is less than that for minor streams of similar description, because banks offer less effective resistance.			
a. Regular section with no boulders or brush	0.025	-----	0.060
b. Irregular and rough section	0.035	-----	0.100

In cases where a bridge opening was completely submerged, the orifice flow equation was used to compute the pressure flow under the bridge. This equation is:

$$Q = A\ 2g\ H/K$$

where,

Q = Pressure flow component of flood discharge (cfs)
A = Total area of opening below bridge (sq ft)
g = Gravitational acceleration constant
H = Elevation difference between upstream energy gradient and downstream water surface (ft)
K = Total loss coefficient

The total loss coefficient must be specified in the computer input. This coefficient is equal to 1.0 plus the sum of loss coefficients for intake, intermediate piers, friction, and other minor losses. The total loss coefficient for this study ranged from 1.1 to 1.3.

Where the bridge opening was inadequate to carry the desired peak discharge, the weir equation was used to compute flows over the roadway. The weir equation is:

$$Q = C\ L\ H^{3/2}$$

where,

Q = Weir flow component of flood discharge (cfs)
C = Coefficient of discharge
L = Effective length of weir controlling flow (ft)
H = Elevation difference between energy grade line and roadway crest (ft)

The HEC-2 Users Manual recommends a value of C between 2.6 and 3.0. A value of 3.0 was used for the bridges crossing Rock Creek. When a weir is submerged by the tailwater, the coefficient of discharge is lower than in the case of a free-flowing spillway. This reduction is done automatically by the HEC-2 program.

Expansion and Contraction Loss Coefficients. A fairly abrupt change in the configuration of the flow area in the form of a constriction or an expansion will result in a loss of energy. The magnitude of the loss is a function of the velocity of flow and a specified loss coefficient. Energy losses resulting from expansion are usually much larger than losses resulting from constriction.

Typical values for expansion and contraction coefficients are shown in Table 4-5. These coefficients are based on the rate of change in cross section shape.

TABLE 4-5
LOSS COEFFICIENTS

Change in Cross Section Shape	Expansion	Contraction
No transition	0.0	0.0
Gradual transition	0.3	0.1
Bridge section	0.5	0.3
Abrupt transition	0.8	0.6

Historic Floods

Records of previous floods can sometimes be used to calibrate and verify the accuracy of the computer model. Stage and discharge records of Rock Creek have been compiled by the USGS at the Sherrill Drive gaging station since 1929. The accuracy of the simulated flood elevations at this point was checked against the recorded flows. Figure 4-5 compares the stage-discharge relationship determined for this study with the USGS gage records for floods in the range of those studied in this report.

High water marks at Peirce Mill have been recorded unofficially whenever the mill has been flooded. The peak discharge associated with these floods is not known so a detailed calibration at this point cannot be attempted. However, the high water marks do give valuable information. Based on the results of this study, the flood stage recorded at Peirce Mill from the flood associated with Tropical Storm "Agnes" corresponds to a recurrence interval of 70 years. For comparison, the peak stage recorded at the Sherrill Drive gaging station for the same flood has a recurrence interval of 70 years.

Approximate flood elevations from the flood associated with Tropical Storm "Agnes" were available at various locations along Rock Creek. Since these high water marks were not recorded, the exact elevation cannot be determined. Nonetheless, they are useful in getting a "ballpark" estimate of the historic flood. A summary of high water marks associated with Tropical Storm "Agnes" is presented in Table 4-6.

TABLE 4-6
HIGH WATER MARKS FROM TROPICAL STORM "AGNES"

Location	Historic Flood Elevation (ft NGVD[1])	Computed 100-Year Flood Elevation (ft NGVD)
Massachusetts Ave.	39	40.0
Klingle Road*	62	65.2
Peirce Mill	70.2	71.5
Park Police Headquarters	147.0	147.0
Sherrill Drive	165.0	166.2

* Flood plain encroachments at the National Zoo following Tropical Storm "Agnes" may result in higher flood elevations at Klingle Road.

Starting Water Surface Elevations

Flood elevations at the mouth of Rock Creek are influenced by the stage of the Potomac River. Since it is highly unlikely that floods will peak at the same time on both the Potomac River and Rock Creek, flood elevations from each flooding source were determined independently. The higher of the two elevations is the critical flood elevation to be used in planning.

Using the cross sections supplied by the USGS, it was necessary to start the flood profiles for Rock Creek one thousand feet upstream from the mouth. Manning's equation was applied at cross section 1 assuming the slope of the energy grade line did not change appreciably between cross sections 1 and 2. Flood elevations at cross section 1 were determined independent of the Potomac River. Flood elevations on the Potomac River were determined separately at the mouth of Rock Creek and flood profiles for the first one thousand feet were interpolated. The water surface slope at the first cross section was

1 All elevations in this report refer to the National Geodetic Vertical Datum of 1929, formerly referred to as Mean Sea Level datum with the 1929 general adjustment.

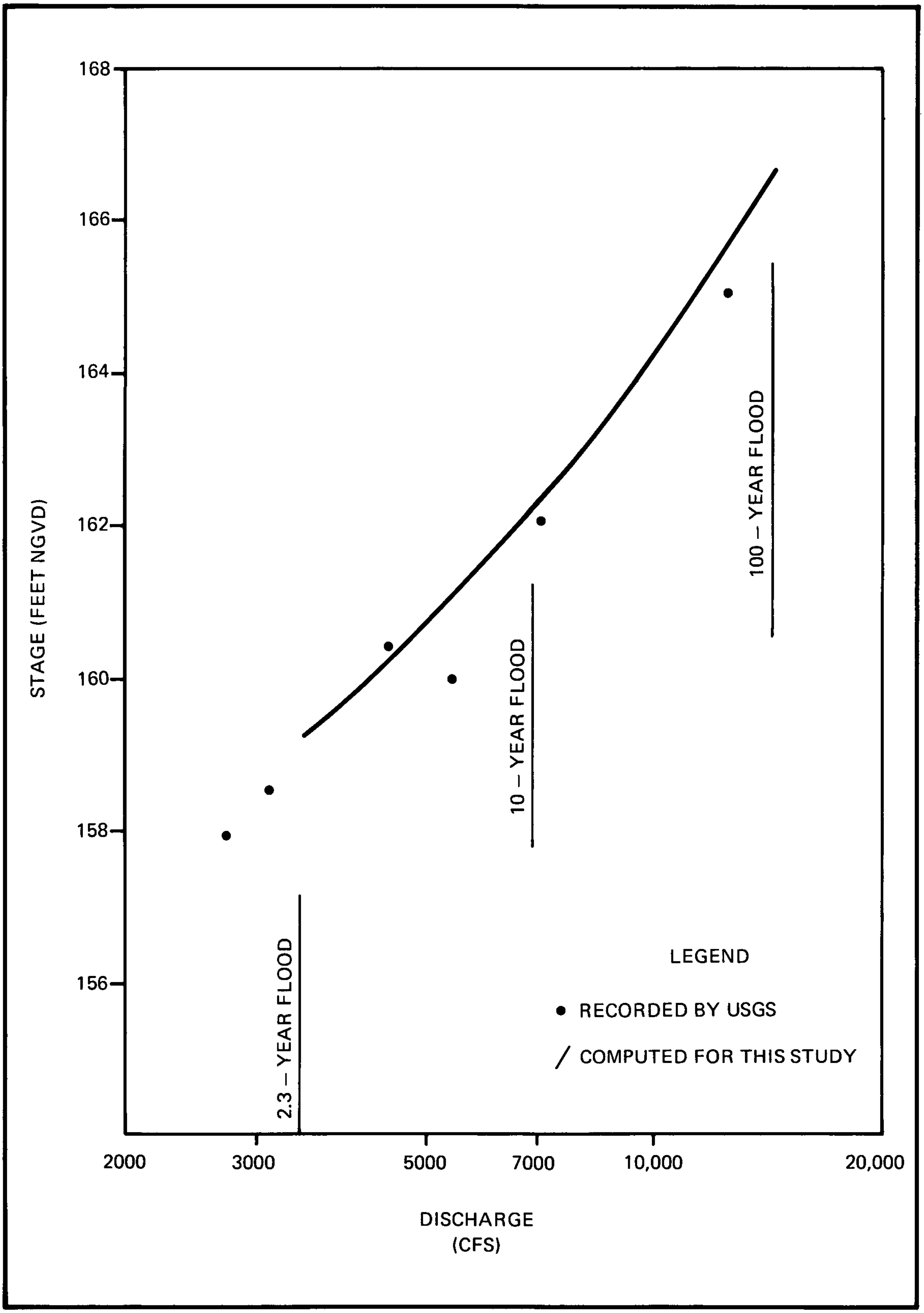


FIGURE 4-5: Stage-Discharge Relationship of Rock Creek at Sherrill Drive Gaging Station

continued downstream until it matched the corresponding Potomac River elevation. The Potomac River elevation alone was used beyond this point.

Even though the Potomac River exhibits tidal variation at the mouth of Rock Creek, the effect is notable only during low flow regime in the creek. The stage of the Potomac during flooding events is an assumption that was made independent of tidal consideration since the former far outweighs the impact of the latter as seen in the following discussion.

Peak stage records were obtained from the USGS for the tidal gaging station on the Potomac River one-quarter mile upstream from the mouth of Rock Creek. Annual peak stages were available from 1936 to 1973 and are listed in Table 4-7. Additional flood heights for various locations were available dating back to 1870. Due to the ususual scatter of the data, a useful stage-frequency curve could not be developed from the data. Instead, a discharge-frequency curve was developed for the Potomac River.

TABLE 4-7
ANNUAL PEAK STAGE OF POTOMAC RIVER

Year	Peak Stage[2] (ft NGVD)	Year	Peak Stage[2] (ft NGVD)
1936	15.9	1955	Not Available
1937	12.9	1956	4.0
1938	6.4	1957	3.8
1939	4.6	1968	4.3
1940	3.8	1969	4.0
1941	3.9	1960	4.9
1942	4.8	1961	4.8
1943	16.3	1962	5.5
1944	3.9	1963	4.9
1945	5.3	1964	4.4
1946	4.0	1965	4.4
1947	3.8	1966	4.0
1948	4.4	1967	5.5
1949	4.1	1978	4.2
1950	4.7	1979	3.6
1951	5.1	1970	4.5
1942	5.5	1971	4.4
1953	5.2	1972	14.1
1954	4.0	1973	4.9

2 Elevations adjusted from District of Columbia low water datum by subtracting 1.4 feet.

A streamflow gaging station with 84 years of record has been in operation on the Potomac River at Point of Rocks, Maryland. A frequency-discharge relationship was established at the gage site using a log-Pearson Type III frequency distribution (Reference 11). The individual storms at the tidal gage were assigned recurrence intervals based on the recurrence interval of the same storm at Point of Rocks. A stage-frequency relationship was derived from the plotted points and flood stages for the recurrence intervals of interest were determined from the graph. The results of the analysis are shown in Figure 4-6 and summarized in Table 4-8. It should be noted that Figure 4-6 contains one observation of Potomac River stage from 1889 which is not included in the systematic record in Table 4-7.

TABLE 4-8
STAGE-FREQUENCY RELATIONSHIP OF POTOMAC RIVER AT THE MOUTH OF ROCK CREEK

Recurrence Interval (years)	Potomac River Stage (feet NGVD)
2.33	5.1
10	9.4
25	12.0
50	14.0
100	15.5

Plan and Profile Sheets

Plan and profile sheets showing flood boundaries and elevations on Rock Creek were developed from Department of Transportation maps of Washington, D.C. These maps are at a scale of 1:2400, with a contour interval of five feet. Each plan and profile sheet shows a reach of Rock Creek with flood boundaries delineated for the 2.33-, 10-, and 100-year floods. The corresponding water surface profiles are shown for all five floods of interest (i.e., 2.33-, 10-, 25-, 50-, and 100-year floods). A location index to the plan and profile sheets is shown in Figure 4-7. The plan and profile sheets themselves have been reduced and included as an appendix to this report.

Plan and profile sheets were prepared for ultimate land use conditions only. Even though water surface profiles were computed for existing land use, the results were so

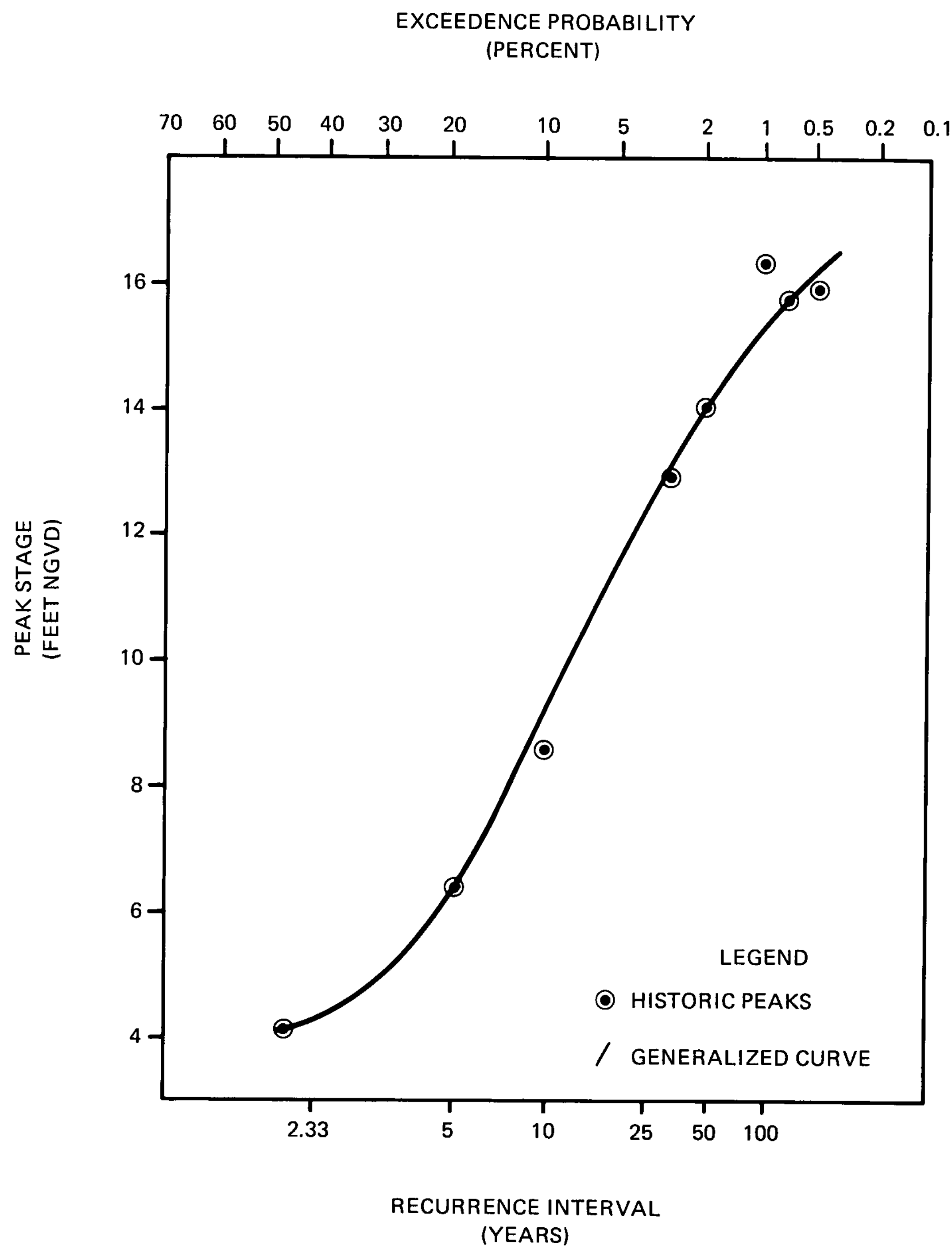


FIGURE 4-6: Stage-Frequency Relationship of Potomac River at Mouth of Rock Creek

close to the ultimate land use that no additional information would be furnished had plan and profile sheets been. developed for the existing conditions. The average differences in water surface elevations between existing and ultimate land use conditions are shown in Table 4-9.

TABLE 4-9
DIFFERENCE BETWEEN EXISTING AND ULTIMATE LAND USE CONDITIONS

Recurrence Interval (years)	Average Difference in Flood Elevation Between Existing and Ultimate Conditions (feet)
2.33	0.3
10	0.2
25	0.1
50	0.1
100	0.0

This small difference, plotted on 5-foot contour mapping, would make no difference in the flood boundaries and only an unnoticeable difference in the water surface profiles. Similar flood plan and profile sheets are available for the Montgomery County reaches of Rock Creek and tributaries from the Maryland - National Capital Parks and Planning Commission as a product of its stormwater and water quality management study.

Notes on Using Plan and Profile Sheets

It is the nature of flood plain mapping to be confusing in congested areas where several flood boundaries are shown. In areas where the different flood boundaries are so close together that they cannot be shown distinctly, the boundaries have been shown with the priority of 100-year, 10-year, and 2.33-year. Where a bridge crosses the flood plain at a high elevation, the flood boundaries have been stopped short of the structure, indicating the roadway is not flooded. If the roadway is below the flood elevation, flood boundaries are carried straight across the road at the appropriate elevation.

In the profile portion of the plan and profile sheets, only the bridges near the flood plain have been shown. The bridge elevation is indicated with the I-beam symbol (I). The top of this symbol indicates the elevation of the roadway at the centerline of the stream; the bottom of the symbol indicates the lowest part of the bridge at the stream centerline.

The base maps with 5-foot contour topography that were used to delineate the flood plain were provided by the National Park Service. Because of recent modifications to the flood plain in the vicinity of the National Zoological Park since the time these base maps were produced, the flood limits in this area may be significantly changed. However, channel cross sections utilized in the HEC-2 hydraulic program reflect the encroachment accurately such that the profile portion of the plan and profile sheets are correct. With updated contour plotting, the flood limits could easily be changed, also.

REFERENCES

1. Anderson, Daniel G., "Effects of Urban Development on Floods in Northern Virginia", Geological Survey Water Supply Paper 2001-C.

2. Maryland National Capital Park and Planning Commission, "Stormwater and Water Quality Management Study - Rock Creek", by CH2M HILL, Inc.

3. U.S. Department of the Interior, Geological Survey, "7.5-minute Series (Topographic) Maps", Scale 1:24000; Contour Interval 10 feet; Gaithersburg, Maryland (1945); Kensington, Maryland (1965); Rockville, Maryland (1965); Washington West, D.C. (1965).

4. Montgomery County Planning Board, "Flood Plain Information - Rock Creek", Plan and Profile Sheets, 1977.

5. District of Columbia, Department of Highways and Traffic, "Topographic Maps of the District of Columbia"; Scale 1:2400; Contour Interval 5 feet; 1965.

6. U.S. Department of the Interior, Geological Survey, "Land Use Map, 1970; Washington Urban Area, D.C.; Maryland; and Virginia", 1974.

7. U.S. Army Corps of Engineers, Hydrologic Engineering Center, Computer Program 723-X6-L202A HEC-2 Water Surface Profiles, Davis, California, December 1968 with updates.

8. U.S. Department of the Interior, Geological Survey, Flood Plain Delineation for Rock Creek Basin, Washington, D.C., for the Department of Transportation, Federal Highway Administration, 1976.

9. Chow, Ven T., Open-Channel Hydraulics, McGraw-Hill Book Company, 1959.

10. U.S. Army Corps of Engineers, Hydrologic Engineering Center, HEC-2 Water Surface Profiles, User's Manual, Davis, California, November 1976.

11. U.S. Water Resources Council, "Guidelines for Determining Flood Flow Frequency," Bulletin No. 17, Hydrology Committee, March 1976.

CHAPTER 5
CHANNEL EROSION AND FLOODING PROBLEM IDENTIFICATION

Erosion and flooding problems can be divided into two classifications; long-term trends or single events. Problems associated with long-term trends in the stream system are more easily controlled since they can sometimes be identified before they become critical. Problems caused by single events are those similar to the results of Tropical Storm "Agnes," where sudden widespread damage is caused with little warning.

Long-term channel erosion will be addressed under erosion, while problems associated with inundation during major storm events will be discussed under flooding. Only the generalized problem areas are identified herein and specific sites and recommendations are addressed in Chapter 7. The problems associated with sedimentation, although related to flooding and channel erosion, will be discussed in subsequent chapters dealing with water quality and environmental issues.

CHANNEL EROSION

Erosion and deposition in stream channels are natural processes which tend to orient channels in a stable configuration. A stable channel is one where the net change in stream channel characteristics over the long-term is zero. That is, any localized erosion is, in time, balanced by sedimentation near the eroded area, and vice versa. These channel characteristics include bottom width and elevation, bank slope and height, and sinuosity of the stream channel (degree of meandering).

In a stable channel, the bank full discharge meets the following two conditions (Reference 1):

1. The discharge can maintain the channel shape without scour of the banks or bed, and without sediment deposition.

2. The banks are not topped frequently enough for berm buildup to be appreciable.

This bank full discharge in a stable channel is called the dominant discharge. In a natural stream, the dominant discharge is, for channel forming purposes, the constant discharge which is equivalent to the widely varying natural flows. Wolman and Leopold found that this dominant discharge in stable channels had an average recurrence interval of 1.4 years (Reference 2).

Erosion and deposition are always acting to try to stabilize a channel. Three of the most obvious characteristics of a channel striving for stability are changes in width, depth and slope. If these three features are not constant over time, the channel has not reached a stable configuration. This instability could be attributed to a number of causes, such as an unusually severe flood which has drastically reshaped the channel, changes in upstream land use which alter the incoming sediment load, and changes in the dominant discharge. As a result of any of these factors, the channel will be in transition and seeking a stable configuration.

When urbanization begins to change the hydrologic response of a watershed, changes in sediment yield and dominant discharge can severely impact a stream system. As the stream channel strives for equilibrium under the new conditions, problems can arise when this new equilibrium is incompatible with existing conditions of the channel and flood plain.

During urban construction, sediment yield from the unprotected land surface can increase the stream load substantially.

Wolman (1964), Guy (1965), and Yorke and Herb (1978) have found annual sediment yields in developing areas of Maryland to be 100,000 tons/mi^2 or more (References 3, 4, 5). This figure can be compared to 20 tons/mi^2 for forest land and 500 tons/mi^2 for agricultural areas (Reference 6). Once construction has been completed, the sediment yield of urban land will return to a much lower value; however, it may remain above the predevelopment figure. York and Herb determined the average annual sediment yield from several urban areas in Maryland to be 2,400 tons/mi^2 (Reference 5).

Increased sediment yield from developing areas can cause erosion, deposition and flooding problems in downstream channels. During large flood events, the increased sediment load will be deposited in localized bars. These sand and rock bars affect the lower flows by redirecting portions of the flow against banks which had not previously been exposed to high velocities. Usually, the bank will begin to erode from the new pressure. The sand bars left after floods will eventually erode or get carried away by another large flood, but they could have a significant impact on the channel during their lifetime. When construction is completed, the large source of sediment will diminish and the sand bars will be less numerous.

The localized sedimentation problems associated with changes in watershed sediment yield from urbanization are usually overshadowed by changes associated with larger runoff from the developed area. Anderson reported that peak discharges for the mean annual flood could increase by a factor of up to 8, but for most cases in the Washington, D.C. area, a factor of 2 to 3 could be expected (Reference 7). If the mean annual flood increases by a factor of 2 to 3, the channel-forming dominant discharge (the 1.4 year flood) will increase by about the same amount. With such a large change in dominant discharge, a previously stable channel will undergo radical changes in its quest for equilibrium. These changes can threaten some land uses near the channel.

In order to estimate the magnitude of channel widening due to urbanization, the relationship found by Leopold and Maddock will be used (Reference 8). Studying numerous United States rivers, they found that moving along any particular river, the width varied with discharge (Q) of a given frequency in this way:

$$\text{Channel Width} = KQ^{0.5}$$

The exponent, 0.5, was an average value, which varied somewhat from river to river. The coefficient, K, fluctuated considerably from river to river. However, to use the relationship derived by Leopold and Maddock, it is not necessary to determine the coefficient, K. It is sufficient to know the fact that along any particular stream the width is proportional to the square root of the flow. That is, if the dominant discharge should double, the average channel width can be expected to increase by about 40 percent.

In order to apply the relationship of Leopold and Maddock to Rock Creek, it is necessary to know something about the channel geometry before the intensive development. It is also necessary to know the ratio of the dominant discharge for ultimate land use conditions to the dominant discharge for the earlier, presumably stable, condition. Isolated cross sections from the mid-fifties are available from a hydraulic study done by Michael Baker, but there is insufficient detail to make generalizations (Reference 9).

Flood discharges under natural conditions can be estimated using the same analysis as for existing and ultimate conditions. In studying the effects of urbanization on floods in the Washington, D.C. area, Anderson determined the mean annual flood at the Sherrill Drive gage site to be 1620 cfs (Reference 7). This analysis was based on an imperviousness of 5 percent (compared with 28.5 percent today). If 1620 cfs is taken as the mean annual flood under predevelopment conditions, then the expected mean annual flood under ultimate land use conditions, 3760 cfs, is roughly twice as large.

It can be assumed that the ratio of the dominant discharges is roughly equal to the ratio of mean annual floods. Using the width-discharge relationship described earlier to compare natural and ultimate conditions:

$$\frac{W_2}{W_1} = \frac{Q_2^{0.5}}{Q_1^{0.5}}$$

where, W_2 = Stable channel width under ultimate conditions
W_1 = Stable channel width under natural conditions
Q_2 = Dominant discharge under ultimate conditions
Q_1 = Dominant discharge under natural conditions

Since $Q_2/Q_1 = 2$, W_2/W_1 will be about 1.4. The stable channel width under ultimate land use conditions is expected to be about 40 percent wider than the stable channel under predevelopment conditions.

EXISTING CONDITIONS

In order to see how the channel of Rock Creek has reacted so far to the higher discharges, flow characteristics were determined for the 1.4-year flood (dominant discharge) using the HEC-2 computer program. Wherever a significant amount of the flow is outside the channel, erosion can be expected to attack the banks. At 59 of the 151 cross sections, two percent or more of the flow was out of bank. Referring to the plan and profile sheets (see Appendix) at the following cross sections, five percent or more of the flow was out of bank:

23, 62, 74, 83, 89, 91, 97, 111, 118, 119,
121, 123, 126, 128, 129, 130, 132, 133, 134,
135, 136, 139, 140, 141, 142, 145, 146, 147,
148, 149, 150

These cross sections represent most of Rock Creek between Peirce Mill and the Maryland-D.C. line.

Erosion problems will be created when the following three conditions exist; 1) there is pressure to erode, 2) the banks are composed of erodible material, and 3) damage will be caused by erosion. With the increase in dominant discharge from upstream development, the pressure to erode exists over the entire length of the stream. Since erosion will occur wherever the banks are not protected, this discussion will be limited to areas where erosion will interfere with man's use of the flood plain. If other areas are determined to need protection, appropriate control strategies can be undertaken.

Between the mouth of Rock Creek and Peirce Mill, the channel of Rock Creek is largely protected by walls and riprap. In areas where the banks are not protected, erosion is occurring leaving exposed tree roots and vertical banks. Wherever roads are near the creek, they are protected by walls, but where the roads are away from the channel, the flood plain is usually left free to erode. This erosion is severe in some places, but the only immediate threat is to the bicycle path in a few areas. The walls and riprap which have been placed along this lower reach of Rock Creek appear to be preventing damage adequately. However, the protection is lacking in some areas and all areas should be inspected regularly to identify flaws before drastic cave-ins occur. Since the flow is confined to a channel which is no longer wide enough, any break in the protection will experience erosion.

Upstream of Peirce Mill to the Maryland State line, the artificial bank protection is not so prevalent. In general, erosion is occurring along the entire length except along the fall line between Joyce Road and Boulder Bridge. The large boulders and rock channel bottom are a natural armor protection that reduce erosion problems, but riprap is still required in some sections.

Where Beach Drive is located close to the channel, riprap is generally present but in many cases is not placed correctly and will not be totally effective. The existing protection, if any, in areas identified as problems in this report should be inspected to determine the adequacy of the fortification. Where deficiencies are noted, proper repairs should be made.

Erosion and localized deposition in the natural flood plain sections is severe in some areas; however, nothing is in immediate danger from the erosion. Where sewer lines cross the channel, care should be taken to insure that there is no undermining and collapse of the structures. Presently, these sewer crossings are safe, but a large flood event could expose them to danger.

Localized erosion is evident on many of the tributaries and along the mainstem of Rock Creek due to inadequate design of sewer outfalls. Gullies have formed along banks where outfalls do not extend to the stream and protection at outfalls by stilling basins and/or energy dissipators is the exception rather than the rule.

FLOODING

The intensive development in the Rock Creek watershed has changed the hydrologic response of the area such that floods are larger and more frequent than under natural conditions. This change is due to the increase in imperviousness of the land surface due to the urbanization in recent years and construction of storm sewers to carry the flows. The impervious surface prevents infiltration and allows more water to run off into the streams. The construction of storm sewers facilitates a more rapid transport of the stormwater to the stream system, thus creating a 'flashier' type of hydrograph. Since the channel has not adjusted to these higher flows (see previous discussion), they overflow the stream channel to the flood plain much more frequently.

The Rock Creek watershed has been developing since colonial times and significant changes are evident over this period. However, it is only in recent years that urbanization has been demonstrated to have a significant impact on floods. Based on conditions in the Rock Creek watershed in 1966, Anderson determined the mean annual flood at the Sherrill Drive gage site to be 1620 cfs (Reference 7). In the 14 years from 1965 to 1978, this value was exceeded 20 times. Using Anderson's methodology, under ultimate land use conditions, the mean annual flow at Sherrill Drive is determined to be 3760 cfs. This value is more than twice the predevelopment figure. With larger and more frequent floods, flooding problems are becoming more common in the Rock Creek watershed.

As noted in Chapter 4, the difference between corresponding flood elevations under existing and ultimate land use conditions is very small. For this reason, only ultimate land use conditions will be considered in the discussion of flood problems.

Roads and Bridges

Other than the major city streets that cross Rock Creek high above the stream valley, there are 17 streets which cross the flood plain of Rock Creek in the study area. The risk of flooding at each of these crossings is shown in Table 5-1. It should be noted that the minimum elevation of the roadway in some cases is not located on the bridge itself. Rather, the low point with the deepest flooding is along the approach to the bridge. Table 5-1 reflects the lowest point of the road in the vicinity of the stream crossing.

The chance or probability of inundation of each bridge during any one year is also indicated. A probability in

Table 5-1
Flooding of Stream Crossings

Stream Crossing	Minimum Elevation of Roadway	100-Year Flood Elevation	Depth of Flooding	Percent Chance of Flooding in any Year
K Street	18.6	18.7	0.1	1-2
Rock Creek and Potomac Parkway at C&O Canal	18.8	23.7	4.9	4-10
Rock Creek and Potomac Parkway at P Street	26.1	32.0	5.9	4-10
Rock Creek and Potomac Parkway near Connecticut Avenue	34.4	42.5	8.1	10-50
Waterside Drive	39.4	44.0	4.6	4-10
Rock Creek and Potomac Parkway at Calvert Street	36.4	45.2	11.2	10-50
National Zoo (at Beach Drive)	42.8	48.2	6.6	10-50
National Zoo (at Harvard Street)	51.1	55.7	4.6	4-10
Porter Street - Klingle Road	76.0	62.3	***	<1
Klingle Road	60.9	65.2	4.3	4-10
Park Road - Tilden Street	70.0	70.6	0.6	1-2
Beach Drive at Broad Branch	73.8	75.6	1.8	2-4
Beach Drive at Boulder Bridge	84.4	88.6	4.2	4-10
Joyce Road	149.7	153.6	3.9	4-10
Beach Drive at Milkhouse Ford	158.8	160.0	1.2	2-4
Sherrill Drive	165.4	167.2	1.8	2-4
West Beach Drive	180.6	175.1	***	<1

*** Not inundated by the 100-year flood.

excess of 50 percent would mean the crossing would be flooded by the 2.33-year flood. Table 5-1 indicates no stream crossings as being flooded by the mean annual flood (2.33-year flood). This is true; however, the Rock Creek and Potomac Parkway and Beach Drive are inundated in some stretches where they parallel the stream channel. Flooding along these roads by the mean annual flood is summarized in Table 5-2.

Table 5-2
Flooding of Roads by Mean Annual Flood

Location	Maximum Depth of Flooding from 2.33-Year Flood (ft)	Length of Roadway Inundated (ft)
Rock Creek and Potomac Parkway (southbound) between Q Street and Massachusetts Ave.	2.8	2,200
Rock Creek and Potomac Parkway at Upstream Side of Massachusetts Ave.	3.0	2,000
Beach Drive Just Upstream of Confluence with Broad Branch	3.0	700
Beach Drive Between West Beach Drive and Maryland Line	4.5	2,400

Footbridges

There are 11 footbridges which cross Rock Creek within the study area. Since it is unlikely that these crossings will be in use during a flood event, mere inundation by the floodwaters does not pose a problem. A flood problem will only be created if damage is caused to the structure that necessitates repairs. Testing the structural integrity of the bridges under flooding conditions is beyond the scope of this report. Types of damage that can commonly occur are: walkway surface buckling, pitting, or cracking; walkway and railing washout; abutment undermining and erosion; erosion of tie-in to stream bank; or complete washout.

The structure elevations are compared to predicted flood elevations on the plan and profile sheets.

Erosion and Deposition

Erosion and deposition during floods can cause widespread damage over the entire length of Rock Creek. Any time flood waters reach places which are usually safe from flooding, localized scour can be expected to occur. This scour will be most pronounced in areas of natural soil or fill which are not protected by rock, stone or other nonerodible material. The scour in erodible areas strips away the foundation from roads and other structures, causing cave-ins. Especially susceptible to scour are areas where high velocities are created by constrictions in the flood plain. Bridge sections with improperly protected banks can experience severe scour from the concentrated flow. A prime example of this is the L Street Bridge collapse caused by Tropical Storm "Agnes." The foundation for the north span was completely washed out on one side, leading to the collapse.

Since most of the study area is a national park, aesthetics and preservation of recreational areas are important considerations in assessing flood and erosion problems. Even though erosion may not cause damage to roads or other structures, the destruction of picnic areas and parklands can be substantial. Depending on local conditions, large gullies could be cut, mounds of sediment could be deposited or general degradation of the stream banks could occur. Some picnic areas have been known to wash away completely in a large flood, necessitating major renovation projects.

Structures

Other than several buildings along the Potomac River, only six major structures are located within the 100-year flood plain of Rock Creek in the District of Columbia. These are two buildings at the National Zoo, Taft Stable under Connecticut Avenue Bridge (Taft Bridge), Peirce Mill, the Park Police Headquarters, and Miller Cabin. The building on Connecticut Avenue and the Park Police Headquarters are on the fringe of the 100-year flood plain and would not be subjected to high velocities or great depths during a flood. Peirce Mill and Miller Cabin are very low to the stream, but would not suffer great damage in a flood due to the nature of the buildings. The buildings at the National Zoo are low to the channel also. During Tropical Storm "Agnes," over 6 feet of water was in the boiler room, but no serious damage was done. An adjacent building is used for storage and would suffer little damage in a flood.

More commonly damaged are structures and equipment in picnic areas. By design these areas are located close to the stream and are exposed to the most damaging forces of the flood waters. Picnic tables, swingsets, trash containers, and other debris are carried away causing additional damage downstream.

SUMMARY

Due to the wise land use in the Rock Creek flood plain, erosion and flooding do not cause such serious problems as in other watersheds. The danger to human life is minimal and the potential damage to structures is small since there are only six buildings in the 100-year flood plain. The principal problems of erosion and flooding are the destruction of roads and bridges, and damage to recreational and undisturbed park areas.

Due to increased flood peaks from upstream development, roads and bridges are subjected to worse damage than under predevelopment conditions. Anderson estimated a mean annual flood of 1620 cfs at the Sherrill Drive gage site for the predevelopment period of 1929 to 1966. Under ultimate land use conditions, this flow will be more than doubled to 3760 cfs. For this reason, many previously safe areas are now in danger of erosion or flood damage. Wherever roads and bridges are subjected to floods, the foundations should be protected by nonerodible material to prevent undermining of the structure.

Since aesthetics are an important consideration, artificial fortification of the banks may be undesirable. In areas where channel widening would cause only loss of parkland in the flood plain, taking no action may be the best solution. The stream will establish a new stable channel to carry the higher flows. Once this occurs, the channel will assume a more pleasing appearance, with more mildly sloping banks and with less bank cave-ins. Channel and flood plain damage from large floods is generally unavoidable but the long-term trends of the channel can be brought under control with proper planning.

A summary of the principal erosion problems in Rock Creek is shown in Figure 5-1. The tributaries were not studied in as great detail as Rock Creek, and do not pose as many problems as Rock Creek. Where problem areas were noted in the course of field work on the tributaries, they have been included in this section.

ECOLOGICAL IMPACT

Urbanization occurring within the Rock Creek watershed over the years has resulted in the construction of storm drainage systems to rapidly remove large volumes of storm water. Impervious materials and structures such as concrete, asphalt, and different types of residential and commercial buildings constructed in the watershed necessitated installation of these systems to convey the increased runoff. Where the rainfall once soaked into the ground and recharged the ground water supply, water now runs off roofs, streets, and parking lots into the stormwater drainage system and then into the stream. The ecological effects of this action are examined in detail below.

The effects of flooding and channel erosion result in several changes in the physical stream environment. These changes in turn affect the plants and animals which live in the stream. Impacts to the ecology result from:

- Fluctuation of water level.
- Increase in sediment, silt load, and turbidity in the water column.
- Deposition of sediments and silt in the stream bed and along the margins.
- Abrasion and scouring of the stream by the sediment and silt particles.
- Increase in stream velocities due to increased runoff and more rapid conveyance to the stream channel.

AQUATIC BIOTA

It has been well documented in the ecological literature that streams which are more susceptible to floods have a less abundant and less diverse population of animals (Reference 10). In fact, it has been found that in areas in a watershed where the forest is cleared and consequentially the intensity of runoff increases, the variety and abundance of the stream fauna is decreased (Reference 11). All parts of the stream community are affected, from the algae and aquatic plants, to the plankton, benthic macroinvertebrates, and fish.

Algae are common community components and normally occur in all surface waters exposed to sunlight (Reference 12). When stream discharge is low and the water is clear, large populations and growth of algae are present on all substrates, including stones, rocks, boulders, submerged wood and other objects. Silt surfaces commonly appear brownish in color due to large populations of diatoms.

These surfaces will be dotted with patches of blackish-green filamentous blue-green algae. These low water populations are very unstable, and as a result, a single storm event may wash large quantities away. In effect, the algae on substrates are "scoured" away and smothered by silt.

Occurrence of rooted aquatic plants or macrophytes is governed by many factors, one of which is susceptibility to floods. At very low current speeds the stream bottom is inhabited by still water macrophyte species. In areas where the scour of high water keeps rocks and other substrates clear of fine organic silts and deposits, only a few species occur, notably some aquatic mosses and members of the Family Podostemaceae. Members of this family are aquatic flowers commonly called riverweeds. *Podostemum ceratophyllum* occurs in the eastern United States as a mat attached to substrates in rivers. As turbidity increases, fewer aquatic macrophytes are found because photosynthesis is hindered by the decrease in light. On course gravel, plants such as *Potamogeton* spp., with tough stems and stolons and a well-developed adventitious root system, can maintain a foothold in the substrate, even under high water conditions.

Plankton is affected by floods and silt. Any stream which is always turbid will contain few plankton (Reference 11). Many small crustaceans, for example, cladocerans, are eliminated by silt. They feed unselectively on materials caught in their appendages. In turbulent water, they almost always ingest some silt and small sand grains. As a result, they become heavy and are no longer able to maintain their position in the water column. They sink and are swept away with fatal results. The number of rotifers is reduced by silt. Rotifers are, in general, less common in silty rivers than in clear areas (Reference 13).

Periods of high water, due to floods, reduce the mass of benthic macroinvertebrates in streams. Recovery of the invertebrate populations occurs very slowly with recolonization occurring from the headwaters in the case of aquatic insects. The high water carries many animals downstream and this recolonization is related to the rate of drift from the upstream areas. A flood may affect the center portion of a stream, but not the stream margins. Some groups of invertebrates appear to be affected in a greater degree by floods, than others. Even within some species the effect may vary with size, as the larger individuals are more susceptible. The increase in current causes the invertebrates to be swept away.

Silty habitats also contain fewer animal species. Common to this type habitat are tubificid worms, chironomids, and burrowing mayflies (Ephemeridae). These aquatic insects are adapted to living in silty habitats by having flattened bodies which are covered with numerous hairs. These adaptations enable the animal to avoid sinking and smothering by keeping the animal's body free of fine silt particles. Silt also causes difficulty in constructing tunnels by some benthic invertebrates. Small animals are enveloped and smothered. Fauna, for example crayfish and darters, occurring on stony stream substrates is changed by siltation (Reference 14). In general, the fauna of clear, stony reaches of a stream is richer in the diversity and quantities of animals than that of silty reaches and pools (Reference 15.)

Floods and the consequent instability of flow and increases in silt in rivers affect fish. Eggs and young fish can be destroyed by high water and smothered by silt. Flooding of areas adjacent to the stream may cause some stranding of fish when the waters recede. Most species of fish have fairly well-defined diets and invertebrates form an important part. When invertebrate populations decline due to flooding, fish are forced to utilize other food sources or forage in other areas of the stream where invertebrates are more common. Some species of fish also utilize algae growing on substrates. If the algae are scoured from substrates by sediment, then again, fish must change food sources and/or stream areas.

TERRESTRIAL BIOTA

The effects of flooding on plants should also be discussed since flood plains are extremely productive and diverse ecosystems (Reference 16). There are both short and long-term responses which the plant life will exhibit when flooding occurs. During flooding an anaerobic environment is created around the plant root system which interferes with normal root functions. A variety of stresses are created, including hormonal changes, effects on water and nutrient uptake, water and food transport, photosynthesis, and transpiration.

Plant tolerance to flooding is governed by the degree of growth of adventitious roots and new secondary roots under low oxygen conditions. Proper root function must be maintained in order for the plant species to survive. Adaptations of plants to flooding can be categorized into physical and metabolic. Both types function to decrease the stresses caused by the creation of an anaerobic environment. Physical adaptations are comprised of processes designed to increase the oxygen content in the roots. This increase is accomplished by oxygen transport from the stem or from parts of the root system where oxygen is more available. Metabolic adaptations involve modifications to anaerobic respiratory pathways which enable the plant to use less toxic end-products. These end-products are transported to the upper portions of the plant. Due to these adaptations both aerobic and anaerobic respiration is utilized at the same time and at different rates.

Various water level factors may affect the response of plants. These include time of the year in which flooding occurs, frequency and duration of floods, flood water depth, and siltation. Except for the most tolerant plant species, growth rates will be reduced during flooding. As flood frequency decreases, diversity of understory shrub vegetation increases.

PROBLEM IDENTIFICATION

The general biological effects of floods previously discussed can be specifically applied to the Rock Creek watershed. The urbanization of lower Rock Creek has severely affected the watershed. Impervious materials and structures such as asphalt parking lots and buildings, in addition to a vast network of gutters and storm sewers, allow the rainfall to rapidly run off and quickly enter the creek. Previously, before urbanization, the rain water percolated into the soil and entered the creek in a more gradual manner. The effects of this flooding are quite obvious throughout the lower watershed. Drastic fluctuations of water level, increases in sediments and turbidity in the water column, streambank erosion, large deposits of sediment and silt on the bottom of some areas of the creek, and scouring of the creek in other areas are all evident. Where stream velocity decreases, large quantities of sediment have settled out. This is particularly evident in the lower reaches near the mouth.

Sedimentation and siltation in Rock Creek have greatly limited stream productivity. Aquatic benthic macroinvertebrates are severely impacted and benthic algae, which are normally found on many submerged substrates, are limited.

The abrasive and scouring effects of continual flooding have also affected the Rock Creek watershed. This is particularly evident in some of the tributaries of the creek and also at several stream locations. High water from floods cause sand, rocks and boulders to be moved around in the stream bed. This affects animals attached to substrates on the bottom by causing them to be scoured or washed downstream. Algae, which also grow on substrates, are scoured off and washed downstream. Stream productivity in terms of algal biomass per square meter decreases at these affected upstream areas. The scoured algae decompose at lower stream stations causing increases in BOD and release of nutrients tied up in the algal cells.

Many aquatic plants are found in slow moving, clear areas of the stream. Conditions of flooding, with high current speeds and turbidity, dislodge many of the plants and limit photosynthesis. This may be one reason why there are so few aquatic plants found in Rock Creek.

Fewer fish species occur in lower Rock Creek than in the upper portions of the watershed. The general effects of flooding upon fish have already been discussed and they apply directly to the conditions in Rock Creek.

Water quality of lower Rock Creek in the District is intimately associated with conditions in the upper part of the watershed in Montgomery County. The watershed can be viewed as a single ecosystem or ecological unit. Areas or parts within the ecosystem are intimately dependent upon one another and coupled closely together. Measures instituted to improve water quality in the lower watershed could very well be negated or overwhelmed by activities and conditions in the upper watershed.

SUMMARY

The previous discussion provided a generalized synopsis of the ecological impacts of flooding and channel erosion. It can be surmised that, within the Rock Creek basin, the urbanization of the upper Montgomery County basin and subsequent change in flooding regime has exerted an impact primarily in the form of siltation and destruction of habitat, increased turbidity, and more frequent inundation of the flood plain.

Unfortunately, since this process has been continually developing since the colonization period, it is impossible to quantify the changes that have occurred nor the effectiveness of control strategies. Also, the problems associated with sedimentation and turbidity are generally considered to be water quality oriented. For this reason, the identification and assessment of ecological conditions and problems will be addressed in subsequent chapters on water quality considerations of Rock Creek.

There is no evidence that the flooding or channel erosion in Rock Creek is threatening any of the environmentally sensitive areas described in Chapter 3. There is a need for more extensive and accurate mapping of these valuable natural features in order that they may be protected for the future.

REFERENCES

1. M.G. Wolman and L.B. Leopold, "River Flood Plains: Some Observations on Their Formation," U.S. Geological Survey, Professional Paper No. 282-C, 1957.

2. M.G. Wolman, "A Cycle of Sedimentation and Erosion in Urban River Channels," Geografiska Annaler, V 49A pp 385-395, 1967.

3. M.G. Wolman, "Problems Posed by Sediment Derived from Construction Activities in Maryland," Report to the Maryland Water Pollution Control Commission, Annapolis, Maryland, 1964.

4. H.P. Guy, "Residential Construction and Sedimentation at Kensington, Maryland" in Federal Inter-Agency Sedimentation Conference Proc., 1963: U.S. Department of Agriculture Misc. Pub. 970, pp 30-37, 1965.

5. T.H. Yorke and W.J. Herb, Effects of Urbanization on Streamflow and Sediment Transport in the Rock Creek and Anacostia River Basins, Montgomery County, Maryland, 1962-1974, Geological Survey Professional Paper 1003, 1978.

6. J.W. Wark and F.J. Keller, "Preliminary Study of Sediment Sources and Transport in the Potomac River Basin," Interstate Comm. Potomac River Basin Tech. Bull., 1963-11, 1963.

7. D.G. Anderson, "Effects of Urban Development on Floods in Northern Virginia," U.S. Geological Survey Water Supply Paper 2001-C, 1970.

8. L.B. Leopold and T. Maddock, Jr., "The Hydraulic Geometry of Stream Channels and Some Physiographic Implications," U.S. Geological Survey, Professional Paper No. 252 (1953).

9. Michael Baker, Jr., Engineering Consultant, "Hydraulic Report, Rock Creek Park, Washington, D.C.", April 1956.

10. Nevins, F.R., "A Study of the Larger Invertebrate Forage Organisms in Selected Areas of the Delaware and Susquehanna Watersheds", Rept. N.Y. State Conservation Dept. 1936.

11. Hynes, H.B.N., The Ecology of Running Waters, Liverpool Univ. Press, 1970.

12. Palmer, C.M., Algae and Water Pollution, U.S. Environmental Protection Agency, EPA-600/9-77-036, Cincinnati, Ohio, 1977.

13. Williams, L.G., "Dominant Planktonic Rotifers of Major Waterways of the United States", Limnol. Oceanogr. 11:83-91, 1966.

14. Sprules, W.M., "The Effect of a Beaver Dam on the Insect Fauna of a Trout Stream", Trans. Amer. Fish Soc. 70:236-248, 1941.

15. O'Connell, T.R. and Campbell, R.S. "The Benthos of the Black River and Clear Water Lake, Missouri", Univ. Missouri Stud. 26(2):25-41, 1953.

16. Teskey, R.O. and Hinckley, T.M., Impact of Water Level Changes on Woody Riparian and Wetland Communities, Vol.I: Plant and Soil Responses to Flooding, U.S. Department of Interior, Biological Services Program, FWS/OBS-77/58, 1977.

CHAPTER 6
CHANNEL EROSION AND FLOODING CONTROL STRATEGIES

Many types of control strategies will help mitigate both flooding and erosion problems. For this reason, all strategies will be discussed in one section with a reference to how they apply to flooding or erosion. In general, there are five approaches which can be used in dealing with flooding and erosion:

1. Source control
2. Large impoundments
3. Channel and flood plain modifications
4. Removal of the potential problem from the danger area
5. Status Quo

SOURCE CONTROL

Source control of stormwater problems refers to localized efforts which are employed over the entire watershed. These controls are designed to prevent increases in flood peaks, sediment, and debris from ever reaching the stream system. When flood peaks are minimized, so is the the tendency of the stream to erode its banks, and so is the potential for damage from inundation by flood waters.

LAND USE PLANNING

In the context of this report, the term land use planning refers to the methods by which the effects impervious surfaces can be minimized. In principle, the object of urban land management is to encourage efficient use of land through open space planning, cluster-type development, and density control. All impervious areas do not have the same effect on flood peaks. Some impervious areas are termed "connected"; that is, they discharge runoff to sewer lines or drainageways leading directly to a stream. This situation may alleviate flood problems in the original area, but it tends to increase flood peaks, flood velocities and channel erosion downstream.

One way to mitigate these problems is to design the impervious area as "unconnected". Unconnected impervious areas discharge runoff to a buffer zone of natural vegetation or to grass-lined drainage swales. The velocities of water flowing through vegetation are decreased, thereby delaying flood peaks and providing a chance for the water to infiltrate the soil. The end result is lower peak flows in downstream channels and less channel erosion. The hydrologic effects of "connected" versus "unconnected" impervious areas are shown in Figure 6-1.

Reduction of imperviousness and the degree to which impervious areas are connected to streams can be accomplished most easily in clustered developments and "new towns" employing open space planning and unit development techniques. Current federal housing legislation includes provisions for new town and community development; and since the mid-1960's, land planning techniques have incorporated cluster-type subdivision design. These trends are expected to continue.

Urban land management can best be achieved through regulatory controls; the most effective of which are zoning and subdivision regulations. The education of builders and developers to this concept can also be effective - particularly as a means to improve the quality and amenity value of new residential developments. Creative use of open space increases the aesthetic appeal of all types of land use. This appeal tends to add to stable values for residential neighborhoods and long-term viability of commercial districts.

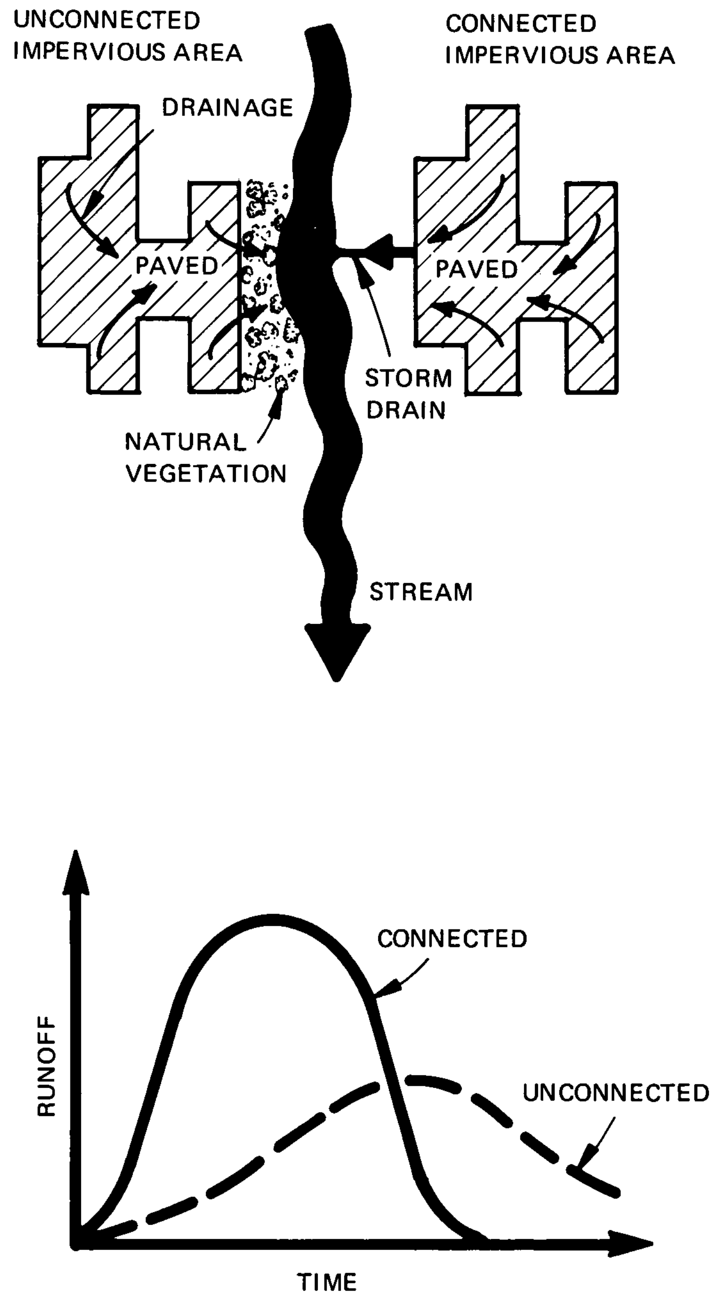


FIGURE 6-1: Categories of Imperviousness

DETENTION AND RETENTION PONDS

In some situations, ponds can be placed in a development to collect runoff from small areas. The collected runoff is retained for a short while and discharged to the natural stream system more slowly than if no ponds were present. This results in smaller peak flows in the channels downstream. An additional benefit of these ponds is that they can trap sediment and debris, preventing these pollutants from reaching the streams. The effects of ponds on the hydrologic response of an impervious area is illustrated in Figure 6-2.

Localized flood control ponds are called retention ponds if they are designed to retain water even in dry weather. Ponds which dry up between storms are termed detention ponds. In addition to flood control, retention ponds can have benefits of aesthetics and recreation but maintenance is required to keep the areas clean and attractive. One of the chief drawbacks of both detention and retention ponds is the availability of suitable land. The "Town Center" concept can be used to get around this deficiency. This idea has been used successfully in Reston, Virginia and Columbia, Maryland. Under this strategy, a large retention pond is created as the center of a residential neighborhood with shops and some residential property on the shoreline. A pleasant living environment is created and flood and sediment control is maintained with the retention pond.

A significant drawback to the use of detention/retention ponds is that of inspection and maintenance. Sediment deposits and debris accumulation must be removed on a periodic schedule from a large number of sites. This is a major consideration that cannot be overlooked if the effectiveness of the ponds is to be realized.

RURAL AREAS

In rural areas, several options are available to decrease storm runoff and sediment loads to the streams. Contour farming, no-till planting, terracing, crop rotation, vegetation cover, woodland management, strip cropping and detention ponds can be used to effectively control stormwater. All these strategies are designed to slow the surface runoff, providing more time for infiltration to the soil and less energy for land-surface erosion.

As a rural area begins to urbanize, stormwater management should be kept in mind to avoid creating problems downstream. Instead of designing topography and stormwater collection systems to carry off the runoff as quickly as possible, the area should be designed with grass-lined drainage swales and detention ponds to delay the runoff whenever practical.

SUMMARY

The source control measures mentioned above are most useful if they are employed as an area begins to develop. The basic idea of all these strategies is to catch the excess runoff as early as possible and delay its entry to the stream system. The principal advantages of source controls are as follows:

1. Flood peaks and flood velocities are reduced in downstream channels.

2. Channel erosion downstream is reduced due to the lower peak flows.

3. Debris and excess sediment are controlled before they get into the stream system.

4. Groundwater is recharged from the increased infiltration and increasing the base flow of streams in the area.

Disadvantages of source controls discussed above include:

1. Continued maintenance is required in ponding and vegetated areas.

2. Flooding and drainage problems may be created due to the slower transport of the runoff.

3. Open ditches and swales may attract children to play in poor quality water.

4. Improperly maintained or stagnant ponds can cause insect breeding problems.

5. High flows may cause erosion in swales and ditches.

Montgomery County has recently recognized the value of stormwater management and is requiring controls on all new development. However, it is not so easy to go back to a completed housing project and force one of these control alternatives on the community. Since substantial development has occurred without source control of stormwater and sediment yield, it is too late for these strategies to be useful in solving existing problems on the main stem of Rock Creek. However, these practices are encouraged as a control strategy to control potential localized problems and to avoid compounding the present situation.

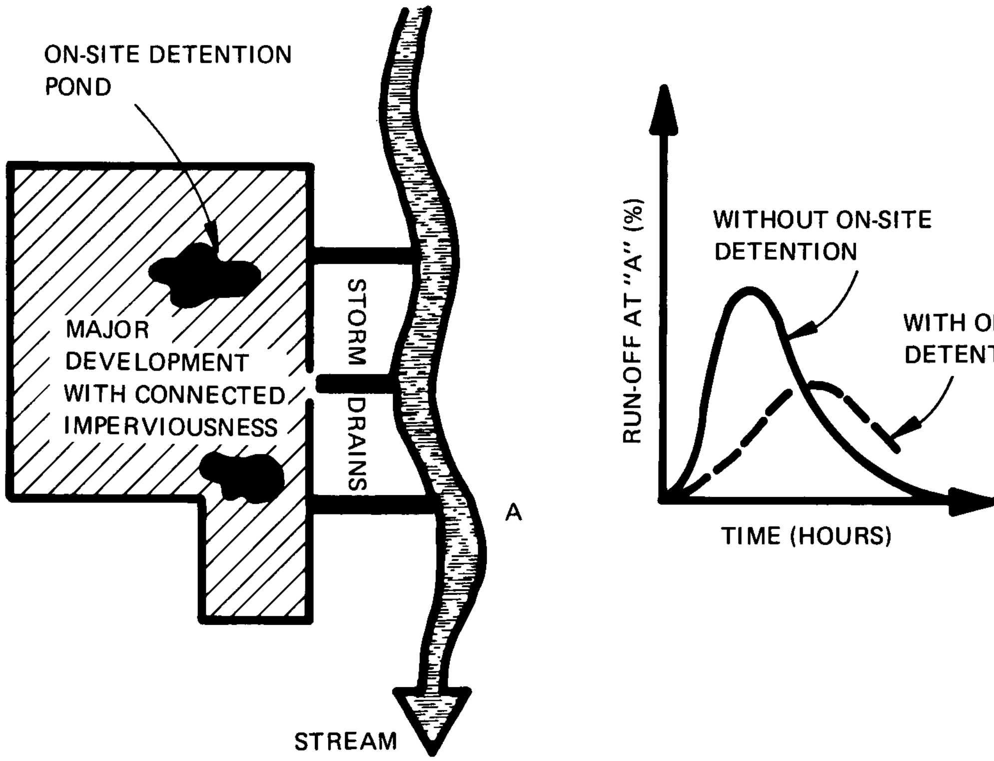


FIGURE 6-2: Effect of On-Site Detention On Runoff

LARGE IMPOUNDMENTS

One alternative to controlling excessive stormwater at the source is to collect the peak flows in large impoundments. Impoundments have the potential for a wide variety of recreational activities including boating, swimming and fishing; and multiple uses such as supplying water, controlling floods, trapping sediment, augmenting low flows, and, in appropriate areas, generating hydro-electric power. Drawbacks of large impoundments include difficulties in finding an appropriate location, flooding of land by the reservoir and sediment removal.

The principal function of large impoundments is to control large floods. In doing so, such impoundments can prevent channel widening by reducing peak flows. However, reservoirs have been known to cause downstream erosion due to the decreased sediment concentrations in the outflowing water (Reference 1). The effects of a large impoundment on the storm hydrograph at a downstream location are illustrated in Figure 6-3.

CHANNEL MODIFICATION

When nothing can be done to prevent changes in dominant discharge or incoming sediment load, channel modification is often the best solution to erosion problems. This also may be the most effective control measure when only small areas need artificial protection. Five types of channel modification will be discussed here; flexible linings, rigid linings, reshaping of the channel, channel deflectors, and retards.

FLEXIBLE LININGS

Fortification of the channel banks is necessary whenever it is desired that the channel alignment remain essentially as it is. Under this control alternative, erodible banks are protected with non-erodible material, such as concrete, riprap, gabions, or stone walls.

Fortification of channel banks is classified as flexible or rigid, based on the ability of the protective material to adjust to localized changes in the natural bank. The three principle types of flexible lining for erosion control are riprap, gabions and stone-and-wire mattresses. Riprap is a collection of large, irregularly shaped, and loosely packed stones which cover an erodible bank, providing a surface less likely to wash away during a flood. Gabions are wire baskets filled with smaller stones and firmly anchored in place to prevent erosion of the underlying surface. Stone-and-wire mattresses are, as the name implies, large sheets of wire fencing which enclose stones and form a blanket over the area to be protected. This type of protection is usually not as thick as gabions, and is best applied on mild slopes. Examples of riprap and gabions are shown in Figures 6-4 and 6-5.

The use of riprap protection in Rock Creek Park is extensive and has been an effective stopgap measure to many of the problem areas along the channel. The primary reason for the use is that it provides the most aesthetically pleasing and convenient method that the Park Service has at its disposal. Rock from the Metro subway system excavation has been readily available to the Park. Problems arising in its use are generally failures of design and placement. Much of the slope protection in Rock Creek Park was emergency repairs of damages caused by Hurricane Agnes in 1972. The proper use of riprap requires a certain size gradation of the material being placed (i.e., small particles mixed with the bigger rocks to fill in the voids) and a blanket of finer, bedding material underneath. Ideally, the larger boulders should

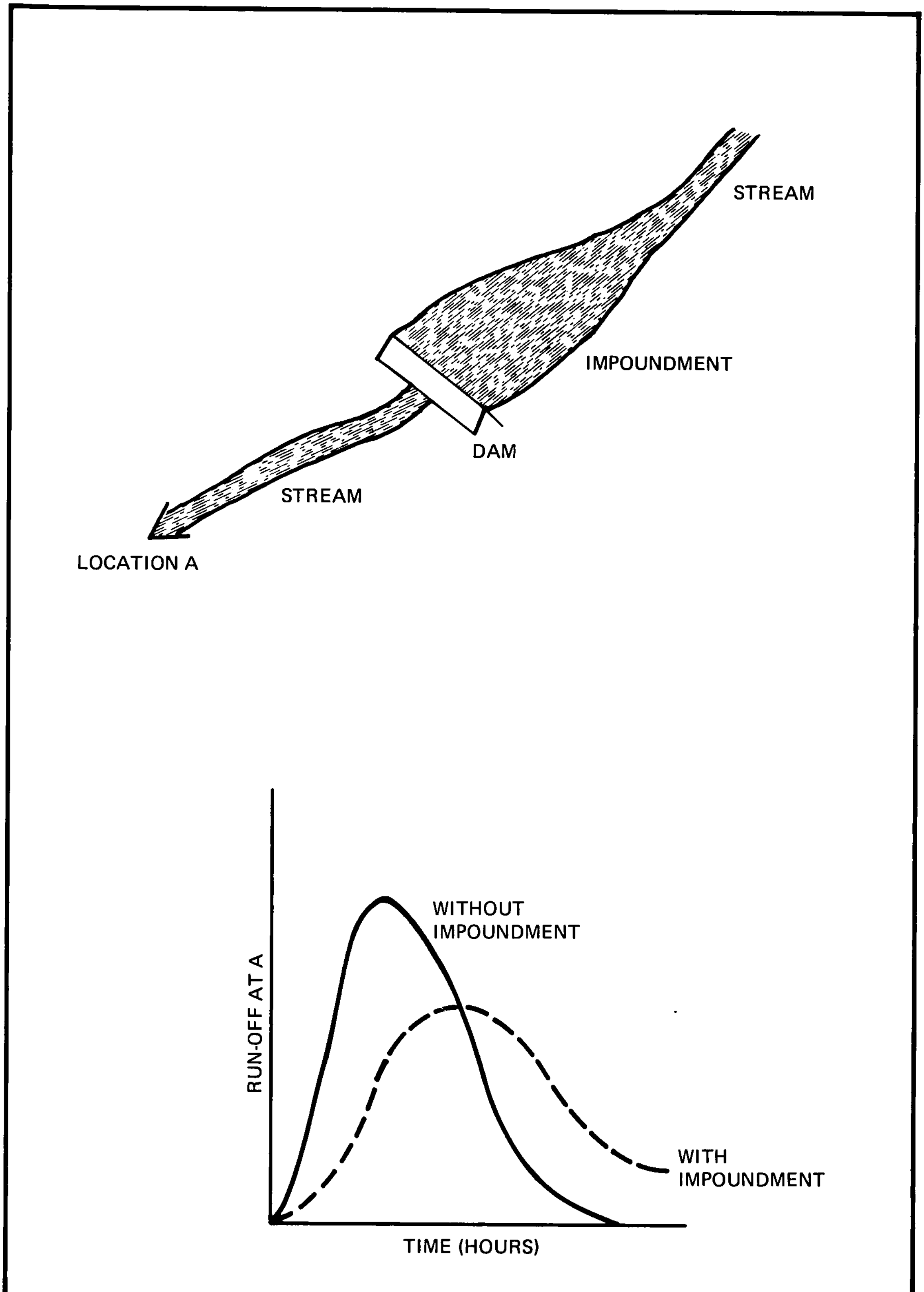


FIGURE 6-3: Effect of Impoundment on Runoff

Figure 6-4   Riprap Protection

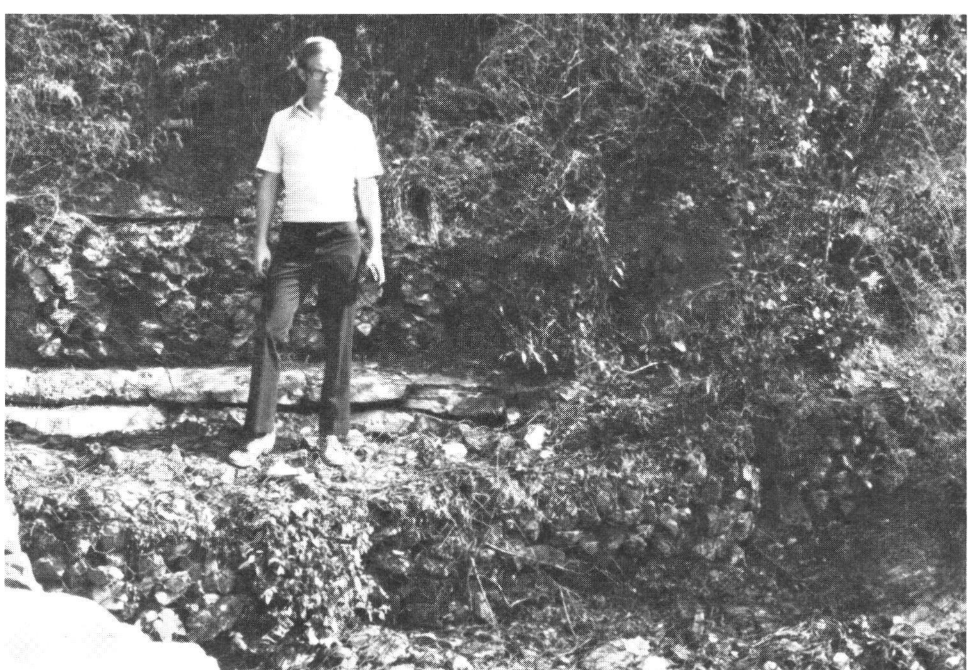


Figure 6-5   Gabions Used for Bank Stabilization

be hand-placed to assure complete and uniform coverage. A great deal of the Metro material was simply 'dumped' in place. Also there are maximum slope limitations that must be considered in the design of riprap protection. Gabions are much better suited to steep slope applications.

RIGID LININGS

Rigid linings are concrete or stone walls which are built as a continuous, rigid unit to protect the natural bank. These structures are ideal where space does not permit the construction of a more natural protection. There are several drawbacks of rigid linings which tend to bias a designer toward flexible linings. Rigid linings usually have a much smoother surface than the natural banks, which allows higher velocities during floods. These higher velocities tend to scour the toe of the structure, undermining the foundation. When flaws or breaks develop in a rigid lining, it is a major project to make repairs, whereas the flexible lining lends itself more to small-scale repair. One of the rigid linings currently in place along Rock Creek near the National Zoo is shown in Figure 6-6.

Figure 6-6 Retaining Wall Along Rock Creek at the National Zoo

The advantages of bank fortification are that it can be applied in localized areas where damage would result from erosion, it can be laid quickly and the channel can be shaped to fit man's uses. The most significant drawback is the fact that the stream will be unable to form its own naturally stable channel. During high flows, velocities in fortified areas will be increased, increasing the potential to carry sediment. Since the modified banks are non-erodible, sediment will not be picked up until farther downstream, where the banks are not fortified. The downstream erosion could be more severe than if no channel modification was attempted. Downstream flooding may also be increased due to the high velocities and straighter flow lines of the fortified channel.

Flexible linings are best applied in areas where mild bank slopes can be accommodated. They are also ideal for areas where erosion must be controlled on one side of the creek only. As the opposite bank erodes, widening the channel, the pressure to erode on the protected side will decrease, increasing the useful life of the fortification. Where space is more limited and the stream bank must be steep, flexible linings become more unstable. Although gabions can function effectively on a relatively short vertical bank, rigid linings of concrete or stone and mortar may be stronger. The higher flood velocities near a steep bank or confined cross section are handled better by the smoother walls of a rigid lining. The drag on the rougher surface of the gabions will exert more destructive power on the bank and increase flood elevations in the local area.

RESHAPING THE CHANNEL

Other than fortifying the channel banks to prevent unwanted erosion, the stream channel could be reshaped to handle the anticipated flow. If it were desirable for erosion to be prevented on one side of the stream only, the channel could be artificially widened on the opposite bank. With the unusually wide cross section, erosion is less likely to occur. If this strategy is employed, it should be carefully planned and monitored to make sure that the stream responds to the changes as anticipated, instead of leaving a pool to collect sediment in the excavated area. Even if this control alternative is successful over the long run, it may be undesirable due to damage that may be caused on both banks by large storm events.

An extreme example of reshaping the channel is to move it entirely to another area. This relocation of the channel has limited uses and is a very large undertaking. It could be employed where a meandering section of the stream is advancing toward a road or other valuable structure. A shortcut channel can be cut across the floodplain, leaving the old channel bed as an oxbow lake. The dry channel is available to help handle large floods, but it is free from the continuous erosion from lower flows. Although the relocated channel may serve to protect the intended area, it will generally cause accelerated erosion upstream and increased flooding and sedimentation downstream.

CHANNEL DEFLECTORS

Channel deflectors can be used to prevent erosion by redirecting the water away from the area needing protection. Retards perform a similar function by reducing the velocities of flood waters adjacent to the erodible surface. The decreased velocities near the structure will reduce the scouring force, and promote deposition. The deposited sediment will rebuild the bank and reduce the potential for damage.

One type of channel deflector is a groin. A groin is a short, solid structure placed at approximately right angles to the bank. The velocities of the water near the bank protected by groins is relatively slow and will not cause the severe erosion encountered before the structure was placed. One problem with this type of channel deflector is that eddies can form at the tip of the groin and can cause unexpected damage.

To avoid the erosion problems with eddies, the groin can be modified into a different shape. An "L-head revetment" is such a shape. This structure protrudes normal to the bank but then is continued downstream along the channel alignment in an "L" shape. L-head revetments are more efficient than groins at capturing sediment, and the scour from eddies is greatly reduced. Where aesthetics are important, the channel deflectors can be built of rock and made to resemble a natural feature.

RETARDS

If large structures in the channel are undesirable, retard structures can be installed to control erosion. Retard structures are devices placed along the bank to reduce flood velocities there. Typical retard structures are fences, jacks, timber pilings, and permeable jetties. A timber pile retard is shown in Figure 6-7. The drag on water flowing through and around these structures slows velocities and keeps the fast-flowing water away from the bank. This control strategy works best when only one side of the stream needs protection. The bank opposite

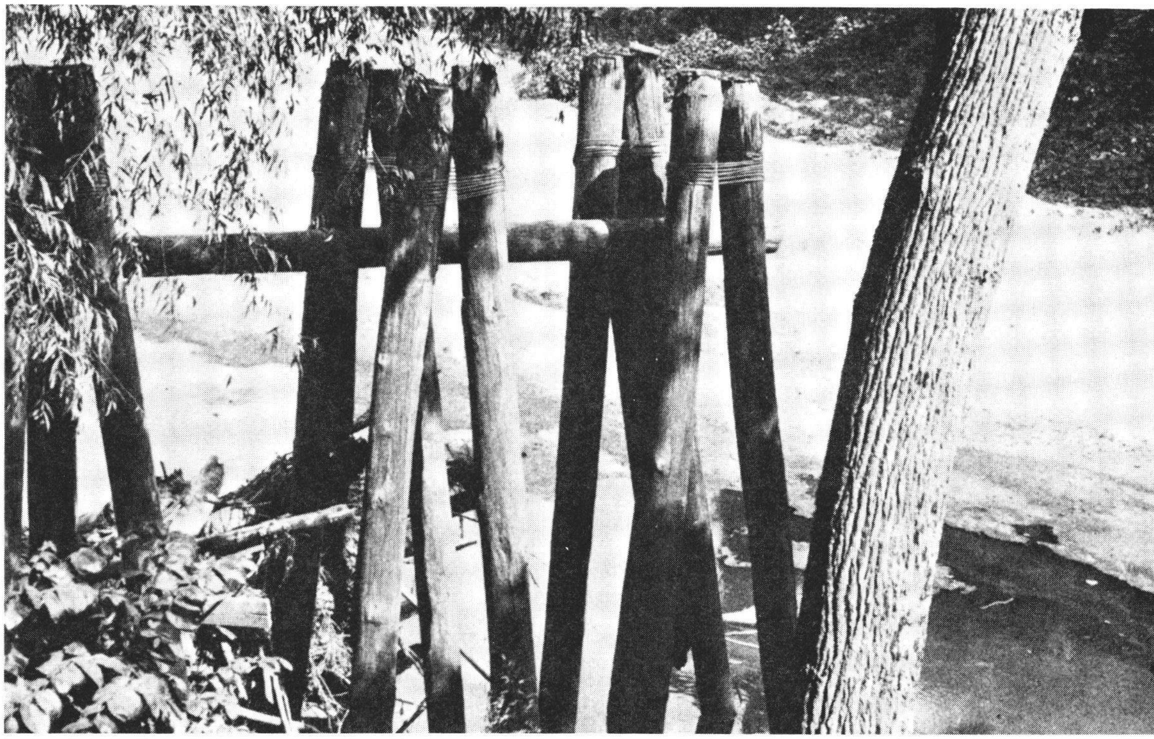


Figure 6-7   Timber Pile Retard

the retards will experience greater pressure to erode than if both banks were left untouched, so retards should be located such that erosion of the opposite bank will not create problems.

One specialized type of retard is vegetation on the stream banks. Dense brush and trees can increase hydraulic roughness, reducing flood velocities and preserving soil. Vegetation is not as strong as wood or steel structures, and should not be used alone in areas of high erosion potential. Curves in the channel and constrictions require more protection than vegetation, but vegetation should always be added to improve the stability and the appearance of other structures.

The main idea of all channel deflectors and retards is the same, to keep the higher velocities away from the eroding bank, and to capture sediment in the slower moving water near the structure. During the construction phase of a watershed, channel deflectors can be especially useful due to the unusually large sediment load in the stream. The excess sediment can be trapped where it will do some good, instead of settling in unwanted areas or being carried downstream. The drawbacks of channel deflectors are that they are unsightly until covered with sediment, and they can not always provide adequate protection in critical areas. Also, if they are overtopped by a large flood, severe erosion behind the structure can occur.

FLOOD PLAIN MODIFICATIONS

Sometimes the flood plain can be modified to protect small areas from flood damage. This can be accomplished my means of raising the ground elevation or constructing levees. This control strategy should be approached with caution as any encroachment in the flood plain will change the flow characteristics. Flood problems could be created elsewhere while solving a problem in another location.

Where high flood elevations are not particularly a problem, but high velocities are, steps can be taken to reduce the flood velocities and the accompanying erosion. Recreational areas along the channel are prime targets of erosion due to their proximity to the channel and the reduced hydraulic roughness from the cleared underbrush. Strips of dense vegetation normal to the channel at each end of the cleared area would help reduce flood velocities, but would not greatly change the hydraulic characteristics. Water could still flow through the vegetation but would not have nearly the same power to erode as earlier. Vegetation is a much more valuable erosion control measure in the flood plain than in the channel because high velocities are unavoidable in the channel, but not in most overbank areas. In localized overbank areas where high velocities cannot be controlled, protection as described earlier in this section for the channel may be needed.

A specialized form of flood plain modification is flood-proofing. Flood proofing is the prevention of damage to something without removing it from the flood plain. In the case of buildings, creating a water-tight seal to all areas below the flood elevation is an example of flood-proofing. Another way to floodproof a building is to use the lower floors in such a way that little damage would be done if they were inundated by water. Structures in the flood plain, such as roads, bridges, and building foundations, can be floodproofed by providing a non-erodible layer of protection around the supports. This will prevent scour around the supports and dramatic collapses. Finally, objects in the flood plain such as playground equipment, picnic tables, trash containers, etc., can be flood proofed by securely anchoring them to the ground. As long as these objects are not carried away, they are relatively immune to flood damage.

Flood plain modification can be used to reduce the unsightly gullies and sediment deposits left after floods. Gullies are formed when depressions in the flood plain channelize the overbank flow, creating high velocities outside the main channel. Sediment mounds are deposited when water in depressions is blocked from flowing by downstream obstructions. The relatively still water in these ponding areas cannot carry the sediment load which is picked up by the higher velocities upstream. Proper grading of the flood plain can help keep the fast-moving water close to the channel and eliminate the ponding areas. Care must be taken in employing this strategy as flood velocities could be greatly increased by keeping the water near the channel. Possible dangers downstream must be weighed against the local benefits of the protection.

The advantages of flood plain modification include:

1. It can be applied as needed in local areas.

2. A potential problem can be eliminated without costly moving of the protected structure.

3. It is usually not a complex design or construction project.

4. Maintenance following a flood is reduced.

Some disadvantages of flood plain modification are:

1. Flow characteristics will be altered with possibly unpredictable results.

2. If flood waters are forced back to the channel, increased channel erosion will occur.

3. Usually, flood velocities are increased, adding to erosion and flood problems downstream.

REMOVAL OF POTENTIAL PROBLEM FROM DANGER AREA

The surest way to prevent flooding and erosion problems is to avoid situations which cause problems. In a broad sense, this is called flood plain management. Once the natural processes in a stream are recognized and respected, problems caused by man's intrusion into the flood plain should be minimal. With decreased activity in flood-prone areas, damage from flooding and erosion would be significantly reduced.

Examples of flood plain utilization which are compatible with the natural processes are parks, recreational areas and natural woodlands. These areas are expected to flood occasionally but little damage is anticipated. Problems can be created when a recreational area is "forced" on a stream, pushing the channel aside or otherwise constricting the flood plain. Only the natural flood plain areas should be used and the channel should not be overly restricted.

When roads, bridges, buildings, and other constrictions are placed in the flood plain, problems are likely to occur because of the changes in the natural flow characteristics of the stream. Any encroachment in the flood plain usually raises flood elevations and increases velocities of flood waters. After these flood plain alterations, flooding and erosion problems can become more severe than under the natural conditions. Perhaps the greatest obstruction encountered by a stream is bridge abutments. For economy, the channel opening is usually made as small as possible. But this contracted opening results in unseen costs of bank stabilization along the roadway and major repairs due to structural damage from erosion. Problems can be avoided if bridge openings are shaped similar to the surrounding flood plain, such that water will always be flowing parallel to the channel.

If flooding and erosion problems are to be avoided, the best solution is to stay away from areas susceptible to damage. When this is not possible, structures should be built with flooding in mind so that total destruction is averted. With some effort, structures can be floodproofed so that damage is greatly reduced under flooding conditions. However, continual maintenance will be required whenever the natural territory of the stream is invaded.

There are two principal benefits from removing a potential problem from a critical area. First, the the threat of damage from erosion and flooding is completely eliminated; and second, the stream and flood plain can be left in a natural condition, instead of being cluttered with channel protection works. The disadvantages of removing the potential problem are cost of obtaining a new location; possible inaccessibility of the new location; and less pleasing scenery than the stream banks.

The principle of avoidance of potential problems is the underlying concept of the stream valley acquisition program currently being implemented in the upper Rock Creek watershed by the Maryland-National Capital Parks and Planning Commission. The National Park Service serves the same purpose by expansion of its park boundaries. Public ownership of stream valleys serve to avoid potential flood damages and concurrently provides significant conservation, wildlife habitat preservation, and recreation benefits. Recreational activities that are well suited to stream valleys include hiking, nature study, wading, biking, and horseback riding.

The park system in Rock Creek basically follows stream valleys which have ben acquired for their aesthetic value as well as a means of restricting development in sensitive areas. The process of maintaining lands subject to flooding and retaining them in a natural undeveloped state is best obtained by direct purchase. Other methods of maintaining these land areas include restrictions to development by zoning, donation as open space in subdivision approval, and trade-off agreements between developers and communities for development rights elsewhere.

STATUS QUO

Letting the stream find its own equilibrium under changing conditions can sometimes be a reasonable solution alternative. This strategy will not be wise for the entire length of the stream but in some areas it could be the best solution. Obviously, source controls which limit the negative impacts on the watershed should not be dismissed, but the impact of flooding and channel widening in noncritical areas does not always necessitate or justify the cost of corrective action. The status quo strategy of allowing periodic damage may be the most economical or cost-effective approach to problem areas.

The advantages of doing nothing to control flooding and channel widening are that it preserves the natural condition of the floodplain, continual maintenance of channel structures is not required, and, initially, it costs nothing. Usually, when this option is employed, some damage is expected, and rebuilding is planned after the damage is done. Problems arise when the actual damage is greater than the anticipated damage. Since funding for renovations is not always readily available, repairs associated with this strategy are usually the quickest and least expensive available solutions. These quick solutions usually leave the area vulnerable to attack, just as before. If solutions are carefully planned during non-emergency periods, perhaps they will be more permanent.

Status quo is not a wise option to follow where severe flood problems and economic loss are expected. If no action is taken, it is just a gamble as to whether or not a damaging flood will occur. Eventually, a large flood will occur. Hence, appropriate actions should be taken, when possible, to mitigate the damage from large floods. If severe damage is caused due to not protecting an area, that is a good time to consider removal of the potential problem from the critical area since large scale renovations will be necessary anyway.

The advantages of doing nothing to control potential problems are the following:

1. Initially, the cost is nothing.
2. The stream channel is free to find its stable configuration.
3. Continual maintenance of channel structures is not required.

4. Funding for reconstruction is usually more readily available than funding for preventive actions in non-emergency times.

The disadvantages of inaction include:

1. The channel could assume some unexpected characteristics which create different problems.

2. Damage could be worse than anticipated, necessitating major renovations.

3. Repairs made immediately following a destructive flood are often the quickest and least expensive solutions. This can leave the same area vulnerable to attack, just as before.

4. Until the channel assumes a stable configuration, it could be an eyesore, decreasing public respect for the park.

Usually, when status quo is used as a control alternative, there is planning for the future included in the strategy. Even though nothing physical may be done, a redesign of the problem area should be made and implemented at the appropriate time.

REFERENCES

1. K.J. Gregory and C. Park, "Adjustment of River Channel Capacity Downstream from a Reservoir", Department of Geography, University of Exeter, Volume 10, No. 4, Water Resources Research, United Kingdom, August 1974.

2. State of California, Department of Public Work, Division of Highways, Bank and Shore Protection in California Highway Practice, November 1970.

3. S.P.A. Officine Maccaferri-Bologna, Flexible Linings for Canals and Canalised Water Courses, January 1976.

4. U.S. Department of Agriculture, Soil Conservation Service, Planning and Design of Open Channels, Technical Release 25.

5. U.S. Department of Agriculture, Soil Conservation Service, Vegetative Bank Stabilization with Woody Vegetation, (M-2430-58), 1958.

6. U.S. Department of Agriculture, Soil Conservation Service, Standards and Specifications for Soil Erosion and Sediment Control in Developing Areas, July 1975.

CHAPTER 7
CHANNEL EROSION AND FLOODING ALTERNATIVE ANALYSIS AND RECOMMENDATIONS

Historically, encroachments have been made into the flood plain and even into the channel of Rock Creek without a full understanding of the damaging effects of these actions. When damage was done, only then was the problem recognized and some degree of protection offered. Repairs made hastily following a damaging flood are often not well planned and usually inadequate for the protection desired. It is unfortunate that authorization and funds for repairs are generally granted in emergency situations for the quickest solution. The National Park Service recognizes the fallacy of past crisis actions and is undertaking a carefully planned course of action, beginning with this study, to alleviate the identified problems. If preventive solutions to flooding and erosion problems can be carefully planned and implemented in non-critical times, perhaps there will be more permanent solutions to recurring problems.

This study concentrates on the main stem of Rock Creek. Erosion on some of the tributaries is severe, particularly on parts of Fenwick, Pinehurst, Klingle, Soapstone and Luzon Branches. However, structural encroachment on the steep tributary valley flood plains is minimal and there is little threat of damage save sewer outfalls, footbridges, and aesthetics. One notable exception to this is the retaining wall beside Piney Branch Parkway, which will be discussed later. If erosions begins to threaten something valuable, or if the erosion is to be controlled for aesthetics, control strategies similar to those discussed here can be employed once the problem area is identified. The recommendations presented here are meant to provide a long-term solution to recurring problems uncovered in the course of this study. If other areas become areas of concern, similar control strategies can be employed.

Specific designs of channel protection works are not attempted here. Figure 7-1 shows the channel velocities to be used in designing riprap, gabions, or other bank fortification. The velocities shown are the channel velocities from the 100-year flood, as determined by the HEC-2 computer program. An upper envelop curve is included in Figure 7-1 to be used as general guidance in selection of a design velocity. However, care in analysis of specific sites should be used as velocities at constructions, bends, and abutments can exceed this level. These velocities and other local considerations can be used with any of numerous design handbooks to determine the specifics of the needed protection. Some of these manuals are included in the reference list at the end of this section. Recommendations are presented for all problem areas addressed previously and delineated in Figure 5-1.

Primary considerations employed here in the identification of problem areas and proposed recommendations are; the type and magnitude of damage associated with problem, various control strategies applicable for mitigation of the problem and criteria of application, secondary impacts of the control strategies, relative costs of control strategies, and Park Service goals of preservation of the natural aspect of the watershed. Detailed design of control recommendations is not an element of this study. A summary of all recommendations is presented at the end of this chapter.

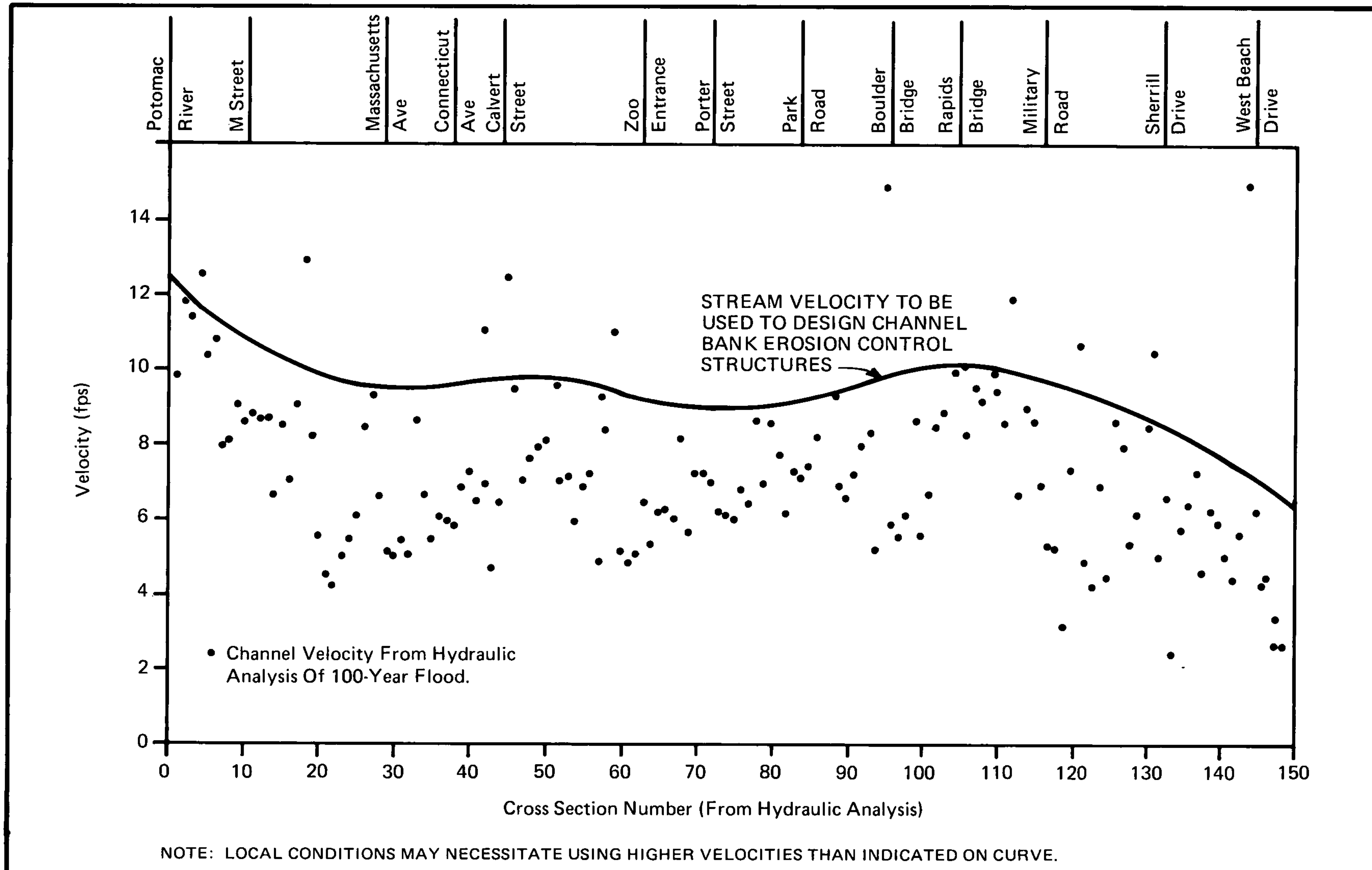


FIGURE 7-1: Stream Velocities for the Design of Stream Bank Protection Works

SOURCE CONTROL ALTERNATIVES AND RECOMMENDATIONS

As briefly explained in Chapter 6, the implementation of source control strategies for flooding and channel erosion mitigation is extremely difficult after development has already occurred. The most effective use of this technique would occur in the upper portion of the watershed in Montgomery County in order to alleviate the observed problems on the main stem in the District. The National Park Service unfortunately has no jurisdictional control over practices taking place in the upper watershed. However, as a policy, several control strategies should be strongly endorsed and perhaps subsidized to mitigate upper basin contributions.

Montgomery County has adopted a Functional Master Plan for the Conservation and Management in the Rock Creek Basin, Montgomery County, Maryland that will provide for control of increased mean annual peak flows as a result of future development. The principal strategies promoted in the watershed management plan by M-NCPPC are the use of onsite detention/ retention facilities and urban land management concepts. Other recommendations embodied in the Functional Master Plan that should be agressively pursued are:

- All new development should incorporate concepts of unconnected impervious surfaces. This shall include minimization of street gutters and storm drains with maximum use of grass-lined ditches and swales for storm drainage. The Wayside subdivision in Fairfax County, Virginia is an example of how this concept can be applied.

- Cluster and unit developments with planned open space should be the preferred type of development in order to minimize impervious surface.

- Where new development takes place near an existing subdivision, joint use of the onsite detention/ retention facility or construction of an offsite storage facility should be considered as an alternative in order to take advantage of the opportunity to mitigate present problems. The City of Rockville, Maryland, has adopted a set of ordinances whereby developers, subject to city approval, have the option of onsite management, offsite management, or contributions to an offsite management program. It is recommended that the County provide similar flexibility in its policy, with the same goal of controlling the increased mean annual (2.33-year) flooding volume from all past development in addition to that of the future.

- All new road construction should utilize grass-lined ditches and swales for storm drainage. This will require a larger right-of-way for transportation routes but erosion, flooding, water quality, and aesthetic benefits are all realized.

- Where new commercial and industrial development or major rehabilitation is planned, the concepts of rooftop and/or underground storage should be considered in order to meet stormwater detention requirements. These practices can be used where limited space for detention ponds is available.

- The use of porous pavement is strongly encouraged in all new parking lots and low-intensity roadways. Since porous pavement application requires the renewal of both surface and base courses during roadway reconstruction, the practice of renewing present streets and parking lots with porous surfaces could not be routinely incorporated in regular resurfacing activities without significant additional expense. It is recommended, though, where rebuilding the base course is already a necessary maintenance activity.

- Parking lot storage can be provided at nominal expense to owners or the County by simply throttling drainage outlets in curbed lots. This practice is strongly recommended as an inexpensive technique to control runoff from existing development and mitigate the flooding and erosion problems thereby incurred.

It is very difficult to go back after development and institute onsite practices in residential areas simply because of the diverse ownership. However, the above strategies lend themselves very easily towards existing commercial, industrial, and high-rise development where onsite controls can demonstrate the greatest effectiveness. An aggressive and powerful program, not policy, must be implemented to alleviate the problems that exist presently in addition to those of the future.

The District of Columbia portion of the watershed represents a different set of conditions when considering source control strategies. The urban areas of the District are much more congested with very little available space for onsite detention/retention ponds. There is also very little additional development taking place within the District, hence the source control strategies to be implemented would have to take place as rehabilitation of existing urbanization. Another problem here is that of timing of peak flows. Control strategies in the District could very likely increase peak flows on the Rock Creek main stem by detention of runoff until the upstream peak from Maryland has reached the District.

This factor must be considered in all control projects. The main benefit of source control implementation in the District will be realized on the Rock Creek tributaries where some of the worst stream bank erosion problems have been observed. Within the combined sewer areas, any form of source control of stormwater is strongly endorsed despite the prospect of adverse hydrograph timing impact. The water quality benefits far outweigh the possible damages of increased flooding.

Once again, similar to Montgomery County, the Park Service has very little control of stormwater sources within the District. One method that it can employ to control its own fate is in the form of stormwater drainage permits. All new drains that enter the park require permit applications and approval by the Park Service. As a condition to these permits, the Park Service should require adequate source control strategies to be implemented as part of the storm drainage project. Within the District, the only practical strategies that can be employed are rooftop, underground, and/or parking lot storage, porous pavement, and offsite storage.

Recommendations of policies and actions that the Park Service can adopt for source control of stormwater are:

- Minimize impervious surfaces within the Park and begin a program of road, bicycle path, and parking lot rehabilitation with porous pavement.

- Throttle the drains, where practical, to all parking lot and recreation areas within the park to provide storage of stormwater.

- All new drainage facilities within park bounds should utilize grass-lined ditches and swales where possible. On steeper slopes, rock and masonry-lined ditches will be necessary.

- Carefully review all storm drainage permits and require adequate source control of stormwater within the tributary area of the facility. Swales should be required where possible in addition to parking lot storage. Where practical, the Park Service may dedicate land area for offsite detention storage facilities, underground or surface, to be built to meet the requirements for permit approval.

- All rehabilitation and development plans within the Rock Creek watershed should be reviewed by the Park Service such that suggestions may be offered, prior to construction, of best management practice techniques that can be employed. Arrangements can be made with the appropriate District of Columbia governmental agencies to obtain copies of building permit applications and submit review comments.

Source control of stormwater runoff is a very difficult strategy to implement. Many of the recommendations offered here will require years of continual, piecemeal rehabilitation and construction, often with public opposition, and the cumulative benefits will not be immediately visible or realized for years. The inconvenience of flooded recreation areas, parking lots, and rooftops leads owners to readjust controlled outlets such that storage potential is not met. Hence, rigorous inspection and maintenance of facilities will be required. Porous pavement has not yet received public acceptance, is more expensive than conventional pavements, and is essentially unproven for long-term use. Grass-lined swales and ditches are difficult to maintain and require additional land area. Detention/retention ponds require land, are expensive to construct, and require maintenance and inspection. The financial burden of source control strategies generally is borne by the local owner or developer. Hence, public acceptance is difficult in a country where flood control is considered a governmental function.

As mentioned, the Park Service has little control of its own fate as the recipient of flood waters from beyond its boundaries. The program outlined here will require extensive coordination of effort and subsidization should be considered. Sincerity must be demonstrated and the first step should be to implement the aforementioned practices within the park bounds.

LARGE IMPOUNDMENT ALTERNATIVES AND RECOMMENDATIONS

Multipurpose impoundments designed for recreational uses and flood control have been in use in the Rock Creek watershed since 1966. Lakes Needwood and Bernard Frank control 25 square miles of drainage area in Montgomery County. Unfortunately, there are 37 square miles directly above the Maryland-D.C. line that are not controlled by the lakes, and this area is the most highly developed part of the Maryland watershed. There is also the factor of the diminishing effect of these reservoirs in flood peak reduction with distance downstream. The elongated shape of the Rock Creek basin is such that very little of the peak flow in the lower portion of the watershed originates in the upper basin, with or without the reservoirs. The travel time, estimated to be 5.5 hours at bankfull stage, from the lakes to the Maryland-D.C. line, is too great for peak flows in the upper basin to significantly impact peaks in the lower basin.

The construction of a large, instream impoundment to control the observed flooding and channel erosion problems in Rock Creek Park would necessarily be located on the main stem near the Maryland-D.C. boundary. Previous hydrologic/hydraulic analysis has concluded that the present channel capacity at this point is approximately that of the predevelopment (1929-1966) mean annual flood (1620 cfs). Literature cites this frequency flooding event to be the dominant or channel-forming discharge. Under ultimate land use conditions the mean annual (2.33-year) flood will be increased to 3760 cfs. In order to determine the storage volume requirement to control the increase in flooding and thus return the stream hydrologic/hydraulic regime to its former status, a number of storm hydrographs at Sherrill Drive were analyzed. The results are listed below:

Date	Peak Flow (cfs)	Approx. Return Period (years)	Vol. Above Baseflow of 1620 cfs (acre-ft)	Duration of Flow Above Baseflow of 1620 cfs (hrs)
12/2/74	2,220	--	280	10
1/26/78	2,700	1.4	660	13
8/10/69	3,020	1.6	860	11
8/24/67	3,440	2.0	810	9
9/14/66	5,060	4.5	1,780	12
6/21/72	12,500	75	8,260	17

From this data, it is estimated that 1150 acre-feet of storage will be required to attenuate the ultimate mean annual flood to predevelopment level. To evaluate the possibility of providing this quantity of flood storage, two likely detention sites were selected; the West Beach Drive bridge in the District and the Baltimore and Ohio Railroad bridge in Montgomery County. These were chosen solely because they already provide a constriction of the flood plain and there is a large amount of available upstream storage. The elevation-area-storage relationships for each site were determined by planimetry of 5-foot contour, 1:2400 scale topographic maps and are tabularized below:

West Beach Drive Bridge			B&O Railroad Bridge		
Elevation	Area (acres)	Storage Vol. (acre-feet)	Elevation	Area (acres)	Storage Vol. (acre-feet)
160	6	15	185	6	15
165	17	72	190	29	102
170	37	207	195	111	452
175	87	517	200	192	1,210
180	143	1,092	205	259	2,338
185	198	1,945			

As can be seen, to provide the desired amount of storage, it would necessitate inundation of the West Beach Drive site to 180 feet NGVD or the B&O Railroad site to 200 feet NGVD. This would require temporary inundation of approximately 145 or 190 acres, respectively, at the two locations. Interestingly, this corresponds closely to the 100-year flood plain at both sites at ultimate land use conditions. Note that the estimates presented here assume that the impoundment is operated solely as a detention facility and there will be no permanent pool during normal flow conditions.

Generally, the principal obstacle to the use of a large impoundment to control floods is the acquisition of land in a suitable location. This is not a major problem in Rock Creek, however, since the great majority of land that would be required is presently with park bounds (National Park Service and/or Montgomery County). The major problem would be the relocation of transportation routes and park facilities that presently occupy the flood plain at these sites. Either these facilities will have to be relocated, or much more frequent and deeper inundation will have to be tolerated.

At the West Beach Drive site, virtually the entire length of Beach Drive from the bridge to the East-West Highway (1.5 miles) would be flooded by up to 10 feet of water in some places. It is not possible to estimate the increase of the 100-year flood elevation as a result of the impoundment without extensive routing of flood hydrographs and hydraulic analysis, but it is estimated that approximately 10 private residences in Montgomery County, presently safe, would fall within the expanded flood limits. Numerous Montgomery County Park facilities would also be affected.

The B&O Railroad site is more advantageous in that 1.5 miles of Jones Mill Road and Beach Drive would be inundated by only 2 to 3 feet of water during the mean annual flood event and there are few park facilities in the flood plain. It is estimated that the increased 100-year flood elevation would encompass an additional 12 private residences and a small portion of Interstate 495.

Of the two sites that were evaluated, the B&O Railroad Bridge would be preferable. However, the use of a large impoundment to control flooding and channel erosion problems in the District reach of Rock Creek is not a recommendation of the study. The damages that have been observed as a result of flooding do not warrant such an extensive expenditure and sacrifice of valuable park land. An impoundment of the size analyzed here would not appreciably attenuate the peak flow of larger events such as Hurricane Agnes which cause the great majority of observed physical damage to bridges and other facilities. The main benefit of this strategy would be to limit the channel erosion occurring in natural stream segments. The basic premise for analysis of problem areas did not include this type of damage. Control alternatives strictly for mitigation of natural streambank erosion are not recommended. Costs of relocation or elevation of roads, construction of the dam, relocation of affected facilities and private residences, and maintenance of the impoundment would far outweigh the accrued benefits. Wildlife habitat and vegetation in the impoundment site would eventually be destroyed or shifted in nature by the increased frequency and depth of flooding and the silt load that would be deposited. An additional detraction to the concept of a large impoundment is that, although immediate benefits would be realized downstream, the source of the problem is not directly addressed and the erosion problems upstream and on tributaries are not alleviated. For these reasons, large impoundments are considered an impractical strategy for Rock Creek and will not be considered as a flood or erosion control alternative.

Within the District, impoundments could be effectively utilized to control erosion problems on the tributaries. The steep valley walls at the headwater outfalls of all these streams provide ideal dam sites and large amounts of available storage. It is not within the scope of this study to evaluate this type of alternative. Problems on the main stem of Rock Creek would not be mitigated and may be worsened by this type of strategy because of hydrograph peak timing considerations. Further hydrologic/hydraulic analysis of the tributaries is recommended prior to consideration of this alternative control strategy.

EROSION

CONSTRICTIVE BRIDGES

There are three sources of problems at constrictive bridges. The first is the most obvious and usually is controlled adequately. That is, the high velocities at the most restricted part of the opening. The concrete or stone faces of the bridge abutments usually protect the underlying ground from damaging erosion. The other two sources of problems are often neglected. These are the upstream face of the embankment and the stream channel just downstream of the structure. The three principal sources of erosion at constrictive bridges are illustrated in Figure 7-2.

The three-dimensional flow in the backwater behind a constrictive bridge is a complex situation. The problem can be simplified as follows. When water flowing in the overbank areas runs into the bridge embankment, it must turn and flow normal to the channel to pass through the contracted opening. In deflecting the water, the roadway embankment is subjected to erosion. The tangential flow along the bank further aggravates the problem. Commonly, the embankment material is artificial fill with a grass covering. This is a highly erodible medium. The embankment should be made less likely to erode by using milder slopes or some type of lining. Depending on the situation, dense vegetation may be sufficient to keep the high velocities away from the bank.

The third problem area at bridges is the area where the water which has passed through the contracted opening expands to the downstream flood plain. In addition to the high exit velocities, eddies are formed which attack the channel banks downstream of the bridge. The accompanying scour can damage the foundation of the structure and lead to major failures. The banks downstream of a structure must be fortified for a great enough distance to prevent damage to the bridge.

In designing artificial slope protection for these areas, it is difficult to estimate design velocities due to the three-dimensional character of the flow. At the most constricted opening, velocities predicted by the HEC-2 computer program should be accurate but are generally higher than the envelope depicted in Figure 7-1. Away from the bridge itself, the velocities presented in Figure 7-1 are appropriate.

Potential problems with the bridges along Rock Creek are summarized on the following page:

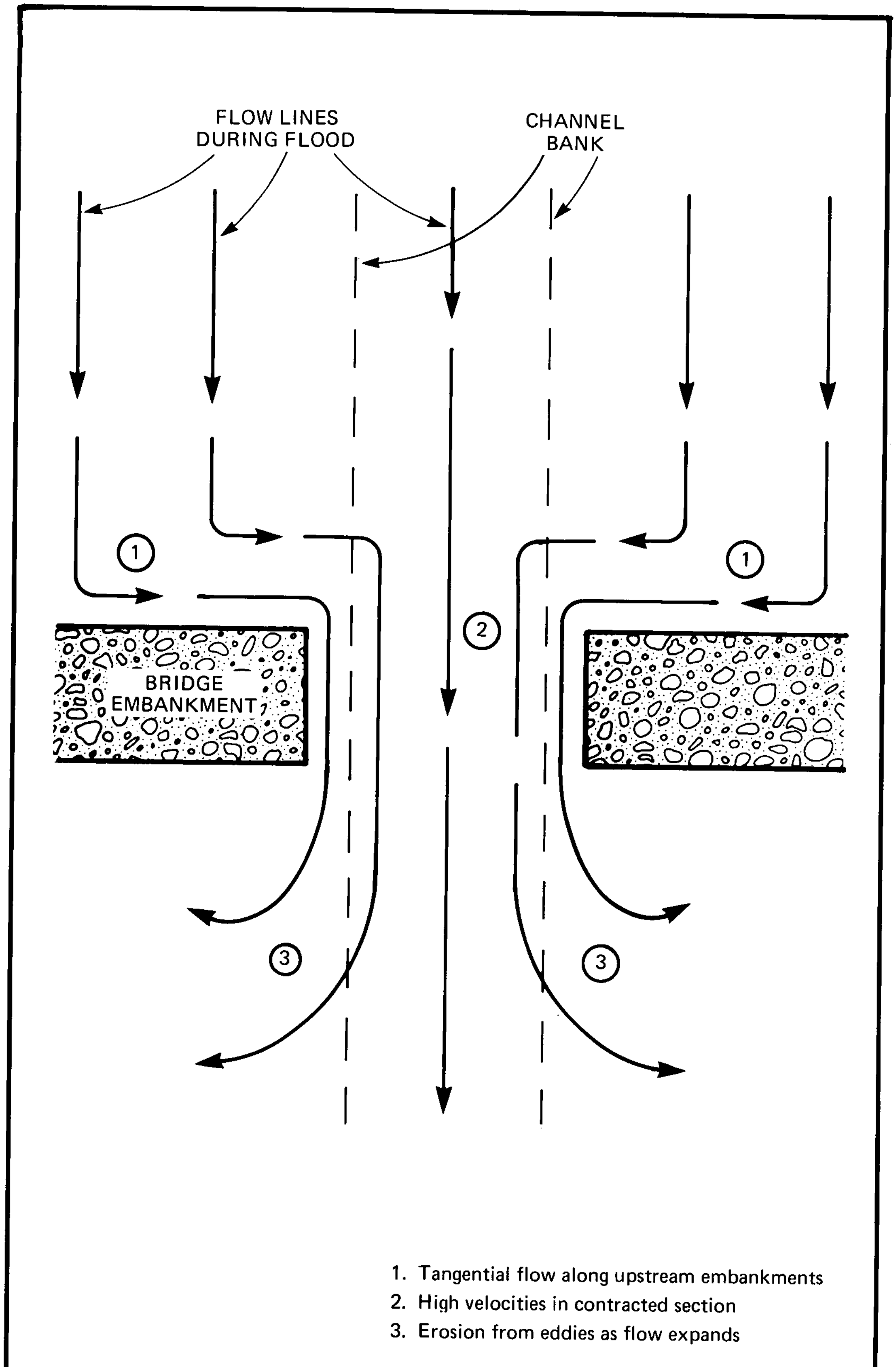


FIGURE 7-2: Erosion Problem Areas At Constrictive Bridges

L Street Bridge. The bridge exit section is not adequately protected. Loose stones which have been dumped here are too small and the bank is too steep for riprap protection. The ground below the sidewalk on the southwest corner is eroded a large amount. A stronger protection, such as gabions or a rigid lining is required to achieve the desired protection. Reconstruction of the bridge is being planned and provisions for this problem should be included.

Rock Creek and Potomac Parkway Bridge at Bottom of Shoreham Hill. Deposition under the bridge has reduced the available flow area, increasing scouring potential and backwater elevations. The channel under the structure should be cleared of the debris to conform to the natural channel shape of the upstream reach. This would require approximately the top two feet of the material, mostly sand and gravel, to be removed. It would be advantageous to deposit the material on the downstream west bank where a bend in the channel is eroding and fortifying this with larger riprap placement. The problem is shown in Figure 7-3.

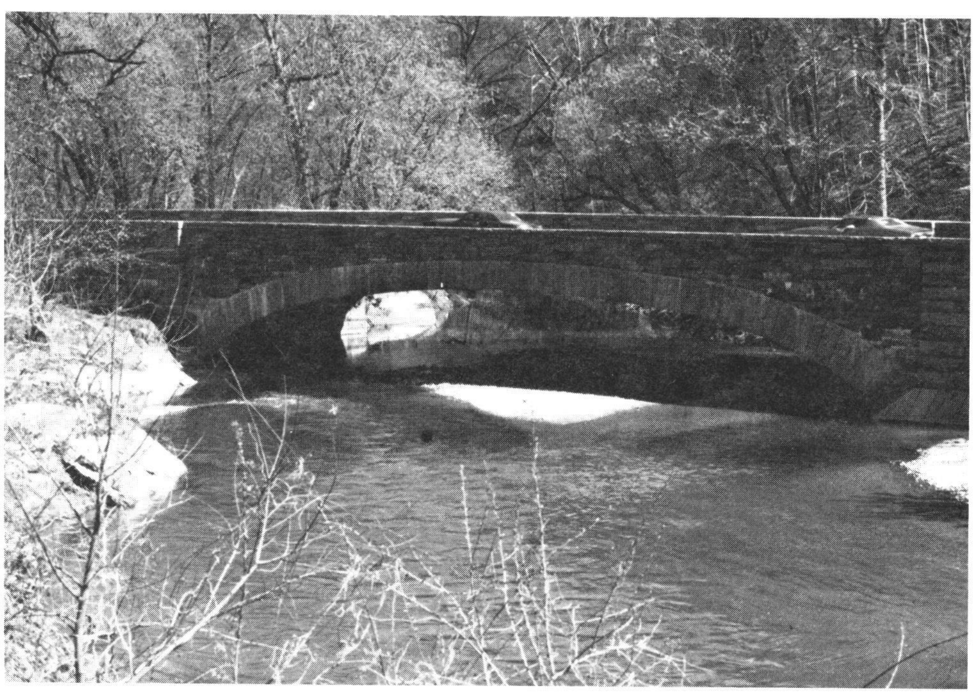


Figure 7-3 Deposition Under Rock Creek and Potomac Parkway Bridge at Bottom of Shoreham Hill

Park Road - Tilden Street Bridge. The Park Road-Tilden Street Bridge exhibits two of the three problems depicted in Figure 7-2. The west embankment on the upstream side is subject to erosion from floodwater returning to the channel from the overbank area below the dam. Due to the proximity of Peirce Mill, fill to create a gradual transition is not recommended. Artificial armoring of exposed areas is necessary here. The opposite, east bank has been stabilized and a bay of the bridge filled in. Opening the bay would increase flow capacity, but possibly endanger Beach Drive and create new problems. It is not recommended.

The second problem at the bridge occurs at the downstream outlet where both banks are exposed and eroded by eddy currents. The west bank has little artificial protection, and the east bank is too steep for the loose stones which are there. A possible solution for the downstream side is to cut back the west bank or allow natural erosion into Picnic Grove Number 1, providing more channel area and reducing the pressure to erode on both banks. If the bank slope on the east bank cannot be graded mild enough for riprap, a rigid lining will be needed to protect Beach Drive.

Boulder Bridge. In this area a natural constriction in the flood plain has been magnified by the presence of the bridge. The contracted opening on the west bank is shown in Figure 7-4. Due to the historic nature of the structure, large-scale renovations are unlikely; however, localized protection at the worst spots is recommended. On the west bank, where flood waters rush between the bridge and the stone bank, the foundation of Beach Drive should be strengthened to reduce damage to the road. This new foundation can be covered with soil and vegetated to preserve the natural look. After a large flood which might wash away the soil, fill will be needed to rebuild the facade.

Joyce Road. The principal problem at Joyce Road is the water rushing over the road and carrying soil from the downstream (south) embankment with it. The problem is most prevalent on the east side embankment at the intersection of Beach Drive and Joyce Road. The solution here is to fortify the bank so that it is non-erodible.

Beach Drive at Milkhouse Ford. The west embankment for Beach Drive at Milkhouse Ford is a barrier to flows in the overbank. A sharp transition from broad flood plain to narrow bridge opening creates high lateral velocities (see Figure 7-2). As the water is deflected back to the channel, erosion of the embankment will occur. This problem can be avoided by having a more gradual transition from flood plain to constriction and/or more dense vegetation on the bank. Creating a gradual transition will require extensive fill and grading of the west bank with subsequent vegetation stabilization for approximately 500 feet along Beach Drive. An intermediate measure would be to discontinue mowing of existing grass and planting willow trees

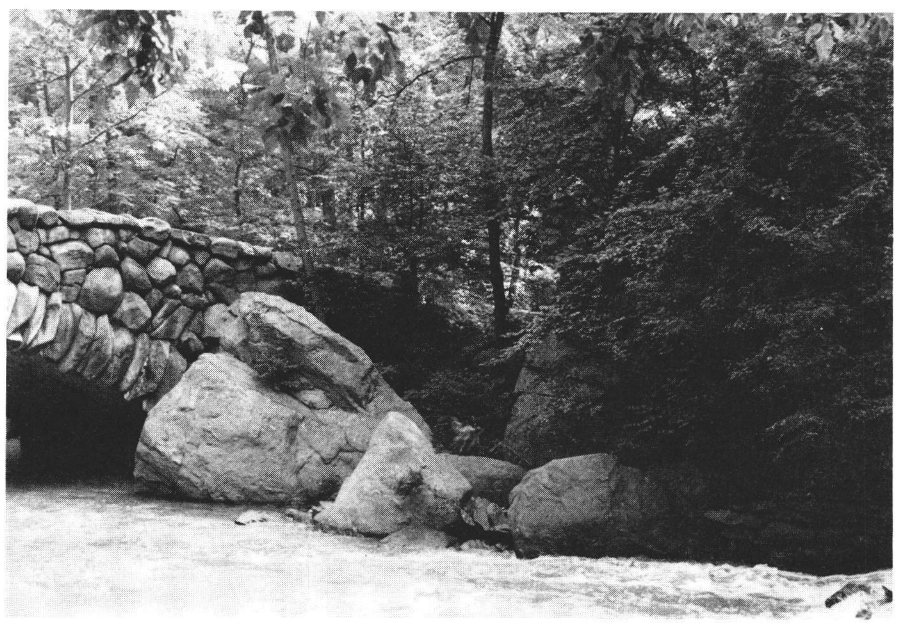


Figure 7-4 Contracted Section at Boulder Bridge

(see discussion on vegetation). If these solutions are impractical, artificial armoring of the embankment may be needed.

Sherrill Drive. The embankments at Sherrill Drive block the flow in the overbanks, especially on the west side. The abrupt transition from wide flood plain to constricted opening exposes the upstream embankment to erosion. The problem is similar, but more severe, to that at Beach Drive at Milkhouse Ford. Presently, there is only grass protecting the bank. As with Beach Drive at Milkhouse

Ford, the flood plain should be filled, graded and vegetated to provide a more gradual transition between cross section shapes. At the very least, dense vegetation should be used instead of grass to slow the eroding velocities along the embankment. As always, the embankment could be lined with non-erodible material. This would obviate the need for extensive grading and filling operations.

West Beach Drive. The problem at West Beach Drive is exactly the same as the Sherrill Drive, except on the east bank. Here, dense vegetation exists but it was not sufficient to prevent damage from a large flood in 1972. Upstream of West Beach Drive, the east flood plain carries a great deal of flow which must be redirected toward the channel. If compatible with desired land uses, the flood plain upstream of West Beach Drive could be altered in the same manner as Sherrill Drive to keep the water flowing closer to the channel. The extent of such an operation would necessarily be large and destroy extensive vegetation, habitat, and park facilities. For this reason, fortification of the embankment by riprap is in order. Some stones were placed here after the previous damage, but they are insufficient for complete protection in the future.

RECREATIONAL AREAS

The principal problems in recreational areas are the instability of the stream banks and the general destruction which accompanies large floods. Picnic Groves 8, 9, and 10 in the upper reaches of Rock Creek are practically identical in their flooding and erosion problems. Each grove is located on a meander in the stream that is on the easternmost side of a broad, flat flood plain and cleared of underbrush. As a result, two problems are created. First, the west bank at the upstream end of each picnic grove is eroding badly, due the energy used in turning aside the flows. Secondly, once the flow goes overbank, the cleared area provides a shortcut path for the water to rush through the picnic grove without using the channel. The high velocities in the unchannelized areas are the source of most damage in floods. Additionally, the natural tendency of the stream channel to widen is eroding the bank along the entire area. This bank erosion is shown in Figure 7-5.

As far as the channel banks are concerned, they should be allowed to widen and should be graded and vegetated at the new location. Since it has been the policy to push the channel back to its original location following a large flood, the present channel should be widened by

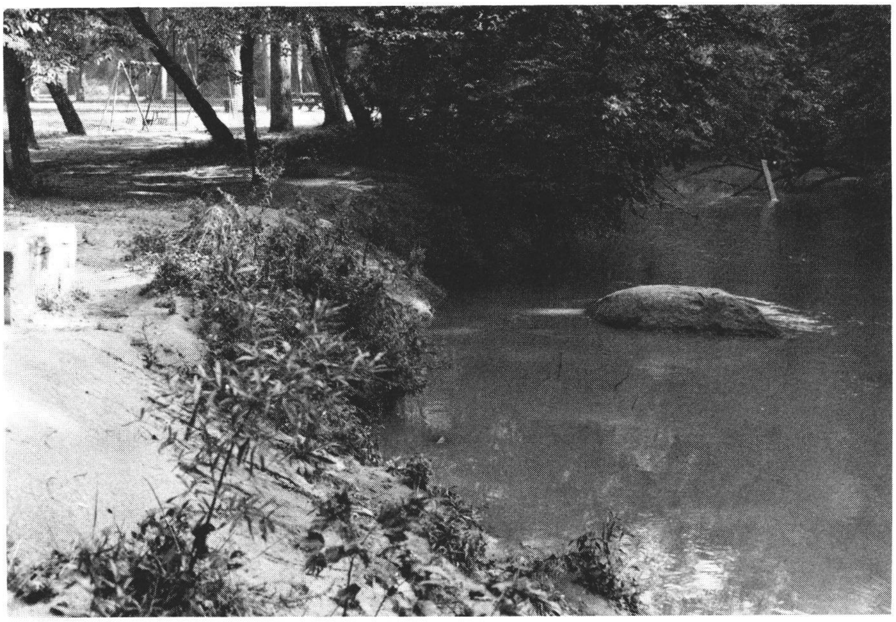


Figure 7-5 Stream Bank in Picnic Grove

the entire 40 percent, as determined earlier. This would be the increase required to accommodate a naturally stable channel under ultimate conditions.

It must be distinguished that there is a significant difference in the upper reaches of the Park (where the groves are located) between channel widening and channel meandering. In a broad, flat flood plain, a stream channel is never 'stable'. The natural tendency is to meander by eroding the outsides of bends and depositing at the inside (note the sand and pebble bars of these areas). The Park Service cannot nor should not attempt to control this process by any wholesale bank stabilization project. Only where structural damage is imminent should remedial measures be implemented.

At the upstream ends of the picnic groves, an artificial lining is required to keep the curved sections from expanding. Since mild bank slopes can be obtained, riprap is recommended because it is the artificial lining which least destroys the natural aesthetics of the stream channel. The downstream limit of the protection should be the point where the curve reverses itself and the upstream limit should be a stable bank somewhere upstream. Local conditions may necessitate extending either of these limits beyond the stated distance. The design velocities from the HEC-2 analysis of the 100-year flood can be obtained from Figure 7-1.

Grading

Regrading is most effective at controlling problems created by local runoff. Large floods can react unpredictably to regrading by washing away the new obstruction, increasing flood elevations downstream, or deflecting the flow to unprotected areas. One exception is near constrictive bridges where encroachment has already redirected the flow and channelization is needed. This discussion will be limited to local problems at picnic areas.

The biggest problem with most picnic areas is that most of them are shaped like big bowls, collecting all the runoff at one point before sending it to Rock Creek.

This makes for muddy ponding areas and an eroded channel where the ponded water makes its way to the creek. These problems can be avoided if the following steps are taken.

The flood plain should gradually slope toward the channel to avoid ponding areas. An average slope of 2 percent is recommended to provide adequate drainage. This slope should not be so great that it interferes with children walking or playing ball. The flood plain should further be graded so that the runoff is separated into many small drainage areas, each having a small swale draining to Rock Creek. With the much reduced flows in the many drainage swales, there will not be enough water in any one to cause damage. Again, the grading and drainage swales should not be enough to trip people as they walk, but they should have a definite slope.

Vegetation

As far as flood damage is concerned, vegetation has three functions in preventing damage: (1) the roots give the soil something to hold on to so it is not so easily eroded, (2) the aboveground parts of plants reduce the velocities of water near the surface, reducing the power to erode the soil, and (3) dense vegetation can keep humans and animals away from the channel bank so they do not trample the grass and underbrush or cave in the banks. Usually the third factor is the reason there is often not enough vegetation in the right places. Since the picnic groves are recreational areas, they must be be made accessible to visitors. This usually means reducing the ground cover substantially. A good compromise would be to make the areas as accessible as possible without exposing the ground to increased erosion.

Where artificial armoring of the channel will not be done, the channel banks should be vegetated with trees having good root systems to help hold the banks. The trees should be placed somewhat back from the existing bank to allow the channel to reach a more stable width before being restrained. In some areas there is only a single row of trees (Picnic Grove 6) which is on the verge of eroding away. This would leave the bank completely unprotected. The channel should be flanked by several rows of trees so that as the channel expands, it will not encounter an easily erodible material. The expected new width is about 40% larger than the existing width.

Vegetation in the flood plain can help prevent damage when the flows go overbank. The most damage is caused during large floods when the water takes a shortcut across the flood plain to avoid going all the way around the meander of the channel. The main idea here is to reduce the velocities of the water in the flood plain and keep the flows in the channel as much as possible. This can be done by placing obstructions to the flow in the flood plains to increase the hydraulic roughness. Trees, bushes, barbecues, embankments and other obstructions placed perpendicular to the channel will help prevent damage during large floods. Between Broad Branch and Peirce Mill, there are strips of vegetation and open space running parallel to the channel. This only compounds the problem by creating overbank channels to carry the floods. If these strips were perpendicular to the channel, they would keep water from flowing in such volumes in the overbanks and damaging the recreational area. Ideally, the upstream ends of picnic areas should be left in the natural state without clearing the underbrush or cutting the grass. This would create an area of dead storage behind them where floodwaters would pond instead of rushing through taking soil and other material with them. This area of wild vegetation should extend from the upstream limit of the area to a point where floodwaters would not be able to cut across the cleared part of the picnic area without leaving the channel. These areas should have lots of low branches and bushes such that it is difficult to walk through. If footpaths are cut through these areas, the paths should be winding so that water will not be able to follow them too easily.

These actions will help prevent damage from large floods. They will cause higher flood elevations locally, but should reduce the damage to the recreational areas. Even though damage may still occur, the channels will not be cut so badly with the new trees in place, and a lot less soil will be lost due to the lower velocities in the flood plain. Deposition in the flood plains from the lower velocities can be expected to occur; however, this new soil should not pose a large problem.

ERODIBLE BANKS

In many cases, Beach Drive and the Rock Creek and Potomac Parkway have been built in the flood plain of Rock Creek, obstructing flow in overbank areas. In some cases, the roads appear to be encroaching on the channel. This situation provokes several problems, including erosion around the roadway, decreased flood plain storage and higher velocities in the constricted areas. In cases where the road is too close to the channel for natural protection from erosion, artificial armoring of the channel is necessary to prevent damage.

Due to the tendency of the Rock Creek channel to widen with the higher flows in recent years, the roadways in the flood plain are being threatened by the advancing erosion on the unprotected banks. Figure 5-1 shows the locations of this type of problem. In some of the areas shown, some protection is provided by riprap but, in general, this has proven inadequate. An example of inadequate riprap along Beach Drive is shown in Figure 7-6.

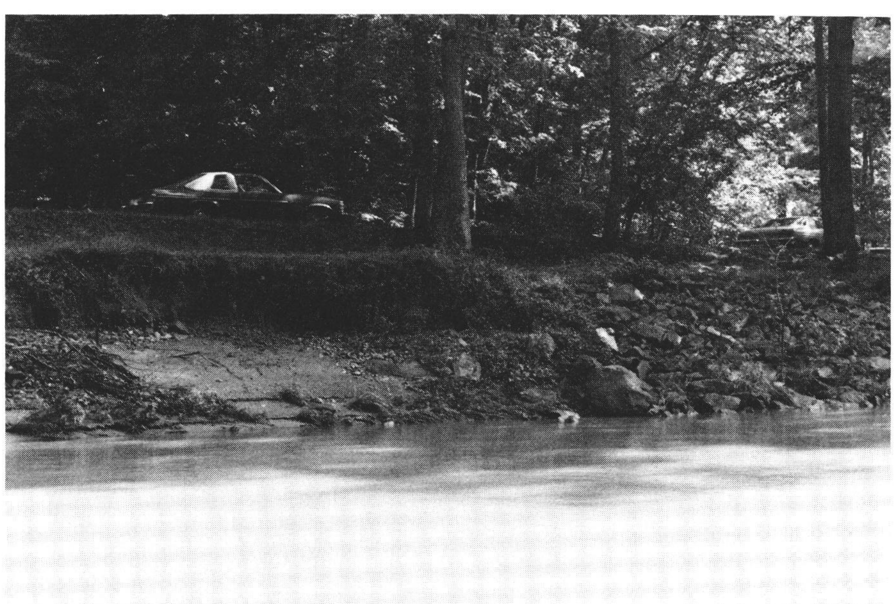


Figure 7-6 Inadequate Riprap Along Beach Drive

The existing characteristics should be compared to a stable design to determine which areas need added protection. Figure 7-1 shows the channel velocities for the 100-year flood, which should be used as the design velocity for the area in question.

A description of each problem area is listed in Table 7-1, with an indication of the severity of the problem. The risk of damage is termed "severe" if a moderate flood would do great damage, "moderate" if a large flood is required to cause damage, and "limited" if the problem is expected to escalate to moderate or severe in the near future.

The recommended actions listed in Table 7-1 are based on a field reconnaissance of the problem area and evaluation of the suitability of the alternatives presented in Chapter 6. There are numerous ways to solve any of the problems listed, but the recommendations are offered as the most reasonable permanent solution. The guidelines for selecting a solution alternative are the following:

1. Try to remove the problem from the critical area; or

2. Provide natural looking protection, such as vegetation or riprap; or

3. Where space does not permit (1) or (2), provide a stronger structure, such as gabions or rigid walls.

Channel structures were not recommended as a control alternative in these areas because, initially, they are not in keeping with the aesthetics of the National Park.

RETAINING WALLS

In many places, rigid walls have been built to protect the roads which are too close to the channel. There are several places where flaws in these walls were discovered, which could lead to a major collapse. These locations are summarized below.

The problems discussed here are generally the result of poor maintenance of the structures after storm events. The walls are well designed and constructed and have successfully weathered large floods in past years. However, some spots will always need repair. If regular inspection and maintenance is not performed, these 'spots' will grow and failure will be imminent. Generally, all that is needed is in place repair of existing

TABLE 7-1
SUMMARY OF EROSION PROBLEMS FROM ERODIBLE BANKS

Location on Rock Creek	Description	Risk	Recommended Action
East bank between Penn. Ave. and P St.	Steep bank with dense bushes	Limited	Watch for breaks in protection to develop; introduce woody plants with good root structure in weak areas
Bike path near Oak Hill Cemetery	Unprotected bank threatening bike path	Severe	Design relocated path; implement after destruction
East bank just upstream of Mass. Ave.	Remnants of retaining wall provide inadequate protection	Moderate	Rebuild wall or provide adequate riprap
Between Rock Creek Parkway and footbridge downstream of Conn. Ave.	Foundation of footbridge endangered by erosion	Severe	Riprap or channel deflector
Bike path at downstream part of National Zoo	East bank eroding toward bike path	Moderate	Design relocated path; implement after destruction
Bike path at upstream part of National Zoo	East bank eroding toward bike path	Moderate	Riprap bank in danger area
East bank just upstream of Piney Branch	Stream is turned 90°, causing erosion; threatening bike path and Beach Drive	Moderate	Gabions or rigid lining

TABLE 7-1
SUMMARY OF EROSION PROBLEMS FROM ERODIBLE BANKS
(CONTINUED)

Location on Rock Creek	Description	Risk	Recommended Action
East bank between Broad Branch and Military road	Inadequate riprap in the reach with a couple areas of severe risk to Beach Drive; see Figure 5-1	Moderate	Design riprap for entire reach; fortify areas of severe risk immediately; increase protection in other areas as funds are available
Bike path at Picnic Grove 6	Erosion on east bank threatening path	Severe	Sacrifice 4 or 5 parking spaces from lot and reroute bike path through corner of parking lot
Upstream limit of Picnic Groves 9 and 10	Bank eroding where stream is turned to bypass picnic area	Moderate	Riprap area exposed to damage
West bank upstream of West Beach Drive to Maryland line	Where stream is close to Beach Drive, road-way is unprotected from erosion damage	Moderate	Riprap areas exposed to damage, or retards on west bank with removal of some trees on east bank
West bank near Riley Spring Bridge	Stream is turned 90°, eroding bank and threatening Beach Drive; existing rip-rap is inadequate	Moderate	Design riprap protection and upgrade the existing riprap to meet the design

failing facilities at minimal cost, and catching up on maintenance such as repairing cracks and removing large vegetation.

Piney Branch Parkway. Along Piney Branch, the retaining wall which protects Piney Branch Parkway has been badly undercut and is in serious peril. Large trees have grown among the rocks, further disrupting the effectiveness. This wall should be inspected by someone knowledgeable about the structural integrity of such walls, and the necessary repairs should be made. Figure 7-7 shows the condition of the wall.

Figure 7-7 Retaining Wall Along Piney Branch

P Street. Along Rock Creek near P Street, the east bank is protected by a stone and mortar wall which appears to be in good shape. There are, however, numerous large trees growing in and around the wall which could in time destroy the supporting capability of the structure. This area should be inspected more closely to identify and repair any potential weak spots caused by vegetation or scour.

Upstream of P Street. Just upstream of the wall described above is the remnants of a wall made of loose stone. The wall is in such disrepair that the stones appear to be riprap. The sparseness of the protection in this area makes it susceptible to erosion. Although this is not considered to be a critical problem, the wall should be rebuilt or the bank fortified by gabions. It is too steep for riprap to be effective.

Massachusetts Avenue. Upstream of Massachusetts Avenue on the east bank is again the remnants of a stone wall. The wall has caved in a great deal and the breaks in protection should be repaired.

National Zoo. The retaining wall along Rock Creek on the grounds of the National Zoo between the zoo entrances and Klingle Road is in need of some spot repairs. Increased stream velocities caused by fill and riprap (encroachment) along the west bank have accelerated the deterioration of the wall. Weak areas have failed in recent floods and need repair to avoid erosion of the east bank and damage to the fence and bike trail. This retaining wall should be closely inspected and the design reassessed by a structural expert and the necessary repairs made.

Beach Drive near Klingle Road. The wall retaining Beach Drive between Klingle Road and the Klingle Road turn-off is also in need of repair. As with the other areas, this section should be closely checked by a structural expert to identify dangerous points.

LOCAL DRAINAGE

A large percentage of the flooding problems and subsequent transportation interruption on Beach Drive is the result of inadequate local drainage rather than overbank flooding of Rock Creek itself. Even though an in-depth analysis of local drainage problems is beyond the scope of this report, some problem areas were discovered in the course of the field work.

Perhaps the worst case of inadequate local drainage is along Beach Drive between Joyce Road and Broad Branch. The stream valley is very steep in this area and drainage from the slopes runs across Beach Drive in many locations. Due to the topography, drainage swales on the bank are not always defined so water may flow across the road at almost any location. Where drainageways are discernible, culverts have been placed under Beach Drive but these are insufficient to carry the flows. Most of the carrying capacity of these drains is choked off by leaves or other debris as illustrated in Figures 7-8 and 7-9. A comprehensive study and design of local drainage across Beach Drive is needed between Joyce Road and Broad Branch.

In any case, the existing drains should be checked and cleared to increase their capacity.

The upper reaches of Rock Creek, although not in such bad shape, could also benefit from such a study. One location in particular is just south of Wise Road. A rather large valley has been blocked off by Beach Drive with a relatively small culvert. If this culvert is choked with debris, water cannot flow anywhere and backs up considerably. If the backwater gets high enough, water will start flowing through the ground under Beach Drive. The embankment holding the road cannot take the strain of water flowing through it and could possibly suffer great damage. There are two solutions to this problem; either 1) keep the cleared opening of the culvert large enough to prevent backwater, or 2) design the embankment of Beach Drive as an earthen dam. In its present condition, it is not suitable to act as a dam, due to the high permeability.

Another common local drainage problem in the Rock Creek watershed is bank erosion from local runoff. In many areas, runoff which collects in the flood plains cuts a path down the bank into the channel. This problem can be avoided by proper grading, which separates the runoff into smaller segments that do not have the power to destroy the bank, or adequate design of the drainage ditch. In most areas, the design of local drainage works appears to be ignored.

The excess water is left to find its own path to the stream. This problem is especially obvious at Picnic Groves 8, 9, and 10. These areas are shaped like large bowls, collecting water in the middle. The ponded water eventually cuts a path to Rock Creek and leaves puddles, gullies, and eroded banks that greatly detract from the recreational value of the groves. It is recommended that proper grading for drainage by grass-lined swales be implemented and maintained in the groves (see discussion on vegetation and recreation areas).

Another form of bank erosion comes from culverts which discharge along or even at the top of the bank of streams. The concentrated flow cuts deep ravines down the bank as it rushes to the channel. An example of this condition is illustrated in Figure 7-10. This problem can be avoided by proper design of the culverts which will carry the water all the way to the stream. This may include extending the culvert to the mean water line, providing a non-erodible path down the bank, or dissipating the errosive energy by a stilling pond, kinetic energy dissipator, or flow dispersion. This type of bank erosion

Figure 7-8 Culvert Choked by Leaves

Figure 7-9 Culvert Capacity Reduced by Siltation

Figure 7-10 Erosion from Culvert at Top of Bank

problem occurs more on tributaries than on Rock Creek since culverts on the tributaries are usually much higher above the channel than on the main stem of Rock Creek.

The Park Service must review and approve designs for all storm drains that contribute to the park. As a part of these permits, it is recommended that the permittee be required to provide and maintain adequate erosion protection at the outfall. At stream edge, masonry headwalls in general disrepair abound in Rock Creek. A more flexible lining (riprap) should be utilized with the toe extending below channel bottom and upper limit above 10-year flood elevation as a provision of the permit.

Where outfalls discharge above the channel, protection by a natural-looking rock or masonry spillway should be required, once again extending to channel bottom, as a part of the permit design. All permits should include definite provisions for regular inspection and maintenance, with penalities for neglect of such, by the permittee.

A large portion of the channel erosion problems on the tributaries is related to this cause as the headwaters of all tributaries originate as large storm sewer outfalls. Inadequate or defunct stilling basins and/or kinetic energy dissipaters at these headwater outfalls promote the downstream channel erosion problems. Examples of this situation are depicted in Figures 7-11 and 7-12.

Despite the unattractive aspect created by this situation, the erosion created by the unimpaired discharge at storm sewer outfalls is generally not threatening or damaging any structures or facilities and may not warrant large expenditures for correction. It is recommended that large boulder placements be instituted at the headwater outfalls and downstream culverts of Fenwick, Soapstone Valley, Pinehurst, Klingle and Normanstone Branches as a mitigation measure to slow exit velocities and impede bowl formation and downstream erosion. This will not necessarily eliminate the problems observed, especially downstream. A much more extensive study and analysis beyond the scope herein will be required to thoroughly alleviate these conditions. It is the opinion of this consultant that the situation is chronic for streams of urban setting and cannot be solved short of extreme measures of complete rigid lining of the channel or construction of detention ponds at the headwater outfalls.

Debris Control and Maintenance

All the analyses presented in this report are based on unobstructed flow conditions. Unexpected obstacles and debris can greatly affect the predicted flood elevations, flood velocities, and erosion characteristics. On a small scale, leaves or trash may block drains causing flooding from local runoff. Along Rock Creek, downed trees, picnic tables or other debris can block portions of the channel or bridge openings, greatly increasing flood elevations. If the blockage should suddenly come free, a large wave of water with terrific force will pound the channel downstream. Obstructions in the channel can act like channel deflectors, focusing the power of the rushing water on a particular area of the bank. If the bank is unprotected, the erosion could be quite damaging before it is ever discovered.

To avoid compounding problems, proper maintenance of the stream area is required. Stormwater intakes should be checked and cleared 2 to 3 times during the year. This may prove too infrequent in some critical areas, so certain areas may need to be cleared more frequently. A record could be kept on the condition of each site so that the worst areas can be identified. These areas may require structural changes to reduce the hazards of debris blockage.

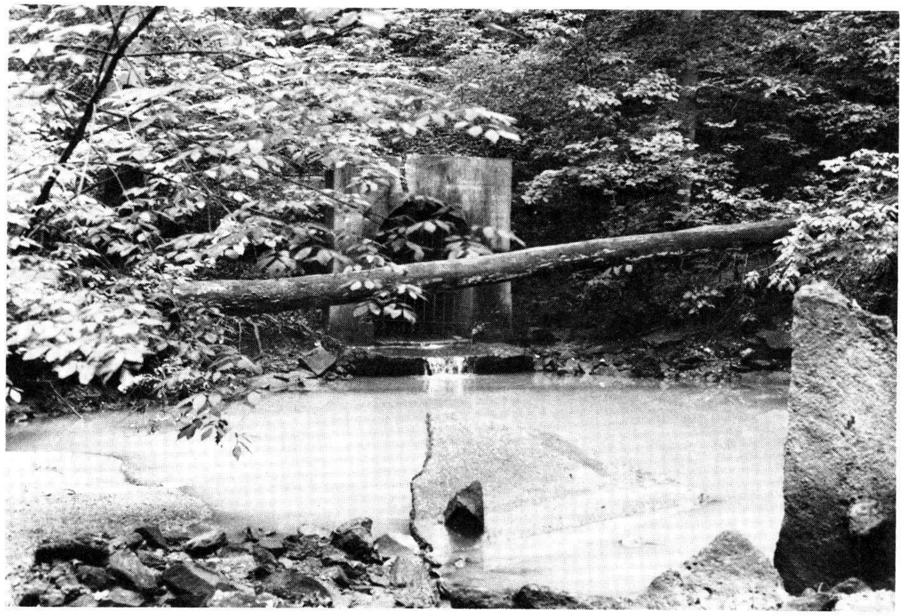


Figure 7-11 Remnants of Stilling Basin in Soapstone Valley

Figure 7-12 Scour at End of Concrete Apron

Large obstacles blocking bridge openings or the channel of Rock Creek are more difficult to control. Large trees in the channel can be beneficial in localized control of erosion by slowing velocities and detaining floodwaters. However, logs left in the stream channel will cause siltation and channel aggradation as depicted in Figure 7-13. Such accumulations of debris and sediment reduce channel capacity, cause backwater problems, raise flood elevations, and promote downstream erosion. In addition, siltation at these locations destroys fish habitat. Problems arise when the downed trees float downstream during high water and become lodged where they can perform damage. Even trees which were standing at the start of a storm can fall or break off during storms, so merely clearing the downed trees in dry weather is not enough protection. There are also detrimental impacts to the practice of clearing and snagging of the stream channel. Pools that form at blockages and decaying detritus provide aquatic habitat and a food source that would be eliminated. Extensive clearing of streambank vegetation would raise water temperature. Fish behavior, territoriality and spawning could be impacted by clearing and snagging.

Figure 7-13 Debris and Siltation in Rock Creek Channel

Thus, selective clearing and removal of debris is recommended. Large tree trunks and branches should be snagged from the channel and smaller limbs, brush, and detritus left. Sediment should be left to follow its natural course.

A plan for clearing the debris during and after storm events should be developed and instituted for quick and expedient removal of all large debris and blockage from the stream channel. The personnel and equipment to be used should be identified in advance to insure a smooth operation. Care should be taken in removing blockages so that large pieces are not simply left to float downstream and create problems again. Methods for removal should be determined on a site by site basis and can include hauling up to a road, controlled floating it to a collection point (road or bridge), depositing it on the flood plain (above 100-year level), or other methods.

The problem of fallen trees and debris causing channel erosion is similar to the flooding problems caused by the trees and debris. During storms, obstructions which deflect the floodwaters into an eroding bank should be removed as quickly as possible, before much of the bank is lost. In addition to times of flooding, these accidental channel deflectors can cause damage in periods of low flow as well. The times of low flow are not usually a problem because the obstruction in a critical area will probably be removed for aesthetics before real damage is done.

Preventive maintenance is a concept of debris control that is all too often neglected. Fallen trees, logs and underbrush originate from the channel banks and flood plain. Dry-weather removal of dead trees and brush from these areas, in addition to cutting of all trees teetering at the brink of falling into the stream, is a practice that, if regularly practiced, will eliminate the need for removing them from the stream channel during and after storm events. In addition, this will mitigate the damage they cause prior to removal. Care should be exercised to leave stumps and root systems intact for bank stabilization purposes.

An additional source of debris is that created by erosion and damage to storm sewer outfalls. Widening and meandering of the channel has undermined and/or exposed outfalls and sewer lines in numerous areas (see Figures 7-14, 7-15, and 7-16) along Rock Creek and its tributaries. As a result, pipes, culverts, and headwalls are frequently found in the middle of the stream. There is an obvious lack of maintenance at these structures that result in collapse and cause additional erosion along the bank.

Figure 7-14 Damaged Storm Sewer and Headwall on Rock Creek

Figure 7-15 Erosion Exposes Sewer Line on Fenwick Branch

Figure 7-16 Erosion Undermines Sewer and Headwall on Fenwick Branch

Aesthetics

Since most all of the stream banks of Rock Creek are in park land, aesthetics can be an important consideration in erosion controls. No one will dispute that vertical banks, gullies, sewers, and exposed tree roots are detrimental to the physical aspect of recreational areas. However, cosmetic surgery to these areas in the form of artificial structures is hardly a more pleasing prospect and should be kept to a minimum. Left to its own processes, the stream should eventually form a stable channel. It is only when this stabilization is too slow or incompatible with man's plans that alterations are necessary.

When alterations to the flood plain or channel are made, consideration should be given to future trends of the stream. Past practice has been to return the area to the previous condition, preventing the stream from establishing a new stable configuration. Such practice is never-ending and does not constitute a solution. Aesthetics aside, the channel should be allowed to widen the predicted 40 percent per the status quo strategy.

The aesthetic quality of logs within the stream channel and trees leaning over the bank is a matter of personal preference. However, as previously discussed, the potential damage to structures, stream channel erosion, siltation of aquatic habitat, and flood enhancement require removal of such obstructions, existing and potential.

Vegetation

The planting of a natural vegetation cover is strongly recommended as an integral part of all erosion control structures proposed herein. This can come in the form of tough grasses such as ryegrass or fescue or some native species of tree willows. The grasses are most effective in flood plains and should be utilized in shallow, wide drainage swales of no greater than 4:1 bank slope or design velocity greater than 4 feet per second. All picnic grove areas should be graded thus and drained by these type of grass-line swales. Limited usage and infrequent mowing is the best practice to establish an effective ground cover. Swales should be mowed more frequently than slopes and the flood plain, but maximum cut height settings are recommended.

Native willows such as the black willow, planted either as rooted plants or cuttings at 3-foot spacing, can be used to stabilize stream banks. They should be placed two feet above normal water level and cut when they reach 6 to 8 inches in diameter leaving 1 foot stumps. The root systems of these trees can help to maintain bank stability but must be controlled and maintained for effectiveness to be realized.

FLOODING

Flooding problems are defined herein as those caused by inundation by flood waters of Rock Creek. The following recommendations will help alleviate the flood problems identified in Chapter 5.

ROADS

Beach Drive between Broad Branch and Military Road is subject to frequent flooding from local runoff not associated with flows in Rock Creek. The lack of adequate drainage beneath Beach Drive is the main cause of flooding and traffic interruption along this stretch. The solution here is to design a system of culverts to carry the runoff under Beach Drive and keep them free of debris, sediment, and leaves. This problem is discussed more fully earlier in this chapter under "Local Drainage."

There are four sections of Beach Drive and the Rock Creek and Potomac Parkway that would be flooded by the Rock Creek mean annual flood. These areas are listed in Table 5-2. To keep these roads from being flooded once every other year, they would have to be elevated above the predicted flood level. The other alternative, reducing the peak flood discharge, was not considered for reasons discussed earlier in Chapter 6. In light of the fact that structural damage from flood water inundation is minimal and other routes of travel are available, it does not seem reasonable to elevate the roads subject to flooding at such a low frequency. We thus recommend that no action be taken to eliminate road flooding from Rock Creek.

BRIDGES

Of the bridges in the flood plain of Rock Creek, there are none which are inundated frequently enough to pose a real problem. Structural problems at these bridges are not associated with inundation but by erosion of the foundation and stream banks (refer to "Erosion" section in this chapter). If one of these bridges should be considered a problem in the future, the HEC-2 computer program can be used to determine the general characteristics required to keep it free from inundation.

BUILDINGS

The buildings in the flood plain of Rock Creek do not pose a great problem. The two buildings at the National Zoo, the Park Police Headquarters and the Taft Stable should be floodproofed to the elevation of the 100-year flood. Alternately, flood insurance could be obtained for these structures to avoid a complete financial loss in a flood. Miller Cabin and Peirce Mill are located low in the flood plain and are not easily floodproofed. They have been flooded many times in the past without great damage and they will be flooded in the future. This fact is duly recognized and the Park Service should institute a plan of removal of items of value from danger during flooding events, if one is not currently in effect.

SUMMARY

The results presented in this report are meant to identify areas of potential damage from flooding or erosion. The report also recommends the required action to reduce the risk of damage or prevent any further damage. No attempt has been made to determine a cost-benefit ratio for the proposed solution alternatives. Determining just how much a particular area is worth protecting is basically a subjective matter except where structural damage can have a repair or replacement cost assigned to it.

Some control alternatives, such as large impoundments and channel rerouting are not practical for the lower Rock Creek area. For this reason, these strategies are not proposed in the recommendations. Source control recommendations have been previously discussed and are a most heartily endorsed strategy. Unfortunately, implementation of these recommendations will be difficult, at best, and will require a long period of time of piecemeal rehabilitation to rectify mistakes of the past. Initial actions should be those that can be accomplished within park bounds. A cooperative program with the Maryland and District of Columbia governmental agencies must be instituted to adopt the control strategies outside park limits.

In determining which alternatives were best suited for the Rock Creek area, it was attempted to preserve the natural appeal of the park as much as possible. For this reason, channel structures, such as groins and retards, and rigid walls were avoided where possible. Natural, even though wider, channels are the ideal where space permits the banks to expand. Riprap of natural-looking stone is recommended where bank slopes are mild enough but futher erosion cannot be tolerated. Rigid linings are recommended where slopes do not permit the effective use of riprap. Vegetative management is strongly encouraged in all areas as the most aesthetic and natural control strategy and should be an integral part of all planned projects and a continual maintenance program.

The priorities for implementing control strategies in these problem areas identified should be based on an in-depth evaluation of the benefits and costs of actions or inactions. There are, however, several situations where immediate action should be taken to avoid large-scale damage. These areas are summarized below.

L Street Bridge. After the hasty rebuilding of the L Street Bridge following the collapse in 1972, additional stones were placed on the banks for riprap protection. At the exit section of the bridge, the stone size is too

small and the slope is too steep for the protection desired. About ten feet of sidewalk is suspended in the air where the earth below is eroded. The stream bank in this area should be secured with gabions or a rigid wall to prevent undermining of the bridge foundation.

Piney Branch Retaining Wall. Where Piney Branch Parkway is protected from erosion by a retaining wall, the rocks making up the wall appear to have been loosened with age, creating an unstable situation and possible safety hazard. Large trees and bushes growing through the wall contribute to the likelihood of a collapse and should be removed. The wall should be inspected for structural soundness and the necessary repairs made.

Beach Drive Between Picnic Grove 10 and Wise Road. In this area, the stream is turned almost 180° by the west bank of Rock Creek. The stream bank rises directly from the channel at about a 45° angle with Beach Drive perched high on the bank. The grade of the stream valley is such that any soil loss from the bank near the channel will result in a large landslide. The west bank should be fortified with non-erodible material up to the elevation of the 100-year flood to minimize the risk of overtopping the protection.

Channel modifications in non-critical areas listed in Table 7-1 should be made starting at the mouth. This will avoid compounding an existing problem since channel modifications usually increase the hazards downstream. Flood plain and local drainage problems can be corrected according to the priorities set forth by the National Park Service.

A large number of the sediment, erosion, debris, flooding and aesthetic problems noted in this chapter can be mitigated by a regular inspection and maintenance program. A yearly inspection, preferably in late fall when vegetation is of least hinderance to motion and visibility, is strongly recommended. This would require walking the entire stream channel and tributaries to the headwaters and noting debris to be removed, trees that should be cut down, deficiencies of and damage to bank stabilization controls, damage to bridge abutments and foundations, channel and gully erosion problems, and storm sewer outfalls that are damaged and/or are causing damage. Subsequent to this thorough inspection, a yearly maintenance program should be set up. Debris control, storm drain cleaning, and vegetation management should be on a regular maintenance schedule. Other maintenance should be performed on a priority basis.

REFERENCES

1. State of California, Department of Public Work, Division of Highways, Bank and Shore Protection in California Highway Practice, November 1970.

2. S.P.A. Officine Maccaferri-Bologna, Flexible Linings for Canals and Canalised Water Courses, January 1976.

3. U.S. Department of Agriculture, Soil Conservation Service, Planning and Design of Open Channels, Technical Release 25.

4. U.S. Department of Agriculture, Soil Conservation Service, Vegetative Bank Stabilization with Woody Vegetation, (M-2430-58), 1958.

5. U.S. Department of Agriculture, Soil Conservation Service, Standards and Specifications for Soil Erosion and Sediment Control in Developing Areas, July 1975.

CHAPTER 8
WATER QUALITY ASSESSMENT

Water quality standards are established to provide for the continued safe use of a stream for a desired beneficial purpose. Physical and chemical parameters are measured that can be compared to the standards to determine if the stream's water quality is sufficient to meet its intended use and, further, to identify problems and their sources.

WATER QUALITY PARAMETERS

The water quality parameters considered in this study and their units of measurement are:

Temperature	degrees centigrade (°C)
Dissolved oxygen (DO)	milligrams per liter (mg/l)
Biochemical oxygen demand (BOD)	milligrams per liter (mg/l)
Turbidity	Jackson turbidity units (JTU)
Total suspended solids (TSS)	milligrams per liter (mg/l)
Fecal coliform bacteria	most probable number per 100 milliliters (MPN/100 ml)
Ammonia-nitrogen (NH_3-N)	milligrams per liter (mg/l)
Nitrite and nitrate-nitrogen (NO_2 + NO_3-N)	milligrams per liter (mg/l)
Orthophosphate-phosphorus (PO_4-P)	milligrams per liter (mg/l)
Phytoplankton (chlorophyll a)	micrograms per liter (ug/l)
Benthic algae (chlorophyll a)	micrograms per square meter (ug/M^2)

TEMPERATURE

Temperature is one of the of the major water quality indices, as it influences practically all other water quality factors. Temperature will influence the species of biological organisms present and the rate of many chemical and biological processes in aquatic ecosystems.

Higher temperature will increase the rate of degradation of organic materials (BOD) and decrease the solubility of oxygen in water resulting in a lower in-stream DO than would exist under the same conditions but at a lower temperature. Higher temperatures also place higher oxygen demands on fish and other aquatic organisms. Because of the low solubility of dissolved oxygen, high organic decomposition rates, and high oxygen demands from aquatic organisms, high temperature periods are generally the most critical for a stream. High temperatures can also be lethal to many organisms. For these reasons thermal discharges must be carefully planned and designed with consideration to environmental impact.

DISSOLVED OXYGEN (DO)

Dissolved oxygen is perhaps the single, most universally measured parameter of water quality since it is such an important element for sustaining life. Without sufficient quantities of dissolved oxygen (usually 4.0 mg/l), fish have difficulty in reproduction and survival. The absence of dissolved oxygen can result in the production of foul odors by anaerobic bacteria.

Gasses in the atmosphere are soluble in water to some degree. Oxygen is not readily soluble, i.e., it does not rapidly dissolve or mix in the water. The amount of dissolved oxygen in the water depends upon water temperature, salinity, and barometric pressure.

The above parameters determine the saturation value of the dissolved oxygen concentration. The actual dissolved oxygen content usually differs from its saturation value due to various oxygen demands or sources. There are demands for oxygen from aquatic animals, decaying organic matter, aquatic plants during respiration at night, and various chemical sources. These demands are offset by oxygen replenishment at the air/water interface by the process of reaeration and through the photosynthesis of aquatic plants during the day. The oxygen regime of an aquatic system is thus an ever changing phenomenon, yet one that tends to remain within narrow bounds unless imposed upon by externalities.

BIOCHEMICAL OXYGEN DEMAND (BOD)

The biochemical oxygen demand of the stream is oxygen consumed by micro-organisms utilizing organic matter as food and breaking down complex compounds to simpler products. Introduction of an organic waste to a stream will eventually decrease the dissolved oxygen and increase the nutrient concentration. BOD is generally used to determine the pollutional strength of waters in terms of the degree of oxygen depletion. It is possible to think of BOD as a measure of organic matter and as the amount of oxygen used in the oxidation of the organic matter.

The oxidation reactions are a result of biological activity and the rate of activity is substantially influenced by temperatures. The oxidation process is further comprised of two components.

The first component is the breakdown of carbon based organic matter and is called carbonaceous BOD while the second component consists of converting ammonia to nitrate-nitrogen. Usually only the first component, carbonaceous BOD, is measured and will be considered in this study.

TURBIDITY

Turbidity is a measure of the degree of interference of the passage of light through water. Causes of turbidity range from colloidal to coarse suspensions, and from organic matter to minerals or chemicals.

Turbidity is often used as a water quality standard because it gives an indication of the ability of light to penetrate water and hence the depth to which aquatic biologic activity can take place. Also, highly turbid waters are not aesthetically appealing for swimming, fishing, boating, etc.

TOTAL SUSPENDED SOLIDS (TSS)

Total suspended solids is a measurement of the amount of material suspended in the water. High suspended solids concentrations can significantly increase the turbidity, thereby, reducing the depth of aquatic plant activity. Although similar, TSS and turbidity are not directly correlated. Turbidity is dependent on the type and size of suspended particles as well as the quantity or concentration. Also, there are other water quality constituents not in particulate form that can cause tubidity. Bottom dwelling organisms can be covered by deposited sediment and some species of fish, particularly trout, can be adversely affected by high total suspended solids concentrations.

In many cases, suspended solids is also the carrier of other pollutants such as nutrients and heavy metals. This is particularly the case for agricultural and urban nonpoint sources.

FECAL COLIFORM BACTERIA

From the public health standpoint the bacteriological quality of water is as important as the chemical quality. A number of diseases can be transmitted by water, either by consumption or just by direct contact. Among them are typhoid and cholera. However, it is one thing to declare that water must not be contaminated by pathogens (disease-causing organisms) and another to determine the existence of these organisms. First, there are many pathogens. Each has a specific detection procedure and must be screened individually. Second, the concentration of these organisms can be so small as to make their detection impossible. The answer to this problem of measurement lies in the concept of indicator organisms. The indicator most often used is a group of microbes called fecal coliforms which are organisms normal to the digestive tracts of warm-blooded animals.

Attributes of fecal coliform bacteria that support its role as an indicator organism are: 1) they are plentiful, 2) they are easily detected with a moderately simple test, 3) they are generally harmless to handle except in most unusual circumstances, and 4) they are hardy and survive longer than most known pathogens. Coliforms have thus become universal indicator organisms. But the presence of coliforms does not prove the presence of pathogens. If a large number of coliforms are present, there is a good chance of recent pollution by wastes from warm-blooded animals, and therefore the water may contain pathogenic organisms.

NITROGEN CYCLE - AMMONIA-NITROGEN, NITRITE-NITROGEN AND NITRATE-NITROGEN

Nitrogen compounds in a water body are important because of public health reasons, their effect on the oxygen level in a water body, their contribution to algal growth, and their toxicity to the aquatic ecosystem. There are three forms of nitrogen usually measured in water quality determinations: ammonia (NH3), nitrite (NO2), and nitrate (NO3). Nitrogen may also occur in various organic forms resulting from biological processes and in complex organic molecules arising from industrial or municipal wastes.

Ammonia nitrogen is formed by two processes. The major process is the decomposition of organic matter while the other source is as an excretory product of animals. Ammonia in water is usually present in two forms, as ammonium ion (NH_4) or ammonium hydroxide (NH_4OH). Ammonium hydroxide can be highly toxic to fish. The amount of ammonium hydroxide present depends upon the concentration of ammonium ion, temperature, salinity and pH. Figure 8-1 portrays the potentially toxic level of ammonia nitrogen in fresh water as a function of temperature and pH.

In addition to its potential toxicity, ammonia nitrogen can exert a significant oxygen demand on the water by the process of nitrification. Nitrification is a two-step process; first oxidizing ammonia to nitrite, and then oxidizing nitrite to nitrate. The rate-limiting, or slower process, is the oxidation of ammonia to nitrite. The nitrification process is an important consideration in determining the quality of a water body. Historically, carbonaceous oxygen demand was considered to be the most critical index for determining the dissolved oxygen content of a stream or impoundment that was receiving waste discharges. It has been shown by numerous investigators that nitrogenous oxygen demand can have a more pronounced effect on the oxygen resources of a water body than carbonaceous oxygen demand and the need for incorporating nitrogenous oxygen demand in stream analyses has been stressed. The process of nitrification is complicated as only certain autotrophic bacteria are responsible for nitrification, namely the Nitrosomnas species for ammonia oxidation and Nitrobacter species for nitrite oxidation. It has been shown that the rate of nitrification is dependent on the concentration of the various forms of nitrogen and activity or number of these nitrifying organisms.

Nitrite is an intermediate form, usually in very low concentrations, of the nitrification process. The nitrate form of nitrogen is important not only because of the oxygen consumption during nitrification but for public health and algal growth reasons. High nitrate-nitrogen concentrations (greater than 10 mg/l) in drinking water can cause methemoglobinemia in infants.

Nitrogen is a necessary element for the growth of algae. Nitrate is the usual form that phytoplankton use; however, some forms of phytoplankton can use ammonia or fix nitrogen from the atmosphere. For aesthetic reasons, excessive algae and aquatic vegetation is a water quality concern.

ORTHOPHOSPHATE PHOSPHORUS

Phosphorus, along with nitrogen and potassium, constitute the primary nutrient elements essential to the growth of plant and animal organisms. Phosphorus is often the controlling algal growth factor when the requirements for nitrogen have been met. A small increase in the phosphorus concentration can result in a large increase in the amount of algae.

Phosphorus occurs in natural waters almost solely in the form of various types of phosphate. These forms are commonly classified into orthophosphates, condensed phosphates, and organically bound phosphates. These may occur in soluble form, tied up in particles of sediment and detritus, or in the bodies of aquatic organisms.

Of primary concern is the concentration of inorganic orthophosphate in a natural water body, as this is the form utilized by aquatic organisms. It is worthy of note that some forms of organic phosphorus are readily hydrolyzed to orthophosphate. For this reason, many criteria and standards are written relating to total phosphorus in water bodies.

PHYTOPLANKTON (Chlorophyll a)

The general term for microscopic plant life that is suspended in the water column and subject to the physical transport mechanism by water currents is phytoplankton.

The significance of phytoplankton in surface waters lies in the numbers and kinds that may be present under different water conditions. Phytoplankters respond to physical and chemical qualities of their aquatic habitat in much the same way as do terrestrial plants. Heat, light, and nutrient level are the primary influences on plankton communities but other externalities such as toxic wastes also apply.

Phytoplankton can be used as an indicator of water quality along with other biological, physical, and chemical properties. Main species groups of phytoplankton include algae, diatoms, and flagellates. Under natural non-polluted conditions species diversity is very high, but the populations of individual species is low.

Phytoplankton thrive by the process of photosynthesis, an essential of which is the presence of the green pigment, chlorophyll. Test for chlorophyll can thus be used to express the abundance of phytoplankton biomass.

When suitable nutrients and light are available, algae concentrations can reach high levels. Such high concentrations, called blooms, can result in fluctuations of dissolved oxygen in water detrimental to aquatic life, as well as unsightly, odorous masses of decaying algae.

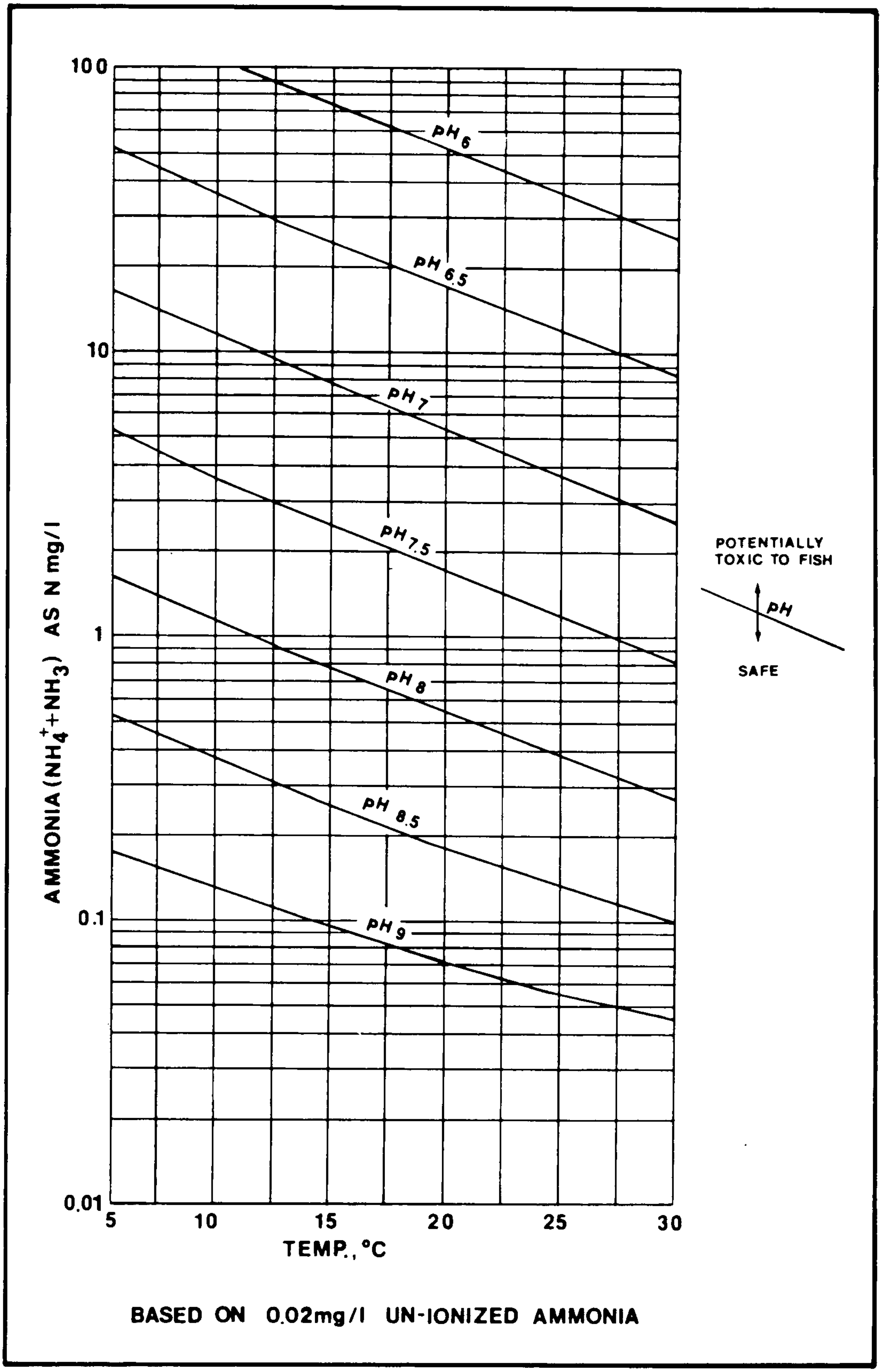


FIGURE 8-1 Total Allowable Ammonia as a Function of Temperature and pH

These problems are particularly noted on lakes, ponds, reservoirs and estuaries.

Algal blooms are generally characterized by a growth phase, a peak or plateau of population, and either a gradual recession or a rapid crash. The growth phase can be initiated by one of the following:

1. An increase in the water temperature
2. Increase in light intensity
3. Nutrient addition
4. Reduction in zooplankton population
5. Reduction in settling velocities of algae

The recession of the standing crop can be caused by several of the following:

1. Progressive depletion of one or several nutrients
2. Increased rate of grazing by growing zooplankton population
3. Progressive light limitation by self shading
4. Bacterial diseases and toxic waste introduction
5. Decreasing temperature
6. Increased settling velocities
7. Scouring by stormwater flows

Most of the phytoplankton in Rock Creek originate from Lakes Needwood and Frank or detachment of algal mats from pools and eddies.

BENTHIC ALGAE (Chlorophyll a)

Benthic algae or periphyton are those algae that grow attached to submerged objects (substrates). These are usually unicellular or filamentous algae. The type and abundance of algae depends on the nature of the substrate, water current, water level, temperature and chemical nature of the water. Areas of reduced flow often have heavy siltation which covers the substrate and inhibits periphyton growth, while rapids tend to scour the periphyton. Thus the nature of the periphyton community continually changes along the streams length.

The effects of the periphyton on dissolved oxygen concentrations can be very significant depending on the concentration (measured as chlorophyll a) of the algae, the streamflow and the time of the day. Moderately flowing waters can have their dissolved oxygen levels lowered considerably during the night respiration periods.

RECEIVING WATER USES AND WATER QUALITY STANDARDS

The District of Columbia water quality standards for interstate waters, which includes Rock Creek, were established in 1969 and recently revised in 1979. The standards have three major elements: 1) designation of water uses; 2) specification of criteria to protect the designated uses and; 3) development of a plan to meet the criteria.

The following are the water use categories for the District of Columbia (Reference 1):

"Category A: Primary Water Contact Recreation: Any activities that require prolonged intimate water contact and involve risks of ingestion. Included are swimming, wading, and any water contact sports.

Category B: Secondary Water Contact Recreation: Any activities on or near the water. Included are recreational boating, fishing and recreation along the shores.

Category C: Propagation of Aquatic Life and Wildlife

Category D: Public Water Supply

Category E: Industrial Water Supply

Category F: Navigation"

The District of Columbia has developed the following general criteria that applies to all interstate waters:

> "The waters shall at all times be free from: substances attributable to sewage, industrial waste, or other waste that will settle to form sludge deposits that are unsightly, putrescent or odorous to such degree as to create a nuisance, or that interfere directly or indirectly with water uses;
>
> Floating debris, oil, grease, scum, and other floating materials attributable to sewage, industrial waste, or other waste in amounts sufficient to be unsightly to such a degree as to create a nuisance, or that interfere directly or indirectly with water uses;

Materials attributable to sewage, industrial waste, or other waste which produce taste, odor, or appreciably change the existing color or other physical and chemical conditions in the receiving stream to such degree as to create a nuisance, or that interfere directly or indirectly with water uses; and high temperature, toxic, corrosive or other deleterious substances attributable to sewage, industrial waste, or other waste in concentrations or combinations which interfere directly or indirectly with water uses, or which are harmful to human, animal, plant, or aquatic life."

Rock Creek is presently designated for water use as Categories B and C, secondary water contact recreation and propagation of aquatic life and wildlife, with intentions of eventually upgrading it to Category A, primary water contact recreation. The specific water quality criteria are:

Dissolved Oxygen: Minimum level not less than 4.0 mg/l - daily average not less than 5.0.

Fecal Coliform: Log mean not to exceed 200 organisms/100 ml for primary contact recreational use or 1000 per 100 ml for secondary contact.

pH: 6.0 - 8.5.

Temperature: No increase in natural water temperature caused by artificial heat inputs shall exceed 5°F after reasonable allowance for mixing. Maximum water temperature not to exceed 90°F. There shall be no sudden or localized temperature changes that may adversely affect aquatic life.

Suspended Solids: Not more than 80 mg/l (seasonal average concentration).

WATER QUALITY CONDITIONS

LITERATURE REVIEW

Water quality conditions in the Rock Creek Park Watershed have been studied and documented since the 1930's when the impact of combined sewer discharge to the creek was recognized to be a serious pollution source and health hazard to the community This section shall trace the chronology of studies and their findings to date in an effort to establish existing conditions and assess sources of pollution.

In their report for the National Park Service, Sherman and Horner (Reference 2) noted a progressive contamination of Rock Creek from the Maryland boundary to the mouth on the Potomac River in the form of biochemical oxygen demand (BOD) and coliform organisms. BOD concentrations averaged from 2.85 mg/l at Sherrill Drive to 4.35 mg/l at M Street on the main stem. Even though the upstream drainage basin in Maryland was relatively undeveloped and served by a separate sewer system at the time, it was acknowledged to be the source of the relatively high concentrations at Sherrill Drive due to newer areas that had not been sewered at all. Dissolved oxygen levels were observed to improve between Sherrill Drive and the Zoological Garden (from 87 to 90 percent saturation) due to natural instream reaeration, but significantly decrease downstream from this point (78 percent saturation).

At the time, sewer capacity was at such a level that overflows to the creek occurred 30 to 40 times per year and there were many complaints from residents and visitors to the park of unsanitary conditions and foul odors. This was accredited to sewage deposits left stranded or pooled along the banks of Rock Creek between Piney Branch and the Potomac River. The Klingle and Luzon areas were still partly served by combined sewer systems at the time and completion of the separation program was recommended along with sewer expansion in Maryland to alleviate problems in the upper basin. Additional recommendations of sewer relief and interceptor construction were promoted with the estimated result of reducing combined sewer overflows to 3 or 4 times per year.

A great number of the recommendations of Sherman and Horner were instituted in later years in one form or another and conditions were improved greatly. However, water quality conditions were still of an unsanitary nature, as predicted in the report, and limited water recreational use. Recent studies of water quality in the watershed document the status during the last 10 years and point to particular sources and trends within the system.

A Summary of Water Quality and Waste Outfalls, prepared by the Federal Water Pollution Control Administration in 1966 (Reference 3) investigated sources of pollution throughout the entire watershed and monitored quality of both outfalls and instream reaches. A biologic survey previously performed in 1966 (Reference 4) was incorporated in the study as a further indication of water quality status. Conclusions from this study are:

> "Upper Rock Creek, Montgomery County: The reaches north of Rockville are not free of bacterial contamination; however, the concentrations of coliform bacteria did approach levels generally considered acceptable for body contact recreation. Pollution sources appeared to be of animal and agricultural origin and, as such, would not pose serious health hazards in the concentrations found. The biological survey indicated a good quality of water, as evidenced by the numerous schools of minnows and the existence of a balanced population of clean-water aquatic life.
>
> Lower Rock Creek, Montgomery County: Water quality within this portion of the Watershed was found to be somewhat degraded (when compared to the upper rural areas). An increase was observed in coliforms identifiable as originating from warm-blooded animals (possible humans). The increase in surfactants in the East-West Highway area extending to the District line suggested this pollution was from domestic sources. While the counts are generally low, they are consistent. The biological survey identified variable populations of minnows and suppressed numbers of clean water genera, and, when compared with the bacteriological results, suggested only fair water quality in this reach.
>
> Upper Rock Creek, District of Columbia: In general, the lower coliform counts suggest this reach as one of recovery, especially between Sherrill Drive and Peirce's Mill. Although some schools of minnows were observed, the biological conditions suggested mild organic pollution.
>
> Lower Rock Creek in the District of Columbia: The reach of the Creek extending from Piney Branch to the mouth shows high counts of coliforms, fecal coliforms, and fecal streptococci. The contribution

of urban runoff caused by storms cannot be entirely separated from the effects of periodic discharges of combined storm and sewage flows into Rock Creek below Piney Branch. At M Street the biological survey indicated severe organic pollution, and the high incidence of surfactants suggested this pollution to be of domestic origin. Moderate to heavy pollution was indicated from P Street to the Potomac River. Dominant bottom organisms consisted of intermediate and pollution-tolerant genera. Only one bottom organism was found at the mouth of Rock Creek."

The survey of waste outfalls during the study listed 211 outfalls to Rock Creek of which 124 were within the District. Observations of significant pollution sources include:

"It appears that, since a small part of the Coquelin Run area is served by individual septic tanks, significant seepage from the sub-surface disposal systems may at times reach the watercourse."

"A large sewer outfall at Klingle Road, presumably plugged and out of service, had a small discharge into a pool that was turbid and discharging gas bubbles with a characteristic sewage odor, suggesting that septic action was taking place."

"A discharge with a distinct sewage odor was also observed entering Broad Branch at Albemarle and 32nd Streets."

"Oil seepage from the ground, noticed on the east side of Connecticut Avenue just north of 3701, was assumed to originate from an apartment house heating plant. The oil was transported by a spring-fed tributary to Rock Creek."

"A broken or leaking sewer crosses Broad Branch behind the shopping center at 4400 Connecticut Avenue and was discharging at a low rate directly into the stream. The leakage from the defective sewer resulted in very high coliform counts in Broad Branch. The FC/FS ratio indicated the bacteria to be of human origin."

"A seepage of dark and obviously septic liquid was entering the Creek under the north abutment of the highway bridge leading to the tunnel, approximately

200 feet north of the Calvert Street Bridge during the initial survey, but it had stopped flowing on later observations."

"The bacteriological and chemical samples taken near the Slash Run Interceptor, south of P Street in Washington, D.C., were extremely high in fecal bacteria, phosphorus, chlorides, and ammonia, and biological samples indicated the presence of only pollution-tolerant and intermediate forms. Visual observation of particulate human fecal and attendant matter, coupled with olfactory evidence, confirmed severe pollution by sanitary sewage. Flow was observed from the Interceptor during early sampling, but it had stopped on later observations."

"The high fecal counts at the ford below the zoo are evidence of pollution by warm-blooded animals, with the lower surfactant level indicating a lesser contribution of domestic wastes. The National Zoological Park has initiated corrective action to control discharge of sanitary wastes into Rock Creek, but there are outdoor exhibit areas, paved and unpaved, from which surface discharges eventually reach the watercourses."

"At the time of inspection, piles of bedding and animal wastes were observed on the ground at the Park Police stables at Connecticut Avenue, and there was evidence of movement of these wastes toward and into the Creek. Drainage from the parking lot, corral, and stable discharges into Rock Creek."

The study noted several other discharges of suspect flows throughout the basin and recorded the following nutrient levels at the M Street bridge during January to May 1966:

	Maximum	Minimum	Average
Ammonia Nitrogen (mg N /l)	0.47	0.04	0.16
Nitrate Nitrogen (mg N/l)	1.59	0.54	0.94
Orthophosphorus (mg P/l)	0.41	0.06	0.18
Total Phosphorus (mg P/l)	0.70	0.12	0.33

Sludge control operations on boilers and air-conditioning cooling towers in commercial and larger residential buildings were cited as sources of phosphorus in the watershed.

A subsequent FWPCA document (Reference 5) in 1969 came up with the following conclusions after a review of data that had been collected by other agencies and previous reports:

> "Generally throughout the waters of the basin, dissolved oxygen levels are above the minimum standard of 5.0 mg/l with a corresponding biochemical oxygen demand concentration of 1 to 3 mg/l.
>
> There is no significant increase or decrease in biochemical oxygen demand (BOD) or dissolved oxygen (DO) between the District line and the confluence with the Potomac River. There appears to be no significant change from 1960 to 1967.
>
> Extremely high coliform densities with monthly means ranging between 10,000 to 100,000 MPN/100 ml, have been routinely observed in Rock Creek at the District Line.
>
> While the coliform densities within the District of Columbia are slightly higher than in Maryland due to the periodic overflowing of the combined sewerage system, high coliform densities have also been observed in the upper portions of the basin in Montgomery County where the sewers are separated.
>
> In general, the maximum fecal coliform standards of 200 MPN/100 ml in the District of Columbia and 240 MPN/100 ml in Maryland are being exceeded.
>
> High concentrations of suspended matter, often over 100 mg/l, have also been routinely observed in Rock Creek at the District Line. These high concentrations are a result of erosion in the upper portions of the watershed during the periods of high runoff.
>
> Biological investigation of bottom organisms in Rock Creek indicates a better aquatic environment in the upper portion of the basin than in the lower.
>
> Sewer inspection and maintenance programs have been intensified by both the Department of Sanitary Engineering in the District of Columbia and the Washington Suburban Sanitary Commission in Montgomery County. Vandalism appears to be one of the major causes of failures in the sewerage systems.
>
> Pollution control projects at the National Zoological Park are now about 80 percent completed and wastewater from the Zoo is no longer a major source of pollution to Rock Creek.

From an analysis of the water quality data, it appears that the two principal problems are high coliform densities and high suspended solids concentrations resulting mainly from urban and agricultural runoff."

A study by Stanton, et al. (Reference 6) in 1971 dealt primarily with bacteriological quality of Rock Creek in both Maryland and the District of Columbia. A large number of dissolved oxygen analyses were performed at reference sites within the D.C. portion of the watershed. There were also some chemical analyses performed, but these were limited. Consistent exceedance of fecal coliform standards was documented, particularly during storm events. Dry-weather concentrations were lower than wet-weather levels but still exceeded direct contact recreation criteria and were attributed to malfunctioning and leaking sewer lines throughout the entire basin. Wet-weather concentrations were presumably caused by combined sewer discharges. Discharges from the National Zoo were monitored and concluded to be a significant source of contamination to the creek. A cumulative summary of all data collected in this study during the summer of 1971 is presented in Table 8-1. In addition, monitoring information at the Maryland-District of Columbia boundary by the Montgomery County Department of Environmental Protection from 1971-1978 is summarized.

Ragan and Dietemann (Reference 7) in 1976 researched the impact of urban runoff on several Maryland streams by comparison of streams, including Rock Creek, with different degrees of development. The basic mode of analysis was calculation of BOD loadings. Rock Creek was found to carry 20% more BOD than a relatively undeveloped watershed but dissolved oxygen levels were comparable. Even during storm runoff periods, the dissolved oxygen levels were not considered a major problem. Of major importance was the conclusion that the observed reduction of fish species and diversity in urbanized watersheds is not directly attributable to degradation of water quality. Their major conclusion was that the major ecological impact was due to physical habitat destruction through erosion and sedimentation from the increased peak runoffs experienced rather than specific pollutant loadings.

EXISTING WATER QUALITY

The review of past studies of water quality in Rock Creek provides a valuable data base to document trends and design future data needs and studies. Assessment of present conditions within the watershed require the analysis of recent data, however, as circumstances within

TABLE 8-1
SUMMARY OF EPA STORET WATER QUALITY DATA 1971-1978

Station Location	Monitoring Agency	Temperature (°C)			pH (SU)			BOD-5 (mg/1)			Dissolved Oxygen (mg/1)		
		Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.
Rock Creek at MD-D.C. line	Montgomery County	24.0	0.0	13.0	8.1	6.6	7.3	8.3	0.6	2.4	15.7	5.5	9.66
Rock Creek at* Military Road	University of MD	25.0	17.5	22.0	-	-	-	-	-	-	13.9	4.5	7.51
Rock Creek at* Peirce Mill	University of MD	24.0	18.0	22.0	-	-	-	-	-	-	10.5	5.3	8.02
Rock Creek at* Connecticut Avenue	University of MD	29.0	18.0	22.9	-	-	-	-	-	-	10.0	5.0	7.73

Station Location	Monitoring Agency	Total Phosphorus (mg P/1)			NO_2+NO_3-N (mg N/1)			Fecal Coliforms (MPN/100 ml)		
		Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.
Rock Creek at MD-D.C. line	Montgomery County	0.79	0.01	0.07	3.27	0.30	1.74	240,000	230	9,000
Rock Creek at* Military Road	University of MD	-	-	-	-	-	-	1,100,000	300	67,900
Rock Creek at* Peirce Mill	University of MD	-	-	-	-	-	-	460,000	400	38,600
Rock Creek at* Connecticut Avenue	University of MD	-	-	-	-	-	-	460,000	2,300	51,000

* Samples all collected during summer 1971

the basin continually change. This section shall focus on sources of water quality information collected within the Rock Creek Park watershed during the last few years for the dual purpose of assessing existing water quality conditions and providing a data base for development of a water quality model of the stream system.

Data Sources

The primary source of information for this assessment is data that have been collected and analyzed at six stations on the main stem of Rock Creek within the District by the D.C. Department of Environmental Services (DES) (Reference 8). An intensive monitoring program has been in progress since May 1978 with daily sampling (4-5 days per week) of dissolved oxygen, BOD, suspended solids, total phosphorus, total Kjeldahl nitrogen, nitrite nitrogen, nitrate nitrogen, ammonia nitrogen, temperature, pH, and fecal coliform bacteria. Locations of the DES sampling stations are depicted in Figure 8-2.

A statistical summary of all data collected at DES instream monitoring sites from May 1978 through March 1979 is presented in Table 8-2. A valuable mode of analysis of such an extensive set of information is to evaluate the data in subsets. In this case, streamflow is a highly related factor to instream water quality and Table 8-2 also lists statistics of the DES data for two different regimes of flow as recorded at the USGS streamflow gage at Sherrill Drive. Data collected on days where streamflow was less than 40 cubic feet per second and that collected when streamflow exceeded 80 cubic feet per second are summarized.

An additional source of recent water quality data is a series of water quality surveys performed by O'Brien and Gere Engineers as part of the Phase 1 Combined Sewer Overflow Study Potomac-Anacostia River System for the DES (Reference 9). Five sites on Rock Creek were monitored for dissolved oxygen, temperature, suspended solids, volatile suspended solids, and fecal coliforms from July to October 1978. A summary of their findings is listed in Table 8-3 and portrayed graphically in Figure 8-3. In addition, a wet-weather survey was performed after the storm of August 31, 1978 to gauge the impact of stormwater on the water quality of Rock Creek. Results are given in Table 8-4. It is to be noted that the sampling of this storm began approximately 6 hours after the peak runoff at Sherrill Drive was recorded and cannot be regarded as a complete documentation of the event.

TABLE 8-2
STATISTICAL SUMMARY OF DES MONITORING DATA, MAY 1978 TO MARCH 1979

	DES Station No.	Dissolved Oxygen (mg/l)			BOD (mg/l)			Suspended Solids (mg/l)			Total Phosphorus (mg P/l)			NO_3-N (mg N/l)			NH_3-N (mg N/l)			Fecal Coliforms (MPN/100 ml)		
		Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.
All Data 5/78-3/79	1	2.8	8.4	13.9	1.0	3.4	11.0	2	187	1,648	.040	.234	.975	0.12	1.60	4.28	.120	.674	1.89	20	33,652	400,000
	2	2.8	8.4	14.9	1.0	3.4	11.0	1	228	2,537	.040	.229	.954	0.50	1.54	4.01	.020	.635	2.47	30	42,812	2,500,000
	3	3.0	8.5	13.7	1.0	3.3	11.0	1	234	2,792	.016	.244	1.050	0.40	1.49	3.21	.060	.682	2.13	30	37,157	600,000
	4	3.5	8.7	14.0	1.0	3.4	12.0	6	189	1,850	.024	.229	1.320	0.18	1.49	3.18	.030	.641	2.12	30	40,446	400,000
	5	3.1	9.0	15.9	1.0	3.1	11.0	1	253	2,280	.016	.237	1.450	0.38	1.44	3.26	.020	.560	1.87	50	38,260	600,000
	6	3.2	9.1	16.2	0.3	3.1	11.0	2	186	2,315	.034	.255	2.339	0.54	1.39	2.80	.020	.524	1.80	30	61,800	1,150,000
Flow at Sherrill Dr. Less than 40 CFS	1	2.8	7.9	11.2	1.0	2.9	6.0	2	78	360	.044	.147	.673	0.53	1.92	4.28	.160	.687	1.82	300	3,394	12,000
	2	3.2	7.9	13.0	1.0	3.0	8.0	10	180	1,145	.040	.165	.600	0.50	1.78	3.35	.020	.685	2.00	60	3,966	25,000
	3	3.1	8.0	13.2	1.0	2.8	7.0	7	115	436	.016	.144	.402	0.40	1.71	3.21	.080	.760	2.13	200	4,020	30,000
	4	3.6	8.3	13.6	1.0	2.9	8.0	8	80	328	.024	.148	.371	0.19	1.73	3.18	.050	.697	1.76	500	7,228	60,000
	5	3.1	8.3	14.1	1.0	2.2	8.0	1	142	1,746	.016	.154	.973	0.38	1.61	3.26	.020	.565	1.55	350	5,580	60,000
	6	3.4	8.4	13.9	0.3	2.1	7.0	2	47	233	.034	.152	.401	0.54	1.52	2.80	.020	.538	1.59	50	15,400	50,000
Flow at Sherrill Dr. Greater than 80 CFS	1	3.5	9.4	13.9	2.0	4.1	11.0	3	441	1,648	.040	.322	.975	0.53	1.37	2.89	.120	.617	1.89	20	86,711	400,000
	2	3.7	9.6	14.9	2.0	3.9	11.0	1	455	2,537	.051	.312	.954	0.52	1.40	4.01	.060	.512	1.87	140	98,792	2,500,000
	3	3.0	9.6	13.6	2.0	4.0	11.0	1	499	2,792	.045	.313	1.050	0.54	1.33	2.23	.060	.532	1.85	300	71,737	400,000
	4	3.5	9.6	13.9	1.0	4.0	12.0	6	468	1,850	.032	.284	1.011	0.54	1.32	2.07	.030	.496	2.05	110	67,234	250,000
	5	4.0	10.3	15.9	1.0	4.2	11.0	2	590	2,280	.032	.318	1.450	0.55	1.30	2.03	.050	.472	1.87	250	95,200	600,000
	6	4.2	10.4	16.2	1.0	4.4	11.0	6	579	2,315	.045	.347	1.456	0.65	1.33	2.05	.040	.445	1.80	30	114,875	1,150,000

TABLE 8-3
Rock Creek Water Quality Sampling Data - 1978

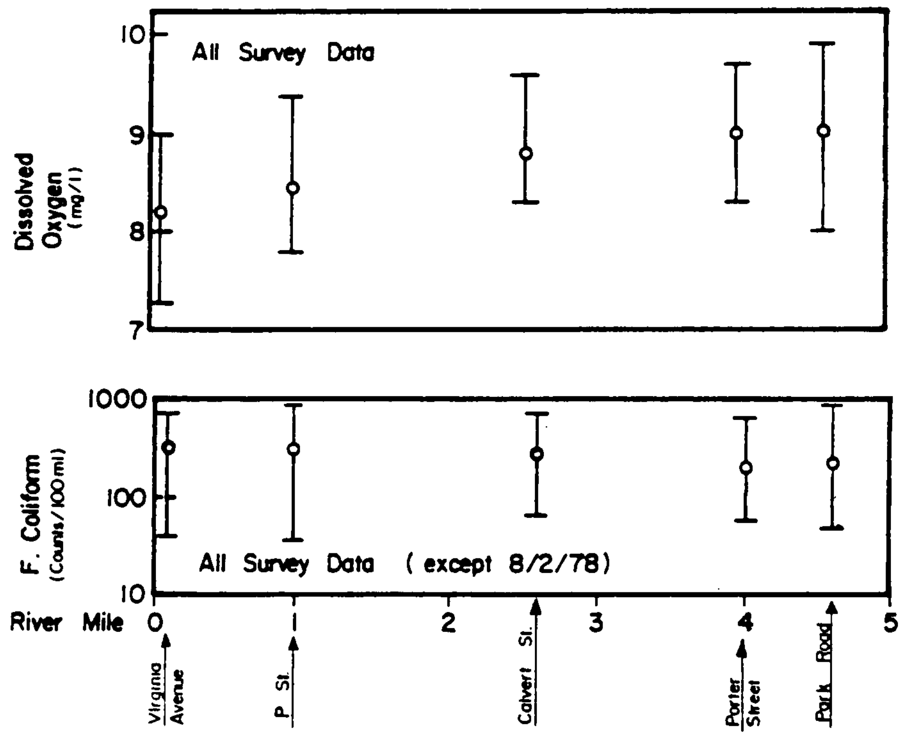
Station	Parameter	Date of Sampling 7/25	8/2	8/7	8/10	8/17	8/22	8/24	8/28	9/18	9/20	9/25	9/27	10/2
Virginia Ave.	F. Coliform*	125	6600	330	440	470	42	630	230	580	166		700	550
	TSS, mg/l	22	98	23	61	16	11	9	12	14	16		7	11
	VSS, mg/l	5	15	3	11	4	3	3	4	5	5		5	4
P Street	F. Coliform*	110	7000	640	500	400	190	850	36	300	900	490	260	300
	TSS, mg/l	6	241	69	69	10	5	5	6	10	6	6	5	2
	VSS, mg/l	2	25	11	11	4	3	2	2	2	2	2	4	<1
Calvert St.	F. Coliform*	65	12700	390	440	210	300			750		<100	320	420
	TSS, mg/l	4	249	19	72	8	2			5		5	5	4
	VSS, mg/l	2	19	3	11	4	1			1		3	4	2
Porter St.	F. Coliform*	55	35500	280	600	280	150	210	64	290	170	200	190	330
	TSS, mg/l	4	434	15	68	11	23	4	4	8	7	4	3	3
	VSS, mg/l	2	53	4	9	3	6	2	2	3	3	2	2	3
Park Road	F. Coliform*	60	14000	860	50	140	100	220	60	190	390	200	230	260
	TSS, mg/l	5	329	22	69	13	12	5	7	8	5	6	5	2
	VSS, mg/l	2	45	3	10	4	5	1	3	2	2	2	2	<1
Virginia Ave.	DO, mg/l		9.0	8.7	7.7	7.6	8.1	7.8	7.3	8.4	8.1	7.7	9.0	8.6
	Temp. °C		23.0	25.5	26.0	27.8	23.8	26.0	27.0	23.0	23.0	21.0	18.0	17.8
	% Sat.		1.03	1.03	0.93	0.96	0.95	0.95	0.90	0.96	0.93	0.85	0.95	0.91
P Street	DO, mg/l		9.2	8.6	8.0	7.9	8.7	8.5	8.3	8.1	8.0	7.8	9.4	9.1
	Temp. °C		23.8	26.0	28.0	29.0	25.0	25.5	26.5	24.0	23.0	19.5	18.0	17.5
	% Sat.		1.06	1.05	1.01	1.01	1.03	1.02	1.01	0.95	0.92	0.84	0.99	0.95
Calvert St.	DO, mg/l		8.6	8.8	8.3		9.3			8.4		8.5	9.2	9.6
	Temp. °C		24.5	26.5	28.0		22.5			24.0		19.5	17.0	17.5
	% Sat.		1.01	1.07	1.05		1.06			0.99		0.91	0.95	1.00
Porter St.	DO, mg/l		8.5	8.4	8.3		9.3	9.3	8.7	8.8	9.2	9.4	9.3	9.7
	Temp. °C		25.0	27.0	23.2		23.5	26.0	27.0	24.0	22.0	20.0	18.0	17.1
	% Sat.		1.01	1.04	1.05		1.08	1.13	1.07	1.03	1.05	1.02	0.98	1.00
Park Road	DO, mg/l		9.3	9.0	7.9	8.0	9.6	9.2	8.7	9.0	9.1	9.5	9.5	9.9
	Temp. °C		26.0	27.0	29.0		24.0	25.5	26.5	24.5	22.5	21.0	17.0	18.0
	% Sat.		1.13	1.14	1.01		1.13	1.11	1.07	1.06	1.03	1.06	0.98	1.04
Stream Flow, cfs at Sherrill Dr.					76.2	49.1	35.1	31.0	28.7	24.5	24.5	21.5	20.5	19.5
Previous Day's Rain, in.		0.1	0.5	0.0	0.3	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0

*Expressed as counts/100 ml

SOURCE: Phase 1 Combined Sewer Overflow Study Potomac-Anacostia River System, D.C. Department of Environmental Services, 1979 (O'Brien and Gere Engineers)

FIGURE 8-3

Rock Creek Water Quality Sampling Data - 1978
Stream Profile Plots



SOURCE: Phase 1 Combined Sewer Overflow Study Potomac-Anacostia River System, D.C. Department of Environmental Services, 1979 (O'Brien and Gere Engineers)

TABLE 8-4

Wet Weather Survey - Rock Creek Water Quality Data
September 1, 1978

Virginia Ave.			P Street			Porter Street		
Time	F. Coli	DO	Time	F. Coli	DO	Time	F. Coli	DO
0930	8750	8.1	0845	9000	8.2	1010	39,000	11.5
1130	4200	7.9	1030	5000	8.2	1140	85,000	
1827	1000	7.7	1230	4500	7.9	1850	1,200	
1920	7000	7.0	1853	3800	7.4	2000	3,000	10.2
2007	1000	6.8	1943	12600	7.1			
			2028	7300	7.0	1120	160	8.2
1025	80	7.3						
			1055	190	8.1			

Park Road			Sherrill Drive		
Time	F. Coli	DO	Time	F. Coli	DO
0900	95,000	10.4	0935	69,000	7.7
1040	43,000	11.0	1110	45,000	8.8
1910	35,000	10.1	1925	900	8.5
2020	8,600		2040	1,700	
1140	24	8.3	1225	24	7.3

* 1.5 inches of rain 2300 Aug. 31 to 0030 Sept. 1
** F. Coliform in counts/100 ml DO in mg/l

SOURCE: Phase 1 Combined Sewer Overflow Study Potomac-Anacostia River System, D.C. Department of Environmental Services, 1979 (O'Brien and Gere Engineers)

Recognizing the importance of the sediment-water interface in the evaluation of overall stream water quality status, the O'Brien and Gere study included a survey of the bottom sediments of Rock Creek at twelve locations to gauge the levels of several possible toxic substances. Site locations and analysis results are depicted in Figure 8-4 and Table 8-5, respectively.

A supplementary source of information of water quality is supplied by the Environmental Protection Agency computerized data storage and retrieval system, STORET. Summaries of sampling records at various locations throughout the watershed were accessed and compiled within Table 8-1. The agencies that collected and analyzed the data referenced here include the Montgomery County Department of Environmental Protection and the University of Maryland study previously mentioned (Reference 6). Note that the University of Maryland data, although encompassing a large number of analyses, cover only a small time period during the summer of 1971.

Ensuing discussion is an evaluation of the recently accrued information with regard to previously discussed water quality criteria. Only trends and relative concentration levels are addressed with little consideration to sources of pollution. These will be addressed separately in subsequent sections.

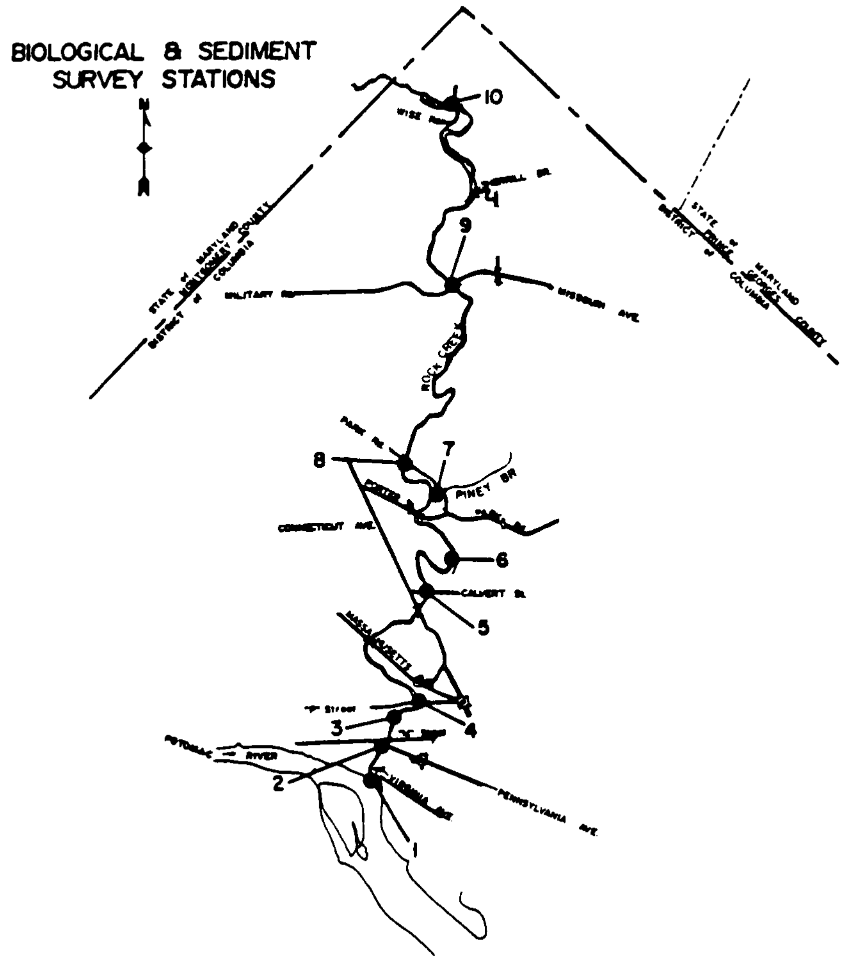
Temperature

Water temperature in Rock Creek generally varies from 0°C (ice) to 24°C with maximum levels to 29°C being attained occasionally during the summer months. At no time is there evidence that the standard of 90°F (32.2°C) has been violated. Data sources indicate a slight temperature gradient along the stream profile with higher temperatures being recorded in the lower reaches in D.C. This gradient is due primarily to the reduction in natural tree canopy and shading of the stream surface in this portion of the system. However, the difference is generally less than 1°C. There are no known sources of thermal pollution in the Rock Creek Park Watershed that impact water temperature.

pH

Levels of pH within the D.C. portion of Rock Creek generally vary between 6.4 and 7.8 with very few excursions beyond these limits. The average is approximately 7.1 according to available sources of data on the main stem. No spatial or temporal trends can be discerned from long-term records and concentrations are well within the D.C. standards of 6.0 to 8.5.

FIGURE 8-4 and TABLE 8-5
Rock Creek Sediment Sampling Stations and Analysis



(Data given as ppm dry weight)

SITE	NONIONIC CHLORINATED PESTICIDES												METALS			
	LINDANE	DDE	DDT	DDD	ALDRIN	HEPTACHLOR	TOXAPHANE	CHLORDANE	DIELDRIN	ENDRIN	METHOXYCHLOR		MERCURY	LEAD	CADMIUM	ZINC
1	0.01	<0.01	<0.03	0.007	<0.01	0.005	< 1.0	0.17	<0.01	<0.05	< 0.1		<0.01	256.7	0.65	131.9
2	0.01	<0.01	<0.03	0.007	<0.01	0.005	< 1.0	0.030	<0.01	<0.05	< 0.1		<0.01	53.4	0.16	48.9
3	<0.01	<0.01	0.032	0.007	<0.01	<0.005	< 1.0	0.025	<0.01	0.05	< 0.1		<0.01	55.9	0.11	42.3
3a	<0.01	<0.01	0.044	0.007	<0.01	<0.005	< 1.0	0.036	<0.01	<0.05	< 0.1		<0.01	215.1	0.36	105.7
4	<0.01	<0.01	0.03	0.007	<0.01	0.005	< 1.0	0.028	<0.01	<0.05	< 0.1		<0.01	14.4	0.09	35.5
5	<0.01	<0.01	0.03	0.007	<0.01	<0.005	< 1.0	0.028	<0.01	<0.05	< 0.1		<0.01	23.2	0.11	40.2
6	0.01	<0.01	0.074	0.008	<0.01	<0.005	< 1.0	0.05	<0.01	<0.05	< 0.1		<0.01	170.4	0.27	113.3
7	<0.01	<0.01	< 0.03	0.008	<0.01	<0.005	< 1.0	0.068	<0.01	<0.05	< 0.1		0.017	212.6	0.68	173.2
8	<0.01	<0.01	<0.03	0.007	<0.01	<0.005	< 1.0	<0.025	<0.01	<0.05	< 0.1		<0.01	112.2	0.11	52.9
9	<0.01	<0.01	<0.03	<0.007	<0.01	<0.005	< 1.0	0.058	<0.01	<0.05	<0.01		<0.01	47.0	0.26	50.8
10	0.014	<0.01	<0.03	0.006	<0.01	0.017	< 1.0	0.152	<0.01	<0.05	<0.01		<0.01	127.0	0.39	108.7
10a	0.01	0.01	<0.03	0.007	<0.01	0.005	< 1.0	0.032	<0.01	<0.05	< 0.1		<0.01	20.9	0.12	54.7

SOURCE: Phase 1 Combined Sewer Overflow Study Potomac-Anacostia River System, D.C. Department of Environmental Services, 1979 (O'Brien and Gere Engineers)

Biochemical Oxygen Demand

Concentrations of biochemical oxygen demand (BOD) in a stream are not, in themselves, addressed in the District of Columbia water quality standards. However, BOD levels, as a quantity of oxygen consumed in the breakdown of organic material by micro-organisms, directly affect the dissolved oxygen content of Rock Creek and thus are an important water quality indicator.

BOD concentrations in Rock Creek, as measured by DES, range between 0.3 and 12 mg/l with an average of approximately 3.3 mg/l. Concentration profiles of BOD at the six DES sampling sites provide valuable insight to trends in this data (see Figure 8-5). It can be seen that much higher concentrations are recorded during the high flow regime (flows greater than 80 cfs) compared to the low flow regime (flows less than 40 cfs). This relationship is an obvious impact of storm washoff pollutant loads.

The profile of low flow concentrations indicates a decrease from the upstream reach to the downstream of almost 1 mg/l. Implications of this are that sources of BOD from the Maryland headwaters are being consumed faster than sources in D.C. are being added in the D.C. reaches. It is also feasible that, since a significant portion of BOD is tied up in suspended organic particles, siltation in the upper D.C. reaches results in the observed reduction.

The trend seems to reverse itself during high flows with marginally higher concentrations being recorded in the lower D.C. reaches. This is an indication of the impact of urban runoff and combined sewer overflow loads in the District.

For all that the data indicates as far as trends and sources of BOD, it must be noted and kept in mind that the concentrations recorded here are not generally regarded as high. Ragan (Reference 7) concluded that urbanization in upper Rock Creek had resulted in a 20% increase in annual BOD loads, most of the difference being exerted during storm events. He did not note any significant difference in dissolved oxygen levels as a result of this increase.

Dissolved Oxygen

Concentration of dissolved oxygen (DO) in the natural aquatic environments is a key water quality parameter and indicator of overall ecologic suitability. The District of Columbia has adopted a minimum standard of 4.0 mg/l of dissolved oxygen with a daily average not to fall below 5.0 mg/l in order to preserve the usage of Rock Creek for fish and wildlife propagation.

Dissolved oxygen is a highly variable water quality parameter that responds to a number of factors including temperature, salinity, barometric pressure, BOD concentrations, sediment oxygen demand, nitrogenous oxygen demand, and the diurnal photosynthesis-respiration cycle of phytoplankton and attached aquatic plants. In order to evaluate trends, problems and causal relationships of dissolved oxygen concentrations, it is necessary to include all these factors in the analysis.

Historically, there have been no contraventions of standards recorded in the studies previously referenced and dissolved oxygen has not been documented to be a water quality problem in Rock Creek. Figure 8-6 portrays the profile of concentrations recorded at DES sampling stations. This plot bears out the conclusion of several documents that the D.C. portion of Rock Creek is one of recovery in terms of dissolved oxygen. Lower levels are recorded in the upper, sluggish reaches of D.C. Faster velocities and natural turbulence along the fall line in the middle D.C. reaches result in reaeration and higher DO levels. Not recorded in this profile, due to the lack of a DES monitoring station at the mouth, is the decline in DO below Calvert Street that was observed by O'Brien and Gere (Reference 9) and Stanton (Reference 6). This is presumably due to a return to a sluggish and deep stream in this reach.

Although dissolved oxygen trends are fairly well established and in agreement within the literature, the relative levels of DO recorded by DES within the last year are significantly lower than those documented by other sources. According to this data, DO standards were frequently violated throughout the entire D.C. portion of Rock Creek from late May through August 1978. Concurrent sampling by O'Brien and Gere from August to October 1978 recorded levels that averaged 1.7 mg/l higher than those of DES, despite the fact that higher temperatures were also recorded.

It is possible that variations might occur due to difference in the method of sampling and analysis. DES utilizes an iodometric method (laboratory procedure) while O'Brien and Gere employed a membrane electrode procedure that determines in situ DO concentration. It is also feasible that diurnal fluctuations of DO due to aquatic plant respiration and photosynthesis be of such a magnitude that the DES, who consistently monitor in the early

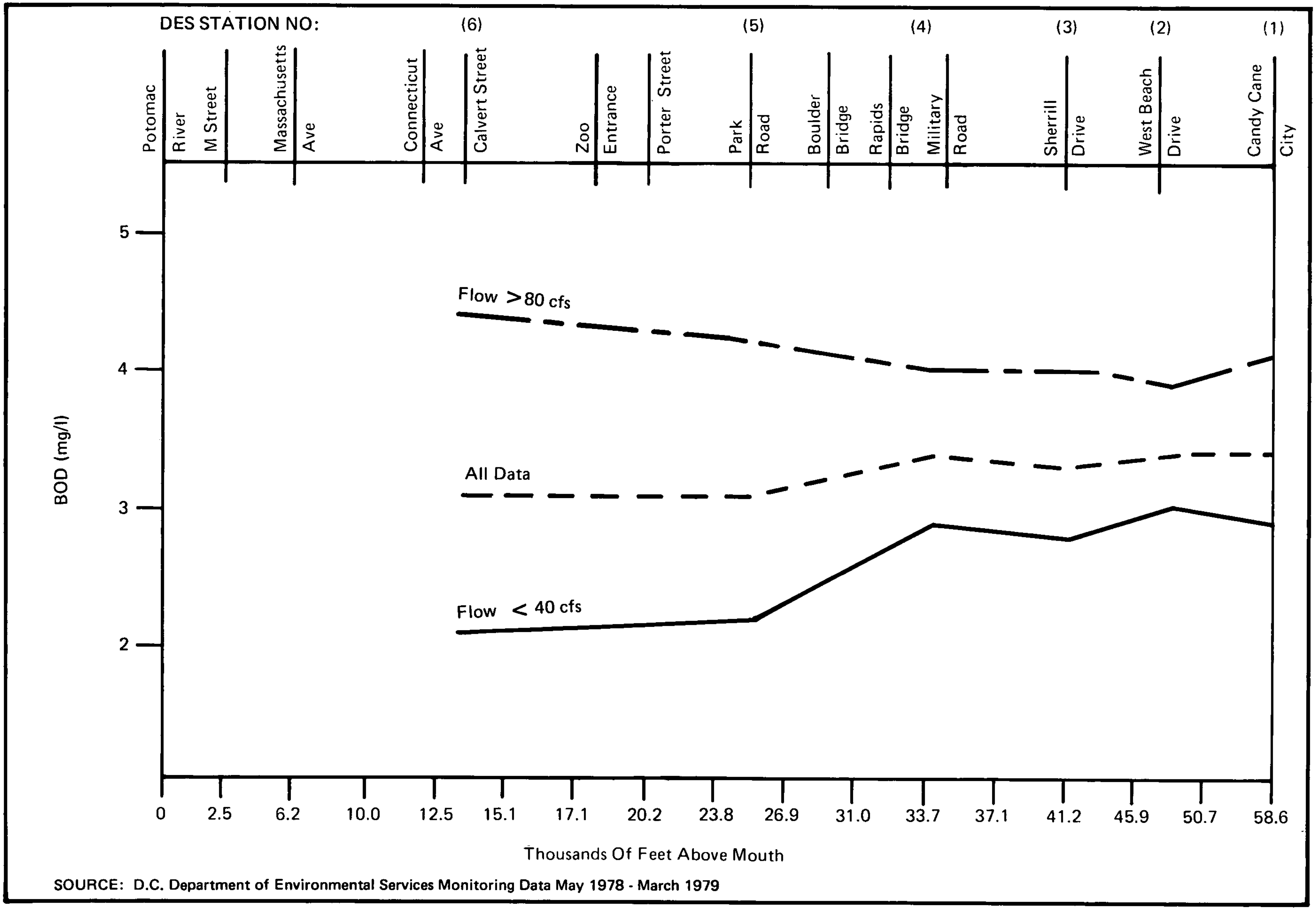


FIGURE 8-5 Stream Profile of Biochemical Oxygen Demand

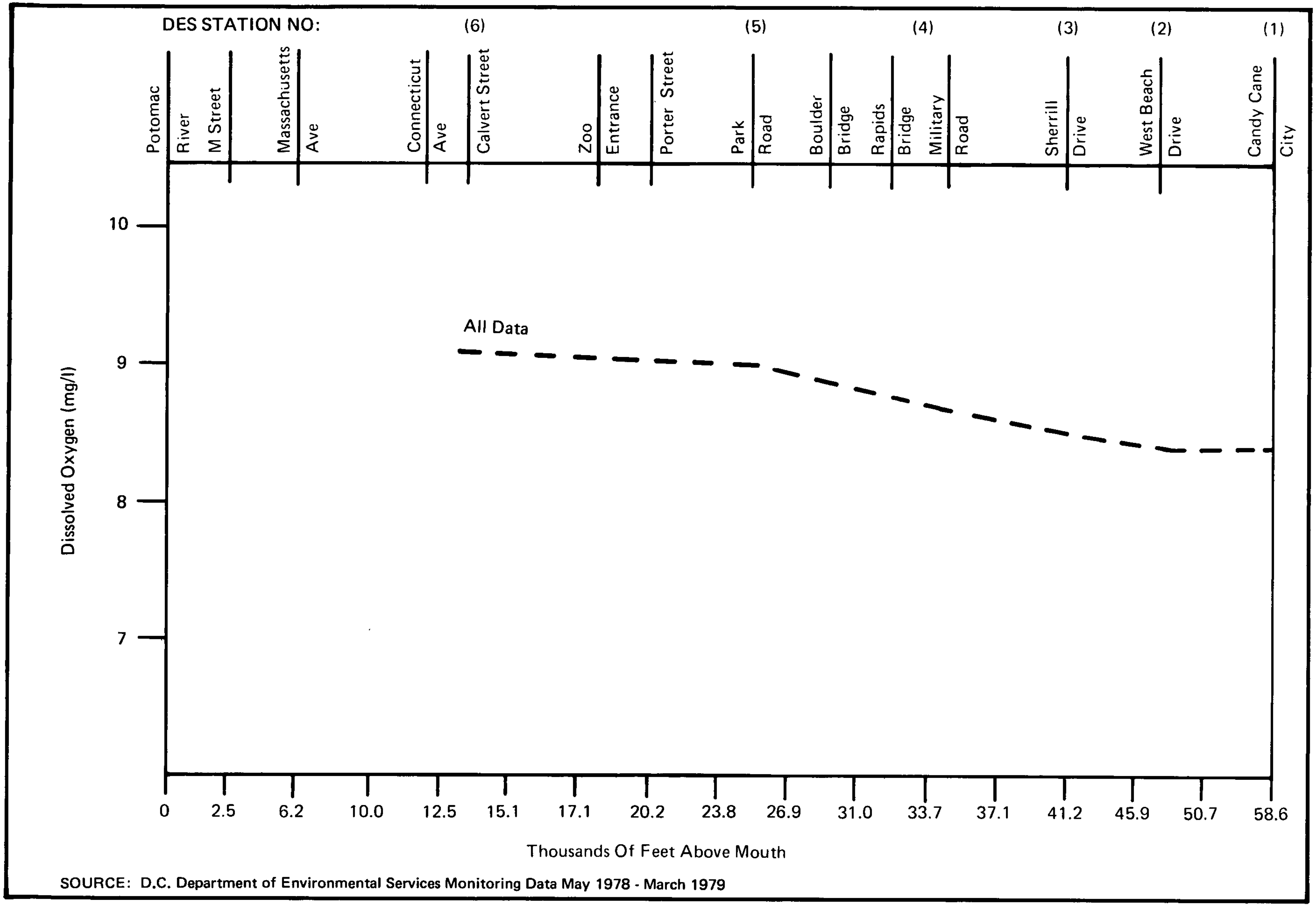


FIGURE 8-6 Stream Profile of Dissolved Oxygen

morning, might be recording the daily minimum that all other studies have missed. This would also explain the temperature differential.

The diurnal cycle of dissolved oxygen is a phenomenon that, although well-documented in literature, has not been studied in detail in Rock Creek. Stanton (Reference 6) recognized the importance of algal activity in the DO balance of a natural stream and monitored diurnal variations in his 1971 study. Levels recorded slightly below 5.0 mg/l give credibility to DES monitoring in 1978. In an effort to further define the diurnal cycle of dissolved oxygen, a series of one-day DO surveys was initiated is a part of this study. Table 8-6 lists the results of monitoring at 2-hour intervals during three periods of the last year. A membrane probe was employed for in situ measurement of temperature and dissolved oxygen. Monitoring was performed by personnel of the Ecological Service Laboratory of the National Park Service.

It can be seen that a large variation was recorded in the November 1978 survey with a swing of up to 3.9 mg/l observed in the upper stations. That such a large fluctuation could be seen so late in the fall lends credence to DES data and indicates the possibility of a large aquatic plant population during the summer of 1978. Less fluctuation was observed in the April and June 1979 surveys. During these periods, dissolved oxygen concentrations by DES did not even approach the lower levels recorded in the previous summer.

In conclusion, the dissolved oxygen balance of Rock Creek involves a complexity of interactions that have yet to be totally defined. There are few infractions of standards recorded in past literature, yet recent data include several violations unassociated with high BOD concentrations or storm events. There appears to be a disparity in data collected concurrently, yet this could be justified by indications of diurnal variability during that time. All sources apparently agree as to trends of DO concentration, however, with lower levels in the upper and lower D.C. reaches and higher concentrations in the middle reaches. The development of a water quality simulation model shall help to define some of the interrelationships that can only be hypothesized here in examination of recorded data.

Total Phosphorus

As previously discussed, phosphorus is an essential nutrient for the growth of aquatic plant life and is most

TABLE 8-6
ROCK CREEK DIURNAL DISSOLVED OXYGEN SURVEY

SITE

	#1 (Candy Cane City)				#2 (West Beach Dr.)				#3 (Sherrill Dr.)				#4 (Missouri Rd.)				#5 (Park Rd.)				#6 (Calvert St.)				#7 ("P" St.)			
	Time	Temp.	D.O.	% SAT	Time	Temp.	D.O.	% SAT	Time	Temp.	D.O.	% SAT	Time	Temp.	D.O.	% SAT	Time	Temp.	D.O.	% SAT	Time	Temp.	D.O.	% SAT	Time	Temp.	D.O.	% SAT
Nov 6-7, 1978	1200	9.0	12.0	104	1150	8.3	10.7	91	1140	8.9	11.8	102	1120	8.3	12.0	102	1100	8.3	12.2	104	1050	8.3	12.4	105	0950	7.6	11.7	98
	1400	9.4	12.5	109	1340	8.6	11.8	101	1330	9.4	12.4	108	1320	8.7	12.7	109	1310	8.9	13.0	112	1250	9.2	13.1	114	1240	9.0	12.4	107
	1520	9.7	13.1	115	1510	8.9	12.2	105	1500	9.3	12.5	109	1450	8.9	12.5	108	1430	9.2	12.8	111	1420	9.5	13.2	115	-	-	-	-
	1720	9.7	12.2	107	1710	9.3	12.1	105	1650	9.0	11.7	101	1640	9.2	12.2	106	1630	9.2	12.5	108	1610	9.5	12.9	113	1550	9.5	12.4	108
	0730	7.9	9.2	77	0800	8.0	8.8	74	0820	8.0	9.4	79	0840	8.0	10.0	84	0900	8.2	11.8	100	0910	8.1	12.0	101	0930	8.4	11.0	94
	1010	8.4	11.1	94	1020	8.2	9.7	82	1040	8.9	10.9	94	1100	8.8	10.9	94	120	8.5	12.4	106	1140	9.0	12.8	110	-	-	-	-
Apr 16-17, 1979	2255	9.0	10.8	93	2310	9.0	11.2	97	2330	9.0	11.2	97	2345	10.0	11.2	99	2355	9.0	11.0	96	0010	9.0	11.5	99	0025	9.0	11.4	98
	0050	9.0	11.4	98	0105	9.0	11.4	98	0115	8.5	11.4	97	0125	9.0	11.4	98	0135	9.0	11.4	98	0145	9.0	11.4	98	0155	9.0	11.4	98
	0305	8.5	11.6	99	0320	8.5	11.6	99	0330	8.5	11.8	101	0345	8.5	11.8	101	0355	8.5	11.5	101	0410	8.5	11.5	101	0420	8.5	11.5	98
	0500	8.5	11.4	97	0515	8.5	11.5	98	0525	8.5	11.5	98	0535	8.5	11.5	98	0545	8.5	11.5	98	0600	8.5	11.5	98	0610	8.5	11.5	98
	0645	8.5	11.5	98	0700	8.5	11.3	96	0705	8.5	11.5	98	0715	8.5	11.5	98	0725	8.5	11.5	98	0740	8.5	11.5	98	0850	8.5	11.5	98
	0935	9.0	11.6	100	0940	9.0	11.0	95	0950	9.5	11.5	100	0955	10.0	11.4	101	1005	9.5	12.0	105	1010	9.5	12.5	109	1020	9.5	12.5	109
	1100	10.0	11.3	100	1105	9.5	11.1	97	1115	9.5	11.5	100	1120	10.0	11.6	102	1125	9.5	12.4	108	1135	10.0	12.5	110	1155	10.0	12.5	110
	1255	10.5	11.6	104	1305	10.5	11.4	102	1310	10.5	11.5	103	1315	10.5	12.0	107	1325	10.5	12.2	109	1335	11.0	12.5	113	1345	11.0	12.2	110
	1455	11.0	11.7	106	1505	11.0	11.5	104	1510	11.0	11.9	107	1515	11.0	11.8	106	1525	11.0	12.2	110	1530	11.2	12.4	112	1540	11.2	12.1	110
	1655	11.0	11.7	106	1700	11.0	11.4	103	1710	11.0	11.7	100	1715	11.0	11.8	106	1725	11.0	11.7	106	1730	11.0	11.9	107	-	-	-	-
	1855	10.5	11.1	99	1905	10.5	11.0	98	1910	10.5	11.1	99	1915	10.5	11.2	100	1925	10.5	11.0	96	1930	10.5	11.2	100	1940	10.5	11.0	98
	2055	10.0	11.8	104	2105	10.0	10.6	94	2110	10.0	11.0	97	2115	10.0	10.6	94	2130	10.0	10.6	94	2135	10.0	10.6	94	2145	10.0	10.5	93
	2300	10.0	10.7	94	2310	10.0	9.9	87	2315	10.0	10.2	90	2320	10.0	10.3	91	2300	9.5	10.4	91	2335	9.7	10.4	93	2345	9.8	10.3	92
Jun 13-14, 1979	2200	18.5	9.2	97	2210	18.5	9.3	98	2215	18.2	9.2	97	2220	18.0	9.5	100	2230	17.9	9.3	97	2235	18.0	9.5	100	2245	18.5	9.3	98
	0005	18.0	9.4	99	0010	17.5	9.5	99	0020	17.0	9.6	99	0025	17.5	9.5	99	0035	17.0	9.5	98	0045	17.5	9.6	100	0050	17.5	9.4	98
	0210	17.5	9.5	99	0220	16.5	9.7	98	0230	17.0	9.7	100	0235	17.0	9.6	99	0245	16.5	9.7	98	0250	-	9.6	97	0255	16.5	9.5	96
	0410	17.0	9.6	99	0420	16.5	9.6	97	0430	16.7	9.7	99	0435	16.5	9.6	97	0440	16.5	9.7	98	0445	16.5	9.7	98	0455	16.2	9.6	97
	0600	16.5	9.6	97	0610	16.5	9.6	97	0615	16.5	9.7	98	0620	16.2	9.7	98	0630	16.2	9.7	98	0635	16.0	9.8	98	0645	16.0	9.8	98
	0800	16.0	9.7	97	0810	15.7	9.9	99	0815	16.0	9.7	97	0825	16.0	9.8	98	0830	16.0	9.9	99	0845	16.0	9.9	99	0850	16.0	9.8	98
	1010	16.5	9.8	99	1015	16.5	9.8	99	1025	16.2	9.7	98	1030	16.5	9.8	99	1040	16.5	9.7	98	-	-	-	-	-	-	-	-
	1205	17.5	9.6	100	1210	17.2	9.7	100	1220	17.2	9.6	99	1225	17.1	9.6	99	1235	18.0	9.5	100	-	-	-	-	-	-	-	-
	1405	19.0	9.3	99	1410	18.5	9.4	99	1420	18.5	9.5	101	1425	18.0	9.5	100	1435	19.5	9.3	100	1445	20.2	9.1	100	1450	19.2	9.2	99
	1605	19.5	9.2	99	1610	19.0	9.3	99	1620	19.0	9.2	98	1625	19.0	9.2	98	1635	19.5	9.2	99	1645	20.0	9.2	100	-	-	-	-
	1800	19.5	9.2	99	1805	19.0	9.3	99	1815	19.7	9.2	100	1820	19.2	9.2	99	1830	19.5	9.2	99	1835	20.5	9.0	99	1845	20.5	9.1	100
	2005	19.5	9.3	100	2010	19.5	9.2	99	2015	19.5	9.2	99	2020	19.0	9.2	98	2030	19.0	9.2	98	2040	20.0	9.1	99	2040	20.0	9.1	99
	2200	19.3	9.1	98	2205	19.0	9.2	98	2215	19.2	9.2	99	2230	19.0	9.3	99	2235	18.9	9.2	98	2240	19.0	9.3	99	2250	18.0	9.2	98

often the controlling algal growth factor in natural streams. Orthophosphate is the form of inorganic phosphorus which is utilized by aquatic organisms and can occur in both a dissolved state or tied up in suspended particles of sediment.

Phosphorus concentrations in Rock Creek have not been very well documented. Data collected at the D.C.-Maryland boundary by Montgomery County indicate an average concentration of 0.07 mg P/l. Data collected by DES over the last year is much more extensive, but relates much higher concentrations of total phosphorus. Figure 8-7 displays the profile of levels recorded at the six DES stations. Discrepancies between different sources can be explained by a number of factors including a difference in analytical procedures (filtered or unfiltered samples). It is also notable that the DES data includes a period of time during which the Rock Creek Interim Advanced Wastewater Treatment Plant was in operation and contributing a phosphorus load.

The profiles in Figure 8-7 indicate no appreciable change in phosphorus levels throughout the D.C. reaches. It can be seen, however, that concentrations are much greater during high flows due to storm runoff loads.

The District of Columbia has no phosphorus standard for its water bodies, but a generally accepted criterion of 0.05 mg P/l for natural streams is widely assumed in order to prohibit excessive aquatic plant growth. Under this criterion, Rock Creek is constantly in violation.

Nitrogen

Nitrogen forms that have been monitored in Rock Creek include nitrite, nitrate, ammonia, and organic nitrogen. Ammonia nitrogen concentrations are available exclusively in the DES monitoring program and are portrayed in Figure 8-8. The impact of ammonia in a natural stream is manifold: 1) nitrification of ammonia to nitrate consumes free oxygen within the stream; 2) high ammonia concentrations can be toxic to fish, and 3) some forms of aquatic plants can utilize ammonia as a nitrogen source.

The profiles of ammonia concentration in Figure 8-8 indicate a definite trend of decreasing levels from the upper to lower reaches. In addition, high flow concentrations are lower than those of the low flow regime. Implications are that background and/or point source loads contributed from the Maryland portion of Rock Creek are the origin of ammonia nitrogen in the D.C. reaches.

Nitrification and dilution reduce this background source. Storm runoff loads also act to dilute the low flow concentrations.

Figure 8-8 also shows, in all three profiles, a distinct increase in ammonia concentration between the West Beach Drive and Sherrill Drive stations. A larger difference is noted in the low flow regime. It is apparent from this data that a point source discharge between these stations, perhaps on Fenwick Branch, is contributing a significant load of ammonia nitrogen.

The toxic level of ammonia in a stream is dependent on the temperature and pH. By Figure 8-1 it can be seen that, at a feasible condition in Rock Creek of a pH of 7.5 and a temperature of 27°C, the potentially toxic ammonia concentration is 1.0 mg N/l. Such a level is observed frequently in DES data.

It is worthwhile to note that, although there are no contradictory data available, the DES monitoring information is not without questionable validity in ammonia measurement. Conjunctive measurement of total Kjeldahl nitrogen, filtered ammonia nitrogen, and unfiltered ammonia nitrogen has yielded all too numerous occasions of ammonia concentrations greater than Kjeldahl nitrogen and unfiltered ammonia less than filtered. The frequency of these improbable occurrences in the data create doubt as to the validity of analysis results.

Nitrate nitrogen is the form of nitrogen preferentially utilized by most aquatic plant species and is a potential health hazard in public water supplies if found in concentration greater than 10 mg N/l. Profiles of nitrate concentration in Figure 8-9 display characteristics similar to ammonia nitrogen. There is a significant decrease in concentration from the upper to lower end in the D.C. reaches and low flow levels are higher than those during high flow regime. Once again, implications are that Maryland background sources are the principle origin of nitrate nitrogen. Dilution and/or aquatic plant life utilization reduce the boundary source load throughout the D.C. stream segment. Storm runoff serves to dilute the low flow concentrations.

The District of Columbia has no nitrate nitrogen standard for a Class C stream. It is generally regarded that phosphorus rather than nitrogen acts as the limiting nutrient for algal and plant growth in natural freshwater streams and criteria are not commonly imposed. The nitrate standard for water supply usage is not imperiled in Rock Creek.

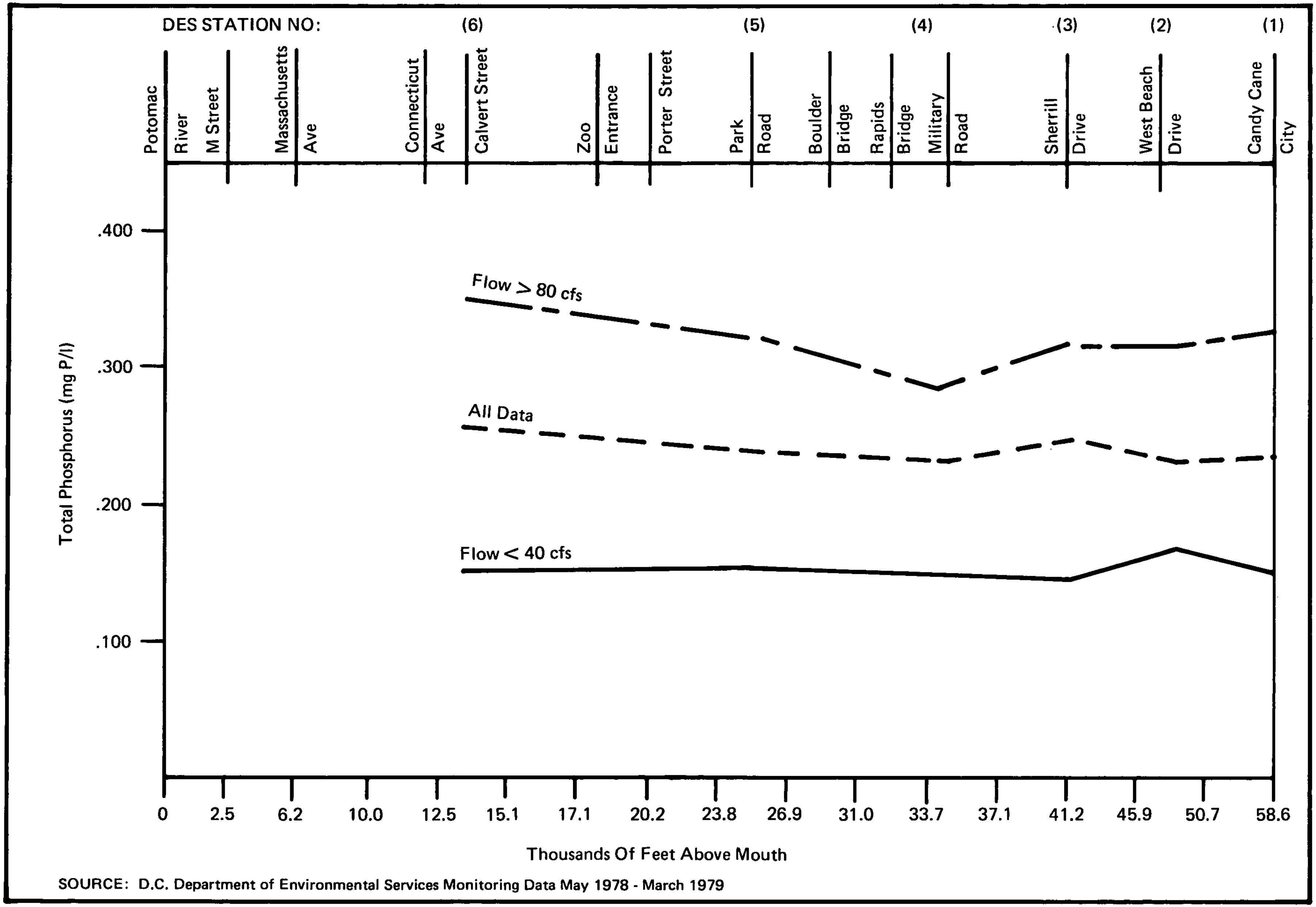


FIGURE 8-7 Stream Profiles of Total Phosphorus Concentration

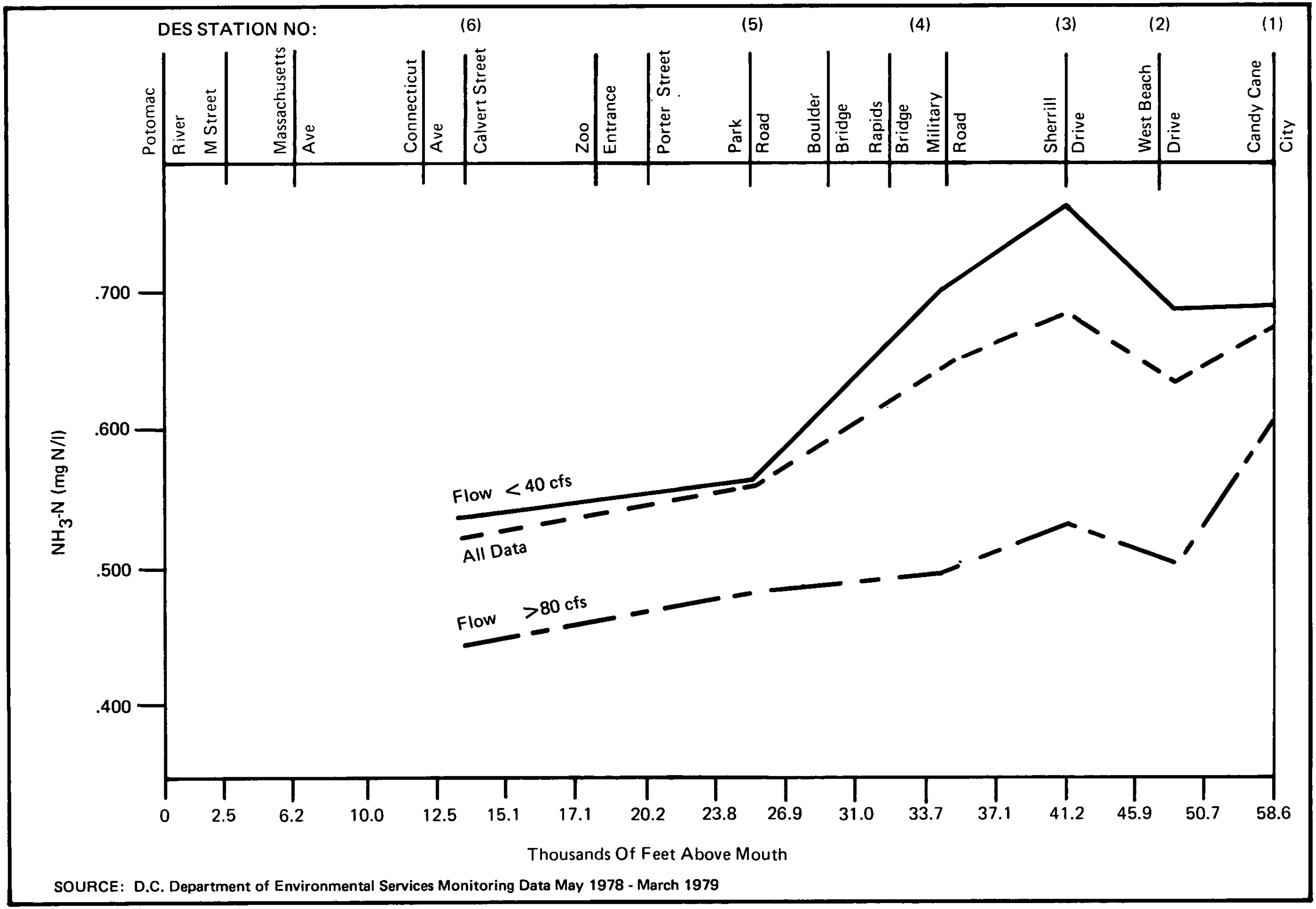


FIGURE 8-8 Stream Profiles of Ammonia Nitrogen Concentration

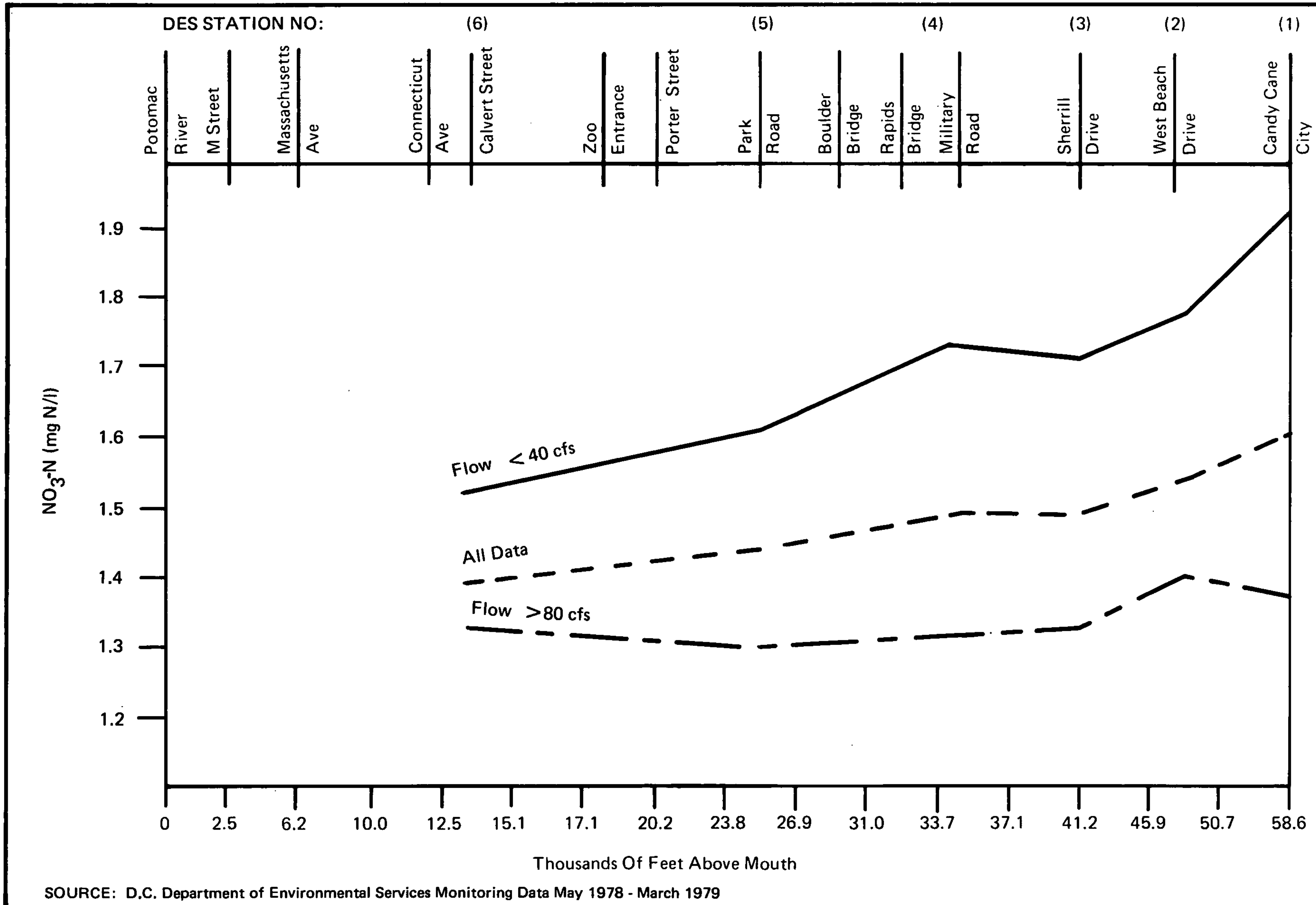


FIGURE 8-9 Stream Profile of Nitrate Nitrogen

Fecal Coliform Bacteria

Fecal coliform bacteria as an indicator of the bacteriological integrity and health safety of a stream have been the subject of numerous past studies and sampling surveys in Rock Creek. Although different sources of contamination are noted throughout the chronology of documents, the common conclusion is that Rock Creek throughout the District part of the basin is in constant violation of standards for any kind of body contact recreation (200 organisms per 100 ml) and imposes a serious health hazard.

Measurements of fecal coliforms exhibit a large variability, even when duplicate samples are analyzed. To complicate matters, there are several different analytical procedures that can be employed that will bias the results one way or the other. Hence, quantitative comparison of different studies and a limited number of samples is impossible. The DES data base provides a large set of uniformly analyzed fecal coliform concentrations by which trends can be observed. Figure 8-10 depicts the profile of arithmetic average concentrations at the six sampling sites. A large variance can be seen in the profiles between the Park Road and Calvert Street stations. This phenomenon is expected as a result of combined sewer overflow during storm events, but the low flow profile is evidence of significant point source contributions.

It is worthwhile to comment on the high levels of coliform bacteria recorded at the upper stations where there are no combined sewer effects. There is an obvious implication of bacteriologic contamination from Maryland waters.

Suspended Solids

The District of Columbia presently maintains no standard for suspended solids concentration in its waters. High concentrations have been documented to greatly impact bottom dwelling organisms and aquatic habitat and a warm water fishery standard of 80 mg/l is widely accepted. This criterion is attained in Rock Creek only during extended low flow periods. The impact of stormwater loadings is evident in examination of concentrations of suspended solids in Table 8-2. A relatively constant profile of concentrations throughout the District indicate Maryland agricultural, construction, and urban sources to be major contributions of sediment.

A secondary impact of sediment delivery to Rock Creek is the nutrients and other pollutants associated with the suspended particles. This has been in evidence in previous discussions of BOD and phosphorus. Aesthetic quality of the stream is also greatly affected with the turbidity associated with sediment loads. Turbidity can also greatly impact the ecology of a stream by limiting the photic zone or light penetrating depth. Aquatic plants that photosynthesize are greatly impacted by light reducing turbidity. Since plankton are on the lower food chain level in aquatic biologic systems, the consequences of turbidity can be enormous.

Phytoplankton

Phytoplankton are a water quality parameter that is generally ignored in freshwater streams. The impact of algae is more notable in lakes and estuaries. However, pools and eddies can nuture significant concentrations of phytoplankton that can significantly impact oxygen concentrations and aesthetic quality in the stream. In an effort to document a previously unmonitored seasonal variation of phytoplankton, a series of sampling surveys was initiated as a part of this study. Results of chlorophyll a measurements are portrayed in Table 8-7. The levels recorded here are appreciable for a natural stream like Rock Creek but not excessive. A seasonal trend can be seen in the limited amount of data. Wet weather conditions in the spring and early summer of 1979 may have inhibited the potential algal growth. There is no discernable trend in the stream profile of these data.

Bottom Sediment

The composition of aquatic bottom sediment has been recognized to play an important role in natural water chemistry and biological quality. The sediment survey by O'Brien and Gere (Reference 9) of metal and pesticide concentrations in Rock Creek sediments recorded detectable levels of lead, cadmium, zinc, chlordane, and DDT. Highest levels were found in the lower D.C. reaches near combined sewer outfalls. It was concluded that levels of lead and zinc were of such an extent in these areas to warrant classification as moderately to heavily polluted. Urban sediment sources and deposition in the sluggish lower reaches of Rock Creek were cited as the cause.

The organic content of bottom sediments is also in important quality parameter in the water-sediment interface. Decomposition of organic material on the bottom exerts an oxygen demand that, in extreme cases of organic sludge deposits, can result in anaerobic conditions in the bottom water layer. A similar sediment survey was

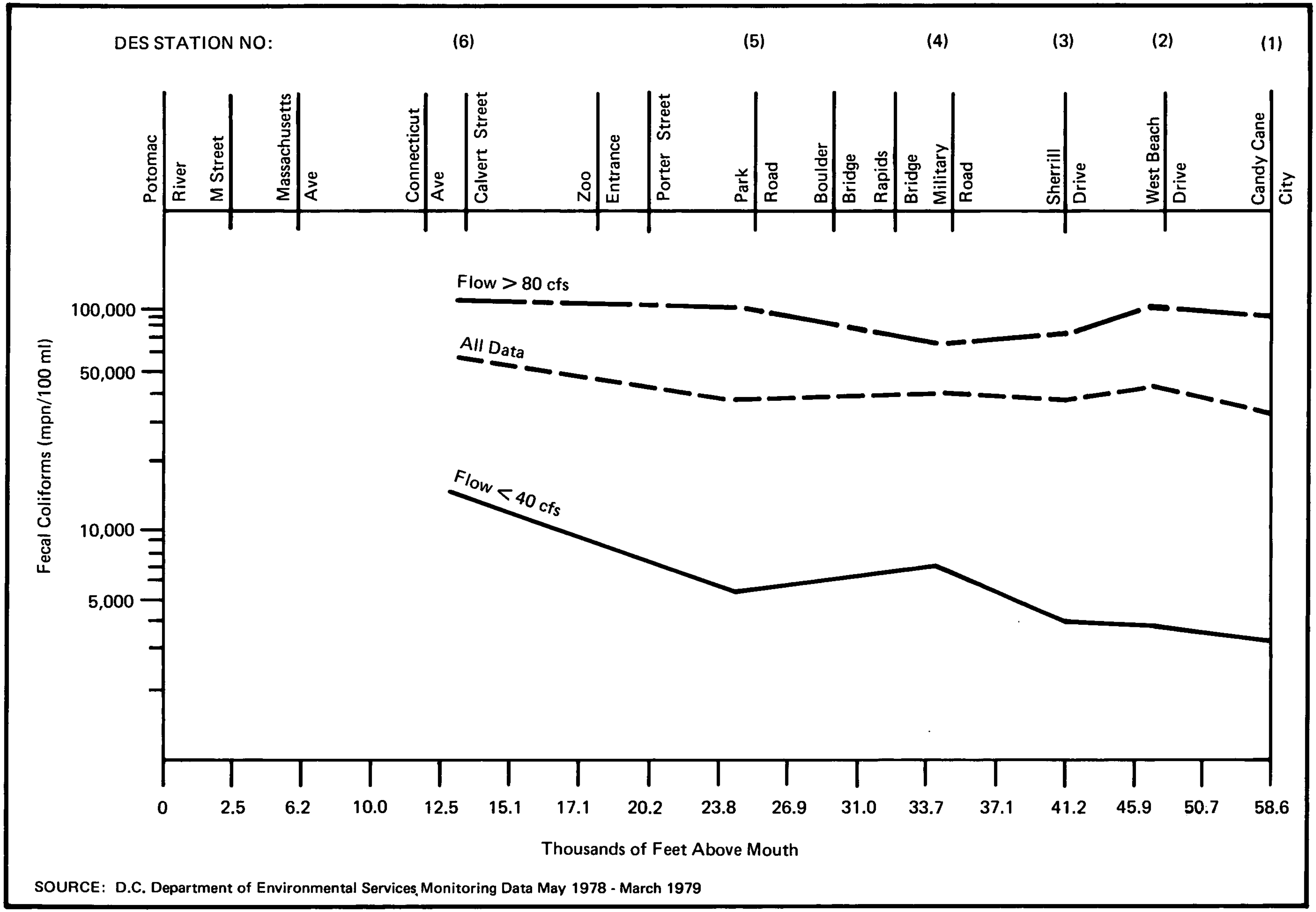


FIGURE 8-10 Stream Profiles of Fecal Coliform Concentrations

TABLE 8-7
ROCK CREEK SEASONAL CHLOROPHYLL a SURVEY

	Chlorophyll a Concentration, ug/l		
	Nov. 6, 1978	Apr. 18, 1979	Jun. 27, 1979
#1 (Candy Cane City)	5.8	0	11.6
#2 (West Beach Drive	5.8	11.0	5.8
#3 (Sherrill Drive)	0	5.8	0
#4 (Missouri Road)	0	11.0	11.6
#5 (Park Road)	0	5.8	0
#6 (Calvert Street)	0	5.8	5.8
#7 (P Street)	-	5.8	11.6

conducted under the auspices of this study of the volatile content and chemical oxygen demand (COD) of sediment in the main stem and tributaries of Rock Creek. In addition, several sites that were noted to have a vivid orange tinge were analyzed for concentrations of iron, lead, mercury, and zinc. Results are listed in Table 8-8 and sample site locations are depicted in Figure 8-11.

For evaluation of the results, guidelines developed by Region V of the Environmental Protection Agency are employed and presented below:

Parameter	Non-polluted	Moderately Polluted	Heavily Polluted
Volatile Solids (%)	<5	5-8	>8
COD (micrograms/gram)	<40,000	40,000-80,000	>80,000
Iron (micrograms/gram)	<17,000	17,000-25,000	>25,000
Lead (micrograms/gram)	<40	40-60	>60
Mercury (micrograms/gram)	-	-	>1
Zinc (micrograms/gram)	<90	90-200	>200

TABLE 8-8
ROCK CREEK SEDIMENT SAMPLE RESULTS (JUNE 1979)

Sample Site	Volatile Content (percent)	COD (micrograms/gram)	Metals (micrograms/gram)			
			Fe	Pb	Zn	Hg
RC-S1	0.47	5,820	-	-	-	-
RC-S2	3.10	2,000	-	-	-	-
RC-S3	0.97	400	-	-	-	-
RC-S4	2.27	330	-	-	-	-
RC-S5	1.76	-	-	-	-	-
RC-S6	0.46	600	-	-	-	-
RC-S7	0.82	546	-	-	-	-
RC-S8	6.27	11,200	-	-	-	-
RC-S9	2.52	6,800	-	-	-	-
SV-S1	3.35	4,940	-	-	-	-
DB-S1	2.24	4,800	13,870	58.0	89.5	<0.04
MH-S1	1.88	1,080	-	-	-	-
NS-S1	1.09	9,320	8,640	46.1	29.5	<0.04
PB-S1	13.10	5,400	21,240	<5	13.3	<0.04
KV-S1	4.54	5,820	6,192	19.7	28.1	<0.04
BB-S1	5.30	10,200	-	-	-	-
LZ-S1	-	650	-	-	-	-
LZ-S2	-	-	4,980	9.8	32.3	<0.04
PH-S1	1.75	1,040	-	-	-	-
**-S1	-	-	8,440	21.1	21.8	<0.04
FW-S1	6.73	8,020	-	-	-	-
FW-S2	-	-	3,240	133	27.3	<0.0

** Small tributary of Rock Creek

Results of the sediment sampling are generally inconclusive. Organic content as measured by chemical oxygen demand is well within criteria throughout the basin. Highest levels were recorded in the upper and lower reaches where siltation is evident, and in the headwaters of Fenwick, Normanstone, and Broad Branches. The volatile content of the sediment samples does not necessarily correlate to COD and a few samples indicated moderate pollution according to criteria. Generally, the same relative trends can be seen with higher levels at the upper and lower Rock Creek locations and the headwaters of the heavily urbanized tributaries.

Despite the distinct iron oxide coloration of the sediments at those sites analyzed for heavy metal content, the iron levels were within criteria at all but one station, a small tributary to Piney Branch. Zinc and mercury concentrations were also acceptable. Lead, similar to the O'Brien and Gere data, once again showed up in excessive amounts in several of the samples.

It can be generally concluded that the bottom sediments of Rock Creek display marginal quality. Areas of siltation in the main stem exhibit the marks of urban pollution; higher organic content, trace metals, and pesticides. Tributaries within the District that drain the more heavily urbanized areas demonstrate similar attributes.

POLLUTION SOURCES

The relative levels of pollutants in the water and sediment of the Rock Creek Park watershed have been discussed and evaluated with regard to water quality criteria. This section shall evaluate sources of these water quality constituents. Possible pollution sources will be discussed in general, followed by description of identified sources in the Montgomery County and Washington, D.C. portions of the Rock Creek watershed. Point source and nonpoint sources will be included.

GENERAL

Point Sources

Point sources originate from a pipe or easily identified source such as from sewage treatment plant or an industry. The effluent from sewage treatment plants is regularly monitored and subject to regulatory agency controls. The nature of domestic wastewater treatment plant effluents is fairly uniform from day to day and from plant to plant. Industrial discharges, however, can vary considerably from day to day for batch operations and different industries have widely varying effluent characteristics. Although most industries must discharge to a municipal wastewater treatment plant or comply with effluent permit conditions, illegal or unknown discharges still occur.

Traditionally, point sources have been the major identified causes of water quality degradation which has resulted in the recent improvements and regulation of point source effluents. Rock Creek has very few point source discharges.

Nonpoint Sources

Nonpoint sources of pollution result from rainfall or are so diverse in their nature that they cannot be considered as point sources (onsite disposal systems). Nonpoint sources include urban runoff, agricultural runoff, construction site erosion, silvicultural activities, combined sewer overflows, and failing onsite disposal systems (septic systems).

Urban Stormwater Runoff. Urban stormwater runoff as a nonpoint source of pollution has been recognized as a potential cause of serious water quality degradation only within the past fifteen years. Urban runoff pollution occurs when precipitation flushes the urban environment and carries pollutants to receiving waters. Two major points to note are that the pollutants are generated and discharged over a diffuse area rather than at an identifiable point and that the occurrence is intermittent and unpredictable.

In order to better understand the nature of urban runoff pollution, a brief discussion of the steps involved in urban runoff is appropriate. First, pollutants from a wide variety of sources accumulate on the urban land surfaces. A rain event then dislodges, dissolves, or otherwise removes some of the pollutants and the resulting runoff transports the contaminants across the land surface and into gutter and storm sewer systems. Finally, the contaminant-laden runoff discharges into the receiving waters.

The sources of the pollutants involved in urban runoff are extremely varied as are the types of pollutants. Typical sources include air pollution, transportation activities, construction activities, and urban litter. Air pollution, in the form of polluted rain and atmospheric fallout, is a largely undefined contributor of urban runoff pollution.

Transportation activities produce considerable amounts of pollutants as a result of the mechanical wear of tires, road surfaces, brakes, and clutches. Brake and clutch wear produces lead and other metals while oil and gas leaks result in oil and grease pollution. Litter, improperly handled refuse pickup, and unprotected commercial and industrial stockpiles are not only eye sores but also generate pollutants, particularly organics. Lawn care, including fertilizers, herbicides, insecticides, grass clippings, and dead leaves, produce or involve organics, nutrients, and toxins that eventually reach the receiving water. Animal droppings result in bacteriological contamination while construction sites produce large amounts of solids. Catch basins and ponded ditches trap leaves and other organic matter that decompose over a period of time and can add a significant oxygen demanding source to the early phases of a runoff event. Another potential source of pollutants is illegal or ill-advised discharges to the storm sewer or drainage system. These include swimming pool drains, oil from crankcases, and toxic chemicals that may be dumped into the gutter or ditch and sometimes directly into the stream.

Construction activities produce sediment, chemicals from oil fuels, solvents, stabilizers, paints and litter. Erosion and sediment loads are particularly increased by construction activities since the soil surfaces are disturbed and exposed to the impact and detachment by rainfall and runoff.

From the above partial list of pollutant sources, it can easily be seen that different land uses would have different concentrations of pollutants in the runoff. A shopping center with a large degree of traffic would be expected to have a higher concentration of metals and oil and grease than a residential area which would have higher organic and nutrient loadings. Table 8-9 summarizes the sources of urban runoff pollution.

TABLE 8-9
THE SOURCES OF URBAN RUNOFF POLLUTION

- METEOROLOGICAL--Settling of particulates from the air with retention in the urban area.
- TRANSPORTATION RESIDUE--A major source of suspended solids, chemical oxygen demanding materials, and heavy metals, especially lead.
- MAN'S CARELESSNESS--Street litter is a major source of organic material.
- CONSTRUCTION--A major contributor of sediment from accelerated erosion.
- ANIMAL DROPPINGS--Primary contributor of coliform organisms.
- LAWN CARE--Source of nutrients and organic material.
- ILLEGAL STORM SEWER DISCHARGE--Oil and grease, bacteria, chemicals.

Agricultural Sources. Nonpoint agricultural pollutants are organic and inorganic materials entering surface waters and groundwater from nonspecific or unidentified sources. They include sediment, plant nutrients, pesticides, chemical fertilizers, crop residues, and animal wastes from cropland, pastures, and farm woodlands. Sediment is the major pollutant in terms of weight and volume and may be a significant carrier of nutrients, organic materials, and pathogenic organisms. Sediment is not only the greatest single water pollutant in the United States, but also the largest carrier of plant nutrients from agricultural areas. Sources of sediment in rural areas are cropland, farmyards, construction sites, streambanks, and roadbanks.

The principal plant nutrients contributing to algal blooms and eutrophication of lakes are the various forms of phosphorus and nitrogen. Chemical and animal fertilizers applied in agricultural regions are sources of these nutrients. However, the only nutrient form that is readily transported by the leaching process of rainfall is nitrate-nitrogen. Nitrogen in this form is not absorbed by the soil and thus moves readily with water. Ammonia is adsorbed on clay and is not leached. However, all forms of nitrogen, organic and inorganic, are readily converted to nitrate when applied to productive, well-drained soils. Thus, nitrogen in the nitrate form is predominant in both runoff and percolation waters.

Phosphorus, on the other hand, is a highly immobile nutrient. It is not subject to leaching except in certain unusual organic soils. Thus, phosphorus movement is primarily associated with eroded soil particles of sediment.

Sediment is removed by overland flow. Whenever soil is bared, particles at the surface are subject to detachment and movement by raindrop splash. This rapidly reduces the soil's infiltration capacity and enhances overland runoff, thus providing rapid transport of the detached particles from the channel boundaries. Sediment particles in transport may transmit adsorbed substances and plant nutrients from soil to water or adsorb dissolved substances from the water.

Major water pollutants from animal manures are oxygen-demanding matter (principally organic matter), plant nutrients, and infectious agents. Color and odor are potential polluting constituents of secondary importance.

Animal wastes can affect the water quality of streams if animals are allowed access to the stream, if overland flow is present from cropland undergoing manure application, or if runoff occurs from pastures and livestock holding areas.

Forest Sources. Forestland use represents the background or natural condition of the Rock Creek watershed. However, most of this watershed was cleared and has been in continuous use for pasture and cropland since the early 18th century. Under natural forest conditions, sediment sources are limited to extreme events that result in erosion of stream channels and flood plains. Nearly complete recycling of plant nutrients within the forest ecosystem prevents significant concentrations of nutrients leading to eutrophication in receiving waters. Pathogenic organisms from natural fish and wildlife populations are rare. The water quality of the streams represents an equilibrium with chemical leaching of geologic material by rainfall and nutrient adsorbence or use by soil and vegetation.

Precipitation is a major source of sediment and nutrients to the natural forest. It is suspected than pollutant inputs from precipitation are much higher now than they were before the settlers cleared the land. However, the present rate of dust deposition and precipitation input of pollutants is still low enough so that the pollutants can be utilized by the forest ecosystem.

Individual Disposal Systems. Individual disposal systems, commonly called septic tanks, are a potential source of nonpoint pollution, especially if there are failing systems in the area. There are two different classes of failures associated with individual disposal systems. The first type is known as a surface failure because it involves the flow of sewage effluent to the surface of the ground. Surface failures are caused by localized saturation of the soil with effluent or groundwater. This will occur as a result of a decrease in the soil percolation rate caused by; 1) biological slime growth, 2) clogging of the system with excessive solids, or 3) high groundwater table. More generally, a reduced percolation rate will limit the hydraulic loading capacity. Surface failures have localized public health water quality impacts; however, contaminated surface runoff can contravene water quality standards of major surface waters.

The second type of failure, groundwater failure, consists of microbial or nutrient contamination of the groundwater from system leachate. Nutrients of primary concern are nitrogen in the form of ammonia, nitrate nitrogen, and phosphorus as phosphate.

Combined Sewer Overflows

Combined sewers are wastewater collection systems designed to transport both sanitary wastes and stormwater runoff in the same conduits. A separate sanitary sewer system, on the other hand, is designed to transport only sanitary wastewater while storm water is conveyed by separate storm sewers.

During wet weather, combined sewer systems may overflow directly to the receiving water (Rock Creek) and the combined sanitary wastes and stormwater runoff are discharged without treatment. Overflow points and treatment plant bypasses are provided, by design, to prevent damage to the wastewater treatment plant and to reduce local flooding during periods of high flow. Combined sewer discharge can be a major source of pollution during the period of overflow. Combined sewer overflow (CSO) can also be a source of long-term pollution in the receiving water since solids are discharged which settle to the bottom and form sludge deposits. These deposits exert long-term oxygen demand which persist during periods of dry weather and may leach toxins to the receiving water. Combined sewer overflows consist of both urban runoff and domestic sewage which results in CSO's having stronger pollutant concentrations than urban runoff.

Potential Impacts of Nonpoint Sources

Urban Runoff. The four basic types of pollutants resulting from urban runoff are sediment, chemical, biological, and organic materials. Table 8-10 lists these basic types of pollutants as well as their major contaminants and primary impacts on receiving water quality. In addition to the impacts listed in Table 8-10 any pollutant that seriously impacts water quality will also have the adverse effect of decreasing the commercial and recreational value of the receiving water.

Sediment includes solid mineral and organic materials which are transported by the runoff water. Sediment can reduce reservoir storage capacity; fill harbors and navigation channels; increase the frequency of flooding and cause bank erosion; increase turbidity in water and reduce light penetration; increase the cost of water treatment; damage fish life; destroy and cover organisms on the bottom of streams; reduce the velocity and carrying capacity of streams; impair operation of drainage ditches, culverts, and bridges; alter the shape and direction of stream channels; destroy water recreational areas; and impart an undesirable taste to water. Sediment reduces growth of valuable water fowl food plants. Many fish are sight-feeders, and sediment seriously interferes with their food finding activities. Sediment or turbidity is sometimes beneficial in reducing algal blooms and aquatic weeds in lakes and streams by limiting photosynthesis. Turbidity from fine sediment causes light to be scattered and absorbed rather than transmitted. Although turbidity is an extremely poor measure of the total suspended sediment content, it is an important measure of water quality whenever light penetration is necessary for photosynthesis and the production of materials in aquatic food chains. High levels of turbidity reduce the aesthetic value of a stream or lake.

TABLE 8-10
TYPICAL POLLUTANTS AND PRIMARY IMPACTS

Basic Type	Contaminant/Parameter	Primary Impacts
Sediments	Suspended solids/total suspended solids	Sediment deposits; Aesthetic; Associated chemicals
Chemical	Toxic materials/heavy metals, pesticides	Ecological damage
	Nutrients/orthophosphorus, total nitrogen	Excessive aquatic growth (eutrophication)
Biological	Bacteria, virus/total fecal coliform	Public health threat
Organic	Degradable organics/BOD	Dissolved oxygen depletion
	Nutrients/orthophosphorus, total nitrogen	Excessive aquatic growth
Other	Flotables and visual contaminants/oil and grease	Aesthetic

Chemicals include petroleum products, pesticides, fertilizers, synthetic materials, heavy metals, soil additives, and miscellaneous wastes resulting from urban activities. In addition to affecting the odor and taste of drinking water, chemicals can suffocate or poison aquatic plants, oraganisms, and fish; accelerate the eutrophication process; encourage the formation of oxides and salts that can affect aquatic organisms; and increase the acidity or alkalinity of receiving waters.

Biological materials include bacteria, fungi, protozoans, and viruses of human, animal and soil origin which can constitute a health hazard by transmitting diseases.

Organic materials include carbonaceous and nitrogenous biochemical oxygen demanding wastes (BOD) and nutrients (nitrogen and phosphorus). Organic materials have a two-fold effect on receiving waters: (1) they deplete the oxygen supply by providing food for oxygen-consuming bacteria, and (2) they provide nutrients for plant and algae build-up that can cause eutrophic conditions.

Relative Magnitude of the Stormwater Problem. A comparison of the average concentrations for various parameters for untreated municipal sewage, primary and secondary treated municipal sewage, typical urban runoff, and runoff from virgin land is given in Table 8-11. Particularly note that the average BOD concentration for urban runoff is approximately the same as secondary treated municipal sewage while the average total coliform concentration is 400 times greater than secondary effluent and the concentrations considered safe for body contact. The suspended solids concentration for urban runoff are three times greater than raw sewage but nutrient levels are well below secondary effluent levels. Also of significance are the considerably higher concentrations of pollutants in urban runoff compared to virgin land runoff.

TABLE 8-11
GENERALIZED QUALITY COMPARISONS OF WASTEWATER AND STORMWATER AVERAGE CONCENTRATIONS

Type	BOD5 mg/l	Suspended Solids mg/l	Total Coliform MPN/100 ml	Total Nitrogen mg/l as N	Ortho Phosphorus mg/l as P
Untreated municipal	200	200	50,000,000	40	7
Treated municipal					
Primary effluent	135	80	20,000,000	35	5.1
Secondary effluent	25	15	1,000	30	3.5
Typical urban runoff	27	608	400,000	3	0.7
Virgin land runoff	1.5	50	500	-	0.07

In assessing the urban runoff problem, not only must the concentration of the pollutants be considered but also the large volume of runoff occurring with each rain event. The product of the hydrograph (flow vs. time) and the pollutograph (concentration vs. time) gives a mass loading rate curve. The area under the mass loading rate curve is the total pollutant load for the runoff event. There are three ways to reduce the total load; reduce the concentration of the pollutant, reduce the volume of runoff, or reduce both.

Variability. Both the quantity and quality of urban runoff varies significantly. The quantity of runoff varies primarily with the amount of precipitation, the land use, and antecedent meterological conditions. Urban runoff characteristics can change by an order of magnitude within a single storm, from area to area, and from one storm to the next. This variability is influenced by land use and the resulting pollutant sources, the velocity of the runoff, the time allowed for pollutants to build up on the land surfaces, the stage of the storm, and other factors. Highest concentrations of a pollutant are generally expected under the following conditions: the early stages of a storm (first flush); in more densely paved and traveled areas; in response to intense rainfall events; after prolonged dry periods; in areas undergoing construction activities; and on steep surfaces. The average values for urban runoff concentrations all have a standard deviation roughly equal to the mean. In other words, the values given in Table 8-11 for urban runoff are actually more of an order of magnitude value rather than absolutes. BOD, for example, can have an average concentration from 2 mg/l to 54 mg/l and still be within the national average. The concentration of pollutants during an event can vary dramatically.

Urbanization. The effects of urbanization increase the amount of runoff, the peak flow, and the build-up of pollutants on the land surface. Therefore, as more and more land is urbanized, the urban runoff pollutant load will continue to increase unless control measures are initiated. This is in contrast to municipal and industrial point sources which are subject to planned and regulated control of their discharges. In the future, therefore, urban runoff pollution may continue to increase in magnitude while point source pollutants decrease.

The usual result of the urbanization of an area is a change in the factors which affect runoff:

- A decrease in soil porosity through compaction
- An elimination of surface areas which retain precipitation
- An increase in impermeable surfaces

- A construction of channels and storm sewers to carry off the excess water

- A decrease in vegetation (trees, grasses, shrubs, etc.,) thereby decreasing transpiration and interception

- An increase in the smoothness of surfaces

The net result of these changes is an increase in the peak runoff flow, an increase in the total volume of runoff, a decrease in the time for the peak runoff to occur, and a decrease in the groundwater contribution to streamflow. The increase in peak flow can significantly increase the erosion of the land surface, thus increasing the sediment load of the runoff. The higher velocity flow is also capable of transporting more of the pollutants that have accumulated on the urban land surfaces. A larger total volume of runoff provides more potentially polluted stormwater to reach the receiving waters, thereby increasing the pollution load.

Increases in the density of human populations, as a result of urbanization, have caused concentrations of pollutants not found in sparsely developed areas. This can be partially explained by the fact that urban areas are subject to a larger number of sources of pollutants than undeveloped areas. Because of the absence of dense automobile traffic, non-developed areas receive less automobile emissions and wear products resulting in lower build-up rates for these pollutants. Litter, illegal storm sewer discharges, commercial stockpiles, improper fertilizer and pesticide applications, and construction activities are examples of pollutant sources that are primarily concentrated in urban or urbanizing areas.

Moreover, because potential runoff pollutants in non-urban areas accumulate on pervious land surfaces, they are not as readily available for washoff as the same pollutants that accumulate on impervious surfaces (streets, sidewalks, parking lots, roof tops) in urban areas.

From the above discussion it can be readily seen that urbanization causes an increase in pollutant loads by two concurrent means: a change in the hydrology of an area; and an increase in the pollutant build-up rates on the land surface. Urbanizing an area typically increases the pollutant loading rate during a storm event and the total load for the event. For this reason, a large degree of the management alternatives will focus on controlling urban runoff from urbanizing areas.

Agriculture. Most agricultural uses (cropland, pasture, livestock) are not as detrimental to affected streams and lakes as are urban uses in the type and quantity of non-point source pollution delivered to the water body.

Organic material from livestock waste and crop residues serves as a substrate for aerobic bacteria when it enters the receiving stream.

Associated with bacterial metabolism is the utilization of dissolved oxygen. If the rate of oxygen utilization exceeds the reaeration rate of the stream, oxygen depletion occurs. Further additions of organic matter will reduce the oxygen concentration below the level necessary for fish survival and the maintenance of a desirable aquatic environment.

Nitrogen, phosphorus and sediment are a primary concern with respect to the effect of agricultural activities on streams and lakes. These elements contribute to the accelerated growth of aquatic plants in an impounded water body. In addition, toxicity caused by increased nitrate concentration is possible in the groundwater supplies in rural areas. Livestock wastes are also sources of infectious agents that may infect other animals, and in some instances, man. Although contractions of water-borne diseases are relatively rare in our country, increasing emphasis on water-based recreation creates new opportunities for this mode of infection.

Alteration of water temperature is another agriculture related form of pollution. Activities that can change the water temperature include pond and reservoir construction, reduction of water depth and widening of streams, removal of streambank vegetation, and irrigation. A rise in water temperature decreases water's ability to absorb oxygen; increases metabolism, respiration, and oxygen demand of fish and other aquatic life; intensifies the toxicity of many substances; and favors the growth of undesirable kinds of algae, fungi, and bacteria. These changes can alter the composition of the aquatic community.

Onsite Disposal Systems. Failing onsite disposal systems can act as sources of fecal coliform bacteria contamination, nutrients, chemicals, or organic matter. The type of pollution and its magnitude depend on the nature of the onsite system failure.

Construction Site Erosion. Construction sites are one of the primary sources of sediment in urban or urbanizing areas. Stripping large areas of their natural vegetation leaves them subject to accelerated erosion and unless extensive onsite controls are used, significant sediment loads can blanket stream bottoms and destroy the ecology of the benthos.

Combined Sewer Overflows. One of the most important characteristics of combined sewer overflow is its concentrated location. Combined sewer systems are located in some of the most heavily populated urban centers of our nation. Thus, the pollutant discharge is limited to the generally short reaches of the receiving water located near the highest concentrations of population. Thus, many millions of people observe and are exposed to the receiving water impacts resulting from combined sewer overflow.

Combined sewer overflow can be a significant source of pollution in certain cases. The relative importance of CSO depends upon the ratio of combined sewer service area to separate sewer service area. The dilution ratio, i.e., the ratio of stormwater runoff to domestic sewage flow required to produce an overflow, also largely determines the impact of a CSO. Large dilution ratios produce overflows only slightly stronger than urban runoff pollutants. Small dilution ratios, however, result in overflows which can contain the same pollutant concentrations as raw domestic sewage. In general, combined sewers are a major source of oxygen-demanding materials (BOD) and suspended solids (SS). Wastewater content of CSO is generally the major source of nutrients and bacteria and urban stormwater runoff is the major source of lead.

Another important characteristic of CSO is the the intermittent nature of the discharge. Combined sewer overflow occurs only during runoff-producing rainfall events which, in general, range from 200 to 1,300 hours per year or from 2% to 15% of the time. Thus, pollutant loading rates during runoff events may be extremely large. Because combined sewer systems were designed to handle large flows produced by stormwater runoff, they do not efficiently transport the domestic sewage flows. This results in the deposition of raw sewage in the sewer pipes prior to reaching the wastewater treatment plant. It has been estimated that as much as 20 to 30 percent of the solids can be deposited. These solids can be transported during the higher flows that occur when it rains and if a sewer overflow results, will produce a first flush of strong, septic pollutants.

Combined sewer overflow contains raw wastewater which may contain disease organisms, is usally repugnant, and results in unpleasant odors. During combined sewer overflow events, heavier particulate organic material can settle to the bottom of the waterway and contribute to a benthic load which detrimentally impacts the receiving water, even during dry weather periods. Floatable and soluble organic material can impact the waterway with a shock pollution loading which can negate any fishable or swimmable goals. The impact of a large combined sewer overflow event on any viable aquatic biota element in the receiving water can be extremely detrimental.

MONTGOMERY COUNTY, MARYLAND POLLUTION SOURCES

Only a brief summary of the pollution sources in the Montgomery County, Maryland portion of the Rock Creek watershed shall be presented. Conclusions and information are drawn from Stormwater and Water Quality Management Study-Rock Creek and "Draft Functional Master Plan for Conservation and Management in the Rock Creek Basin" prepared by the Maryland-National Capital Park and Planning Commission (References 10 and 11).

POINT SOURCES

For the purpose of this study, point sources of pollution are defined as those that flow during low flow or dry-weather conditions. The primary documented point source discharge in Montgomery County is the Rock Creek Interim Advanced Wastewater Treatment Plant that initiated operation in September 1978. The discharge point is located at Southlawn Avenue (see Figure 8-12) and the following parameters describe the typical average quality of effluent. NPDES permit limitations are listed in parentheses.

Flow - 2.0 mgd (3.0)
BOD-5 - 1.7 mg/l (8.0)
Suspended Solids - 1.6 mg/l (8.0)
Total Kjeldahl Nitrogen - 0.5 mg/l (3.0)
Total Phosphorus - 0.7 mg/l (2.0)
Dissolved Oxygen - greater than 7.0 mg/l (6.0)
Fecal Coliforms - less than 5 MPN/100 ml.(200)
pH - 6.4 to 8.3 (6.0 to 8.5)

The treatment plant provides advanced wastewater treatment with chlorination and dechlorination facilities that limit free residual chlorine in the effluent to less than 0.02 mg/l.

Two small sewage treatment plants serving the Brook Manor and Needwood Country Clubs also have permits to discharge into Rock Creek. However, their treatment lagoons do not appear to discharge to the creek during periods of low flow. Storm runoff may cause overflows of these lagoons, but the frequency, magnitude, and quality of overflow is unknown.

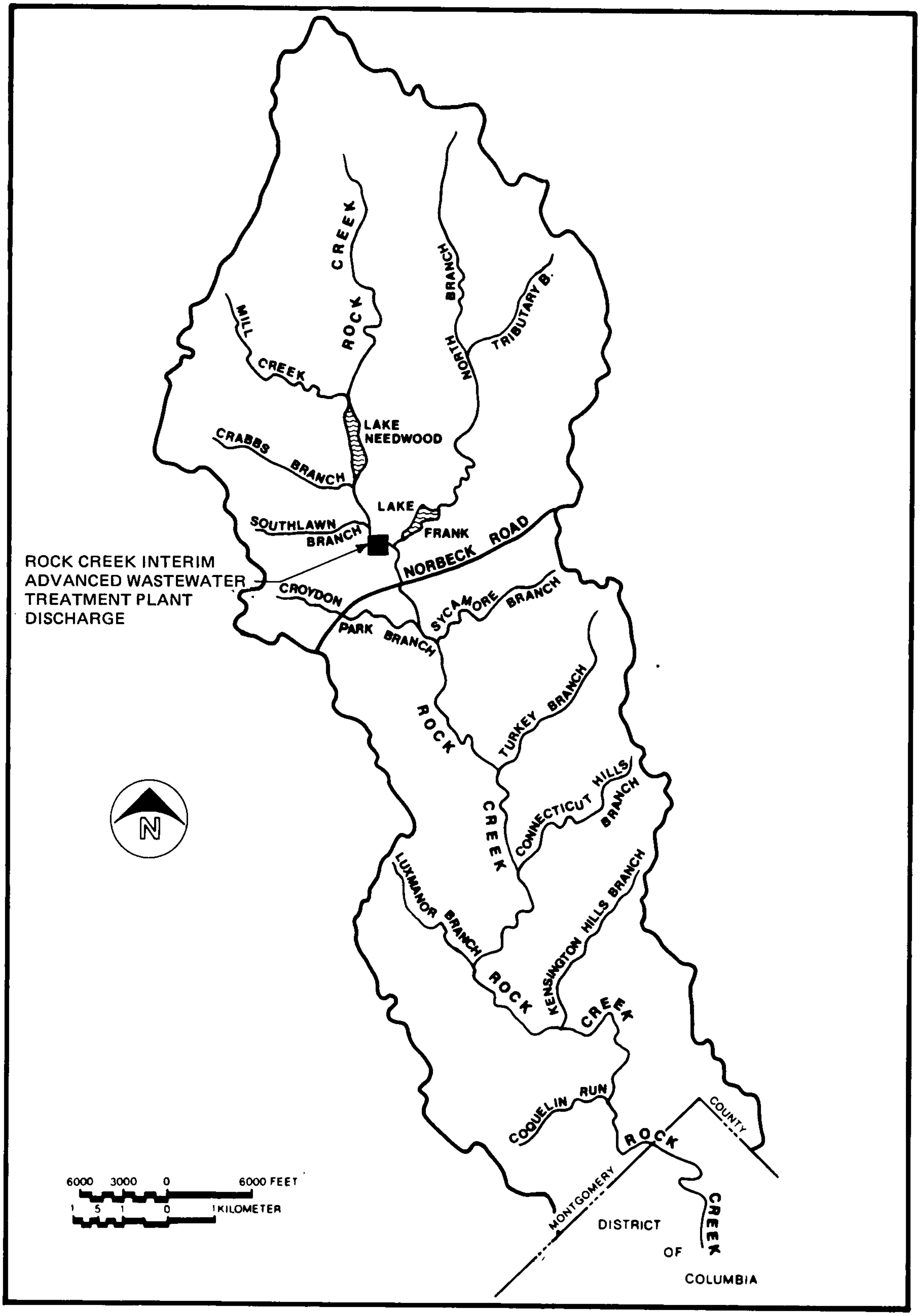


FIGURE 8-12 Upper Rock Creek Watershed Montgomery County, Maryland

The M-NCPPC study did not include any field reconnaissance or sampling to identify other point sources of pollution. Instream water quality records during low flow periods indicated the following sources to exist even though there is little information available on the quantity or quality of this pollution.

Leaking sanitary sewers, including the Rockville interceptor, and illegal sanitary connections to storm drains are evidenced by high fecal coliform bacteria concentrations throughout the entire basin below Lakes Needwood and Frank. There has been no investigation or sampling to determine the extent of these sources of pollution and their presence can only be assumed.

Illegal connections of industrial discharges to storm sewers are indicated by concentrations of metals, oil and grease, and other chemical pollutants. Southlawn Branch is noted to possibly receive discharge from up to three industrial sources on a periodic basis. The extent of illegal discharge of pollutants is unknown.

The Montgomery County Landfill, also located on Southlawn Branch, is the subject of much investigation. Leachate and runoff from the landfill has historically contributed pollution in the form of heavy metals to the stream system. Operation of an incinerator at the landfill prior to 1976 is attributed as the the primary source of contamination and recent data show reduced concentrations. Most high levels were associated with rainfall events.

Additional point sources of pollution may include malfunctioning onsite individual disposal systems. The upper rural parts of the watershed are not served by the sanitary sewer system and septic fields serve the rural population. There is no information to document the performance of these systems. Failure can lead to nutrients and bacteria reaching the stream system and/or groundwater. Excessive bacterial levels in a relatively rural area of Crabbs Branch have been attributed to septic fields.

Nonpoint Sources

For discussion here, nonpoint pollution sources are defined as those generated by storm events. Very little has been offered in the way of analysis of nonpoint pollution sources in Montgomery County. The only evidence that has been documented is that which is measured in the stream. Previous discussion has narrated in general the various sources, characteristics, and impacts of nonpoint source pollution. Literature points to a high correlation with land use patterns.

Recent study and extensive monitoring by the Northern Virginia Planning District Commission has established land use and stormwater quality relationships in the D.C. metropolitan area that are portrayed in Table 8-12 as average water quality concentrations (Reference 12). Such concentrations can be assumed, within reason, to be representative of stormwater quality from areas of similar land use within the Rock Creek basin.

Since the Rock Creek watershed in Montgomery County exhibits a large variety of land uses, the following sources of nonpoint pollution are all applicable within the basin.

Agricultural Sources. There presently are approximately 1640 acres of cropland and pasture in use in the Montgomery County portion of the Rock Creek watershed. Almost all of this acreage is located in the upper reaches above Lakes Needwood and Frank. The primary impact of agricultural sources is the contribution of sediment, nutrients (nitrogen and phosphorus), organic matter, bacteria and pesticides to the stream and lake system.

The two lakes act as traps to sediment and nutrients. An 80% trap efficiency has been documented for the impoundments for reduction of sediment loads. However, during low flow periods, suspended colloidal silt particles in the lakes act as a source of turbidity to the lower Rock Creek reaches. The lakes have been determined to stratify during the summer months with anaerobic conditions occurring in the bottom layers. The possibility of fall and spring turnover events thus exists which could deliver high organic and nutrient loadings to the downstream reaches.

The fecal coliform bacteria loads from agricultural areas originate from livestock sources. In the reaches above the two lakes, this in addition to septic field concentrations, is the primary source of contamination. However, instream bacterial counts are lower here than in any downstream reaches and are considered an insignificant contribution to the District segment.

Urban Sources. The rapid urbanization that has occurred within the Montgomery County portion of the basin has not been limited to the resultant change in hydrologic and hydraulic conditions. As previously discussed, urban runoff contributes large sediment loads, oil and grease, metals, organics, chemicals, and bacteria to the watercourse. The sources of these contaminants include air pollution, transportation systems, construction activities, industrial and commercial activities, and urban litter.

The increased runoff that accompanies urbanization has facilitated easier transport of the pollutants as they accumulate on the denuded surfaces. The impact of urban runoff may be ascertained by comparison of mean concentrations of stormwater pollutants of the urban land uses with those of the natural forested condition once prevalent in the upper watershed (see Table 8-12).

Sediment is one of the more visible and potentially disastrous components of urban runoff pollution. A recent 12-year study of sediment loads in Montgomery County (Reference 13) has documented the following suspended sediment yields:

Forest land	-	0.03 tons/acre
Grassland	-	0.20 tons/acre
Cropland	-	0.65 to 4.3 tons/acre
Urban land	-	3.7 tons/acre
Urban Construction Sites	-	7 to 100 tons/acre (average of 33 tons/acre)

The gradual transition of a natural, forested watershed to pasture/cropland to urban land can be followed and each step shows incremental sediment loads. A large portion of the sediment yield from urban lands was noted to result from channel bank erosion immediately downstream from newly completed residential and commercial areas.

The variability in construction site erosion yields (7 to 100 tons/acre) was attributed to the use of effective sediment control measures. The practices, when properly designed, constructed, and maintained, were estimated to be 60 to 80 percent effective in the reduction of sediment loads from construction sites.

The increase in sediment loads in the Montgomery County portion of the Rock Creek watershed with urbanization is obvious in examination of the data. The adverse impact of these loads in the downstream system is equally obvious.

Surcharged Sanitary Sewers. The rapid growth experienced in Montgomery County has surpassed the construction and rehabilitation of sanitary sewer conveyance to such an extent that the capacity of the main interceptor system is exceeded frequently. These interceptors generally follow the natural topography, hence are located along watercourses. Infiltration and inflow to the system as a result of even small storm events will consequently cause surcharge of the interceptors and discharge through popped manhole covers into the stream system. Detailed

TABLE 8-12
MEAN CONCENTRATIONS OF STORMWATER RUNOFF AND DISSOLVED FRACTIONS (IN PARENTHESES)

Land Use	Biochemical Oxygen Demand (mg/l)	Chemical Oxygen Demand (mg/l)	Total Suspended Solids (mg/l)	Fecal Coliforms (MPN/100 ml)	Ammonia Nitrogen (mg N/l)	Nitrite-Nitrate Nitrogen (mg N/l)	Organic Nitrogen (mg N/l)	Ortho-Phosphate (mg P/l)	Organic Phosphorus (mg P/l)
Large-Lot Single Family Residential (0.1-2.0 DU/Acre)	18.4	116	243	15,800	0.35	0.62	2.57	0.11	0.23
Medium Density Single Family Residential (2.0-8.0 DU/Acre)	31.5	126	203	11,700	0.21	0.44	1.77	0.14	0.24
Townhouse/Garden Apartments (8-22 DU/Acre)	23.7	74	208	137,200	0.08	0.33	1.07	0.07	0.21
High-Rise Residential (>22 DU/Acre)	31.9	101	52	18,000	0.14	0.34	0.79	0.05	0.24
Suburban Shopping Center	52.0	114	118	101,300	0.16	0.40	1.01	0.025	0.215
Central Business District	-	120	189	-	0.09	0.46	1.59	0.014	0.306
Construction Site	6.0	111	-	-	1.36	0.72	1.11	0.04	0.14
Conventional Tillage Cropland	30.0	266	2,814	265,100	1.13	4.45	9.72	1.00	2.34
Minimum Tillage Cropland	17.1	173	461	-	0.47	0.93	3.00	1.13	0.96
Cow Pasture	27.7	159	485	-	0.17	0.44	4.49	0.04	0.68
Forest	12.8	113	290	1,500	0.08	0.02	1.41	0.004	0.166
Rain Water	-	72	-	-	0.53	0.45	1.45	0.02	0.12

TABLE 8-12
MEAN CONCENTRATIONS OF STORMWATER RUNOFF AND DISSOLVED FRACTIONS (IN PARENTHESES)
(CONTINUED)

	Extractable Metals (mg/l) - (% Dissolved)						
Land Use	Zinc	Lead	Copper	Cadmium	Chromium	Iron	Manganese
Large-Lot Single Family Residential (0.1-2.0 DU/Acre)	0.117 (41.0)	0.122 (5.8)	0.013 (15.5)	0.0014 (16.2)	0.013 (9.1)	6.34 (22.2)	0.093 (31.4)
Medium Density Single Family Residential (2.0-8.0 DU/Acre)	0.094 (41.0)	0.052 (7.0)	0.022 (16.3)	0.0023 (11.6)	0.011 (4.2)	5.27 (11.8)	0.111 (24.9)
Townhouse/Garden Apartments (8-22 DU/Acre)	0.200 (38.8)	0.068 (6.7)	0.175 (21.1)	0.005 (17.7)	0.022 (6.6)	4.78 (10.3)	0.130 (23.2)
High-Rise Residential (>22 DU/Acre)	0.253 (69.0)	0.153 (10.3)	0.024 (18.6)	0.0006 (36.7)	0.0045 (6.9)	1.80 (15.6)	0.059 (51.4)
Suburban Shopping Center	0.310 (61.9)	0.357 (15.2)	0.026 (29.6)	0.004 (28.1)	0.016 (5.2)	3.75 (10.8)	0.084 (61.9)
Central Business District	0.755 (31.1)	0.320 (5.5)	0.064 (8.5)	0.003 (4.4)	0.033 (6.1)	6.41 (3.3)	-
Construction Site	0.160 (82.7)	0.056 (21.0)	0.005 (9.5)	0.0005	0.003	3.10 (22.8)	-
Conventional Tillage Cropland	0.208 (21.7)	0.126 (6.3)	0.072 (22.4)	0.0002	0.054 (6.2)	35.4 (18.6)	0.880 (12.1)
Minimum Tillage Cropland	0.260 (26.0)	0.027 (2.7)	0.033 (28.2)	0.0013 (6.8)	0.019 (20.5)	22.4 (18.9)	0.680 (13.3)
Cow Pasture	0.150 (40.6)	0.018 (3.8)	0.005 (23.3)	0.0006	0.015 (9.6)	7.7 (9.6)	0.840 (40.5)
Forest	0.072 (78.5)	0.016	-	0.010 (35.2)	0.010	4.9 (15.4)	0.240 (66.1)
Rain Water	0.258	0.018	0.004	0.001	0.009	0.27	0.010

analysis of the phenomenon is unavailable, but observations are well-documented and bacterial counts in Rock Creek far in excess of those expected from urban runoff attest to the fact.

WASHINGTON, D.C. POLLUTION SOURCES

Pollution sources within the District of Columbia exhibit as wide a variation as those of Montgomery County. Past studies and literature have pointed to numerous culprits of the water quality problems observed in Rock Creek. It is a major objective of this study to identify and quantify these sources for input to a water quality simulation model of the creek. In this way, an analysis of impact and analysis of control strategies is facilitated.

Point Sources

Point source discharges to the District reach of Rock Creek officially do not exist according to permits issued under the National Pollutant Discharge Elimination System. Records do indicate periodic construction permits issued for discharge during road maintenance, sewer installation, building construction, etc, but no constant discharges are noted. However, literature cites numerous sampling results that indicate a considerable amount of pollution entering various locations of the watershed on a continual basis.

In an effort to identify and monitor these illegal discharges to the system, a comprehensive field survey of all outfalls to the creek within D.C. was initiated as a part of this study. This survey included complete walking of the stream and all tributaries. A complete inventory of outfalls and pertinent data (size, construction, material, location, function, flow condition) was compiled and is included in the appendix to this report. A total of 117 outfalls to the main stem of Rock Creek were found and 101 to the tributaries. Locations of all outfalls within the Park Service boundaries are depicted on 1:2400 scale aerial overlays provided to the National Park Service, National Capital Parks, Rock Creek Park.

The initial survey was conducted during an extended dry period to minimize the occurrence of flowing outfalls. Those that showed evidence of pollution at the outlet were especially noted. Those outfalls that were noted to flow during the initial survey were included in a monitoring program conducted during a similar prolonged dry-weather period in mid-June 1979. Locations of sampling sites are depicted in Figure 8-13. Headwater outlets to all major tributaries were included in the monitoring.

Onsite measurement of temperature and pH was accomplished by portable meters. In addition, flow estimates were obtained by timed bucket volume measurement. Samples were collected and preserved per standard procedure for analysis of fecal coliform bacteria and chemical oxygen demand (COD). Results are listed in Table 8-13. In addition to the aforementioned analyses, a series of metals analyses were performed at various outfalls, tributary headwaters, and spring sites that exhibited a distinct orange tint in both the water and bottom sediment.

The detection of high levels of fecal coliforms in any of the sample results is an indication of sanitary contamination. COD is used to measure the organic matter content of the sample. Raw sewage will generally range from 400 to 600 mg/l. In conjunction with a low bacterial count, a high COD concentration is evidence of industrial or commercial discharge. Several of the samples in Table 8-13 indicate severe contamination. These include RC 7, RC 29, RC 33, RC 43, RC 52, RC 57, RC 58, RC 75, and RC 117 on the main stem, and LZ 4, P 1, FW 1, FW 2, BB 1, MH 1, NS 1, PB 4, SV 2, and SV 3 on the tributaries. A second survey of these sites was performed in July 1979 with personnel of the D.C. Department of Environmental Services in order to investigate the origin of this pollution. Additional samples were collected and results are included in Table 8-13.

RC 7. RC 7 is a 24-inch combined sewer overflow located on the very steep east bank of Rock Creek upstream of M Street. DES personnel indicated that flows to the structure were always much higher during the summer, but could only guess as to the source. Flow within the overflow pipe originated as splash water that went over the diversion dam and sump at the overflow structure itself due to an extremely high velocity of flow. Additional flow to Rock Creek came from seepage behind the overflow outlet box; the source was not ascertainable. Both discharges were equally contaminated with high fecal coliform bacteria content.

RC 29. RC 29 is a combined sewer overflow that did not show exceptionally high concentrations but is of concern simply because it flows during dry weather. Located on the west bank downstream of Massachusetts Avenue, the outfall shows debilitation. The presence of springs nearby leads to the conclusion that groundwater infiltration is the source of flow. However, further investigation is warranted.

TABLE 8-13
ROCK CREEK OUTFALL SAMPLING RESULTS

Outfall Identification No.	Temperature °C	Flow (cfs)	pH	Fecal Coliforms (MPN/100 ml)	COD (milligrams/ liter)	Metals (milligrams/liter) Fe	Pb	Zn	Hg
Rock Creek									
RC7	22	.017	7.0	141,000 112,000	180	-	-	-	-
RC7 (Flow from behind structure)	22	.033	7.0	460,000 68,000	140	-	-	-	-
RC29	18	.049	7.5	4,200 2,800	290	-	-	-	-
RC33	16	.100	7.0	24,000 5,400	220	-	-	-	-
RC43	15	.100	10.4	<100	640	-	-	-	-
RC52	16	.011	7.2	400	1,100	-	-	-	-
RC57	16	.011	6.9	25,000 2,100	220	-	-	-	-
RC58	20	.100	7.0	43,000	20	-	-	-	-
RC66	17	.017	7.2	<100	130	-	-	-	-
RC75	17	.200	7.3	3,600 234,000	180	-	-	-	-
RC104	15	.019	8.0	<100	130	-	-	-	-
RC105	15	.073	8.1	<100	77	-	-	-	-
RC108	14	.007	7.1	<100	31	-	-	-	-
RC117	21	.036	8.4	<100	520	-	-	-	-
Fenwick Branch									
FW1	15	.230	5.6	200	300	-	-	-	-
FW2	14	.092	7.2	400	690	-	-	-	-
FW4	15	.020	7.0	-	-	3.61	0.010	<0.01	<0.001
Portal Branch									
P1	16	.190	6.8	1,000	440	-	-	-	-
Pinehurst Branch									
PH1	14	.170	7.4	700	15	-	-	-	-
PH5	14	.002	7.4	<100	12	-	-	-	-
Luzon Branch									
LZ1	16	.160	7.4	200	8	1.45	0.005	0.022	<0.00[illegible]
LZ4	16	.006	7.3	240,000	569	-	-	-	-
LZ6	15	.004	7.3	1,200	48	-	-	-	-
LZ10	15	.011	6.8	500	23	-	-	-	-
LZ12	17	.006	7.5	<100	180	2.14	0.002	0.274	<0.001
LZ13	22	.011	7.7	<100	8	-	-	-	-
Broad Branch									
BB1	16	.840	7.5	16,000	21	-	-	-	-
Melvin Hazen Branch									
MH1	16	.100	7.5	12,000	190	-	-	-	-
MH2	16	.001	6.6	10	360	-	-	-	-
Piney Branch									
PB1	15	.067	7.0	<10	60	63.0	0.005	0.086	<0.001
PB4	19	.052	8.4	<10	230	-	-	-	-
Normanstone Branch									
NS1	15	.170	5.5	20	310	2.25	0.036	<0.004	0.003
NS2	15	.067	7.2	9,400	97	-	-	-	-
NS3	16	.004	5.4	3,200	270	-	-	-	-
Klingle Valley Branch									
KV1	14	.017	5.5	80	430	-	-	-	-
Dunbarton Oaks Branch									
DB1	15	.067	7.2	10	160	1.09	0.010	0.047	<0.001
Soapstone Valley Branch									
SV1	16	.220	7.7	3,900	52	-	-	-	-
SV2	23	.042	5.8	542,000	360	-	-	-	-
SV3	16	.270	7.4	3,900	81	-	-	-	-
Unnamed Tributary	14	.006	6.7	1,300	-	50.2	0.050	0.103	<0.001

RC 33. A large CSO located near the confluence of Normanstone Branch and Rock Creek, RC 33 is a complicated hydraulic structure. The drainage area to the overflow structure was partially separated and only 56 sanitary connections are reported to still exist. A 10-inch dry-weather flow connection conveys this discharge to the Rock Creek Main Interceptor. The excess flow, due to a recent hydraulic modification, is now transported directly to RC 33. To complicate matters, a diversion structure in the Normanstone Branch allows natural streamflow to enter the system. As a consequence, sanitary flow from the non-separated drainage areas mixed with natural streamflow and only a 10-inch connection is available to transport this to the main interceptor. The overflow at RC 33 thus contains an appreciable bacterial count and a septic odor persists.

RC 43. RC 43 is a 36-inch storm sewer located on the east bank of Rock Creek upstream of Connecticut Avenue. No sanitary contamination is in evidence, but a distinct cloudy, flour coloration in the water and bottom sediment is apparent and high COD and pH were measured. The source of this discharge is from Washington, D.C. Metro subsurface tunneling activities that apparently pump groundwater seepage into the storm sewer system. The effect of the turbidity is visible in the creek for 100 feet downstream.

RC 52. Another storm sewer that sample results indicated to be contaminated is RC 52 located on the east bank just downstream of the Potomac Parkway bridge. An extremely high COD was measured here in the first survey. However, in the second survey, very little flow was observed. Indication is that an intermittent discharge of industrial or commercial origin to the storm sewer system is the source.

RC 57. Although there is no outfall at RC 57, seepage in the proximity of a combined sewer diversion structure on zoo premises showed a high bacterial count and a distinct septic odor. Investigation seemed to indicate the source was of too high an elevation to be coming from the diversion structure. The second sampling demonstrated lower concentration but further inquiry is warranted.

RC 58. RC 58 is an outfall belonging to the National Zoo that showed evidence of fecal contamination. Discussion of the zoo sewer system in a subsequent section shall address this discharge to Rock Creek.

RC 75. Another combined sewer overflow structure that remains in an area that reportedly received complete sewer separation, RC 75 is a perplexing and frustrating problem. Observations in the field over the past year, both visual and olfactory, indicated severe sanitary contamination at the outfall. DES personnel provided corroborating evidence. Unfortunately, the first day of sampling found the discharge to be relatively clean. The second survey provided a contrastingly high fecal level. It is apparent that sanitary connections still exist in this area that are now directly discharged to Rock Creek.

RC 117. A small 6-inch outfall on the west bank of Rock Creek near the Joyce Road bridge was observed to have an extremely high rate of flow during dry-weather. RC 117 demonstrated a high chemical oxygen demand but no fecal coliform bacteria. During the second survey, there was no flow. Intermittent commercial or industrial discharge is assumed to be the source.

FW 1, FW 2, P 1, BB 1, NS 1 and MH 1. The headwater outfalls of Fenwick, Portal, Broad, and Melvin Hazen Branches all demonstrated, to some degree, either sanitary or industrial/commercial sources of pollution during dry-weather conditions. The large drainage area and extensive storm sewer system above these points make the task of identifying the sources of contamination enormously difficult and prohibitive. The residential drainage areas of Broad Branch and Melvin Hazen Branch evidence high fecal levels. The industrial and commercial areas of Fenwick, Normanstone, and Portal Branches are the probable source of high COD in these outfalls.

LZ 4. LZ 4 is an old 4-foot brick combined sewer near the headwaters of Luzon Branch that, as a result of sewer separation, has been converted to strictly a storm sewer. Raw sewage has been observed to flow from the outfall and sample analysis results concur. During the second survey, however, the outfall was dry It is apparent that sanitary connections still exist to the sewer system.

PB 4. A 38-inch outfall in the retaining wall of Piney Branch, PB 4 exhibits a cloudy, foamy discharge of non-sanitary nature. Discharge is intermittent, but DES personnel have also observed the occurrence. There is most likely an apartment building laundry or car wash connection to the storm sewer system here.

SV 2. Another outfall that demonstrated direct sanitary discharge is SV 2, a 12-inch pipe near the headwaters of Soapstone Valley Branch. The discharge is also intermittent, but sampling results show strong bacterial contamination.

SV 3. Similar to the flow at RC 43, the discharge of a floury effluent at SV 3 (right next to SV 2) is the result of Metro activities near Connecticut Avenue. The sediment and coloration can be observed far downstream in Soapstone Valley.

Springs. The observation of vividly orange-tinted tributaries, outfalls, and springs throughout the Rock Creek Park watershed warrants examination to determine the source and impact of these waters. Several locations were analyzed in the point source sampling and, as expected, showed high iron concentrations in both the water and sediment. The occurrence of the phenomenon at natural spring sites can only lead to the conclusion that it is a natural condition of the watershed.

The total flow of the pollution sources identified in the sampling is actually very low, but during dry-weather flow conditions in Rock Creek, the net impact of these point source discharges can be substantial, especially in the form of bacterial contamination.

Nonpoint Source

Similar to Montgomery County, the nonpoint pollution sources of the District of Columbia portion of the Rock Creek Watershed are varied and equally difficult to quantify as far as their contribution and impact. The nonpoint sources considered within the District are urban runoff, construction sites, park activities, surcharged sanitary sewers, and combined sewer overflows.

Urban Runoff. The characteristics and impact of urban runoff have been well-documented in previous discussion. Washington, D.C. exhibits a more dense and congested form of urbanization than is seen in Maryland. There is much more commercial and industrial acreage within the District with a large portion of the southeast corner comprising the D.C. central business district. A well-developed storm sewer system and large impervious areas facilitate a much more 'flashy' runoff hydrograph that can transport more pollutant loads than in the less urbanized Montgomery County drainage areas.

There has been little documentation of the water quality and quantity of urban runoff within the District. Data collected by O'Brien and Gere (Reference 9) at three storm sewer outfalls with the past year is summarized in Table 8-14. Land use at the three sites consists of high density residential at Site #101 and high density commercial at the others. Geometric mean concentrations of samples collected during 5 storm events are portrayed.

The range of concentrations agree somewhat to those developed by the NVPDC (Reference 12) (see Table 8-12), but differences can be recognized in certain parameters

TABLE 8-14
WASHINGTON D.C. URBAN RUNOFF WATER QUALITY
SUMMARY-GEOMETRIC MEAN CONCENTRATIONS

Parameter	SITE #101 Naylor Run Storm Sewer	# 102 18th & L Streets N.W.	#103 20th & L Streets N.W.
pH (SU)	7.0	6.9	7.0
BOD-5 (mg/1)	29	31	47
Total Suspended Solids (mg/1)	114	41	10
Total Kjeldahl Nitrogen (mg N/1)	1.17	0.60	0.92
Ammonia Nitrogen (mg N/1)	0.23	0.18	0.20
Nitrate Nitrogen (mg N/1)	0.80	0.71	0.84
Total Inorganic Phosphorous (mg P/1)	0.37	0.19	0.12
Fecal Coliforms (MPN/100 ml)	6,410	1,390	430
Cadmium (mg/1)	<0.01	<0.01	<0.01
Lead (mg/1)	0.18	0.18	0.07
Zinc (mg/1)	0.09	0.23	0.13
Mercury (ug/1)	<0.5	<0.5	<0.5

such as phosphorus. Limited data and difference in analytical and sampling procedures probably account for the discrepancies.

One of the largely immeasurable yet more visible contents of urban runoff is the litter and debris that is left within the channel after the storm event along with the oil and grease slicks floating in pooled areas. Evidence of this urban runoff pollution is prevalent in the numerous tributaries to Rock Creek.

Construction Sites. The District exhibits a much more stable land use pattern than the Montgomery County portion of the basin with relatively little new development taking place. Construction, however, is not totally absent and the effects of excavation are identical to those previously narrated. Notable sources within park bounds that have been observed to create considerable impact are road maintenance activities and the Metro construction sites. These will be discussed separately as a special consideration.

Park Activities. Activities within the park boundaries by both visitors and the National Park Service can contribute a nonpoint pollution load to the creek. The park attracts a great number of visitors to its facilities each day. The trash and debris that are left, not only in recreation areas but in the stream, are a rather obvious resultant pollution load. Visitors typically bring with them pets that defecate on the premises and further contribute bacteria and organics to the stream.

Some of the National Park Service activities can also contribute loads to the stream. These include regular bulk fertilizer applications to turf areas, leaf and soil storage piles, wood chipping and composting operations and applications, and manure piles in stable areas. The stable areas are considered a major bacterial contamination source and will be addressed in following discussion as a special consideration. Also to be analyzed is the storm sewer system of the National Zoological Park which conveys a considerable quantity of nonpoint source loadings.

An 18-hole public golf course located within the park on the east side north of Military Road may also serve as a nonpoint pollution source. Fertilizer and pesticide application will invariably be washed off or leached by stormwater and groundwaters and eventually reach the watercourse.

Surcharged Sanitary Sewers. As previously discussed in Montgomery County narrative, the sanitary interceptor system that parallels the Rock Creek streambed is vastly overloaded during wet weather and surcharges frequently. Manholes such as the one in Figure 8-14 show evidence of sewage overflow including popped manhole covers, toilet paper on the ground, and scoured channels around the manholes. The impact of this source of pollution is most prevalent in the form of bacterial contamination in Rock Creek. Wet weather concentrations within the creek have been recorded that far exceed those to be expected from just urban runoff. The subject of excess infiltration and inflow to the sanitary system is presently being studied in a series of wastewater treatment facilities plans by the DES.

There is also a possibility that the sewer system could exfiltrate during dry weather to groundwater and/or surface water bodies. There is no evidence or indication that this is ocurring in Rock Creek, however.

Figure 8-14. Manhole of Rock Creek Main Interceptor Near Stream Shows Evidence of Surcharge Overflow

Combined Sewer Overflows. The contribution of combined sewer overflow to Rock Creek has been the subject of much study and literature. Unfortunately, for all this paper, very little actual data has been collected at the time of this study to document the frequency, quantity, and quality of CSO within the basin. In fact, the actual operation of some of the regulators and service connections has not been concretely defined. Continual modifications to the sewer system and incomplete separation programs over time have completely muddled the picture.

A description of the D.C. combined sewer system in Rock Creek has been provided in Chapter 3 and the ensuing Chapter 9 shall present a hydraulic analysis for incorporation in the computer simulation model. As a nonpoint pollution source, CSO is composed of a mixture of varying proportions of sanitary sewage and urban runoff. Although no outfalls in Rock Creek have been monitored for water quality, the O'Brien and Gere study (Reference 9) includes water quality analysis results of three other CSO outlets in the District. Table 8-15 presents geometric mean concentrations of various pollutants at these sites for five storm events.

TABLE 8-15
WASHINGTON D.C. COMBINED SEWER OVERFLOW QUALITY
SUMMARY - GEOMETRIC MEAN CONCENTRATIONS

Parameter	SITE #24 Northeast Boundary	#35 Kennedy Center	#43 Potomac & Water Streets N.W.
pH (SU)	6.6	6.6	6.6
BOD-5 (mg/l)	82	83	41
Total Suspended Solids (mg/l)	135	69	86
Total Kjeldahl Nitrogen (mg N/l)	9.12	5.74	4.01
Ammonia Nitrogen (mg N/l)	2.83	1.47	0.55
Nitrate Nitrogen (mg N/l)	0.55	0.57	0.63
Total Inorganic Phosphorus (mg P/l)	2.08	1.40	1.04
Fecal Coliforms (MPN/100 ml)	888,000	423,000	217,000
Cadmium (mg/l)	<0.01	<0.01	<0.01
Lead (mg/l)	0.16	0.14	0.26
Zinc (mg/l)	0.21	0.18	0.16

A great deal of variability can be seen between the sites that is largely due to the degree of dilution provided in the combined sewer prior to overflow. The Northeast Boundary overflow consists of raw sanitary sewage diluted by 1 to 2 parts of urban runoff. CSO's #35 and #43 are diluted 5 to 10 times and thus exhibit lower concentrations. When compared to the average concentrations of urban runoff in Table 8-14, it can be seen that the primary impact of the sanitary component of CSO is in the form of fecal coliform bacteria, nitrogen forms, and phosphorus. Other water quality constituents are comparable at the higher dilution ratio. It is apparent that a complete hydraulic analysis is required to determine the frequency, quantity, and quality of the CSO nonpoint pollution loadings to Rock Creek.

A great deal of the evidence of CSO impact is not necessarily in the water column of Rock Creek nor observed solely during storm events. The most obvious testimony is that of the visual and olfactory senses. The discharge of combined sewage often leaves organic residue on stream banks and in the bottom sediments of Rock Creek. The decay of these organic sediments results in septic odors that can persist long after the actual overflow. The organic deposits in the streambed exert an oxygen demand and can cause severe ecologic damage. Hence, the impact of CSO nonpoint pollution is not isolated to storm events.

Special Considerations

Pollution sources within the District portion of the Rock Creek Watershed that deserve special consideration include: the National Zoological Park; Washington, D.C. Metro; and horse trails and stable areas.

National Zoological Park. Within the last 10 to 15 years, the National Zoological Park has undergone major modifications concerning their internal sanitary and stormwater sewer systems. For the most part the major intent of the modifications was to redevelop the systems in order to minimize the concentrations of point and non-point source pollutants (References 14 and 15).

The redevelopment of the system began in 1961 with the formation of a master plan for the National Zoological Park. Existing problems within the zoo's systems were studied by the U.S. Department of Health, Education, and Welfare. From the results of that study, a report was presented in January of 1963 which served as a guideline for the redevelopment of the Zoological Park sewer system.

Many of the problems to be rectified under the redevelopment were those related to the input of contaminated water directly into Rock Creek. At one time, contaminated water from such sources as the small mammal, reptile, monkey and lion houses, the small bear cages, the waterfowl ponds, and other related sources had direct access or the ability to overflow to Rock Creek.

With the present system functioning correctly, the above problems have been supposedly eliminated. All buildings and exhibits associated with contaminated water have been tied into two of three systems that now exist within the Zoological Park. These facilities comprise a sanitary sewer and contaminated storm sewer system.

The sanitary sewer system generally conveys domestic sewage from lavatory facilities in buildings and exhibits throughout the zoo. In addition, some wash water from these buildings is accepted. This system discharges to either the Piney Branch or Rock Creek Main Interceptor.

The contaminated sewer systems receives runoff, wash water and overflows from the various exhibits. This water contains a certain amount of animal waste from these zoological displays and thus is designated as contaminated. At one time, this system discharged to Rock Creek. Under the new configuration, all lines are tied either into the sanitary system or directly into one of the main interceptors. An underground detention tank was constructed to reduce peak runoff flows in the contaminated system so that the sanitary system could accept all runoff from a six-month frequency runoff event.

A storm sewer system drains the rest of the park grounds, parking areas, rooftops, etc. that are not supposedly recipient to animal waste and discharges to Rock Creek.

In recent investigations, in reference to the outfall inventory (see appendix), the zoo systems seem to be functioning properly for the most part during dry-weather. Out of the numerous outfalls located within the perimeter of the zoo, one (RC 58) was found to be flowing. The outfall reportedly is that of a recently built storm sewer. The flow from the outfall was analyzed and exhibited a high bacterial level. Upon notification of the problem, zoo personnel investigated the source and believe an overflow from the water fowl ponds to be the main contributing source. Field reconnaissance and conversations with various personnel generally resulted in conflicting accounts of the operation of the sewer systems. Historical modifications have left the hydraulic configuration undefined and the account herein is based upon assumptions as a result of this research.

<u>Horse Trails and Stables</u>. Located within the lower Rock Creek watershed are two groups of stables. The largest complex is located in the northwestern portion of the watershed off Glover Road. The complex is divided into two sections, a combination of rental and boarding stables maintained by a public organization and a training center for the National Park Police. The three buildings can house up to one hundred horses. North of this complex is a smaller stable facility located within the vicinity of Oregon Avenue and Old Bingham Road. The stable is maintained by the National Park Police and is occupied by the patrol horses. The stable is capable of housing up to twenty horses.

The stable areas represent a potentially high source of nonpoint pollution. The quantity of manure produced by such a number of horses is surprisingly large and, left on the land surface or in large piles, will contribute bacterial and organic pollution to the stream system during storm events. The stable complexes are not within the immediate vicinity of Rock Creek. However, through overland flow produced by a large or intense rainfall event, it is highly probable that significant concentrations of fecal coliform bacteria will enter Rock Creek. Field investigations have shown that the terrain within the vicinity of the Glover Road complex is somewhat moderately sloped. These areas have swale drainage with incised channels.

The greatest quantities of horse manure are present in the manure pits, paddock areas, the various trails, and the stalls within the stables. Drainage from within the stable buildings is routed to drains that are connected to the sanitary sewer. However, problems may occur due to drain blockage or pump failure. Runoff and seepage originating from the manure pits could be a major source of contamination. Each building has its own pit that conforms to a standard design of an above-ground three-sided cinderblock box structure that lacks any type of cover. The raw manure is mixed with sawdust and bedding material and the pits are periodically emptied by hauling by truck. A typical manure pit is shown in Figure 8-15. The design for the majority of the pits shows drains for sanitary hookups. According to stable maintenance personnel, many of the planned drains are absent or not functioning properly. The manure pit located in the upper complex is the only one believed to be operating per specification. Poor design at the rental building manure pit enables any runoff to flow directly into a storm sewer (see Figure 8-15). The outfall for this storm sewer is behind the rental building in the wooded area. Evidence of manure is present in the channel beyond the outfall as shown in Figure 8-16.

The final location of unattended manure is that found along the various horse trails. At the present time, the manure left on the trails is not removed. The quantity of manure present is not as concentrated as that within stable areas. However, because of the near proximity of the trails to the creek in many areas, the bacteria have direct access to the creek during precipitation events.

<u>Washington, D.C. Metro Construction Sites</u>. Located within the study area are two Metro subway construction sites that have a negative impact on Rock Creek due to sediment loadings. The present Metro activities are located beneath the Connecticut Avenue Bridge and above the headwaters of Soapstone Valley Branch on Connecticut Avenue.

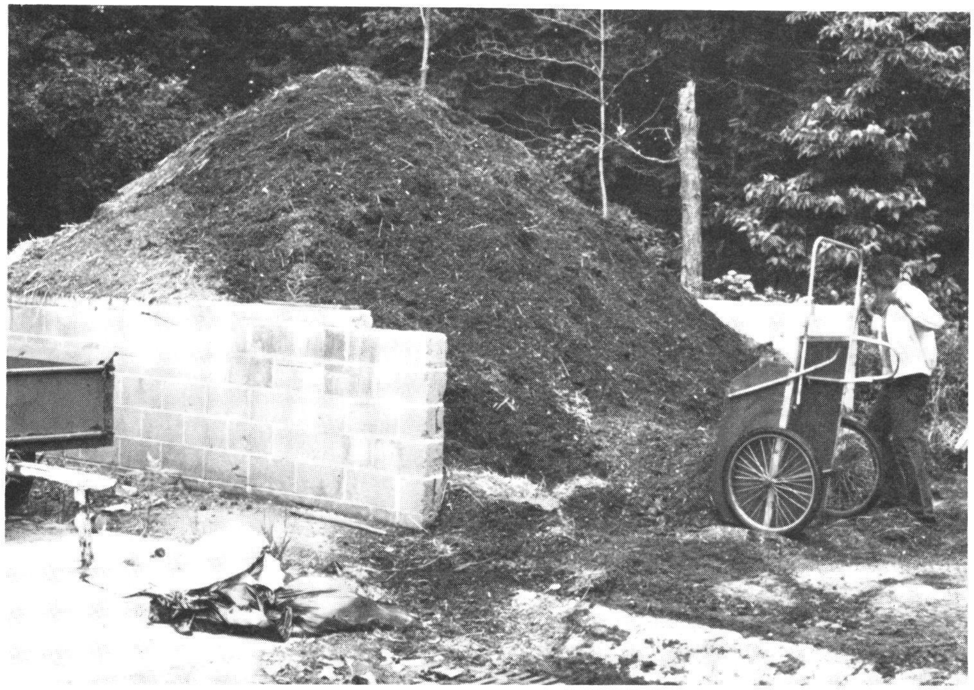


Figure 8-15. Horse Manure Pit and Storm Drain

Figure 8-16. Manure Pit Drainage Outlet

Sediment transport into Rock Creek at the Connecticut Avenue Bridge Site is evident at outfall RC 43. Sources here are discharges into storm sewers and land surface erosion of disturbed ground. According to Metro personnel, this site is classified as a 'mucking-out location.' Mucking-out refers to the removal of fine sediments that are a product of subsurface drilling activities. The mucking-out material is periodically hauled away from the site. However, large concentrations of the material mix with incoming groundwater seepage which is eventually discharged to Rock Creek. According to Metro personnel, the sediment-laden groundwater is conveyed through a series of underground settling ponds before being discharged into Rock Creek. Field investigations have shown that the settling ponds are not removing all of the suspended solids. Large concentrations of suspended solids have been observed flowing from storm sewer RC 43; the source is believed to be that of mucking-out material. As a result of the sediment-laden flow, RC 43 is periodically silted shut, requiring D.E.S. personnel to maintain the outfall by removing the accumulations of sediment from the vicinity of the outlet.

Land surface erosion from disturbed land also creates a large impact by contribution of a sediment load to Rock Creek at this site. The area beneath the Connecticut Avenue Bridge on both banks has been stripped of its natural cover, exposing the soil to runoff and thus resulting in erosion. Conversations with Metro personnel have indicated that devices to prevent surface sediments from entering Rock Creek have been implemented at the site. At the time of the field investigations, few sediment control measures were in evidence. Associated with the surface activities at the site was the pumped discharge of pooled water from a low lying area in the vicinity of the parking lot directly into Rock Creek. The flow from the discharge was extremely turbid, indicating significant concentrations of suspended solids and deposits were observed to be building up in the creek.

The Metro site on Connecticut Avenue above the headwaters of Soapstone Valley Branch is also involved in subsurface construction activities. Groundwater enters the site and is discharged into a storm sewer, the outfall being located near the headwaters of Soapstone Valley Branch (SV 3). On various occasions the entire flow of Soapstone Valley, from the outfall to the confluence of Rock Creek, has been observed to be inordinately turbid, ranging from a milky white to a reddish brown discoloration. Conversations with Metro personnel have indicated that a series of underground settling ponds are present at the site. As observed at the other site, the alleged settling ponds here are not effectively trapping suspended material, thus allowing for continuous point source discharge of suspended solids to Rock Creek.

ECOLOGICAL ASSESSMENT

The quantity and quality of the aquatic biota is a biological parameter, like phytoplankton, that is closely related to and interacts with water quality constitutents and can be used as an indicator of overall water quality. An absence of sufficient mass and diversity of benthic biota is an indication of an unhealthy aquatic environment. In order to evaluate the quantity and quality of the benthic community, a biological survey was performed as a part of this study.

Three groups of organisms; benthic macroinvertebrates, aquatic plants, and fish, were studied to assess the ecological suitability of the water quality at seven stations in Rock Creek Park. Each group possesses certain attributes which make them suitable indicators for measuring the biological impact of stresses upon streams.

Macroinvertebrates at a given station in a stream reflect habitat quality both at the time of collection and over a previous period of time. This is because these animals normally have a stable assemblage of species from year to year even though some seasonal variations due to birth, death, immigration, and emigration occur. Also, since they are relatively sessile animals associated with the substrate, they serve as biological monitors of stream water quality. These organisms are a very important link in the stream ecological balance since they consume algae and small plants and are themselves a primary food source for fish.

In most cases, macroinvertebrate communities respond to stresses (silt, toxic chemicals, etc.) by shifts in structure; that is, changes in the numbers and kinds of species and the number of individuals in each species which is present. A community in a clean water or unstressed environment generally will have a large number of species with relatively few individuals in each species. This situation is reversed in polluted or stressed environments; that is, few species with large numbers of individuals per species.

In severely polluted situations or in areas where stresses have continued over long periods of time, it is easy to measure such shifts in species and individuals. Species can be broadly placed into three categories; pollution-intolerant, intermediate, and pollution-tolerant. Pollution-intolerant forms include immature mayflies (Ephemeroptera); stoneflies (Plecoptera); some caddisflies (Trichoptera); snails, limpets and clams (Mollusca); and crayfish (Decapoda). Pollution-tolerant organisms include sludgeworms (Oligochata), certain caddisflies, and true flies (Diptera).

Streams which receive stresses from point sources (i.e., effluent discharges of organic wastes of toxic chemicals) exhibit various biological-chemical zones. These are zones of active decomposition, anaerobic zones, and recovery zones. In streams which are polluted by non-point sources such as silt, these zones may be masked or lacking entirely due to the pollutants entering many parts of the stream and traveling downstream a long distance.

Algae are the major photosynthetic producers in most streams and respond readily to physical and chemical changes in the environment. Algae also respond by changes in species and numbers of individuals within a species. Usually a reduction in species is indicative of heavy pollution stress. Some species are tolerant of this stress and others intolerant, thus serving as indicators of unpolluted conditions.

Higher aquatic plants or macrophytes also act as producers in the stream and provide surface area for attachment by other organisms. A variety of microhabitats for invertebrates and fish is created, and the root systems of macrophytes serve to help stabilize banks and islands. They respond to stresses by a decrease in species abundance, reduction in numbers of plant individuals within a species, a decrease in biomass, and change in physical structure due to less favorable environmental conditions for growth.

Fish are very important in streams in assessing overall water quality. They are economically and recreationally a valuable resource and utilize other forms of aquatic life such as macroinvertebrates for food. Thus they are directly dependent upon these foods sources for their survival. Fish are mobile and respond to water pollution and stress by avoiding unfavorable areas. Often an effluent or stress condition prevents the fish from using an area as a feeding ground, spawning area, or nursery. Thus, as with macroinvertebrates, the fish community reflects present and past water quality conditions in an area.

The references numbers used in the following discussion are those of the ecological inventory and are listed in the appendix.

BENTHIC MACROINVERTEBRATES

As a part of this study, sampling was conducted at seven stations (Table 8-16) from May to July 1979. Each station was visited several times. Sampling for macroinvertebrates was by two methods, kick net and artificial substrate barbecue baskets. Kick net sampling using a long handled

TABLE 8-16
DESCRIPTION OF MACROINVERTEBRATE SAMPLING STATIONS

Station #1 -	At south foot bridge near Candy Cane City, Montgomery County.
Station #2 -	West Beach Drive Bridge; downstream of bridge in riffle area.
Station #3 -	Sherrill Drive Bridge; downstream adjacent to USGS gaging station.
Station #4 -	Beach Drive, below Joyce Road bridge in riffle areas, upstream of Park Police Headquarters.
Station #5 -	Tilden Street/Park Road Bridge at Peirce Mill; riffle areas under and downstream of bridge.
Station #6 -	National Zoological Park; upstream of Harvard Street Bridge in riffle area.
Station #7 -	Upstream of bridge over Rock Creek Parkway, just before P Street exit.

D-frame aquatic dip net is an effective method of obtaining qualitative and semi-quantitative data in streams similar to Rock Creek. Riffle areas at each station which were similar in terms of substrate type and water current were randomly sampled by placing the net on the stream bottom and disturbing the substrate directly upstream with one's feet for 30 seconds. Dislodged organisms would flow into the net and be captured. A total of six kick net samples were obtained from each station.

Commercial barbecue baskets were used as artificial substrate samplers at each station in order to confirm and expand macroinvertebrate results obtained with kick nets. The basket is a cylindrical, welded-wire unit about 7 inches in diameter and 11 inches long. The basket was filled with leaves and rocks 2.5 to 4 inches in width, 3/4 to 2 inches in thickness, and 3 to 5 inches in length and placed in areas exposed directly to the current. The rocks provide interstices for colonization by organisms. There are several advantages to using artificial substrates; variability in substrate differences are reduced, a high level of precision is possible, and quantitatively comparable samples can be collected from environments where it is impossible to obtain samples by conventional methods. However, there are also some limitations to this method. The samples are vulnerable to vandalism, they are unsuitable for short-term (less than 4-6 weeks) survey studies, they provide no measure of the natural substrate conditions or the effect of pollution on the substrate (i.e., siltation), and the samples only record the macroinvertebrate community that develops during the exposure period so that they have less value as indicators of prior environmental conditions. Nonetheless, this sampling technique has been used profitably in many studies in obtaining valuable macroinvertebrate data.

As previously discussed, benthic macroinvertebrates collected in streams can be broadly placed in three categories depending on their sensitivity and ability to adapt in the long and short term to pollution. In unpolluted streams some crayfish (Decapoda), snails (Gastropoda), stoneflies (Plecoptera), caddisflies (Trichoptera), mayflies (Ephemeroptera), and many other aquatic insects are quite common. They are sensitive to pollution and generally characteristic of clean water situations. Of course, within all these groups, there are some genera which have adapted to, and are commonly found in, polluted situations. Also, sensitive invertebrates are gradually eliminated as pollution increases, so that even though a pollution-intolerant organism may be present in a polluted station, it may only occur in very limited numbers and may be constantly in danger of elimination. Thus, the three categories are actually part of a gradient, with increasing or decreasing pollution progressively influencing specific species numbers and abundance.

A majority of invertebrates can be classified as intermediate or facultative in their response and sensitivity to pollution and are able to live in a variety of polluted and un-polluted habitats. Organisms in this category range from sponges (Porifera) and bryozoa (Ectoprocta) to planarians (Platyhelminthes), worms (Annelida), many crustaceans, some chironomids, and most mollusks.

Pollution-tolerant organisms are those able to exist under moderately to heavily polluted situations. They may be present in large numbers in severely polluted habitats. However, when they occur in moderately polluted habitats, they are generally found in low numbers. Some oligochaets, leeches, chironomids, other insects, and a few mollusks are pollution-tolerant.

The kinds and numbers of benthic macroinvertebrates present in streams such as Rock Creek are indicative of pollution problems and events which have occurred previously.

Toxic chemical discharges and suspended sediments are pollution problems that are non-selective to macroinvertebrates. All species are similarly stressed, and this is dependent upon the individual species adaptability to this type of stress. Sewage wastes and nutrients from runoff are selective pollution problems, that is, certain species are intolerant, unaffected, or tolerant of these conditions.

Table 8-17 indicates the kinds and total numbers of invertebrates that were collected during May-July 1979 from the seven sampling stations. Results of the present study are compared with those of earlier studies (References 61, 70, and 71). Artificial substrate sampling using barbeque baskets was only partially successful. Several of the baskets were vandalized, others were swept away by high water and floating debris. Nevertheless, data obtained from the remaining baskets (4 out of 12) supplemented data gathered by using the kick net sampling method.

Station 1, near Candy Cane City, was the most diverse station of all 7 sites sampled in terms of kinds of invertebrates present (8 kinds present). Plumatella repens colonies were growing on a submerged branch. This organism is found in habitats intermediate between clean and polluted. In general, this station can be classified by the invertebrates present which were both tolerant and intolerant to pollution. Sphaerium transversus and Orconectes limosus are organisms intermediate to tolerant to pollution. Ferrissia rivularis and Tipula sp. are both intolerant to pollution. Chironomidae are pollution-tolerant organisms. LaBuy (Reference 69) considered this station to have fair water quality indicated in 1966 and the same can be said for conditions in 1979.

Only three different kinds of invertebrates were collected at Station 2 at Wise Road and West Beach Drive. This is indicative of moderate to severe pollution. Large quantities of silt and sediment were present along the streambanks. There was a noticeable septic smell here, indicative of anaerobic decomposition. Results of the present study indicated some deterioration in water quality since 1966.

At Station 3 (Sherrill Drive), mildly polluted conditions were indicated. No organisms were collected by kick net

TABLE 8-17
BENTHIC MACROINVERTEBRATES COLLECTED IN LOWER ROCK CREEK, DISTRICT OF COLUMBIA, MAY-JULY 1979

Station Number	Taxa	Type of Sample	Total Number of Individuals
1	Bryozoa	Qualitative	-
	Plumatella repens		
	Oligochaeta	Kick Net	1
	Mollusca		
	Gastropoda		
	Ferrissia rivularis	Kick Net	1
	Pelecypoda		
	Sphaerium transversum	Kick Net	2
	Crustacea		
	Decapoda		
	Orconectes limosus	Kick Net	3
	Insecta		
	Diptera		
	Chironomidae	Kick Net	5
	Tipuliidae		
	Tipula sp.	Kick Net	1
	Tabanidae		
	Chrysops sp.	Kick Net	1
2	Oligochaeta	Kick Net	2
	Mollusca		
	Gastropoda		
	Physa sp.	Kick Net	1
	Odonata	Kick Net	1
3	Oligochaeta	Barbeque Basket	6
	Mollusca		
	Gastropoda		
	Physa sp.	Barbeque Basket	1
	Odonata		
	Argia sp.	Barbeque Basket	1
	Insecta		
	Chironomidae	Barbeque Basket	4
4	Oligochaeta	Kick Net	3
	Hirudinea	Kick Net	3
	Mollusca		
	Gastropoda	Kick Net	5
	Physa sp.	Kick Net	19
	Ferrissia rivularis		
	Pelecypoda		
	Sphaerium transversum	Kick Net	1
	Insecta		
	Trichoptera		
	Hydropsyche betteni	Kick Net	1

TABLE 8-17 (CONTINUED)
BENTHIC MACROINVERTEBRATES COLLECTED IN LOWER ROCK CREEK, DISTRICT OF COLUMBIA, MAY-JULY 1979

Station Number	Taxa	Type of Sample	Total Number of Individuals
	Diptera		
	Chironomidae	Kick Net	2
	Tabanidae		
	Chrysops sp.	Kick Net	1
5	Oligochaeta	Barbeque Basket	1
	Mollusca		
	Gastropoda		
	Physa sp.	Barbeque Basket	1
	Insecta		
	Trichoptera		
	Hydropsyche betteni	Barbeque Basket	1
	Diptera		
	Chironomidae	Barbeque Basket	6
5	Oligochaeta	Kick Net	5
	Hirudinea	Kick Net	1
	Mollusca		
	Gastropoda		
	Ferissia rivularis	Kick Net	20
	Crustacea		
	Isopoda		
	Asellus sp.	Kick Net	1
	Insecta		
	Trichoptera		
	Hydropsyche betteni	Kick Net	27
	Diptera		
	Chironomidae	Kick Net	1
6	Oligochaeta	Kick Net	3
	Mollusca		
	Gastropoda		
	Physa sp.	Kick Net	2
	Insecta		
	Ephemeroptera		
	Baetis sp.	Kick Net	3
	Trichoptera		
	Hydropsyche betteni	Kick Net	9
	Diptera		
	Chironomidae	Kick Net	1
7	Oligochaeta	Kick Net	4
	Mollusca		
	Gastropoda		
	Physa sp.	Kick Net	2

sampling. The barbecue baskets yielded invertebrates generally found in polluted or intermediate conditions.

Station 4, at Missouri Road near the Park Police Headquarters, had organisms which are categorized as intermediate to pollution-tolerant. Hydropsyche betteni, a trichopteran aquatic insect, was first found at this station and at none of the upstream stations. This organism spins a filamentous case glued to the underside of stones and rocks (Reference 72). It is very common in small warm water streams and is one of the most resistant species of this genus to organic pollution. It has been previously reported from states including Pennsylvania and Virginia.

Station 5, at Peirce Mill, was similar to Station 4 in that similar kinds of organisms were found at both stations. Hydropsyche betteni was the most abundant species collected at Station 5. Asellus sp. was collected only at this station and the genus is listed as either tolerant, intermediate, or intolerant to pollution, depending on the species (Reference 52). LaBuy (Reference 69) reported mild organic pollution here, a condition which was not evident in the present study. The types of macroinvertebrates present here indicated that this station was mildly polluted. In fact, some improvement in stream conditions could be inferred from analyzing the invertebrate data.

Organisms found at Station 6, at the National Zoological Park at Harvard St., ranged from pollution-tolerant (Chironomidae) to intermediate (Physa sp.). An ephemeropteran mayfly Baetis sp. was found only at this station. O'Brien and Gere (Reference 71) reported this pollution-intolerant mayfly from Rock Creek at Calvert Street, downstream of Station 6. Thus, as at station 5, station 6 could be classified as mildly polluted based on the macroinvertebrates collected there.

Deterioration of water quality at Station 7, Rock Creek upstream of the P Street outfall, is indicated when the biological results of the present study are compared with those of LaBuy (Reference 69). No fish were observed in 1979 and only two kinds of macroinvertebrates were collected. The oligochaetes are pollution-tolerant and Physa sp. is intermediate. There was a great deal of trash, debris and sediment deposits at this station. The effects of Hurricane Agnes in 1972 are still evident; a portion of Rock Creek, formerly free flowing, is now a stagnant backwater and large quantities of sediment cover the stream bed and banks. Deterioration at this station is evident when compared to stations 5 and 6.

AQUATIC MACROPHYTES

Podostemum ceratophyllum, commonly called river weed, is a plant which forms dense mats on rocks in streams of the Piedmont physiographic province in eastern United States (Reference 17). In Rock Creek, Podostemum was very abundant at Station 1. Most large rocks and boulders had dense growths. Loose gravel and small stones had only slight amounts of this macrophyte. The plant generally decreased in abundance downstream to the mouth of Rock Creek. Stations 2, 3, and 4 had some Podostemum as scattered, small growths on rocks and boulders. At Stations 5 and 6, the plant was very nearly absent. This distribution suggests that the plant is intolerant to moderately tolerant to pollution. Podostemum was not found at all at Station 7. Two forms of P. ceratophyllum are found in North America; f. abrotanoides is a lax, slender form and f. chondroides is a rigid, coarse form. Podostemum in Rock Creek tend to resemble f. abrotanoides.

This aquatic plant is known to be a sensitive indicator of oxygen deficiency (Reference 9), and this may explain the decline in abundance at the extreme lower stations. These stations near the mouth were previously noted to have lower dissolved oxygen levels. The lack of suitable substrate may also be a factor in limiting the distribution of Podostemum. Along the fall line, high stream velocity effectively scours the bottom of any extensive growth. Thus, only in the sluggish reaches can a significant population exist.

Two species of Potamogeton were collected, but only at Station 1. These were P. crispus and P. epihydrus. Identification of species of Potamogeton is sometimes very difficult. This is due to extensive morphological intergradation into complexes of species and phenotypic as well as genotypic variation within the genus (References 16, 17, and 64). In Rock Creek, P. crispus is relatively easy to identify while P. epihydrus is not. The latter can be confused with P. gramineus. Thus, P. epihydrus is tentatively identified as occurring at Station 1. This species is also abundant in streams and tributaries along the fall line in the southeast United States.

Some species of Potamogeton are commonly found in eutrophic or nutrient rich habitats, as was the case at station 1. Aquatic plants, with the exception of Podostemum, were lacking at all of the other stations and this was clearly an indication of the polluted condition of the stream in these locations.

FISH

Thirty species of fish were collected in Rock Creek in 1974 (Reference 41) as compared to 24 species collected earlier in 1950 by Medford (Reference 40). Other workers have reported a total of 27 species (Reference 41). Lower Rock Creek (Station 1 downstream to below Station 6) had a considerably lower number of species than the upper reaches. Only eight species were collected by Dietemann and six were collected by Medford (see Table 8-18). Dietemann collected four species which were not included as species recorded by Medford: Anguilla rostrata (American Eel), Semotilus corporalis (Fallfish), Ictalurus natalis (Yellow Bullhead) and Lepomis gibbosus (Pumpkinseed Sunfish). Also, Medford collected four species which were not recorded by Dietemann: Notropis cornutus (Common Shiner), Exoglossum maxillingua (Cutlips Minnow), Notropis procne (Swallowtail Shiner), and N. analostannus (Satinfin Shiner). Dietemann offers no explanation as to why these four species were not collected from lower Rock Creek. One possible cause may be the deposition of sediments caused by urbanization and flooding. This sediment deposition would render the stream substrate less suitable for the fish by eliminating breeding sites and food sources of benthic invertebrates.

In 1975, Spangler (Reference 37) added five additional species to the eight already found in lower Rock Creek. These are: Notemigonus crysoleucas (Golden Shiner), Cyprinus carpio (Carp), Ictalurus punctatus (Channel Catfish), Lepomis macrochirus (Bluegill Sunfish) and L. cyanellus (Green Sunfish). This brings the total number of fish species from lower Rock Creek to thirteen. During the present study, Hypentelium nigricans (Hogsucker) was found at Station 6, bringing the total to fourteen species.

Only one species, Notropis cornutus, seemed to show a decline in distribution and abundance in Rock Creek between 1950 and 1974. Other species were collected in such small numbers in the above studies that a decline in distribution and abundance are not so evident. Severe pollution problems are indicated in lower Rock Creek because of the lower number of species found there when compared to the higher numbers found in the middle and upper sections of the creek. Also, only the most pollution-tolerant species were collected in lower Rock Creek (Reference 41). Examples of pollution tolerant species found in lower Rock Creek would be Rhinichthys atratulus (Blacknose Dace), Notropis hudsonius (Spottail Shiner), Cyprinus Carpio (Carp), and some members of the Family Ictaluridoe. Lower numbers of species were collected by both Medford

TABLE 8-18
SUMMARY OF FISH SURVEYS OF ROCK CREEK IN THE DISTRICT OF COLUMBIA

Species	6 Below National Zoo (Calvert St.) 1950	6 Below National Zoo (Calvert St.) 1974-1979	5 Peirce Mill (Park Rd.) 1950	5 Peirce Mill (Park Rd.) 1974-1979	4 Park Police Hdqs. (Missouri Rd.) 1950	4 Park Police Hdqs. (Missouri Rd.) 1974-1979	3 Sherrill Dr. 1950	3 Sherrill Dr. 1974-1979	2 West Beach Dr. 1950	2 West Beach Dr. 1974-1979	1 Candy Cane City (Mont. Co. Rec. Center) 1950	1 Candy Cane City (Mont. Co. Rec. Center) 1974-1979
Anguilla rostrata (American Eel)		b,c		c		c,d						b
Rhinichthys atratulus (Blacknose Dace)	a	b		b	a	b		b	a	b	a	b
Notropis rubellus (Rosyface Dace)					a							
R. cataractae (Longnose Dace)	a	b		b		b		b		b		b
Clinostomus funduloides (Rosyside Dace)					a							
Exoglossum maxillingua (Cutlips Minnow)											a	
Semotilus corporalis (Fallfish)		c		b,c		c		b				b
Notropis hudsonius (Spottail Shiner)	a		a	b	a	b		b	a	b	a	b
N. cornutus (Common Shiner)	a		a		a						a	
N. procne (Swallowtail Shiner)											a	
N. analostanus (Satinfin Shiner)											a	
Notemigonus crysoleucas (Golden Shiner)		c										
Cyprinus carpio (Carp)				c								
Catostomus commersoni (White Sucker)								b		b	a	
Hypentelium nigricans (Hogsucker)		d										
Ictalurus natalis (Yellow Bullhead)		c						b				
I. punctatus (Channel Catfish)		c										
Lepomis gibbosus (Pumpkinseed Sunfish)		c						b				
L. macrochirus (Bluegill Sunfish)		c										
L. cyanellus (Green Sunfish)		c		c								

a - Collected by Medford (1950)
b - Collected by Dietemann (1974)
c - Additional species collected by Spangler (1976)
d - Additional species collected during present study

and Dietemann and this indicates that pollution problems in lower Rock Creek have existed for many years. Comparison of these studies with those earlier in the 20th century are inconclusive since these earlier studies did not cite specific stations on lower Rock Creek where collections were made (References 38, 39, and 41). Total number of species in Rock Creek seem to have remained relatively constant (27-30) in this century.

Based on the general biological observations and macroinvertebrate collections, the overall biological condition of Rock Creek may be summarized. Station 1, near the District of Columbia-Maryland state line, was the least polluted, and conversely, the healthiest station studied. Downstream from this station, water quality deteriorated markedly at station 2. However, at stations 3 through 5, the water quality of Rock Creek appeared to improve somewhat, with only mildly polluted conditions noted at these three stations. At station 6 and especially at station 7, water quality again deteriorated. Station 7 was clearly the most polluted of all the stations that were sampled in May - July, 1979. The average water quality of Rock Creek could be generally classified as intermediate. However, this is an oversimplification, as this averaging process tends to obscure the deteriorated water quality evident at station 7 and at observed locations further downstream. Organic and chemical pollution from urban runoff, trash, debris, and the large quantity of sediments entering Rock Creek contribute to lowered water quality. Until these sources are more effectively controlled, the water quality of Rock Creek cannot be expected to improve greatly over that observed in the present study. Also, activities occurring in the Montgomery County portion of the Rock Creek watershed will affect the water quality of lower Rock Creek in the District.

Ideally, a sampling program should be established and conducted on an annual or biennial basis. This program would serve to monitor the water quality of Rock Creek on a continuing basis and could document improvement and deterioration in water quality. Macroinvertebrates and fish could be sampled in this program, at stations established in the District's portion of Rock Creek. Reference on control station's could be established in "healthier" portions of upper Rock Creek in Maryland. Organisms collected at these reference stations would serve as a baseline upon which to document changes, such as presence/ absence and quantitative increases in abundances of the same organisms, in assessing water quality at the lower stations. Groups which might be monitored, and which would be indicative of improving or deteriorating conditions are many types of aquatic insects (orders Plecoptera, Ephemeroptera, Trichoptera, some Odenata, Hemiptera), crustaceans (orders Ostracoda, Amphipoda, Isopoda, and some Decapoda), and clams (Family Unionidae). Also, as the water quality of lower Rock Creek improves, propagation of desirable species of fish, for example, trout and bass, and wildlife may be established on a large scale.

REFERENCES

1. District of Columbia Department of Public Health, Water Quality Control Division, Water Quality Standards Summary for Interstate Waters of the District of Columbia, Document No. WQS. 11-001, U.S. Environmental Protection Agency.

2. Sherman, L.K. and Horner, W.W., Report on Measure for Elimination of Pollution of Rock Creek and its Tributaries in Washington, U.S. Department of the Interior, National Park Service, 1935.

3. FWPCA,Middle Atlantic Region, Summary of Water Quality and Waste Outfalls Rock Creek in Montgomery County, Md. and the District of Columbia, CB-SRBP Working Document No. 5, 1966.

4. FWPCA, Chesapeake Bay-Susquehanna River Basins Project, 'Biological Survey of Rock Creek', Working Document No. 4, 1966.

5. Aalto, J.A., Jaworski, W.A., and Schremp, W.H., A Water Study of the Rock Creek Watershed, FWPCA, Middle Atlantic Region, 1969.

6. Stanton, G. et al. Bacteriological and Chemical Study of the Rock Creek Watershed, Rock Creek Study Project, Report to the National Science Foundation, 1971.

7. Ragan, R.M. and Dietmann, A.J., Characterization of Urban Runoff in the Maryland Suburbs of Washington, D.C., Tech. Report No. 38, Water Resources Research Center, University of Maryland, 1976.

8. District of Columbia Department of Environmental Services, Unpublished Stream Water Quality Monitoring Data, May 1978 to March 1979 at Six Stations on Rock Creek, D.C. Bureau of Wastewater Treatment Laboratory Division.

9. O'Brien & Gere Engineers, Combined Sewer Overflow Study Potomac-Anacostia River System, Department of Environmental Services, Government of the District of Columbia, 1979.

10. Maryland-National Capital Park and Planning Commission, Stormwater and Water Quality Management Study-Rock Creek, CH2M HILL, 1978.

11. Maryland-National Capital Park and Planning Commission, 'Draft Functional Master Plan for Conservation and Management in the Rock Creek Basin, Montgomery County, Maryland', 1979.

12. Metropolitan Washington Council of Governments, Land Use/Runoff Quality Relationships in the Washington Metropolitan Area, Northern Virginia Planning District Commission, 1978.

13. Yorke, T.H. and Herb, W.J., Effects of Urbanization on Streamflow and Sediment Transport in the Rock Creek and Anacostia River Basins, Montgomery County, Maryland, 1962-1974, Geological Survey Professional Paper 1003, 1978.

14. Smith, E.E. 'Pollution Study of Rock Creek within the National Zoological Park', unpublished report.

15. Smith and Faas, Inc., 'National Zoological Park Utility Master Plans (Phase I)', 1975.

CHAPTER 9
HYDROLOGIC AND WATER QUALITY MODEL

In order to increase the understanding of the Rock Creek surface water quality regime, a generalized surface water quality model was adapted to the conditions indigenous to the Rock Creek watershed. The generalized model, the Hydrocomp Simulation Program (HSP), is a continuous computer simulation model and was adapted to Rock Creek through the process of calibration. Calibration of a mathematical model is the process whereby the model is adapted so that its response reflects that of the prototype. The process of calibration involves establishing values for the parameters associated with the mathematical relationships in the model. These parameters are related to the specific basin by successive comparisons of modeled and observed behavior. Calibration is achieved when simulated and observed behavior correspond.

In development of a hydrologic and water quality model of Rock Creek, it is important to remember the purpose for which the model is to be used. One part of this study will provide the National Park Service with a tool for the evaluation of alternative technical strategies, both structural and nonstructural, for improving water quality. If the model is to assist in the evaluation, it must represent the relationships between land use, structural controls, and water quality in such a way that changes in the first two are properly reflected in the latter. Given a technical control strategy, the model must be capable of defining the relative changes which might ultimately affect water quality. Thus, the objective of model development is to satisfy these requirements.

HYDROCOMP SIMULATION PROGRAM DESCRIPTION

The Hydrocomp Simulation Program is a continuous hydrologic and water quality computer simulation program that monitors the complete hydrologic cycle mass balance, performs stream channel and reservoir routing of flow, tracks land surface pollutant buildup and washoff, and models instream water quality parameter interactions on a continuous series of discrete time steps. The program is divided into four separate modules:

LIBRARY is the data-handling module which reads the input data, stores them on disc in a form suitable for access, and searches the data for missing values and errors.

LANDS calculates the runoff volumes resulting from impervious and pervious overland flow, interflow, and subsurface flow. For quality simulations it creates files of runoff from pervious and impervious surfaces. The basic logic is similar to that of the Stanford watershed model, with improvement of algorithms and reduction of input parameters.

CHANNEL uses the output from the LANDS module to compute channel inflow for each reach, progressing downstream, and uses the kinematic wave routing method to calculate the flow at the end of each reach, including impoundments. Point sources and diversions may be specified throughout the stream network.

QUALITY is capable of simulating instream changes in quality on a reach-by-reach basis and, in conjunction with LANDS, surface runoff quality is simulated. A stream system is represented in the model as a series of reaches. A reservoir or lake reach can consist of up to nine layers. Each reach and lake layer is assumed to be fully mixed and a multiple-step explicit solution is used to solve the partial differential equations describing water-quality dynamics. Dispersion is assumed negligible. The model is capable of simulating a watershed with any number of lakes.

HYDROLOGIC SIMULATION

In order to understand the hydrologic concepts that are used in simulation, one must review the hydrologic cycle as depicted in Figure 4-1. The hydrograph of streamflow is the end product of the variable time and areal distributions of precipitation, evapotranspiration, physical watershed characteristics, and soil moisture conditions. HSP represents the processes in the hydrologic cycle from precipitation to outflow from a watershed as a series of mathematical expressions. The physical characteristics of the watershed enter as parameters in these mathematical expressions.

A simplified flow diagram of the HSP hydrologic simulation logic is presented in Figure 9-1 and a brief description of the elements follows. Input parameters are summarized in Table 9-1.

Interception. The first loss to which falling precipitation is subjected is interception, or retention on leaves, branches and stems of vegetation. Interception in any single storm is small in amount and is not important in flood-producing storms. In the aggregate, however, interception may have a significant effect on annual runoff volumes.

In nature, interception is a function of the type and extent of vegetation and, for deciduous vegetation, the season of the year. In HSP, interception is modeled by defining an interception storage capacity EPXM as an input parameter. All precipitation is assumed to enter interception storage until it is filled to capacity. Water is removed from interception storage by evapotranspiration at the potential rate.

Impervious Surface Runoff. Precipitation on impervious areas that are adjacent to or connected with stream channels will contribute directly to surface runoff. An input parameter A in HSP represents this "impervious" fraction of the total watershed area. Rock outcrops, buildings, or roads that are so located that runoff from them must flow over soil before reaching a channel should not be counted in the directly connected impervious area. Such runoff is represented by the direct infiltration functions in the model. The impervious area is usually a very small percentage of the total watershed, except in urban areas where the impervious area term becomes very important. In rural watersheds impervious area does not contribute large amounts of runoff. However, for light rains with relatively dry soil, the impervious area may be the sole contributor to runoff to the stream. Lakes, swamps, stream channel surfaces, and reservoirs create a special class of impervious area. "Runoff" results from all of the precipitation that reaches these surfaces and potential (lake) evaporation occurs continuously.

Infiltration. The process of infiltration is essential and basic to simulation of the hydrologic cycle. Infiltration is the movement of water through the soil surface into the soil profile. Infiltration rates are highly variable and change with the moisture content of the soil

TABLE 9-1
HSP HYDROLOGY MODEL PARAMETER DEFINITIONS

LANDS	
K1	Ratio of average segment rainfall to average gage rainfall
A	Impervious area (fraction)
EPXM	Interception storage (maximum value)
UZSN	Nominal upper zone soil moisture storage
LZSN	Nominal lower zone soil moisture storage
K3	Actual evaporation rate parameter
K24L	Seepage to "deep" groundwater
K24EL	Evaporation from perched groundwater
INFILTRATION	Infiltration
INTERFLOW	Interflow
L	Length of overland flow
SS	Overland flow slope (ft/ft)
NN	Manning's n for overland flow
IRC	Daily interflow recession rate
KV	Groundwater recession, variable rate
KK24	Groundwater recession, constant rate
SNOW	
RADCON	Radiation melt parameter
CONDS_CONV	Convection melt parameter
SCF	Snow correction factor to gage record
ELDF	Elevation difference (gage to segment)
IDNS	Initial density of new snow
F	Forest cover
DGM	Daily ground melt (inches)
WC	Water content of snowpack maximum
MPACK	Snowpack at complete areal coverage
EVAPSNOW	Snow evaporation parameter
MELEV	Mean watershed segment elevation (ft)
TSNOW	Upper limit of temperature at which precipitation is snow
CHANNELS	
REACH	Reach number
LIKE	Reach number that has an identical cross section
TYPE	The type of channel: RECT - Free-flow trapezoidal channel cross section CIRC - Closed circular conduit DAM - Reservoir
TRIB_TO	Reach number to which the reach is tributary
SEGMT	Land surface segment that contributes to the reach

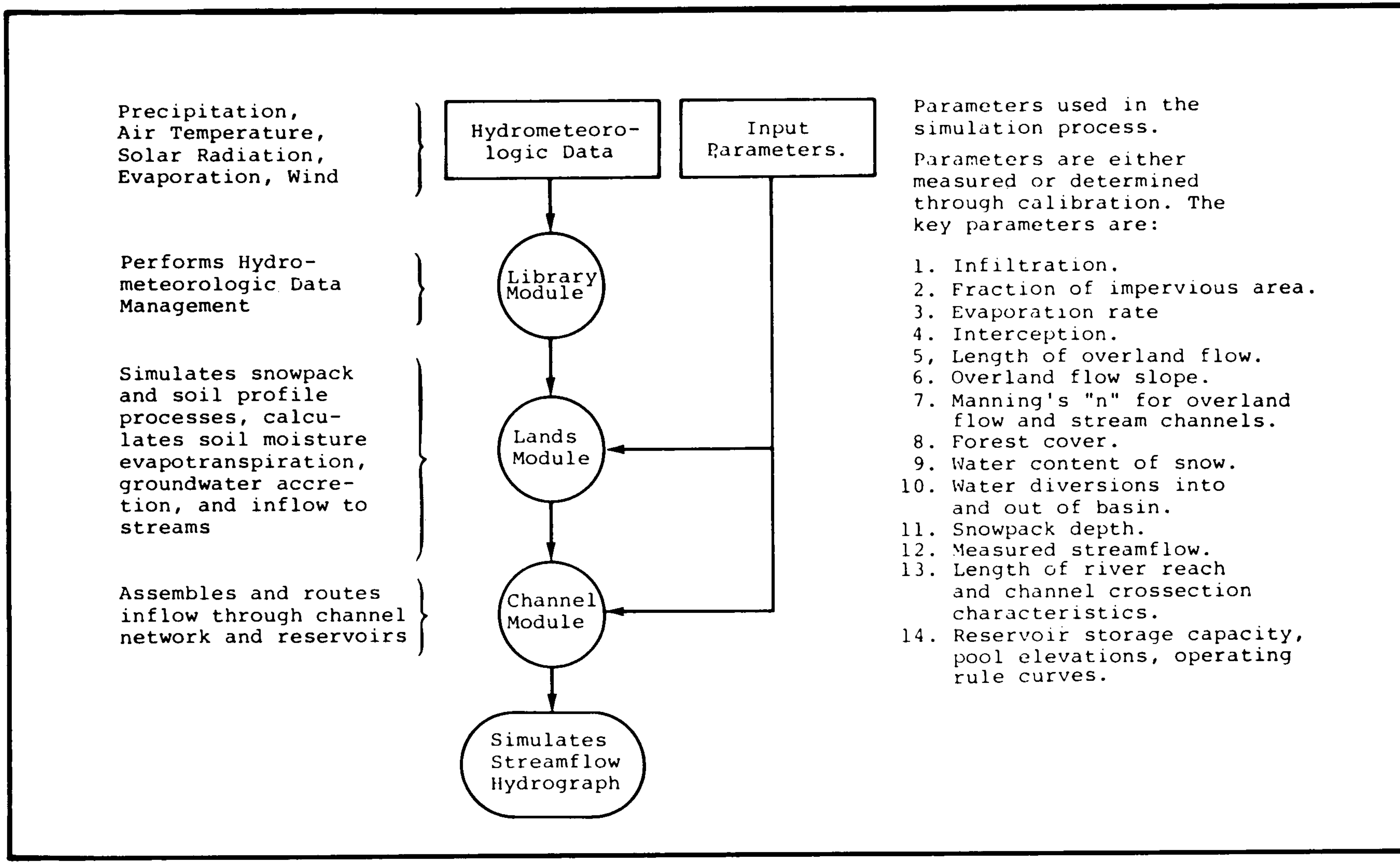


FIGURE 9-1: Basic Hydrocomp Simulation Logic Diagram

TABLE 9-1
HSP HYDROLOGY MODEL PARAMETER DEFINITIONS
(CONTINUED)

IF TYPE IS 'RECT' OR 'CIRC':

LENGTH	Length of the reach in miles
TRIB-AREA	Local area tributary to the reach in square miles
EL_UP	Upstream channel bottom elevation in the reach
EL_DOWN	Downstream channel bottom elevation in the reach
W1	Incised channel bottom width in feet for trapezoidal channels, or the diameter in inches for circular channels
W2	Incised channel top width in feet for trapezoidal channels or Manning's n for circular channels
DEPTH	Incised channel depth in feet
S_FP	Transverse slope for the flood plain in feet per foot
N_CH	Manning's n for the incised channel
N_FP	Manning's n for the flood plain

IF TYPE IS 'DAM':

NAME	Name of reservoir
MAX_ELEV	Maximum pool elevation
STORAGE_MAX	Maximum storage (acre-feet)
STORAGE_NOW	Current storage at start of simulation period
TRIB_AREA	Tributary area in square miles
SURFACE_AREA	Surface area at full pool
RULES	Number of rule curves to be used
ELEV, STOR, DISCHARGE	Pool elevation, storage, and corresponding discharge for each rule curve entered

profile. Infiltration is the largest single process diverting precipitation from immediate streamflow. Usually more than half the water that infiltrates is retained in the soil until it is returned to the atmosphere by evapotranspiration. However, not all infiltrated water is permanently diverted from streamflow. Some infiltrated water may move laterally through the upper soil to the stream channels as interflow, and some may enter temporary storages and later discharge into the stream channels as base or groundwater flow. The infiltration capacity, INFIL, the maximum rate at which soil will accept infiltration, is a function of fixed characteristics of the watershed (e.g., soil type, permeability, land slopes and vegetal cover) and of variable characteristics, primarily soil moisture content.

Interflow. Infiltration may lead to interflow, runoff that moves laterally in the soil for some part of its path toward a stream channel. Interflow is encouraged by any relatively impermeable soil layers and has been observed to follow roots and animal burrows in the soil. Interflow may come to the surface to join overland flow if its flow path intersects the surface.

Upper Soil Moisture Zone. Water that is not infiltrated directly will increase surface detention storage. The increment to surface detention will either contribute to overland flow or enter upper zone storage. Depression storage and storage in highly permeable surface soils are modeled by the upper zone. A nominal storage capacity of the upper zone is defined by UZSN. Moisture is lost from the upper zone by evaporation and by percolation to the lower zone and groundwater storages.

Lower Soil Moisture Zone. The lower zone storage is the main moisture storage for the land surface in HSP. Like the upper zone storage, it is defined in terms of a nominal capacity LZSN. Physically, the lower zone may be viewed as the entire soil from just below the surface down to the capillary fringe above the water table. In practice we are concerned only with the transient portion of this storage; i.e., the volume which is emptied by evapotranspiration and refilled by infiltration.

Groundwater. Percolation of soil moisture to groundwater storage is related to the relative moisture contents in the upper and lower zones. Its return to streamflow is determined by the groundwater recession rate, KK24. If some part of this water is believed to percolate to deep groundwater storage, this is modeled by allowing a fixed percentage of the inflow to groundwater to bypass the active groundwater storage and proceed directly to the deep or inactive storage. This portion is assigned by the input parameter K24L.

Overland Flow. The movement of water in surface or overland flow is an important land-surface process. Interactions between overland flow and infiltration need to be considered since both processes occur simultaneously. The variations in rates of infiltration described above allow overland flow in areas with low infiltration, while preventing overland flow in other areas. During overland flow, water held in detention storage remains available for infiltration. Surface conditions such as heavy turf or very mild slopes that restrict the velocity of overland flow tend to reduce the total quantity of runoff by allowing more time for infiltration. Short, high intensity rainfall bursts are attentuated by surface detention storage, reducing the maximum outflow rate from overland flow.

In HSP, overland flow is treated as a turbulent flow process. Since continuous surface detention storage is computed, the volume of surface detention was chosen as the parameter to be related to overland flow discharge. Average values are used in the calculations for the length (L), slope (SS), and roughness (NN) of overland flow. Using the Chezy-Manning equation, these parameters define a detention storage-discharge relationship for overland flow.

Evapotranspiration. The volume of water that leaves a watershed as evaporation and transpiration exceeds the total volume of streamflow in most hydrologic regimes. Continuous estimates of actual evapotranspiration must therefore be made by HSP. There are two separable issues involved in estimating actual evapotranspiration. Potentional evapotranspiration must be selected, and actual evapotranspiration must be calculated as a function of moisture conditions and the potential evapotranspiration.

Potential evapotranspiration is assumed to be equal to lake evaporation estimated from U.S. Weather Bureau Class A pan records. Evapotranspiration occurs from interception storage at the potential rate. Evapotranspiration opportunity controls evapotranspiration from the lower zone storage. Evaporation from stream and reservoir surfaces, and evapotranspiration from groundwater storages is also simulated. Potential evapotranspiration will result in a water loss or actual evapotranspiration only if water is available. HSP first attempts to satisfy the potential from interception storage and from the upper zone in that order.

The input parameter K3 is an index to vegetative density and governs evapotranspiration from lower zone and groundwater storages.

Snow Accumulation and Melt. The storage of precipitation in a snowpack, followed by the release of water as snowmelt is an important hydrologic process in many watersheds. The continuous heat exchange between the atmosphere and the snowpack must be simulated to correctly reproduce the quantities and timing of melt water reaching the land surface. The main processes that cause melt at the snow surface are radiation, convection, condensation, and rainfall. Ground melt may also occur at the land surface due to heat transfer from the earth.

In the Rock Creek watershed, snow processes were not judged to be a significant hydrologic factor and thus were not simulated as such. All precipitation was assumed by the model to occur as rainfall.

Channel Routing. The land surface phase of HSP described in the previous sections of this chapter calculates a total of the impervious area flow, overland flow, interflow, and groundwater flow for each time increment and stores this information in disc storage. As computed, the data are in inches of depth.

For channel simulation, the channel system is divided into reaches. The dimensions of the channel (or pipe) for each reach (length and cross section) are input data as is the roughness of the channel in terms of Manning's n. The area tributary to each reach between the upstream and downstream limits must also be measured and entered as input.

HSP also includes generalized functions that allow simulation of reservoirs (or lakes) in the channel network. The reservoir storage is a function of elevation for each dam assuming a level pool. Rule curve discharge as a function of elevation must also be specified. Precipitation on the reservoir surface and evaporation from the surface is accounted for directly.

WATER QUALITY SIMULATION

The water quality simulation module of HSP, QUALITY, is directly linked to the LANDS module hydrologic program. Overland, shallow subsurface, and groundwater flows are simulated by LANDS and used by QUALITY to simulate pollutant washoff and instream physical, chemical, and biological processes. QUALITY implements current quantitative knowledge of the aquatic environment. The structure of the model permits an evaluation of the interactions between climate, land use activities, pollutants, and water quality, but the model is limited by the assumptions which enable the representation of these interactions.

QUALITY simulates accumulation and washoff of pollutants from the land surface and pollutant inflow from groundwater (both nonpoint sources); discharges from municipal and industrial point sources; and pollutant inflow from upstream reaches. The flows and pollutants routed through the receiving drainage system are subjected to dilution. Within each reach, whether free-flowing or reservoir, the pollutant concentration is assumed to be uniformly distributed. Stratification is represented in reservoir reaches by different pollutant concentrations for as many as nine layers, and pollutants can be transferred between layers. In addition, interaction with bottom sediments of channel or reservoir reaches is simulated.

Land surface washoff is represented in QUALITY by three hourly time series: IMPRO, OLFRO, and SUBRO. Each time series contains flow and quality components. The flow component is an output from LANDS. The quality components are related to the flows according to land cover, land use, and soil conditions. IMPRO is the washoff time series for impervious land surfaces, OLFRO represents pervious land surfaces such as cultivated or grassy areas, and SUBRO represents groundwater flow. The flow component is the mechanism for removing pollutants from the land surface and subsurface and transporting them to a receiving water body. The nonpoint source loading to the receiving water body is simulated in two steps: the accumulation of pollutants on the land surface and washoff into the water body. Accumulation and removal rates are specified individually for each constituent to be simulated.

The flows and pollutants from each point source to be considered are also represented by hourly time series. The constituents and their concentrations relate to the wastewater characteristics and the treatment processes involved.

Chemical and biological reactions take place only in the receiving waters. In nature and in the model, the aquatic, physical, chemical, and biological processes are interdependent, as shown in Figure 9-2. Dissolved oxygen, for example, is affected by BOD, temperature, and phytoplankton and zooplankton populations. The availability of nitrogen and phosphorus affect phytoplankton and zooplankton. These organisms are influenced by streamflow, depth and other factors. Summarizing, the sources of constituents represented in the model are: pervious surface washoff, impervious surface washoff, groundwater, point sources such as municipal and industrial wastewater treatment plants, and bottom sediments (benthos). The concentration of each water quality constituent over a time interval is the sum of the mass contributions of each source and the losses due to physical, chemical, or biological transformations, divided by the volume of flow times the routing interval.

A generalized water quality reach schematic which depicts the QUALITY model considerations is shown in Figure 9-3. The constituents which are modeled and used for calibration are temperature, dissolved oxygen, BOD, ammonia, nitrate, phosphate, suspended solids, fecal coliforms, and chlorophyll a. The mathematical relationships defining instream interaction of each of these constituents, while too numerous to list in this report, are briefly described as an aid to understanding the model results.

Water temperature is one of the most fundamental measures of the aquatic environment. Many aquatic processes are controlled by temperature. For example, dissolved oxygen solubility and saturation decrease with an increase in temperature. The decay rate of organic matter and hence the oxygen demands caused by the decay increase with rising temperature. In the model, temperature is a function of heat transfer between the water surface and the atmosphere, the thermal mass entering the reach from point sources and upstream reaches, and the thermal mass leaving the reach to the next one downstream.

Dissolved oxygen is an indicator of the overall well-being of a stream or lake. The dissolved oxygen balance is represented as a function of reaeration from the atmosphere, BOD decay, oxygen demand of bottom sediments, oxygen released by denitrification, oxygen demand from nitrification, phytoplankton photosynthesis and respiration, zooplankton respiration, and oxygen loss to the atmosphere. Reaeration is the addition of oxygen to the water from the atmosphere. Oxygen is added in proportion to the difference between the saturation value for the given temperature and the existing dissolved oxygen concentration. The BOD demand is the carbonaceous demand or oxygen consumed by microorganisms as they convert organic matter to protoplasm. The sediment oxygen demand is similar to the BOD demand except that the organisms are attached to the stream bottom and sides. This demand is assumed to be uniformly distributed throughout the reach and is a function of temperature.

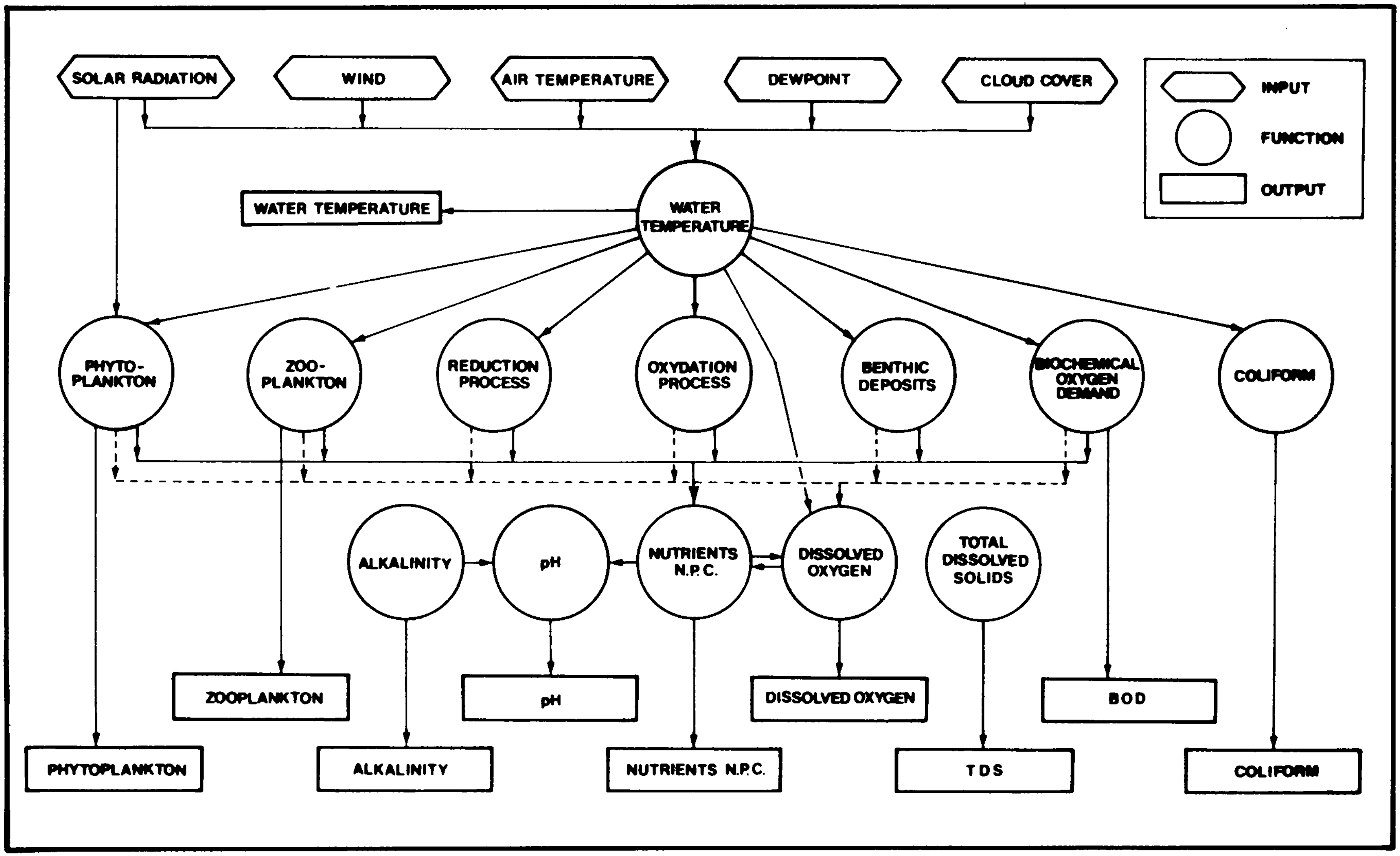


FIGURE 9-2: Hydrocomp Quality Flowchart

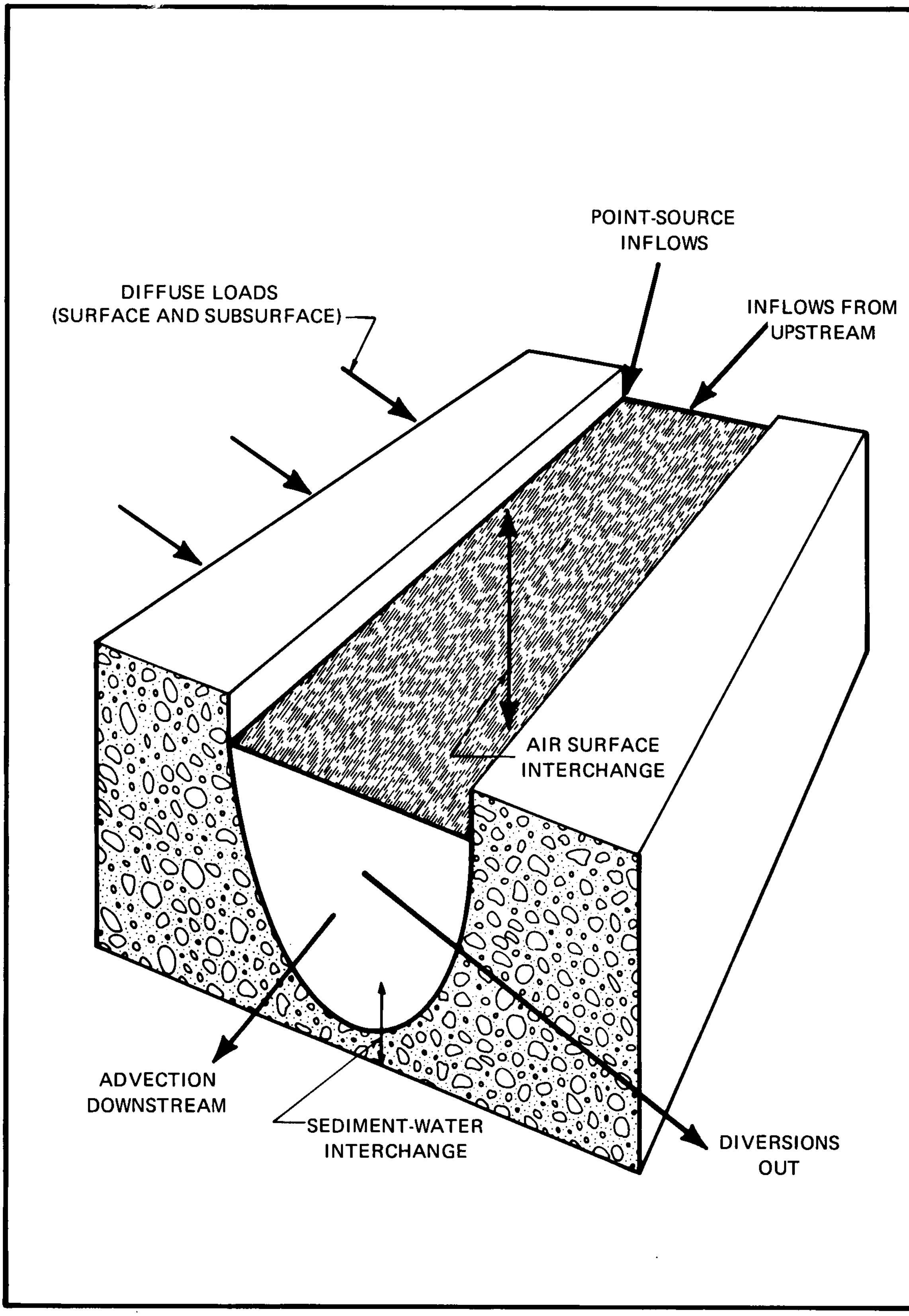


FIGURE 9-3: HSP Water Quality Reach Schematic

Denitrification is the reduction of nitrates to nitrogen gas which usually occurs during anaerobic conditions. The rate of denitrification is dependent upon dissolved oxygen concentrations and bacterial populations. Nitrification uses oxygen for converting ammonia into nitrate and nitrite. Nitrification is dependent on temperature and oxygen concentrations. A byproduct of phytoplankton photosynthesis is oxygen. The amount of oxygen released to the water depends upon the size of the phytoplankton population. The growth of phytoplankton is a function of the available phosphorus, nitrogen, heat light, and other factors. In the absence of light, phytoplankton consume stored protoplasm using oxygen in the process (respiration). Chlorophyll a is used as an indicator of the size of the phytoplankton population. Plant life attached to the bottom substrate are called periphyton or benthic algae, and undergo the same dynamics as phytoplankton.

Zooplankton consume oxygen in building protoplasm. They play an important role in determining water quality by feeding upon algae and excreting nutrients which are used by phytoplankton. Their growth is dependent upon the available phytoplankton and benthic algae and temperature.

In modeling nitrogen and phosphorus, mass balance principles are employed. Incoming nitrogen and phosphorus from upstream reaches, washoff, groundwater, bottom deposits, and point sources are added to the existing mass. Reduction of this mass is achieved by sedimentation, advection, algae growth, and, as in the case of nitrogen, biological and chemical reactions.

Biological growth and death are based on Liebig's Law of the Minimum: organisms grow in proportion to the least available nutrient or life requirement. The assumed requirements are phosphorus, nitrogen, light, and heat, each represented in the model. When the limits of a requirement are reached, biological growth stops. When the available resources decline, organisms die.

Suspended solids is a measure of the amount of sediment carried by the stream and is treated as a conservative constituent. In other words, there are no instream processes that affect a mass balance change. Similarly, fecal coliform bacteria do not interact with other water quality constituents. Temperature, however, does affect the fecal coliform dieoff rate.

A summary listing of the water quality parameters and their definition is given in Tables 9-2, 9-3, and 9-4. For further information, refer to Hydrocomp Simulation Programming Operations Manual, Hydrocomp International, Inc., 1976.

TABLE 9-2
HSP QUALITY CHANNEL PARAMETER DEFINITIONS

NETWORK

REACH	Reach number
LIKE	Reach number that has an identical cross section
	The type of channel: PHBE: Trapezoidal channel cross section RESR: Reservoir IMAG: Feeder reach without routing
N	Number of layers in reservoir
TRIB TO	Reach number to which the reach is tributary
SEGMT	Segment number of primary tributary segment
LENGTH	Length of the reach in miles
TRIB AREA	Local area tributary to the reach in square miles
EL_UP	Upstream channel bottom elevation in the reach
EL_DOWN	Downstream channel bottom elevation in the reach
W1	Incised channel bottom width in feet for trapezoidal channels or the top layer in reservoirs
W2	Incised channel top width in feet for trapezoidal channels or the top layer in reservoirs
H	Incised channel depth in feet
S_FP	Slope of the flood plain in feet per foot
N_CH	Manning's n for the incised channel
N_FP	Manning's n for the flood plain

LKROUTE

RCH	Reach number containing reservoir
KC	Storage constant when top layer volume less than bankfull volume
HEXC	Discharge exponent when top layer volume less than bankfull volume
KF	Storage constant when top layer volume greater than bankfull volume
HEXF	Discharge exponent when top layer volume greater than bankfull volume
VB	Bankfull volume of top layer in acre-feet
VL	Volume of top layer in acre-feet below which no discharge occurs

TRIBAREA

RCH	Reach number
SEGMT1	Segment number of primary tributary segment
A1	Impervious area SEGMT1
A2	Pervious area SEGMT1
SEGMT2	Segment number of second tributary segment
A3	Impervious area SEGMT2
A4	Pervious area SEGMT2
SEGMT3	Segment number of third tributary segment
A5	Impervious area SEGMT3
A6	Pervious area SEGMT3

TABLE 9-3
HSP QUALITY INSTREAM PARAMETER DEFINITIONS

<u>QUALITY</u>	
RCH	Reach number
LIKE	Reach number of reach with identical reaction rates
KBOD	BOD decay coefficient in 1/hr at 20°C
KSET	BOD settling rate in ft/hour
KDO	Reaeration correction factor
KEXP	Exposure factor
KSA	Surface area factor
BASEXT	Base extinction coefficient per foot
KNH320	Ammonia oxidation rate in 1/hour at 20°C
ABENT20	Benthal oxygen demand in mg oxygen/square meter/hour at 20°C
KFD	Fecal coliform die-away coefficient in 1/hour at 20°C
<u>BOTTOM</u>	
RELE1B	BOD aerobic release rate in mg BOD/square meter/hour
RELE2B	BOD anaerobic release rate in mg BOD/square meter/hour
RELE1P	Phosphate aerobic release rate in mg P/square meter/hour
RELE2P	Phosphate anaerobic release rate in mg P/square meter/hour
RELE1N	Ammonia aerobic release rate in mg N/square meter/hour
RELE2N	Ammonia anaerobic release rate in mg N/square meter/hour
<u>LANDS</u>	
KEVAP	Evaporation coefficient
KCOND	Conduction coefficient
KATRAD	Atmospheric long-wave radiation coefficient
<u>WATERSHED</u>	
ALPHA	Advection averaging coefficient
ALRAT	Ratio of chlorophyll <u>a</u> to phosphorous in algae
RIMP	Impervious surface washoff coefficient
RSUR	Pervious surface washoff coefficient
SRAB	Fraction of solar radiation absorbed in first meter of water
VELB	River velocity above which scouring occurs
NONREF	Degradable fraction of algae
ALRES	Algal respiration rate
VMAXL	Maximum light limited algal growth rate
VMAXP	Maximum phosphorus limited algal growth rate
VMAXN	Maximum nitrogen limited algal growth rate
SUPSAT	Maximum degree of super saturation permitted

TABLE 9-3
HSP QUALITY INSTREAM PARAMETER DEFINITIONS
(CONTINUED)

OQ	Photosynthetic oxygen coefficient
SINK	Algal sinking rate in reservoirs
SINKC	Algal sinking rate in rivers
TETNIF	Nitrification temperature correction factor
THETBOD	BOD oxidation temperature correction factor
BNALGR	Ratio of benthic algae growth rate to phytoplankton growth rate
BNALRR	Ratio of benthic algae respiration rate to phyto-plankton respiration rate

TABLE 9-4
HSP QUALITY LAND SURFACE WASHOFF PARAMETER DEFINITIONS

PARAMETER	DEFINITION
SEG	Segment number
CM	Calendar month for which loading rates apply
INITI	Initial surface loading on impervious area in lbs/ac
INITP	Initial surface loading on pervious area in lbs/ac
YI	Loading rate on impervious area in lbs/ac/day
LLI	Loading limit on impervious area in days
YP	Loading rate on pervious area in lbs/ac/day
LLP	Loading limit on pervious area in days
CONC	Subsurface concentration
SMOOTH	Averaging coefficient for subsurface temperature
OFFSET	Offset parameter for mean subsurface water temperature
RIMP	Washoff coefficient for impervious area in 1/inch
RSUR	Washoff coefficient for pervious area in 1/inch

HYDROLOGIC MODEL CALIBRATION

The adaptation and development of HSP on the Rock Creek watershed begins with calibration of the hydrologic program as previously described. Previous applications on the upper Rock Creek, Seneca, and Muddy Branch watersheds performed by the Maryland-National Capital Park and Planning Commission served to provide preliminary calibration parameters, and subsequent refinement accomplished a fine tune of the model.

Previous sections described the HSP model structure and input parameters required for hydrologic simulation. The data requirements can be broken down into three main categories: a meteorologic and hydrologic data base, a land segment definition, and a channel network schematic.

Meteorologic and Hydrologic Data Base

The meteorologic data base for hydrologic simulation consists of two sets of a time series of information: precipitation and evaporation. For this application, hourly precipitation recorded at the National Weather Service Office at Washington National Airport was used to represent precipitation over the entire watershed.

Inherent in this usage is the assumption that precipitation at National Airport, which is located 3 miles south of the mouth of the Rock Creek watershed, is a true measure of what occurs in the basin. On the long-term basis, this assumption is judged valid, but on an individual event basis, especially for summer thunderstorm activity, there is likely to be wide variation. This observation is substantiated by model results to be discussed later. The reason for using National Airport precipitation is, simply, that no other long-term and reliable recording gages exist any nearer to the watershed.

A number of storage gages are located in and around the basin, but these record only daily amounts of precipitation. For the purpose of water quality calibration and analysis, it is required that a truly accurate hydrologic representation be accomplished. For this reason, the National Airport precipitation records for the period of May 1978 to March 1979 were adjusted by hand to give a more true representation of average precipitation over the entire Rock Creek basin. This was accomplished by averaging the daily storage precipitation gaging records of gages within the watershed for each event and distributing the result in the timing and proportioning of hourly precipitation at National Airport. This practice, although time-consuming, yielded much more accurate hydrologic simulation results to drive the water quality model.

Potential evapotranspiration data was generated from records of pan evaporation collected by the U.S. Department of Agriculture at their research station in Beltsville, Maryland. These records were adjusted by standard pan coefficients to convert to lake or potential evapotranspiration and coded in semi-monthly format. Most of the record was available from the previous M-NCPPC studies.

Calibration of a hydrologic model requires hydrologic/ hydraulic data--in this case streamflow--recorded from the prototype. The M-NCPPC study used streamflow records on the North Branch of Rock Creek to calibrate HSP. This study utilized daily streamflow records from the U.S. Geological Survey gaging station at Sherrill Drive (in the D.C. portion of the basin) to modify the previous calibration effort. Selected hourly hydrographs of flow at Sherrill Drive were also obtained and plotted to further test and calibrate the hydrologic response of the model.

Land Segment Definition

To mathematically represent the hydrologic behavior of a watershed, its physical characteristics must be expressed in mathematical terms. Land use, general topography, soil types, vegetative cover, etc. must be reduced to the set of numerical parameters previously described. The study area must be defined in terms of several hydrologically homogeneous land segments, each of which is portrayed by a unique set of these parameters.

For the purpose of this study, the Rock Creek watershed was divided into a set of six such hydrologic homogeneous land segments that followed the land use classification system defined in Chapter 3. A description of these land segments and summary of the HSP LAND parameters developed in the calibration process are presented in Table 9-5.

Channel Network Schematic

CHANNEL parameters provide a detailed description of the stream network and its component parts. The component parts, reaches, can be uniform trapezoidal channels, uniform circular conduits, or layers of a lake. The CHANNEL parameters provide the dimensions of each reach, describe how they are interconnected, and define the type of land segment that is drained by each.

The previous model application by M-NCPPC to the Montgomery County, Maryland portion of the basin was of a highly descriptive nature, with the watershed divided into 70 channel reaches. The detailed channel network in the upper

TABLE 9-5
LAND SEGMENT TYPES AND CALIBRATED LAND PARAMETERS

Segment	Description	K1	A	EPXM	UZSN	LZSN	K3	K24L	K24EL	Infil-tration	Inter-flow	L	SS	NN	IRC	KV	KK24
1	Open land; pasture, crop-land, forest, parkland; natural drainage	1.00	.035	0.18	0.80	10.0	0.85	0.0	0.0	0.08	0.40	400	0.14	0.25	0.1	3.0	0.995
2	Rural residential (less than 2 dwelling units per acre); few storm gutters and sewers	1.00	.080	0.16	0.80	10.0	0.80	0.0	0.0	0.08	0.40	300	0.12	0.15	0.1	3.0	0.995
3	Light density urban resi-dential; single-family detached housing (2-5 dwelling units per acre); local gutters and storm sewers	1.00	.250	0.12	0.80	10.0	0.70	0.0	0.0	0.08	0.40	200	0.08	0.12	0.1	3.0	0.995
4	Medium density urban resi-dential; single-family detached housing with some row housing (5-10 dwelling units per acre); well storm sewered	1.00	.350	0.10	0.80	10.0	0.60	0.0	0.0	0.08	0.40	100	0.06	0.10	0.1	3.0	0.995
5	Multiple-family urban resi-dential; row housing, townhouses, highrise apartment housing with light commercial/industrial (>10 dwelling units per acre); com-pletely storm sewered	1.00	.750	0.08	0.80	10.0	0.40	0.0	0.0	0.08	0.40	75	0.04	0.08	0.1	3.0	0.995
6	Commercial/industrial; concen-trated shopping areas, office buildings, light industry, with some high density resi-dential; completely storm sewered	1.00	.900	0.06	0.80	10.0	0.40	0.0	0.0	0.08	0.40	50	0.04	0.02	0.1	3.0	0.995

basin was required to provide small scale local information and is not required for the analysis of conditions in the District of Columbia section of the watershed. Hence, the upper Rock Creek model schematic was modified to a simple, four-channel network as depicted in Figure 9-4. There is no significant loss of accuracy of the model by this simplification. The end reach of the M-NCPPC model was extended beyond the Maryland-D.C. boundary to the Sherrill Drive streamflow gaging station location within the District for the purpose of calibration. A summary of the calibrated channel input parameters is listed in Table 9-6. The stage-storage-discharge rule curves developed for Lakes Needwood and Frank (Reaches 2 and 4, respectively) are plotted in Figure 9-5.

Each channel reach drainage area comprises a unique mix of the land segment types defined in Table 9-5. A summary of the existing land segment composition of the four channel reaches and a weighted percent imperviousness is portrayed in Table 9-7. All land use data for the Montgomery County, Maryland, portion of the basin was developed from the M-NCPPC study of the watershed.

For the purpose of channel routing, the HSP model can accomodate only one land segment type per channel reach. The weighted percent impervious was used to determine the aggregate land segment type that typifies each of the reaches. Some accuracy of prototype description is lost by this limitation but is regained in the water quality model where up to 3 different land segment types can be specified per channel reach.

Calibration Results

The HSP hydrologic model was calibrated to streamflow records at Sherrill Drive for the period of October 1975 to March 1979. This comprises a total period of 3-1/2 years of the most recent records available. It was selected such that the existing land use definition would be appropriate for the calibration period and so that the water quality calibration period, selected to cover the D.C. Department of Environmental Services sampling program period, would be included.

An additional factor to the hydrologic balance of the watershed during the calibration period is the startup of the Rock Creek Interim Advanced Wastewater Treatment Plant in September 1978. At this point in time, the model incorporates a point source discharge, obtained from monitoring reports at the treatment plant, to Reach 6. On the average, this point source flow was 3.5 cubic feet per second from startup to the end of simulation.

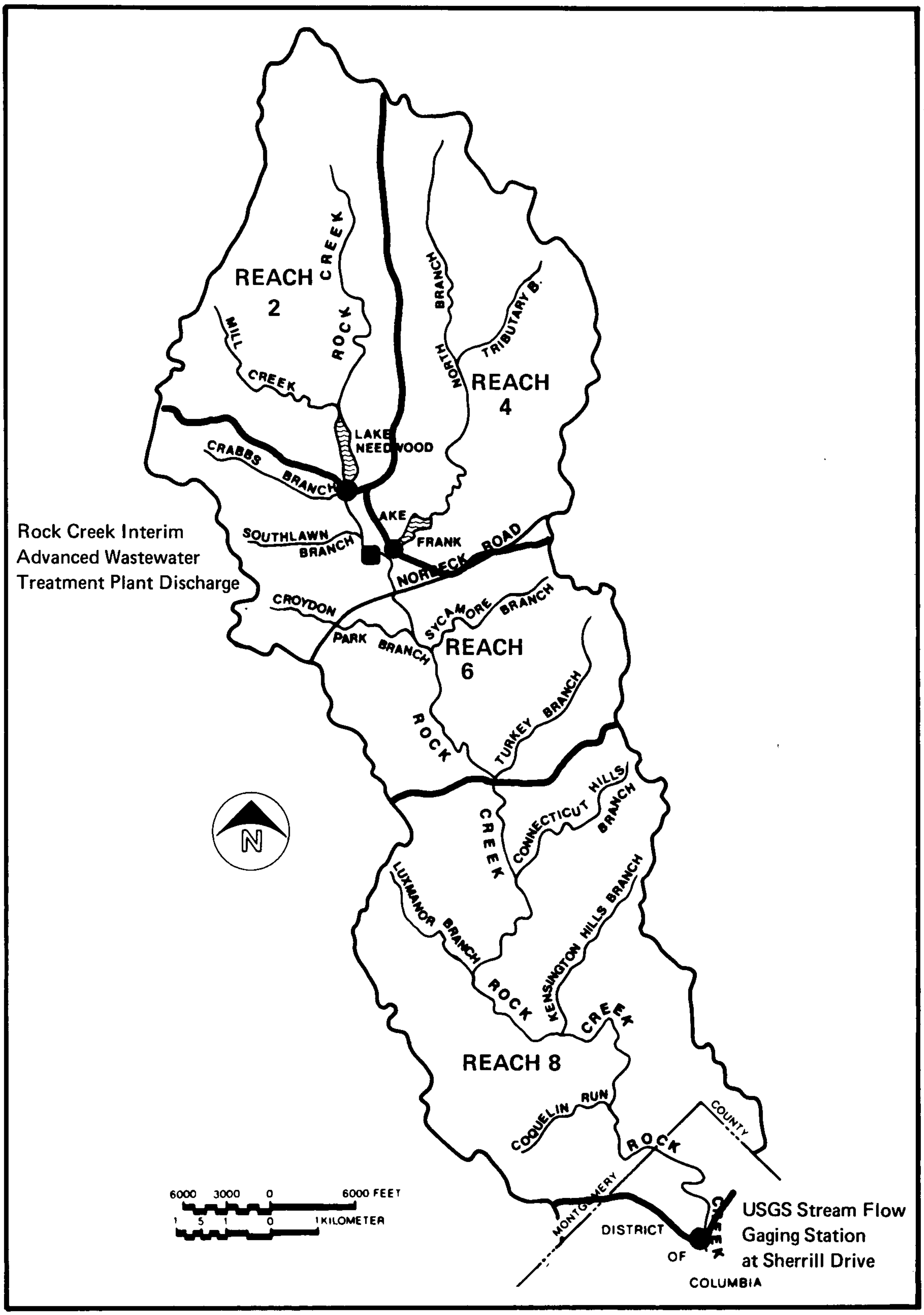


FIGURE 9-4: Hydrologic Calibration Channel Reaches (to Sherrill Drive)

TABLE 9-6
CALIBRATED CHANNEL PARAMETERS

Reach	Type	Trib_To	Name	Max_Elev (ft. msl)	Storage_Max (acre-feet)	Trib_Area (sq. miles)	Surface_Area (sq. miles)	Rules
2	DAM	6	Lake Needwood	363.6	6900	12.26	0.133	1
4	DAM	6	Lake Frank	348.0	7218	12.06	0.087	1

Reach	Type	Trib_To	Length (miles)	Trib_Area (sq. miles)	El_Up (ft.msl)	El_Down (ft.msl)	W1 (feet)	W2 (feet)	Depth (feet)	S_FP (ft/ft)	N_CH	N_FP
6	RECT	8	5.94	15.69	296	228	14	48	6.5	0.008	0.040	0.120
8	RECT	10	10.19	21.00	228	150	25	54	8.0	0.005	0.040	0.100

TABLE 9-7
EXISTING LAND USE COMPOSITION OF CHANNEL REACHES

		Percentage of Total Area						
		Seg. 1	Seg. 2	Seg. 3	Seg. 4	Seg. 5	Seg. 6	
Reach	Total Area (square miles)	Open (3.5% Imp.)	Rural Resid. (8% Imp.)	Low Density Urban Resid. (20% Imp.)	Med. Density Urban Resid. (30% Imp.)	Multiple-Fam. Urban Resid. (50% Imp.)	Comm.-Ind. (90% Imp.)	Weighted Percent Imperviousness
2	12.26	82.5	4.8	11.0	0.0	1.1	0.6	6.6
4	12.06	72.2	10.4	16.8	0.0	0.0	0.6	6.5
6	15.69	36.5	4.6	2.6	38.8	4.2	13.3	27.9
8	21.00	11.9	1.6	7.3	60.7	3.6	14.9	35.4
Total	61.01	44.3	4.8	8.7	30.9	2.5	8.8	22.1

The calibration process involved adjusting HSP parameters until the model was able to reasonably reproduce (simulate) the measured runoff at the USGS gaging station. Criteria used in the calibration were:

1. Simulate annual and monthly volumes;
2. Simulate average daily flows;
3. Simulate peak rates from storm events;
4. Simulate recession of storm hydrographs; and
5. Simulate the base or low flow conditions.

For the most part a very good calibration was achieved. Figure 9-6 shows the simulated vs. measured annual and monthly volumes. It can be seen that the model reproduces the annual water balance quite well for both high and low flow months.

Figure 9-7 shows the mass balance (i.e., the accumulated simulated and recorded water yields for the calibration period. The nearness of these curves indicates a high degree of correspondence and correlation.

The accuracy of the model to simulate peak flow rates from individual storm events can be demonstrated by a comparison plot of simulated versus recorded instantaneous peak flows from the largest storm events during the calibration period, as shown in Figure 9-8. The results exhibit a good correlation by the definition of a 45-degree line. A great deal of the variation noted on this plot can be directly attribute to the lack of sufficient hourly precipitation data coverage of the watershed. Although adequate for long-term hydrologic balance determination, the National Airport precipitation records, for individual storm events (especially summer thunderstorm activity), do not consistently represent the total amount, timing, or distribution of rainfall over the Rock Creek basin.

An additional test or measure of fit of the calibration can be demonstrated by the comparison of recorded and simulated daily flow exceedance frequency plots as shown in Figure 9-9. This figure shows a good match in the distribution of daily flows over the calibration period.

The result of all testing leads to the conclusion that the LANDS and CHANNELS modules of HSP have been successfully calibrated for the Rock Creek watershed. Even though precipitation coverage is sparse, a high degree of correlation between model and prototype behavior is indicated. Given the calibrated model, the D.C. portion of the watershed can be adequately defined and included for analysis. The effects on streamflow of future development, land use changes, structural controls and management strategies can be readily determined and the water quality model developed.

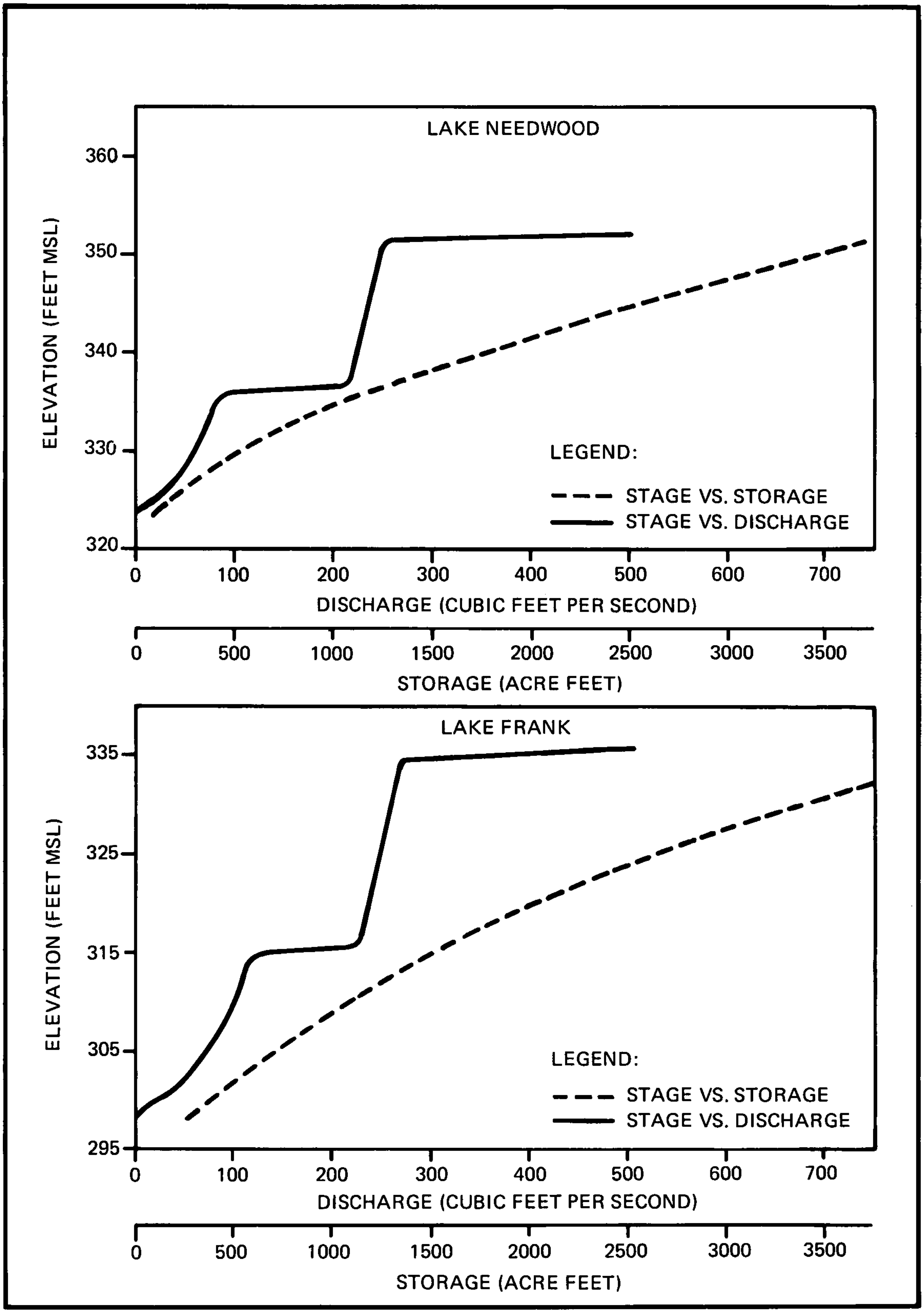


FIGURE 9-5: Stage-Storage-Discharge Rule Curves—Lakes Needwood and Frank

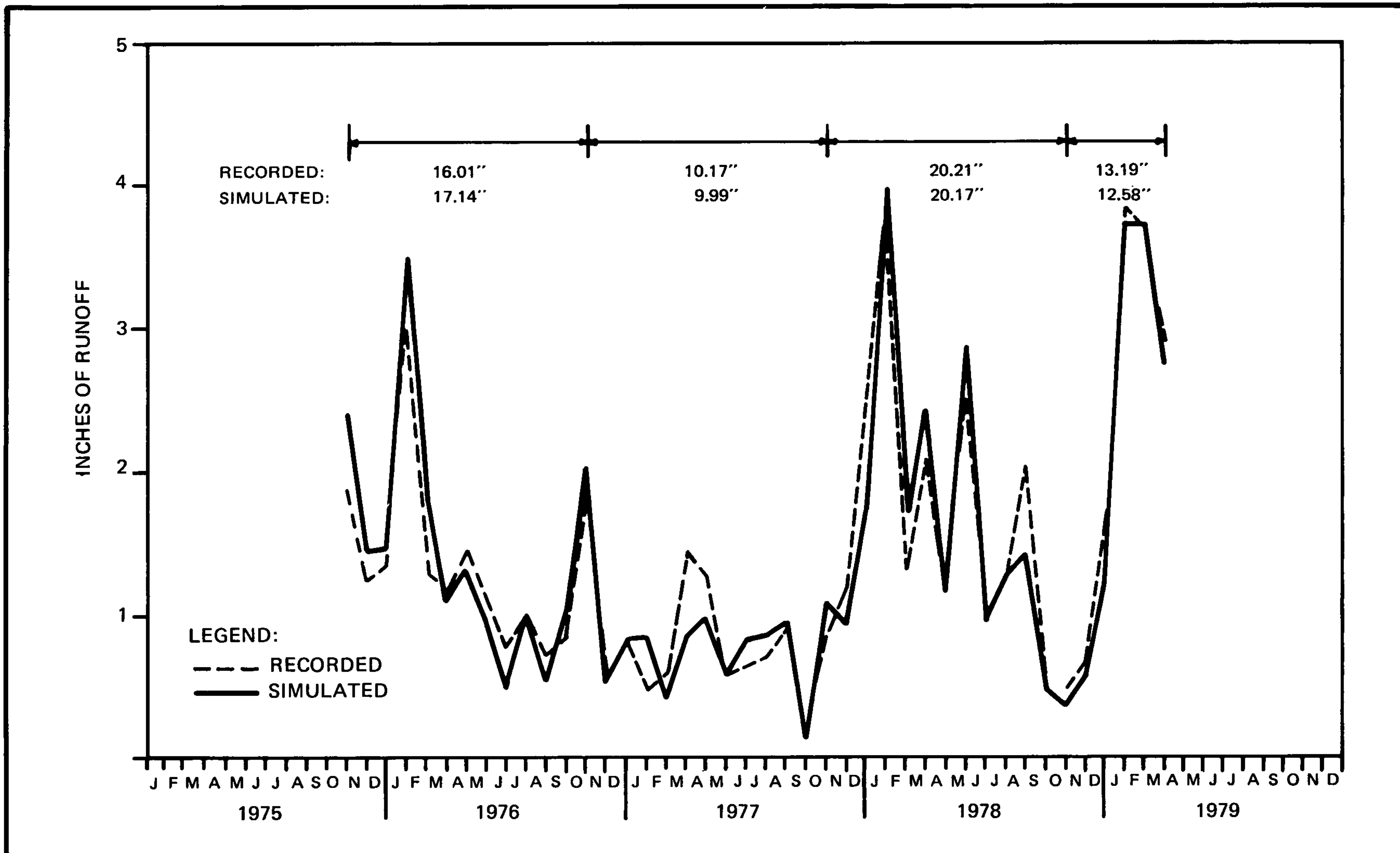


FIGURE 9-6: Simulated Versus Recorded Monthly Runoff in Inches—Rock Creek at Sherrill Drive

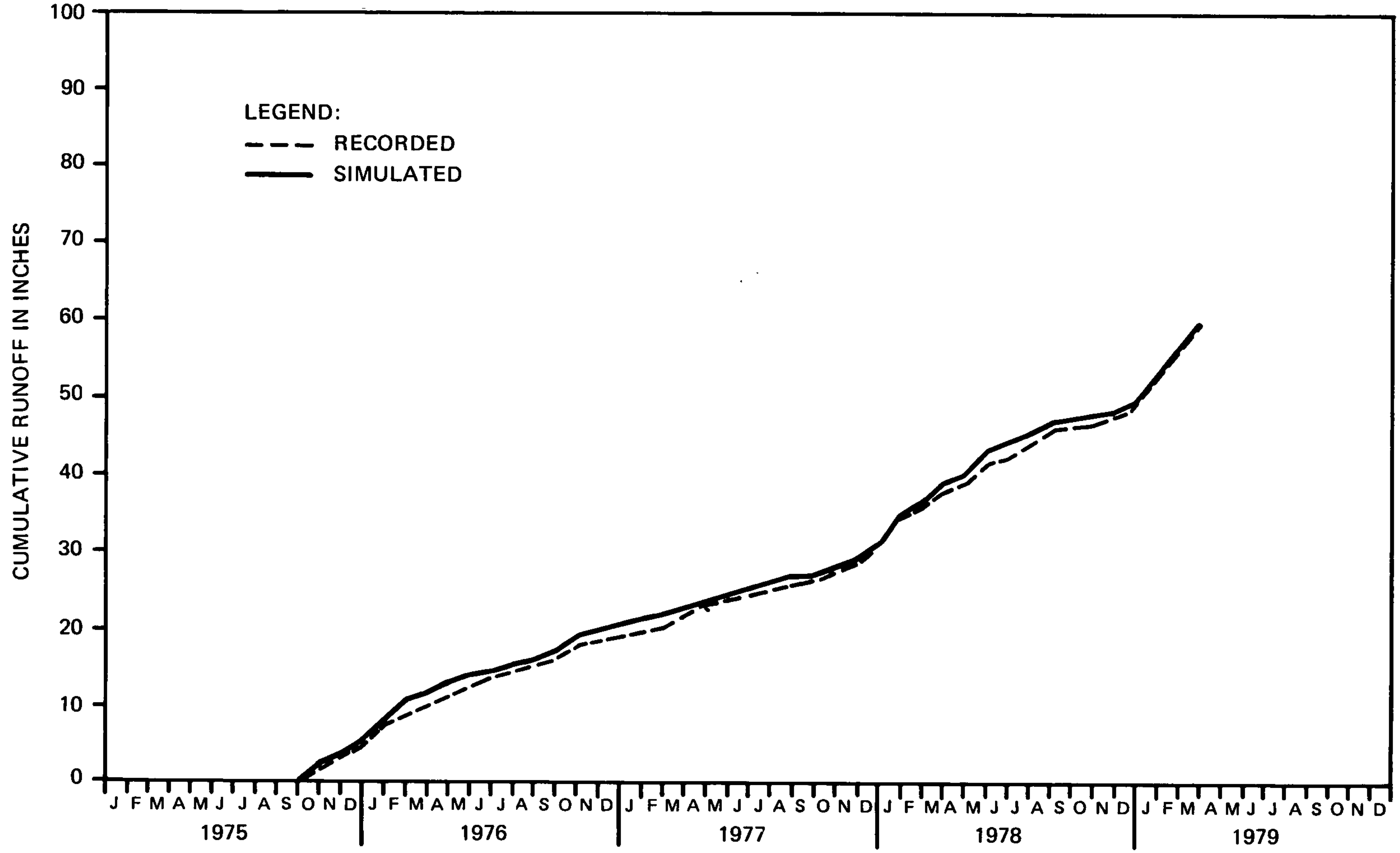


FIGURE 9-7: Simulated Versus Recorded Cumulative Runoff in Inches—Rock Creek at Sherrill Drive

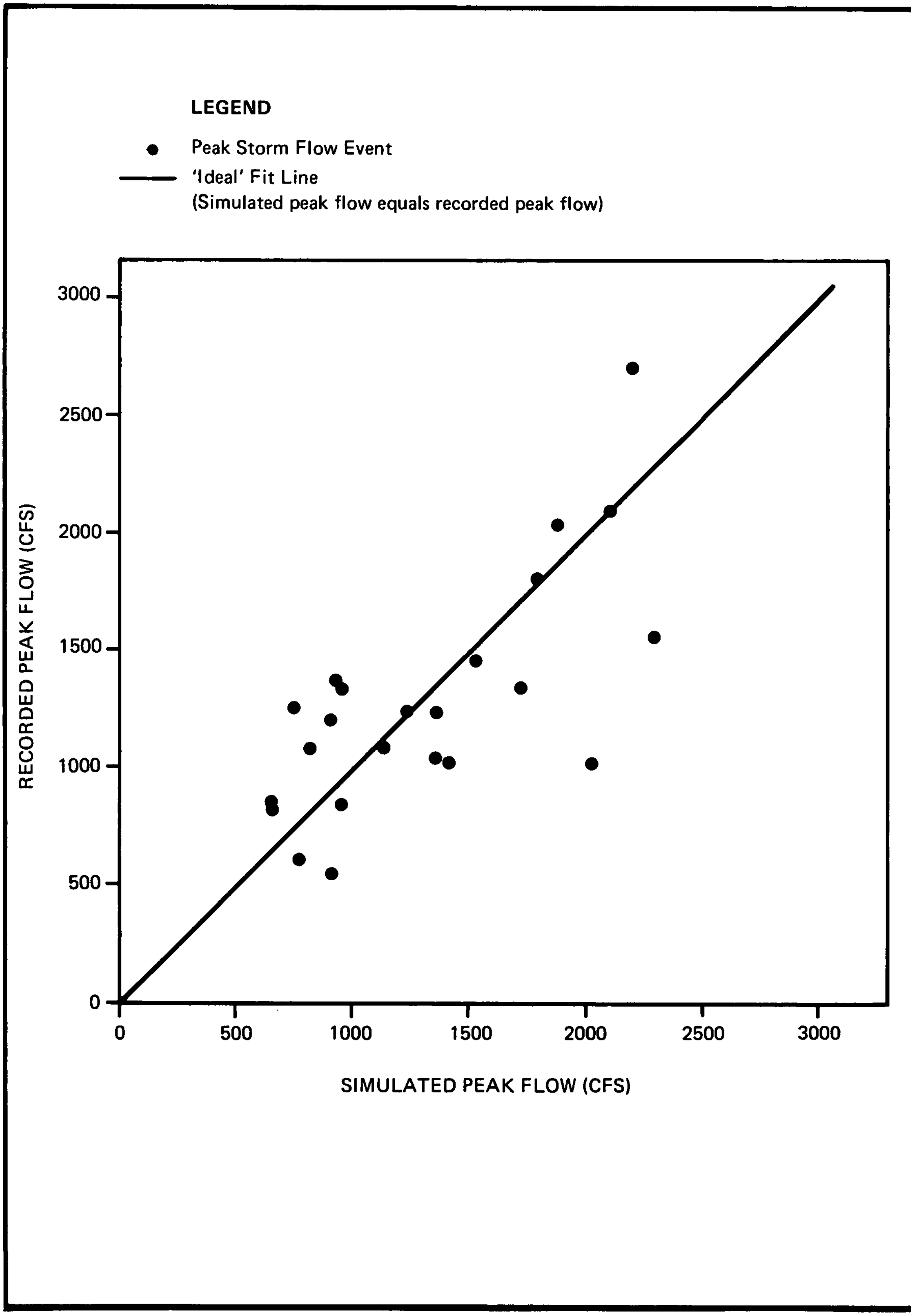


FIGURE 9-8: Simulated Versus Recorded Peak Flows at Sherrill Drive

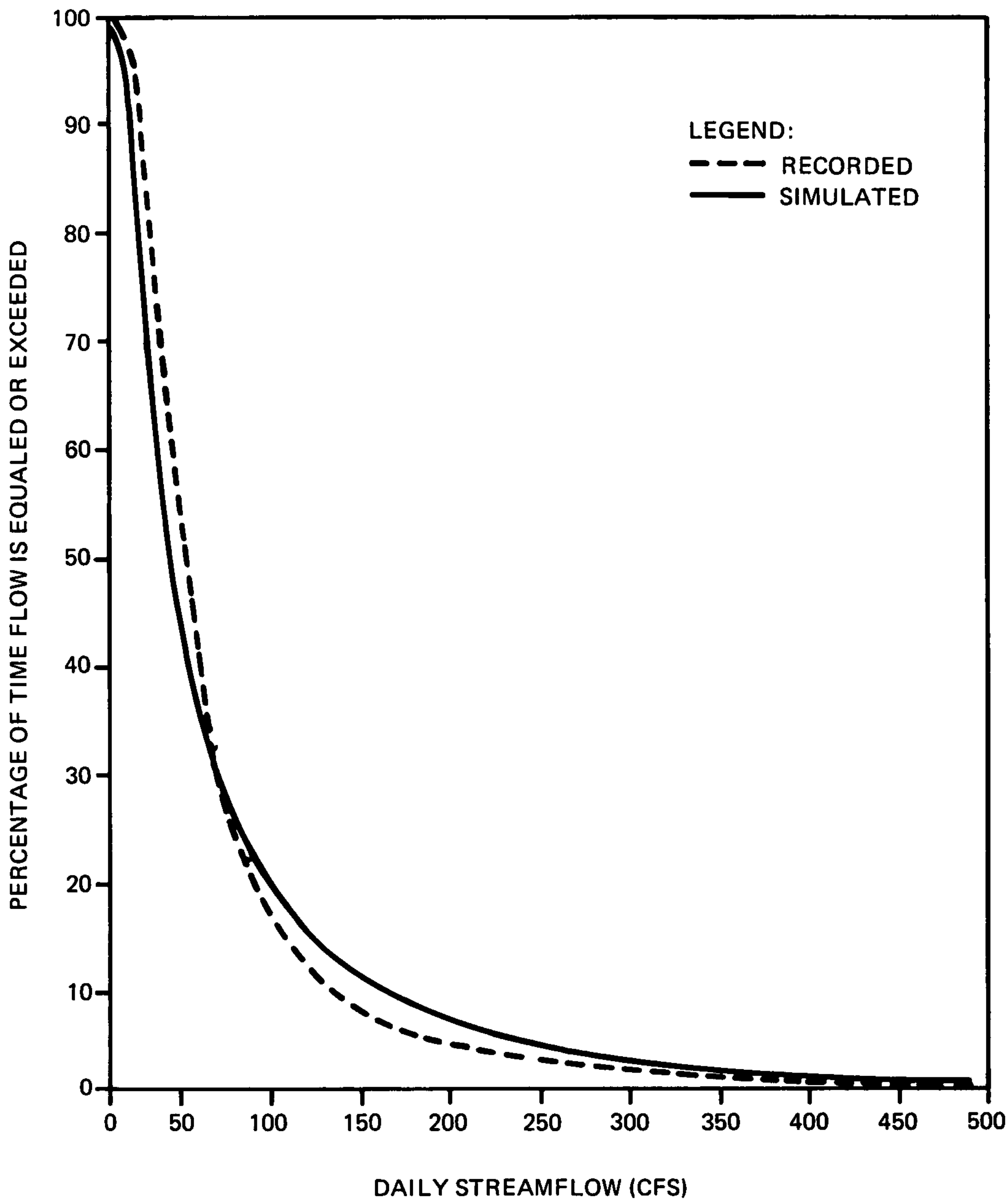


FIGURE 9-9: Simulated Versus Recorded Daily Streamflow Exceedance Frequency—
Rock Creek at Sherrill Drive

WATER QUALITY MODEL CALIBRATION

Having successfully calibrated the hydrologic modules of HSP to the Rock Creek Park Watershed above Sherrill Drive, the model network of the basin must be expanded to the mouth of Rock Creek and the HSP QUALITY module calibrated. In order to model the basin, it must be represented by a characteristic set of climatic data, land parameters, channel network parameters, instream reaction rates, basin loading factors, and point and nonpoint pollution loadings. Description of the HSP QUALITY module and input parameters has been discussed previously and will not be further embellished.

WATER QUALITY DATA BASE AND MODEL REPRESENTATION

The calibration of any type of model requires a set of data from the prototype by which the model behavior may be evaluated and adjusted. The most complete and recent set of instream water quality information is that collected since May 1978 by the District of Columbia Department of Environmental Services. A summary of this data, collected at six stations on the main stem of Rock Creek in D.C., has been previously discussed and Figure 8-2 displays their location in the watershed. The water quality model was calibrated to the data collected during the period of May 1978 to March 1979. During this period, sampling programs in Rock Creek were conducted by other entities and were also employed in model development.

Calibration to this data requires that a channel reach be designated at each of the sampling sites. The water quality model representation was constructed with this constraint. The model configuration in the D.C. portion of the watershed is illustrated in Figure 9-10 showing channel reaches and the tributary area to each. Note that, in addition to the six sampling sites, reaches were defined at the mouth of Rock Creek and at each of two combined sewer segments. The derivation of these segments shall be addressed in later discussion.

CLIMATOLOGIC DATA BASE

The climatologic data base required for water quality simulation with HSP includes dynamic (time-varying) sets of daily wind movement, solar radiation, maximum and minimum air temperature, cloud cover, and dewpoint temperature. A complete set of information was collected and stored in the computerized data base of HSP. The source of this data was the National Weather Service Office at Washington National Airport.

Hydrologic Data Base

In addition to the meteorologic data, the land surface and subsurface runoff generated by LANDS are used for transporting the constitutents to the receiving water body and providing the environment in which the biological and chemical reactions take place. The hydrologic calibration defined a set of six LANDS segments that each represented a certain land use type or condition. It is thus necessary to define the water quality model schematic in terms of these identical land uses. A summary of the land use composition of each water quality reach is presented in Table 9-8. Figure 3-5 served as the source for this definition.

Similarly, the channel characteristics of each reach must be determined and defined in model language. The source of this data is the set of channel cross sections surveyed by the United States Geological Survey and used for the floodplain analysis and mapping in this report (see Chapter 4). Table 9-9 summarizes the channel reach hydraulic input parameters. Note that only the natural stream channel reaches are listed. The combined sewer segment reaches are a conglomeration of the combined sewer system prior to discharge to Rock Creek and will be discussed here separately.

HSP MODEL REPRESENTATION OF COMBINED SEWER AREAS

The combined sewer portions of the Rock Creek Park Watershed require special consideration by the model representation in that the sewer system conveys both stormwater and sanitary sewage. In addition, a certain portion of all flow in the system, determined by its capacity, is conveyed out of the watershed and never enters the stream.

The hydrology portion of HSP (LANDS and CHANNELS), with the diffuse loading segment of the QUALITY module, can calculate the amount and quality of stormwater entering a combined sewer from a given drainage area. If we specify the amount of sewage entering the same sewer, and the quality of that raw sewage, HSP QUALITY can mix the two flows and estimate total flow and quality in the sewer. If we specify how much of this combined flow can flow through the system to the treatment plant, then HSP can calculate the flow entering the stream without treatment, i.e.,

$$\text{Overflow to Stream} = \text{Stormwater Flow} + \text{Sewage Flow} - \text{Sewer System Conveyance} \qquad \text{(Eq. 1)}$$

It is assumed in this approach that the quality of the overflow is the same as the quality of the combined flow in the sewer system.

TABLE 9-8
HSP WATER QUALITY MODEL CHANNEL REACHES - EXISTING LAND USE (ACRES)

Reach	Total Area (mi^2)	Seg. #6 Comm-Ind	Seg. #5 Multi-family	Seg. #4 Urban-Med	Seg. #3 Urban-Low	Seg. #2 Rural-Resid.	Seg. #1 Open-(Pasture/ Cropland)
2	12.26	50	90	-	860	380	6,470 (4,745)
4	12.06	50	-	-	1,300	800	5,570 (3,835)
6	15.69	1,340	420	3,900	265	450	3,665 (1,755)
8	18.02	1,515	125	7,160	695	140	1,895 (0)
10	0.70	35	-	115	55	-	245 (0)
20	2.28	220	175	325	245	85	410 (0)
30	1.65	10	5	75	400	-	565 (0)
40	4.60	355	165	340	1,135	105	845 (0)
50 (CSO#1)	4.15	205	1,390	550	255	-	255 (0)
60	1.33	95	65	10	230	15	435 (0)
70 (CSO#2)	2.90	735	630	10	275	100	105 (0)
80	0.51	45	5	-	5	5	265 (0)
Total	76.15	4,655	3,070	12,485	5,720	2,080	20,725 (10,335)

Note: Reaches 2-8 are in Montgomery County, Maryland
Reaches 10-80 are in the District of Columbia

TABLE 9-9
HSP WATER QUALITY MODEL CHANNEL PARAMETERS

Reach	Type	Trib_To	Name	Max_Elev (ft. msl)	Storage_Max (acre-feet)	Trib_Area (sq. miles)	Surface_Area (sq. miles)	Rules
2	DAM	6	Lake Needwood	363.6	6900	12.26	0.133	1
4	DAM	6	Lake Frank	348.0	7218	12.06	0.087	1

Reach	Type	Trib_To	Length (miles)	Trib_Area (sq. miles)	El_Up (ft.msl)	El_Down (ft.msl)	W1 (feet)	W2 (feet)	Depth (feet)	S_FP (ft/ft)	N_CH	N_FP
6	RECT	8	5.94	15.69	296	228	14	48	6.5	0.008	0.040	0.120
8	RECT	10	8.90	18.02	228	170	25	54	8.0	0.005	0.040	0.100
10	RECT	20	1.29	0.70	170	159	45	64	7.5	0.003	0.060	0.100
20	RECT	30	1.27	2.28	159	148	40	58	7.5	0.010	0.045	0.060
30	RECT	40	1.14	1.65	148	136	38	65	8.2	0.070	0.040	0.060
40	RECT	60	2.14	4.60	136	51	44	80	8.0	0.120	0.070	0.080
50	*	60	*	4.15	*	*	*	*	*	*	*	*
60	RECT	80	2.03	1.33	51	23	55	90	11.0	0.080	0.040	0.080
70	*	80	*	2.90	*	*	*	*	*	*	*	*
80	RECT	90	2.46	0.51	23	-10	34	80	15.0	0.070	0.030	0.070

Combined sewer segment; not applicable.

Necessary inputs to the modeling process are:

1. Drainage area tributary to combined sewers

2. Quantity and quality of sewage influent to combined sewers

3. System capacity for transporting flow from the combined sewer out of the watershed

Details of providing the required input are described in subsequent sections.

Inventory of Combined Sewer System and Overflows

Previous discussion has given a thorough description of the sanitary and combined sewer system within the Rock Creek Park Watershed. The infiltration/inflow analyses performed recently by the District of Columbia Department of Environmental Services provide all necessary information detailing the drainage basin areas, service population, and sewage production rates. This information is listed in Table 9-10. Figure 9-11 delineates the combined sewer areas within the watershed, the locations of all overflow structures to Rock Creek, and the service area tributary to each of these structures.

For the purpose of model representation, it is convenient to construct a schematic of the sewer system which readily portrays the flow pattern. Figure 9-12 denotes the main interceptor and truck line configuration of the combined sewer system in the District and the location of outfalls relative to this network. Note that the sewer and outfall locations are not exact on this schematic.

The analysis of the system to take all elements of the network into account requires a highly sophisticated sewer system hydraulics model that would describe the entire sewer pipe network and each overflow structure. This kind of evaluation is beyond the scope of this work and the capabilities of the HSP model. For the model developed here of the Rock Creek Park Watershed, the entire combined sewer service area is divided into a total of two individual segments. Each of these segments includes a certain number of overflow structures and the drainage areas of these points determine the total drainage of each segment. Figure 9-10 depicts the areas included in the combined sewer segments. A certain amount of accuracy is lost in this approach in that the overflow structures are summed into the two groups and thus exact locations and amounts of combined sewer overflow are lost. However, for the purpose of instream modeling of the cumulative mass input of combined sewer

TABLE 9-10
COMBINED SEWER OVERFLOW HYDRAULIC ANALYSIS

Overflow Number	Infiltration[a] Inflow Analysis Drainage Basin No.	Location	Type of Structure	Drainage Area (acres)	Service[b] Population	Sewage Production Rate (mgd)	Receiving Interceptor	Size of Dry Weather Flow Connection	Estimated Capacity of Dry Weather Flow Connection (mgd)	Size of Overflow Outlet	Segment Number
49	(5)	Penn. Ave., east side of Rock Creek, N.W.	Sump-type regulator	3	-- Included with #53 --		Rock Creek main interceptor	1'-0"(constricted inlet	1.6	1'-0"	2
50	(5)	26th & M Sts., N.W.	Slot-type regulator	11	-- Included with #53 --		East Rock Creek diversion sewer	2'-0"	15.5	3'-0"	2
51	(5)	N St. Ext. west of 25th St., N.W.	Slot-type regulator	9	9	0.100	Rock Creek main interceptor	1'-6"	16.1	2'-0"	2
52	(5)	22nd St. between M & N Sts., N.W.	Cunette-type regulator	32	1,698	0.171	Rock Creek main interceptor	2'-0"	13.8	7'-0" (Slash Run ext.)	2
53	(5)	22nd & M Sts., N.W.	Cunette-type regulator	349	9,523	3.494	Slash run lateral-East Rock Creek diversion sewer	8'-6"	140.8	7'0" (To Slash Run ext.)	2
54	(5)	23rd & O Sts., N.W.	Sump-type regulator	26	1,948	0.175	Rock Creek main interceptor	1'-6"	13.1	3'-0" (To Slash Run ext.)	2
55[d]	(5)	22nd St. south of Q St., N.W.	Cunette-type regulator	532	32,259	3.083	East Rock Creek diversion sewer	5'-0"	161.8	8'-3" (N.W. boundary)	2

[a] (5) - Corddry, Carpenter, Dietz and Zack, Piney Branch Sewer System Drainage Basin No. 5.
(3) - EcolSciences, Inc., Infiltration/Inflow Analysis Drainage Area No. 3.
(1) - Stearns & Wheler, Infiltration/Inflow Analysis Drainage Area No. 1.
[b] Estimated from 1975 census tract supplement, see I/I studies.
[c] Established in I/I studies from average daily water consumption rates, includes only sanitary flows to overflow structure, not in interceptor.
[d] Overflow also acts as relief of surcharged receiving interceptor, capacity of East Rock Creek diversion sewer is approximately 643 mgd at this point.
[e] Overflow acts only as relief of surcharged interceptor, no connection.
[f] Only 35 houses not separated from storm sewer system.

TABLE 9-10
COMBINED SEWER OVERFLOW HYDRAULIC ANALYSIS
(CONTINUED)

Overflow Number	Infiltration[a] Inflow Analysis Drainage Basin No.	Location	Type of Structure	Drainage Area (acres)	Service[b] Population	Sewage Production Rate (mgd)	Receiving Interceptor	Size of Dry Weather Flow Connection	Estimated Capacity of Dry Weather Flow Connection (mgd)	Size of Overflow Outlet	Segment Number
56	(5)	23rd & Mass. Ave., N.W.	Sump-type regulator	81			East Rock Creek diversion sewer	3'-6"	45.9	3'-6"	2
57	(5)	23rd St. south of Q St., N.W.	Sump-type regulator	2			Rock Creek main interceptor	1'-0"	3.7	3'-6" (same as #56)	2
58	(5)	N.W. of Belmont Rd. & Rock Creek & Potomac Pkwy.	Sump-type regulator	33	4,925	0.428	Piney Branch interceptor	1'-3" (constricted inlet)	1.3	3'-0"x2'-0"	2
59	(5)	N. of Belmont Rd., E. of Kalorama Cl, N.W.	Sump-type regulator	16			Piney Branch interceptor	1'-3" (constricted inlet)	1.3	3'-0"x2'-0"	2
60	(5)	Conn. Ave. E of Rock Creek, N.W.	Sump-type regulator	53			East Rock Creek diversion sewer	2'-3"	31.2	3'-0"	2
61	(5)	Biltmore St. ext., E. of Rock Creek, N.W.	Sump-type regulator	33			East Rock Creek diversion sewer	1'-2"	8.9	2'-0"	2

(Service population 4,925 and sewage production rate 0.428 are bracketed across overflows 56–61.)

[a] (5) - Corddry, Carpenter, Dietz and Zack, Piney Branch Sewer System Drainage Basin No. 5.
(3) - EcolSciences, Inc., Infiltration/Inflow Analysis Drainage Area No. 3.
(1) - Stearns & Wheler, Infiltration/Inflow Analysis Drainage Area No. 1.

[b] Estimated from 1975 census tract supplement, see I/I studies.

[c] Established in I/I studies from average daily water consumption rates, includes only sanitary flows to overflow structure, not in interceptor.

[d] Overflow also acts as relief of surcharged receiving interceptor, capacity of East Rock Creek diversion sewer is approximately 643 mgd at this point.

[e] Overflow acts only as relief of surcharged interceptor, no connection.

[f] Only 35 houses not separated from storm sewer system.

TABLE 9-10
COMBINED SEWER OVERFLOW HYDRAULIC ANALYSIS
(CONTINUED)

Overflow Number	Infiltration[a] Inflow Analysis Drainage Basin No.	Location	Type of Structure	Drainage Area (acres)	Service[b] Population	Sewage Production Rate (mgd)	Receiving Interceptor	Size of Dry Weather Flow Connection	Estimated Capacity of Dry Weather Flow Connection (mgd)	Size of Overflow Outlet	Segment Number
62	(5)	Ontario Rd. ext., & Rock Creek Parkway	Sump-type regulator	22			East Rock Creek diversion sewer	2'-0"	30.3	3'-6"	1
63	(5)	Harvard St. & Rock Creek Pkwy.	Sump-type regulator	41			East Rock Creek diversion sewer	2'-3"	32.5	3'-3"x4'-10"	1
64	(5)	Adams Mill Rd. S. of Irving St., N.W.	Sump-type regulator	44			East Rock Creek diversion sewer	2'-3"	34.5	2'-9"x4'-2"	1
65	(5)	Kenyon St. & Adams Mills Rd, N.W.	Sump-type regulator	46	13,452	1.206	East Rock Creek diversion sewer	1'-0" & 1'-3" (2 lines)	10.4	2'-6"	1
66	(5)	Adams Mill Rd. & Lamont St. N.W.	Sump-type regulator	44			East Rock Creek diversion sewer	1'-3"	13.1	2'-6"	1
67	(5)	Park Rd. S. of Piney Branch Parkway, N.W.	Sump-type regulator	25			East Rock Creek diversion sewer	1'-6"	12.4	2'-0"	1
68	(5)	Ingleside Ter., ext. & Piney Branch Pkwy.	Sump-type regulator	26			East Rock Creek diversion sewer	1'-3"	10.2	1'-6"	1
69	(5)	Mt. Pleasant St., ext. & Piney Branch Parkway	Sump-type regulator	32			East Rock Creek diversion sewer	1'-6"	9.0	2'-0"	1

[a] (5) - Corddry, Carpenter, Dietz and Zack, Piney Branch Sewer System Drainage Basin No. 5.
(3) - EcolSciences, Inc., Infiltration/Inflow Analysis Drainage Area No. 3.
(1) - Stearns & Wheler, Infiltration/Inflow Analysis Drainage Area No. 1.
[b] Estimated from 1975 census tract supplement, see I/I studies.
[c] Established in I/I studies from average daily water consumption rates, includes only sanitary flows to overflow structure, not in interceptor.
[d] Overflow also acts as relief of surcharged receiving interceptor, capacity of East Rock Creek diversion sewer is approximately 643 mgd at this point.
[e] Overflow acts only as relief of surcharged interceptor, no connection.
[f] Only 35 houses not separated from storm sewer system.

TABLE 9-10
COMBINED SEWER OVERFLOW HYDRAULIC ANALYSIS
(CONTINUED)

Overflow Number	Infiltration[a] Inflow Analysis Drainage Basin No.	Location	Type of Structure	Drainage Area (acres)	Service[b] Population	Sewage Production Rate (mgd)	Receiving Interceptor	Size of Dry Weather Flow Connection	Estimated Capacity of Dry Weather Flow Connection (mgd)	Size of Overflow Outlet	Segment Number
70	(5)	Piney Branch Pkwy., W. of 16th St., N.W.	Sump-type regulator	2,373	79,159	7.258	East Rock Creek diversion sewer	9'-6"x7'-7"	874.0[a]	Open Channel	1
71	(3)	28th St. west of Rock Creek Pkwy. ext.	Sump-type regulator	35	832 (71 and 72)	0.132 (71 and 72)	West Rock Creek diversion sewer (west part.)	3'0"	66.5	4'0"	2
72	(3)	Olive St., ext. & Rock Creek Pkwy., N.W.	Sump-type regulator	15			West Rock Creek diversion sewer (west part.)	2'-3"	44.5	3'-0"	2
73	(3)	O St. ext. & Rock Creek Parkway, N.W.	Sump-type regulator	105	2,550 (73 and 74)	0.270 (73 and 74)	West Rock Creek diversion sewer (west part.)	2'-6"	54.2	4'-0"	2
74	(3)	Q St. west of Rock Creek, N.W.	Sump-type regulator	8			West Rock Creek diversion sewer (west part.)	1'-0"	3.3	1'-9"	2
75[e]	(3)	West side of Rock Creek, 300 ft. S. of Mass. Ave., N.W.	Side overflow structure	--	--	--	West Rock Creek diversion sewer	9'-6"x7'-7"	-	3'-0"	2
76	(3)	Mass. Ave. & Whitehaven St., N.W.	Sump-type regulator	63	44	0.028	West Rock Creek diversion sewer (east part.)	2'-0"	29.3	2'-0"	2

[a] (5) - Corddry, Carpenter, Dietz and Zack, Piney Branch Sewer System Drainage Basin No. 5.
(3) - EcolSciences, Inc., Infiltration/Inflow Analysis Drainage Area No. 3.
(1) - Stearns & Wheler, Infiltration/Inflow Analysis Drainage Area No. 1.
[b] Estimated from 1975 census tract supplement, see I/I studies.
[c] Established in I/I studies from average daily water consumption rates, includes only sanitary flows to overflow structure, not in interceptor.
[d] Overflow also acts as relief of surcharged receiving interceptor, capacity of East Rock Creek diversion sewer is approximately 643 mgd at this point.
[e] Overflow acts only as relief of surcharged interceptor, no connection.
[f] Only 35 houses not separated from storm sewer system.

TABLE 9-10
COMBINED SEWER OVERFLOW HYDRAULIC ANALYSIS
(CONTINUED)

Overflow Number	Infiltration[a] Inflow Analysis Drainage Basin No.	Location	Type of Structure	Drainage Area (acres)	Service[b] Population	Sewage Production Rate (mgd)	Receiving Interceptor	Size of Dry Weather Flow Connection	Estimated Capacity of Dry Weather Flow Connection (mgd)	Size of Overflow Outlet	Segment Number
77	(3)	Normanstone Dr. ext. west of Rock Creek, N.W.	Float-con-	241			Rock Creek main interceptor,	0'-10"	3.6	5'x5'	2
					2,454 (77 and 78)	1.175 (77 and 78)	West Rock Creek diversion sewer (east part.)	5'-0"	145.4	5'x5'	2
78	(3)	28th St., Ext. west of Rock Creek, N.W.	Sump-type regulator	76			Rock Creek main interceptor	1'-0"	5.6	4'-0"	2
79	(1)	Conn. Ave. & Rock Creek Parkway, N.W.	Float-controlled regulator	123	5,409	0.637	Rock Creek main interceptor	1'-0"	2.3	4'-0"	2
80[f]	(1)	16th & Rittenhouse Sts., N.W.	Sump-type regulator	0.4	-	-	Rock Creek main interceptor	1'-0"	1.9	7'-0"	-

[a] (5) - Corddry, Carpenter, Dietz and Zack, Piney Branch Sewer System Drainage Basin No. 5.
(3) - EcolSciences, Inc., Infiltration/Inflow Analysis Drainage Area No. 3.
(1) - Stearns & Wheler, Infiltration/Inflow Analysis Drainage Area No. 1.

[b] Estimated from 1975 census tract supplement, see I/I studies.

[c] Established in I/I studies from average daily water consumption rates, includes only sanitary flows to overflow structure, not in interceptor.

[d] Overflow also acts as relief of surcharged receiving interceptor, capacity of East Rock Creek diversion sewer is approximately 643 mgd at this point.

[e] Overflow acts only as relief of surcharged interceptor, no connection.

[f] Only 35 houses not separated from storm sewer system.

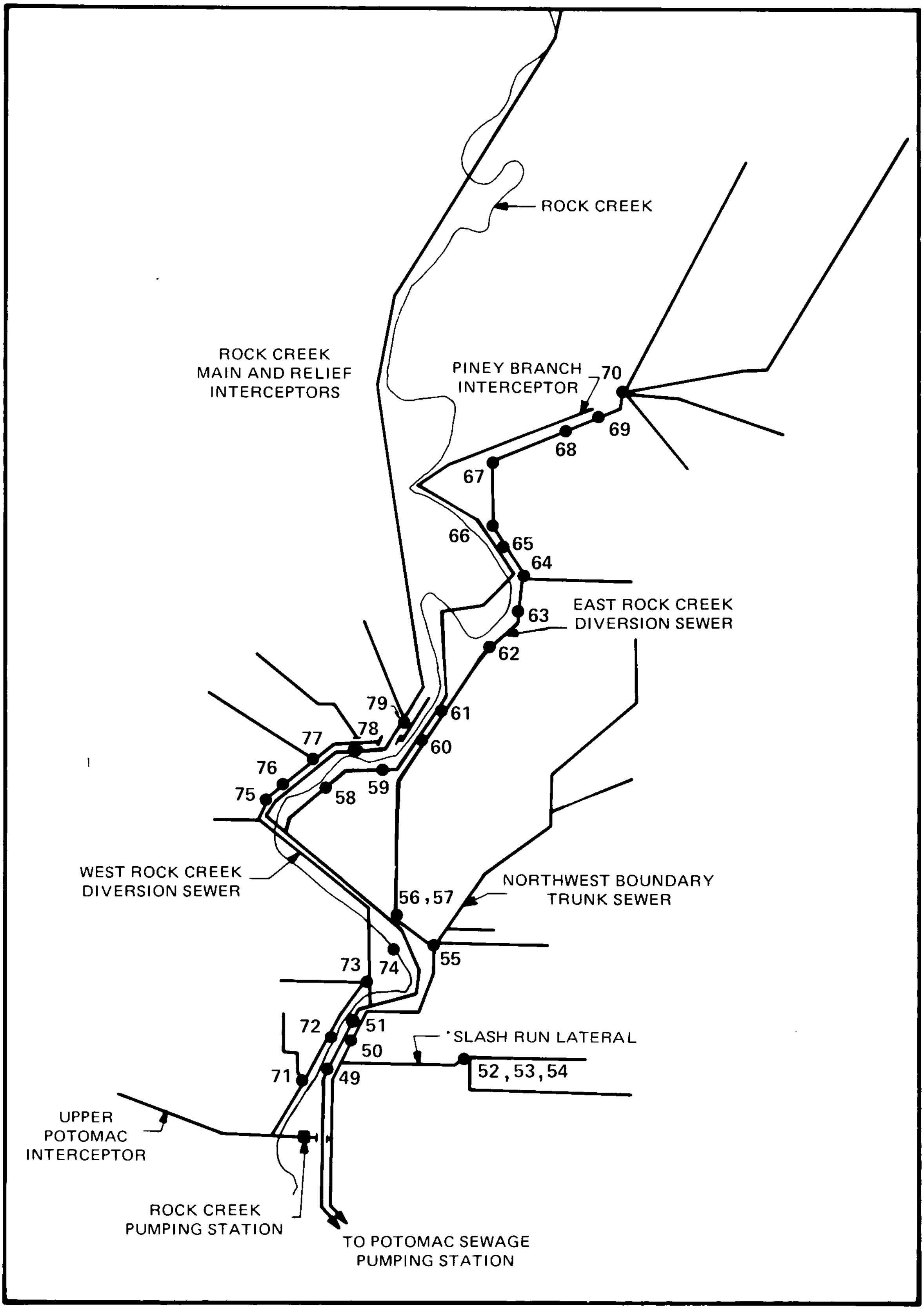


FIGURE 9-12: Sewer Schematic and Active Combined Sewer Overflow Locations

overflows to the stream reaches as depicted, the approach is adequate and valid.

Combined Sewer Segment No. 1 includes all of the northern part of the Piney Branch Sewer System Drainage Basin above Calvert Street. It comprises a total of 2,653 acres and serves a population of approximately 92,700. An average sewage production rate of 8.46 million gallons per day is estimated. Excess wet-weather flow is contributed to Rock Creek via 9 overflow structures in the segment.

Combined Sewer Segment No. 2 includes the rest of the combined sewer areas tributary to the Rock Creek Park Watershed. A total of 22 combined sewer overflow structures convey flow from approximately 1,846 acres of combined or partially separated sewer drainage area. A total of 62,900 people are served by the combined system and generate an estimated 9.82 million gallons per day of sewage. Note that the service population includes those connections to both the separated sanitary sewer system and the combined system in the partially separated sewer districts (see previous discussions).

Estimation of Capacity of Combined Sewer System to Transport Flow

The capacity of the combined sewer system to transport flow is a complex problem that involves the interaction of two controlling factors. The majority of overflow structures in the Rock Creek Park Watershed are of the sump-type regulator variety depicted in Figure 9-13.

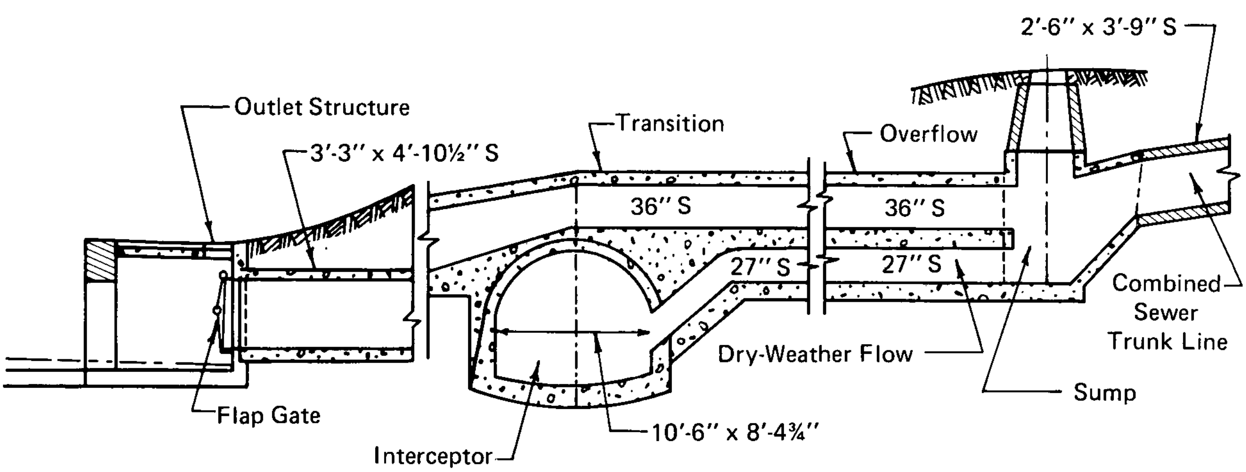


Figure 9-13 Typical Combined Sewer Overflow Structure

A fixed orifice conveys all dry-weather and a portion of wet-weather flow from the trunk combined sewer to the major interceptor. All excess wet-weather flow is transported by the overflow pipe to Rock Creek. The two controlling factors to the hydraulics of this structure are: 1) the dimensions of the dry-weather flow connection and diversion sump and; 2) the flow conditions within the receiving interceptor. Both factors interact to determine the actual flow hydraulics. To complicate the matter even further, since the amount of flow in each contributing sewer will vary with time, the distribution of flows in the structure will also be time-varying.

For the modeling approach taken here, a two-step procedure was adopted to determine the limiting factor in determining the combined sewer system capacity. First, the capacity of the dry-weather connection of each overflow structure was calculated. Details of the overflows were obtained from plan and detail drawings of Sewer System Diversion, Intercepting, and Overflow Structures, D.C. Department of Sanitary Engineering, 1967. Assumptions governing the hydraulic analysis were; a) the receiving interceptor is flowing at full capacity but not surcharged; b) the structure still exists and functions as design drawings indicate; and c) head (water elevation) at the inlet to the dry-weather connection is at the point of overflow (top of diversion structure).

Governed by these assumptions, capacities of the overflows were calculated. Most dry-weather flow connections act as a fixed orifice and are governed by the equation:

$$Q = CA\ (2gH)^{1/2} \qquad \text{(Eq. 2)}$$

where Q = capacity of orifice (ft^3/sec)
A = cross-sectional area of orifice (ft^2)
g = acceleration due to gravity (32.2 ft/sec^2)
H = head (water level) difference between interceptor and overflow structure (ft)
C = entrance loss coefficient dependent on shape of orifice; ranges from 0.6 to 0.95

In some cases where the dry-weather conveyance pipe travels a long distance before connecting to the interceptor, the pipe capacity rather than orifice capacity limits flow in the connection. In this case, capacity was determined by the Manning equation:

$$Q = (0.000614/n)\ D^{8/3}\ S^{1/2} \qquad \text{(Eq. 3)}$$

where Q = capacity of pipe (ft^3/sec)
n = roughness coefficient, assumed to be 0.013
D = pipe diameter (in)
S = slope of hydraulic grade line (ft/ft)

The results of this analysis of all overflow structures are listed in Table 9-10.

The second step in determination of the capacity of the sewer system to transport flow is to calculate the capacity of the main receiving interceptors at certain key locations. This information was obtained from the recent infiltration/inflow study reports and the D.C. Department of Environmental Services. A compilation of major interceptor capacities is listed in Table 9-11 for selected locations. These estimates are based upon average slope and cross-sectional area in the interceptors at free-flowing capacity (not surcharged).

Combined Sewer Segment No. 1 is served by the ERCDS and the Piney Branch Interceptor which have a combined capacity of 881.4 million gallons per day. The total conveyance capacity of the trunk line connections of the 9 overflow structures is only 1026.4 mgd. Hence, it is the capacity of the interceptors that limits the sewer system conveyance (see Equation 1) in this segment.

Combined Sewer Segment No. 2 must be divided into its three major interceptor components. The WRCDS (west side of partition) has a capacity of 188 mgd and the four combined sewer overflow connections can convey a total of 168.5 mgd. Hence, it is the capacity of the trunk line connections that governs wet-weather conveyance in this component.

The Rock Creek Main Interceptor has the ability to transport 125 mgd out of the Rock Creek Park Watershed at the Rock Creek Pump Station. There are a total of 11 overflow structures before that on either the RCMI or the east side partition of the WRCDS that limit wet-weather conveyance from combined trunk lines to 237.1 mgd. In addition, there is the capacity to discharge up to 7.4 mgd and 27.5 mgd to the RCMI from the Piney Branch Interceptor and the upstream, separated portion of the RCMI, respectively. Under these conditions, it can be seen that the limiting factor that determines the amount of combined sewer overflow to Rock Creek from the RCMI is the capacity of the RCMI itself (125 mgd), minus the combined 34.9 mgd from upstream sources, or 90.1 mgd. Note that the sewage from the separated areas in the upper RCMI sewer basin is not included in the sewage flow element of Equation 1. This assumes that none of this flow, already in the interceptor, is allowed to enter Rock Creek within the CSO area of the basin. It only serves to limit the amount of combined sewage that can additionally enter.

That portion of the East Rock Creek Diversion Sewer that contributes to Combined Sewer Segment No. 2 is a much

TABLE 9-11
MAJOR INTERCEPTOR CAPACITIES IN ROCK CREEK PARK WATERSHED

Interceptor	Location	Combined Sewer Segment No.	Capacity (mgd)
East Rock Creek Diversion Sewer	Overflow Structure #70 #70 (head of Piney Branch)	1	874
East Rock Creek Diversion Sewer	Harvard St. entrance to National Zoo	1	1,264
Piney Branch Interceptor	North of Calvert St. Bridge	1	7.4
East Rock Creek Diversion Sewer	22nd and P Street below Overflow Structure #55	2	643
East Rock Creek Diversion Sewer	Above Rock Creek Pumping Station; at K Street	2	1,507
Rock Creek Main Interceptor	Above combined sewer area at Overflow Structure #79 (Connecticut Ave.)	2	27.5
Rock Creek Main Interceptor	Above Rock Creek Pumping Station	2	125
West Rock Creek Diversion Sewer	Above connection to Upper Potomac Interceptor at K Street	2	188
Northwest Boundary Trunk Sewer	Above connection to East Rock Creek Diversion Sewer	2	1,866
Slash Run Lateral	Above connection to East Rock Creek Diversion Sewer	2	228

more complex problem. It can be divided into two portions that act differently. At overflow structure #55, a regulator that prevents surcharge in the ERCDS limits flow to 643 mgd. At and above this point are 4 overflow structures that limit combined trunk line inflow to 247.8 mgd. There is also the input to the ERCDS of Combined Sewer Segment No. 1 which can transport up to 881.4 mgd according to previous analysis. By these figures, it can be assumed that the 643 mgd capacity of the ERCDS is the limiting factor at this point. However, in the HSP model configuration, it will be necessary to continuously simulate that amount of combined sewage that is conveyed in Segment No. 1 and add it to the stormwater and sewage flows (see Equation 1) in Segment No. 2.

Below overflow structure #55 an additional 874 mgd of flow capacity is picked up in the ERCDS but the two combined trunk line connections are limited to 156.3 mgd. Hence, the capacity of the dry-weather connections governs.

A summary of the combined sewer conveyance capacity analysis is presented in Table 9-12 for the two HSP model combined sewer segments.

TABLE 9-12
HSP COMBINED SEWER SEGMENT SUMMARY

	Combined Sewer Segment No. 1	Combined Sewer Segment No. 2
Combined sewer area (acres)	2,653	1,846
Service population	92,700	62,900
Sewage production rate (mgd)	8.46	9.82[a]
Number of overflow structures	9	22
Total sewer system conveyance capacity (mgd) out of combined sewer segment	881.4	1057.9

[a] Does not include the amount flow that is conveyed from Combined Sewer Segment No. 1.

To complete the combined sewer representation within the model, a set of water qulaity parameters must be assigned to the raw sewage that is contributed to the sewer system. Typical water quality constituent concentrations were assigned at the previously specified flow rates:

Dissolved Oxygen	- 2.0 mg/l
Biochemical Oxygen Demand	- 200 mg/l
Ammonia Nitrogen	- 25 mg N/l
Nitrate Nitrogen	- 0 mg N/l
Orthophosphate Phosphorus	- 7 mg P/l
Fecal Coliform Bacteria	- 2,500,000 MPN/100 ml
Suspended Solids	- 200 mg/l
Chlorophyll a	- 0 mg/l

POINT SOURCE DATA BASE

As previously discussed in Chapter 8, there are relatively few documented point source discharges to the Rock Creek Park watershed. The most significant of these is the Rock Creek Interim Advanced Wastewater Treatment Plant in Montgomery County, Maryland, which began discharging an average of 2.1 mgd of effluent to Rock Creek at Southlawn Lane in September 1978. By requirement of the National Pollutant Discharge Elimination System permit for discharge, the treatment plant owners must submit quarterly discharge monitoring reports to the Maryland Water Resources Administration. These have been summarized in Table 9-13 as input to the water quality model.

TABLE 9-13
ROCK CREEK INTERIM ADVANCED WASTEWATER TREATMENT PLANT
DISCHARGE MONITORING DATA - AVERAGE MONTHLY VALUES
SEPTEMBER, 1978 TO MARCH, 1979

Date	Flow (mgd)	BOD-5 (mg/l)	Total Susp. Solids (mg/l)	Diss. Oxygen[a] (mg/l)	Total Kjeldahl Nitrogen (mg N/l)	Total Phos. (mg P/l)	Fecal Coliform[b] (MPN/100 ml)
9/78	--	1.5	1.5	7.0	0.3	0.8	3
10/78	2.29	1.5	2.5	7.7	0.5	0.6	23
11/78	2.10	2.2	1.8	7.9	0.5	0.8	43
12/78	1.90	1.4	2.0	9.0	0.6	0.5	>2400
1/79	1.73	2.7	1.3	9.0	0.6	0.6	3
2/79	2.14	1.8	1.2	8.4	0.6	0.9	4
3/79	2.10	0.9	0.6	9.0	0.4	0.4	4

[a]Only minimum value reported.
[b]Only maximum value reported.

The effluent parameters reported do not necessarily conform to the instream water quality constituents being simulated, and certain assumptions were required to attain the necessary uniformity. Total Kjeldahl nitrogen measures both ammonia nitrogen and organic nitrogen. In an advanced wastewater treatment (AWT) process like the Rock Creek Interim Plant, breakpoint chlorination and dechlorination will effectively remove all ammonia nitrogen from the effluent. Hence, a zero concentration of ammonia nitrogen is assumed.

Chemical coagulation in AWT will preferentially remove organic phosphorus compounds before the inorganic forms. A typical AWT fraction of 70 percent of the total phosphorus levels recorded in the effluent monitoring reports is assumed for modeling of orthophosphate phosphorus.

Nitrate nitrogen concentrations are not a reporting requirement of the NPDES Permit. However, an average level of 7.9 mg/l was calculated from daily effluent monitoring data during October 1978 for the treatment plant. The source of this data was a memo of October 1978 of Greenhorne & O'Mara, Inc.

Further assumptions of treatment plant effluent quality were: 1) the minimum monthly dissolved oxygen value as recorded in the monitoring report, 2) a fecal coliform concentration of 20 per 100 ml, 3) an algal concentration of zero, and 4) a yearly temperature variation of 50°F (winter) to 75°F (summer).

Outfall Sampling Survey. The results of the outfall dry-weather sampling survey previously discussed in Chapter 8 were incorporated into the model configuration as a point source pollutant contribution. Only those sources that proved to be of a contaminating nature were included, and the rest were assumed to be of natural groundwater or spring origin. The total flow and mass input to each channel reach were calculated and are summarized in Table 9-14. Background concentrations and loads were estimated in calculation of the total mass input from unauthorized discharges to the creek. This was done since sources of pollution to the headwater outlets of the tributaries could not be otherwise isolated from the diluting natural groundwater flow at these points.

The concentrations of other water quality constituents were estimated as a function of the relative strength of the contaminated inflow from each point source. Although there is no strong evidence of such, the large COD source that enters Reach 20 (Sherrill Drive) from Fenwick Branch is assumed to contain a large amount of ammonia nitrogen.

TABLE 9-14
POINT SOURCE INPUT SUMMARY - OUTFALL
DRY-WEATHER SAMPLING SURVEY

HSP Model Reach	Total Point Source Flow (cfs)	Weighted Average Fecal Coliform Concentration (MPN/100 ml)	Weighted Average COD Concentration (mg/l)
8	--	--	--
10	--	--	--
20	0.535	300	235
30	0.505	3,000	55
40	1.372	27,600	30
60	0.576	91,100	150
80	0.607	34,200	275

The DES monitoring data indicates that such a source exists at this point. The quantity of discharge was estimated by means of a mass balance calculation to be 3.6 mg N/l at the present rate of flow. All point source pollution was input to the water quality model data base.

An additional point source input was incorporated in the model data base to account for the suspected illegal discharges with the Montgomery County portion of the watershed. A mass balance calculation of fecal coliform contribution at the Maryland-D.C. boundary during dry-weather flow resulted in an estimated 0.025 cfs of raw sewage contribution at the concentration of 2,500,000 MPN/100 ml.

It should be noted that, over the period of DES monitoring, several accidental spills were recorded in the park which will account for some of the anomalous data that was recorded. At the beginning of July 1978, a 15-inch sanitary sewer line broke at 16th St. and N. Portal Drive and discharged to Portal Branch for seven days. A heating oil tank of an apartment building at the head of Soapstone Branch discharged a large quantity of oil to the stream for approximately 10 days beginning on September 13, 1978. The U.S. Coast Guard constructed a barrier boom and used absorbent materials to contain and remove the oil, but seepage was in evidence for 2 to 3 months afterwards. A similar, but smaller, oil leak was discovered on Melvin Hazen Branch on September 11, 1978. It probably had been chronic for a previously long time period. From November 7-9, 1978, a sewer break in Silver Spring, Maryland caused a heavy pollutant load in Portal Branch that was evident even in the main stem of Rock Creek.

Since it is not possible to quantify the impact of these incidents, the only reasonable course of action, for modeling purposes, is to avoid the dates of occurrence such that the recorded data will not bias and/or distort the calibration process.

POLLUTION BUILDUP RATES

The accumulation of pollutants on the land surface is expressed in the model as a dry-weather pollutant buildup rate in units of pounds per acre per day. These rates are dependent on land use and type of surface (pervious versus impervious). Previous application of the model in the upper watershed by M-NCPPC and recent work by the Northern Virginia Planning District Commission served to establish initial loading rates. The calibration process resulted in modification of these rates to match recorded data in the lower watershed.

The M-NCPPC application did not have sufficient wet-weather data to calibrate the accumulation rates. NVPDC rates were applicable and correlated somewhat with the resultant calibration rates for impervious surfaces. Pervious surface buildup rates were not comparable due to differences in model algorithms and methodology. Refinement of loading limits, the maximum amount of buildup, was necessitated to calibrate to multiple storm events during the period of record. The resulting calibrated accumulation rates and subsurface (groundwater) concentrations are listed in Table 9-15.

CALIBRATION AND VERIFICATION RESULTS

Calibration and verification of the water quality model were performed on two separate periods of time of the D.C. Department of Environmental Services monitoring program. Two 12-day periods were selected to represent diverse flow and meteorologic conditions within the watershed. The first, from 21 August to 1 September 1978 was used to initially calibrate the model. This time span comprised an initial long dry period with no precipitation recorded from the 14th to 27th of August, a small storm on the 27th, and a very intense thunderstorm of 1.3 inches on the 30th. During the latter event, combined sewer overflows of 21.3, 11.2, and 3.5 million gallons were recorded at overflow structures #70, #55, and #52, respectively. The hydrographs of streamflow recorded at Sherrill Drive during the calibration and verification time periods are displayed in Figure 9-14. The model simulation of flow is also plotted. Good correlation is exhibited for both periods; this is a necessary requirement

TABLE 9-15
CALIBRATED HSP POLLUTANT ACCUMULATION RATES AND SUBSURFACE CONCENTRATIONS

Land Use	Percent Impervious	BOD-5			NH_3-N			NO_3-N			O-PO_4-P			Suspended Solids			Fecal Coliforms		
		Imp	Perv	Sub	Imp	Perv	Sub	Imp	Perv	Sub	Imp	Perv	Sub	Imp	Perv	Sub	Imp	Perv	Sub
Cropland	.035	.08	0.8	3.0	.020	.30	0.5	.014	.12	1.0	.003	.04	.04	5	250	1	500	2000	500
Forest	.035	.08	0.2	3.0	.020	.05	0.1	.014	.02	0.2	.003	.001	.01	5	25	1	10	40	500
Rural Residential (2 DU/acre)	.08	.15	0.7	3.0	.015	.25	0.2	.014	.06	0.6	.003	.025	.02	10	500	1	400	1600	500
Low-Density Urban (2-5 DU/acre)	.25	.15	0.7	3.0	.015	.25	0.2	.015	.08	0.6	.004	.030	.02	10	500	1	400	1600	500
Med.-Density Urban (5-10 DU/acre)	.35	.15	0.7	3.0	.015	.25	0.2	.018	.09	0.6	.0024	.035	.02	10	500	1	500	2000	500
Multiple-Family Residential (10 DU/acre)	.75	.30	0.6	3.0	.010	.25	0.2	.017	.08	0.6	.0013	.025	.02	8	750	1	600	2400	500
Commercial-Industrial Central Business District	.90	.60	0.5	3.0	.010	.20	0.2	.019	.06	0.6	.0005	.020	.02	6	500	1	800	3200	500

Notes:
* Imp = Impervious surface, Perv = Pervious surface, Sub = Subsurface concentration (groundwater)
* Loading limits of ten days accumulation are used for both pervious and impervious surfaces, respectively
* Accumulation rates are in units of pounds/acre/day except for fecal coliforms which are organisms x 10^8/acre/day
* Subsurface concentrations are in mg/l except for fecal coliforms which are MPN/100 ml
* Accumulation rates and subsurface concentrations include loadings from surcharged sanitary sewer overflows, construction sites, septic systems, feedlots, and stream bank erosion

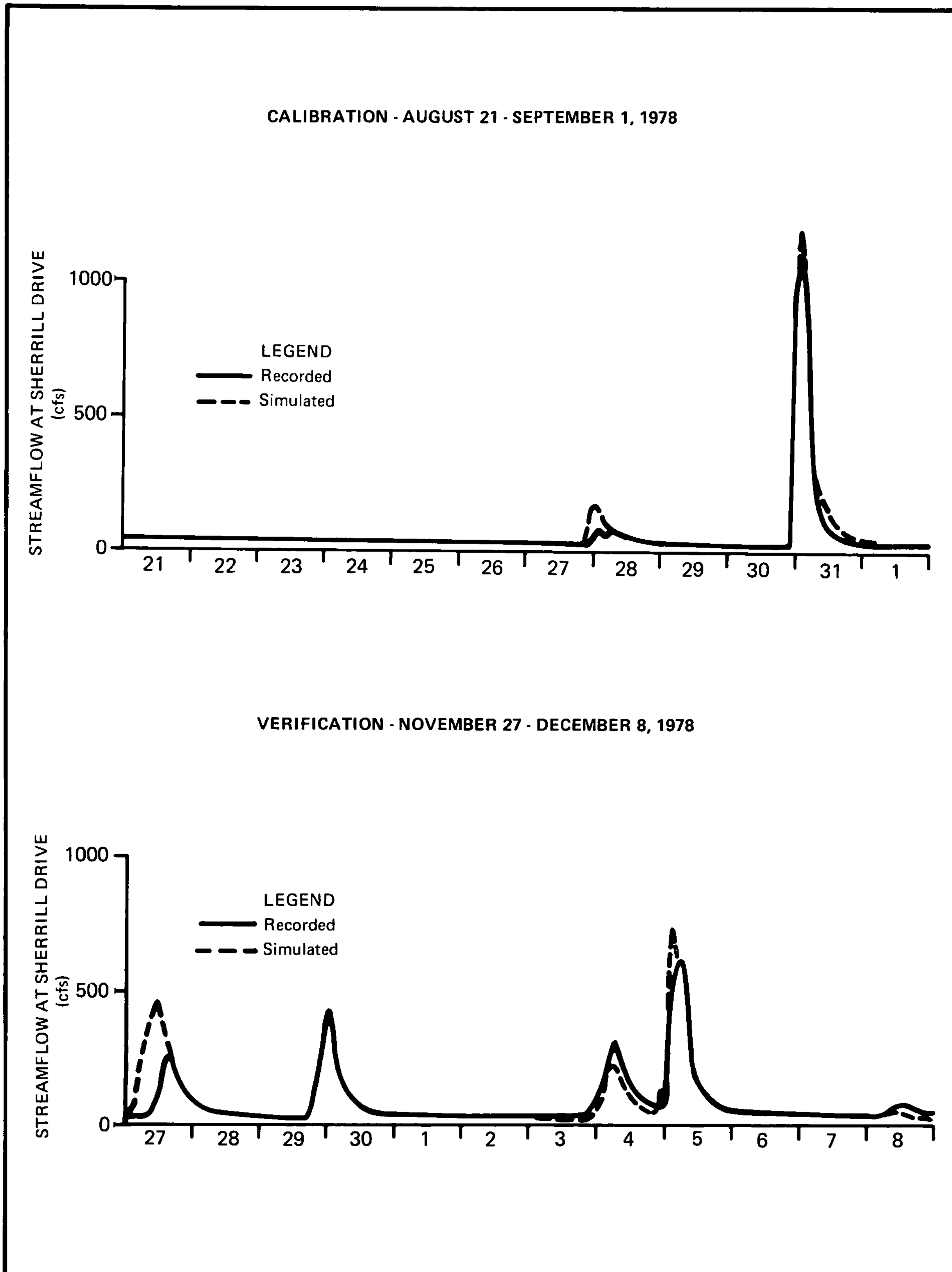


FIGURE 9-14: Water Quality Model Calibration and Verification - Flow at Sherrill Drive

for successful water quality calibration. The DES collected samples at its six stations on 10 of the 12 days during this period.

The verification of the water quality model was performed using the 27 November to 8 December 1978 time span. In addition to the difference in meteorologic conditions, a significant distinction between the two times is that the Rock Creek Interim Advanced Wastewater Treatment Plant was in operation in November and not in August. As can be seen in Figure 9-14, the verification period encompassed several storm events. Not obvious is the 8-day dry period that preceded the first storm on the 27th. No combined sewer overflows were monitored during any of the storm events. There were 10 sets of samples analyzed by DES during this time span, also. However, fecal coliform sampling was discontinued prior to this date.

The process of calibration involved the refinement of pollutant accumulation rates, as previously described, and adjustment of instream reaction rates, channel bottom interactions, and algal growth and respiration rates. Refer to Table 9-3 for details of the model coefficients. The data collected by DES at the 6 sampling locations for 8 water quality constituents (temperature, dissolved oxygen, BOD, ammonia nitrogen, nitrate nitrogen, orthophosphate phosphorus, suspended solids, and fecal coliforms) means that 48 sets of data were involved in the calibration process. In addition, the sporadic analysis of chlorophyll a and observation of aquatic plant communities (see Chapter 8) served as guidance for calibration of phytoplankton and benthic algae. The complexities of the calibration process are obvious. For the sake of expediency, only the calibration and verification results of Station 2 at West Beach Drive are presented. Back-up data is available from the National Park Service for reference. Figure 9-15 displays the comparison of model simulation to recorded data for the two time periods. Recorded data is plotted as distinct solid circles and the model simulation is plotted as a solid line. Time of sampling of all monitoring data, an important factor for storm events and diurnal fluctuations of dissolved oxygen and temperature, is assumed to occur at 8:00 A.M. each day. A discussion of simulation results follows.

Temperature. Water temperature simulations for both calibration and verification time periods proved generally good. The only inconsistencies occurred during the late August days where simulated temperatures were high by 1 to 2°C. Diurnal variations of up to 3°C can be seen; thus the timing of recorded measurements is an important factor. Calibration of temperature was accomplished by adjustment of shading factors (the amount of shading of the water surface) and heat exchange coefficients. Temperature of precipitation during storm events is assumed to be air temperature by the model. This is a limitation that cannot be adjusted within the model and accounts for the anomalous sharp peaks during the storm simulations. There were no appreciable differences in temperature simulation in any of the other reaches within the District.

Dissolved Oxygen. Calibration and verification results of dissolved oxygen demonstrate very good correlation considering the marked scatter and variability of recorded data. Diurnal variations of 1 mg/l during the August period are a combined result of algal processes and temperature fluctuation. Sags during the storm events are pronounced, but more data would be required to truly define their magnitude and verify model simulation. The dissolved oxygen verification is not as consistent as the calibration period but is still within an acceptable limit of accuracy. There is a myriad complex of parameters that are involved in the solution of the equation describing dissolved oxygen. Adjustments of BOD decay rates, sediment oxygen demands, reaeration rates, algal growth and respiration, ammonia decay rates, and temperature all contributed. The differences in dissolved oxygen regimes for the D.C. reaches as noted in Chapter 8 were accurately represented in calibration by accounting for the increased reaeration that occurs along the fall line and at the Peirce Mill Dam (Reaches 40 and 60).

Biochemical Oxygen Demand. The calibration of BOD was accomplished by accounting for background dry-weather loads and adjustment of surface buildup rates, decay rates, bottom releases, and sinking rates. Simulation results are good considering the limited amount and variability of recorded data. The timing of sampling during storm events can be critical (see Figure 9-15). Peak concentrations during first flushing of impervious surface loads can be completely missed, as can the resulting dissolved oxygen sag. There is very little variability of BOD that can be noted between the reaches in the District during storm events. During dry weather, there is a gradual depletion from the upstream to downstream end of Rock Creek as BOD input from upstream (Maryland) reaches is decayed.

Orthophosphate Phosphorus. As noted in previous discussion, the calibration of orthophosphate required the assumption that one-third of the total phosphorus as monitored by DES is of the inorganic form. Calibration results are excellent, including storm simulations. Verification proved to be marginal as dilution during the multiple storm events was simulated and higher levels were modeled during dry periods. This is a result of insufficient initial surface loadings for storm washoff and overestimation of the phosphorus input of the Rock Creek Interim Advanced Wastewater Treatment Plant during this period of time. Inaccessibility of AWTP monitoring data contributed to this inadequacy in assumption. Calibration of phosphorus involved adjustment of subsurface concentrations, surface accumulation rates, bottom releases,

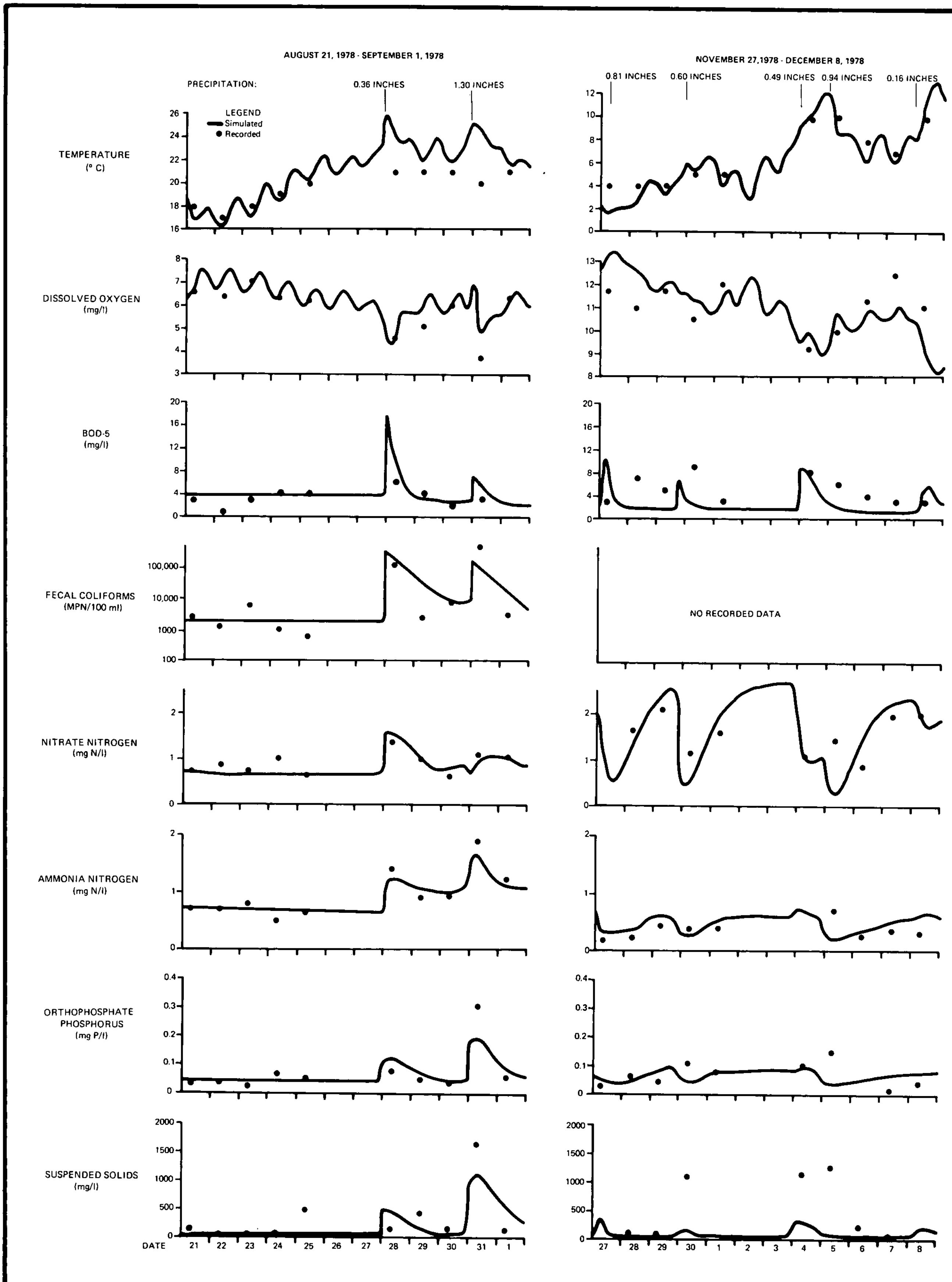


FIGURE 9-15: HSP Water Quality Calibration and Verification
Station 2-West Beach Drive

and algal productivity. Relatively constant levels were simulated throughout the District reaches as no variability in recorded data was noted.

Ammonia Nitrogen. The process of calibration of ammonia nitrogen was performed with skepticism of the recorded data. As seen in Figure 9-15, results are very good, but inconsistencies in methods of analysis (filtered versus unfiltered) for DES monitoring leads to questionable validity of any simulation based thereupon. Higher concentrations were observed in the summer period presumably due to decay of a large algal biomass and/or fertilizer contribution. These sources are not a factor during late fall or winter, hence ammonia levels are lower. Similarly, good results were obtained at other reaches with the suspected point source load in Reach 20 accounting for an increase at this point. Calibration was accomplished by adjustment of subsurface concentrations, surface building rates, bottom releases, decay rates and algal productivity. Calibrated ammonia surface accumulation rates may be inordinately high, as can be seen in the verification results, due to fertilizer application in the summer.

Nitrate Nitrogen. The calibration and verification of nitrate nitrogen proved to be very good considering the large variability exhibited in the data. Concentrations in the summer are dampened due to algal processes. The absence of algae during the fall period and the contribution by the Rock Creek AWTP more than doubles the dry-weather nitrate nitrogen concentration during this time. The storm events during the two periods exhibit reversed trends. The summer events show increased concentration due to storm washoff while the the fall storm events dilute the instream concentration. Lower initial surface loadings during the verification simulation result in slightly excessive dilution, however, than recorded data indicated. Calibration of nitrate nitrogen involved tuning of subsurface concentrations, algal processes, ammonia nitrogen decay, and surface accumulation rates. Similarly good results of simultion were obtained in the other D.C. reaches as a trend of decreasing nitrate was modeled as a result of dilution and algal uptake.

Suspended Solids. The HSP water quality model simulates suspended solids as a conservative constituent that is subject to no instream processes. Such a simplified treatment of the very intricate processes of surface erosion, lake settling, and instream erosion and deposition results in a very poor model representation. Calibration results, as depicted in Figure 9-15, are good but verification did not prove out. Similar to the other water quality constituents, which are closely related to suspended sediment (a good portion of the nutrients and BOD are tied up in particulate form), there was not enough washoff during the multiple storm events of the verification period. Once again, initial surface loads were insufficient to produce the observed storm concentrations. The inability of the model to simulate the settling process of suspended sediment, especially in Lakes Needwood and Frank, results in inordinately long periods of high concentrations after storm events. This is a failing of the model that must be considered in analysis of results. Similar results were obtained in the other District reaches (i.e., good calibration, poor verification). It should be noted that loading rates incorporate contributions from construction sites and upstream channel erosion as a necessity for calibration.

Fecal Coliform Bacteria. The simulation of fecal coliform bacteria proved to be quite good considering the large variability that as inherent in the monitoring of this constituent. The calibration results are plotted on a logarithmic scale in Figure 9-15 to allow the full range of concentrations to be depicted. Unfortunately, the DES elected to discontinue fecal coliform monitoring prior to the verification period. The low flow period at the start of calibration shows a sustained concentration of 2000 MPN/100 ml which is produced by the point source input of the assumed illegal discharges, leaking sewers, and/or failed septic systems in Montgomery County. The point source loads within the District were not sufficient to account for the significant difference between Stations 5 and 6 (see Chapter 8). It is presumed that the large flow observed, but unfortunately not monitored, at Klingle Branch (RC 75) was contributing a large amount of fecal contamination at this time. The dry weather monitoring program did not obtain a sample representative of conditions previously observed at this outfall. Calibration to storm events is good, but it should be noted that the observed instream concentrations far exceed literature values of urban runoff levels and it is suspected that surcharged sanitary sewers are contributing a large source of contamination during these events.

Chlorophyll 'a' and Benthic Algae. The simulation of chlorophyll a as a measure of phytoplankton (algae) biomass and benthic algae as a measure of attached aquatic plant growth is an important factor in the diurnal and seasonal variation of the previously discussed water quality constituents. There is little or no actual monitoring data of either of these parameters. The sampling of chlorophyll a during the course of this study provided guidance but is no sure indication of conditions during the calibration and verification periods. Since algal processes influence virtually all other parameters simulated, the calibration and verification results of these constitutents attest to the validity of the model representation of these important biological elements of water quality.

Combined Sewers. The model representation of combined sewers, as previously described, incorporates the 31 combined sewer overflow structures into two combined sewer segments, each with a certain raw sewage inflow, tributary area, and conveyance capacity. During the calibration period, the model simulated an overflow of each of these segments for the August 30 storm:

	Combined Sewer Segment 1 (Reach 50)	Combined Sewer Segment 2 (Reach 70)
Overflow Volume (million gallons)	14.5	12.9
Duration of Overflow (hours)	1	1
Average Concentration:		
BOD (mg/l)	8.9	13.7
Ammonia Nitrogen (mg N/l)	1.85	1.43
Nitrate Nitrogen (mg N/l)	0.71	0.97
Orthophosphate (mg P/l)	0.23	0.28
Suspended Solids (mg/l)	1,350	1,060
Fecal Coliforms (MPN/100 ml)	247,000	249,000

One reason for the selection of this time period for calibration is the flow monitoring of three combined sewer overflow structures within the basin by O'Brien & Gere Engineers for the D.C. DES (Reference 4). During the August 30 event, these monitors recorded combined sewer overflows of:

Overflow Structure	Location	Overflow Volume (million gallons)	Duration of Overflow (minutes)
52	Slash Run Trunk Sewer	3.5	65
55	Northwest Boundary Trunk Sewer	11.2	20
70	Piney Branch	21.3	30

The combined tributary area to the three overflows here is approximately 3760 areas or 84% of the total 4500 acres of combined drainage in the watershed. Model simulation results indicate a total overflow of 27.4 million gallons compared to 36.0 million gallons measured at these monitoring points. Although this is well within an acceptable margin of error, there is indication of undersimulation by the model representation.

Examination of the hydraulics of the combined sewer system in the District of Columbia is required to denote the limitations of the HSP model configuration to simulate these overflow events. The time of concentration (the amount of time it takes for a raindrop to travel from the outer edge of a drainage basin to the mouth) of the combined sewer drainage basins delineated in Figure 9-11 is generally less than 30 minutes. This means that, to accurately simulate flows in these areas, precipitation and flow routing intervals of 30 minutes or less are required. The Hydrocomp Simulation Program can simulate at smaller time steps, but rainfall data is available at intervals of only one hour. Hence, the model developed here is unable to account for the peak rainfall intensities that occur within the one hour interval and govern combined sewer overflow volumes. For instance, an evenly distributed 1-inch rainfall in one hour may produce no overflow. However, a 0.7-inch rainfall in a one-half hour time period with no subsequent precipitation could very well produce such an event in the District combined system. The net result is that due to precipitation data limitations, the HSP model configuration, although sound in theory and hydraulic representation, is inherently incapable of reproducing overflow events from short duration, intense precipitation events. A uniform one hour distribution of rainfall is assumed, hence overflow volumes can be undersimulated if the distribution of precipitation within this hourly total is uneven.

Unfortunately, there are no water quality monitoring stations established at any of the Rock Creek combined sewer overflows to evaluate water quality model simulation results. The O'Brien & Gere monitoring (see Tables 8-14 and 8-15) of urban runoff and combined sewer overflows elsewhere in the District serve as guidance but are by no means applicable to the Rock Creek situation. Much more dilution of sewage is provided in the Rock Creek CSO's and the monitoring data is based upon a limited number of storm events; comparisons are enlightening but by no means conclusive. Comparison of different storm events, even on the same watershed or combined sewer area, shows a large amount of variability depending on the antecedant dry weather period and size of storm. Since the Rock Creek CSO's discharge only during the larger events, higher dilution of nonpoint source pollutants will be observed compared to monitoring results of the other District combined sewers.

Summary. The water quality calibration proved to be quite good and verified adequately when tested on an entirely different set of conditions of meteorology, hydrologic regime, and point source discharges. Limitations of the model lake simulation algorithms restrict its usage to simulate suspended solids during dry weather flows. Other water quality constituents associated with suspended solids such as phosphorus may also be affected by the inability of the model to simulate lake settling.

The minimum allowable time step within the model restricts its ability to accurately simulate combined sewer overflow volumes. Quality constituents of CSO are assumed to be adequately modeled. Biological simulation of phytoplankton and periphyton cannot be verified for lack of sufficient data, but results of simulation of closely associated and interactive water quality constituents serve witness to an adequate representation.

WATER QUALITY PROBLEM ASSESSMENT

The water quality model provides a tool to assess water quality status under a variety of conditions of meteorology, flow regime, land use, and pollutant discharge. Since all factors and interactions have been quantified by the model representation via calibration, it is now possible to perform cause and effect analysis of the observed water quality problems in Rock Creek.

EXISTING VERSUS FUTURE WATER QUALITY CONDITIONS

The calibrated water quality model was run for a one-year period of time covering the period from March 1978 through February 1979. This time span was selected so that the model could be further verified by the DES monitoring data and so that the model could provide insight as to the seasonal, spatial, and temporal trends that were observed in this data (see Chapter 8). This time period exhibited a higher than average amount of rainfall and runoff in the watershed, but extended dry weather periods provide a representative set of low flow conditions for evaluation. Precipitation for the year was recorded at 48.4 inches and streamflow at Sherrill Drive averaged 91.5 cubic feet per second compared to normals of 38.9 inches and 61 cfs, respectively.

Two separate sets of conditions were simulated for the year-long time period. Existing land use (see Table 9-8) within the watershed was modeled with the Rock Creek Interim Advanced Wastewater Treatment Plant discharging at its NPDES permit limitation of:

Flow	-	3.0 mgd
BOD-5	-	8.0 mg/l
Total Suspended Solids	-	8.0 mg/l
Orthophosphate Phosphorus	-	1.4 mg P/l (assuming 70% of total phosphorus)
Ammonia Nitrogen	-	0 mg N/l (assumed from typical AWT)
Nitrate Nitrogen	-	8.0 mg N/l (assumed from monitoring data)
Fecal Coliforms	-	200 MPN/100 ml
Dissolved Oxygen	-	6.0 mg/l

Future water quality conditions were evaluated using the ultimate land use pattern as proposed by the Maryland-National Capital Parks and Planning Commission and Montgomery County

Planning Board. No significant changes are assumed to occur in land use in the District of Columbia. Table 9-16 lists the ultimate land use acreages according to the model channel reach definition. In addition, future conditions in the watershed assume the Rock Creek IAWTP to be abandoned and no point source discharge from such is included.

Streamflow. Streamflow simulation of Rock Creek for existing and ultimate land use conditions demonstrates a dramatic shift in the hydrologic regime. For the base year of simulation (March 1978 through February 1979), an average streamflow of 89 cfs at the Maryland-D.C. boundary was simulated, 4.6 of which came from the Rock Creek IAWTP (see Table 9-17). During this period of time, an average flow of 91.5 cfs was recorded at the USGS Sherrill Drive streamflow gage. Ultimate land use conditions reflect a high degree of imperviousness in the upper basin and average streamflow increased 10% to 98 cfs (without the Rock Creek IAWTP discharge) at the Maryland-D.C. line.

The distribution of flows over the year shows a significant shift, also. The increased imperviousness for future conditions allows rapid runoff of stormwater and decreases the amount of groundwater recharge which sustains natural dry weather streamflow. As a result, the following changes can be seen at the Maryland-D.C. line (note the additional impact of the 4.6 cfs discharge from the IAWTP on low flow regime):

	Number of Days Flow Exceeds Indicated Amount	
Flow (cfs)	Existing	Future
10	365	336
20	307	292
30	269	262
40	234	223
50	204	197
100	136	134
200	67	87
500	24	35
1000	17	20

Hence, it can be seen that urbanization of the upper watershed will produce a wider range of flows in Rock Creek with lower and more frequent lows and higher highs in the total hydrologic regime.

Temperature. Water temperature in Rock Creek does not exceed the District of Columbia standard of 32°C for either existing or future land use conditions, as was discussed in Chapter 8. However, temperatures in the range of 24-28°C are fairly common and pose a limitation to the survival of

TABLE 9-16
HSP WATER QUALITY MODEL CHANNEL REACHES - ULTIMATE LAND USE (ACRES)

Reach	Total Area (mi^2)	Seg. #6 Comm-Ind	Seg. #5 Multi-family	Seg. #4 Urban-Med	Seg. #3 Urban-Low	Seg. #2 Rural-Resid.	Seg. #1 Open-(Pasture/ Cropland)
2	12.26	225	155	-	2,420	2,650	2,400 (740)
4	12.06	115	40	-	3,065	2,620	1,880 (755)
6	15.69	2,005	975	4,245	385	895	1,535 (170)
8	18.02	1,740	305	7,650	690	135	1,010 (0)
10	0.70	40	5	180	40	-	185 (0)
20	2.28	220	175	325	245	85	410 (0)
30	1.65	10	5	75	400	-	565 (0)
40	4.60	355	165	340	1,135	105	845 (0)
50 (CSO#1)	4.15	205	1,390	550	255	-	255 (0)
60	1.33	95	65	10	230	15	435 (0)
70 (CSO#2)	2.90	735	630	10	275	100	105 (0)
80	0.51	45	5	-	5	5	265 (0)
Total	76.15	5,790	3,915	13,385	9,145	6,610	9,890 (1,665)

TABLE 9-17
MASS DISCHARGE COMPARISON OF WATER QUALITY CONSTITUENTS

Water Quality Constituent	Units of Mass	Existing: Reach 8 (Near Md.-D.C. Line)	Existing: Reach 80 (Mouth)	Existing: Rock Creek IAWTP	Existing: Mont. Co. Discharges	Existing: D.C. Discharges	Existing: Combined Sewer Overflows	Future: Reach 8 (Near Md.-D.C. Line)	Future: Reach 80 (Mouth)	Future: Rock Creek IAWTP	Future: Mont. Co. Discharges	Future: D.C. Discharges	Future: Combined Sewer Overflows
Flow	cfs	89	107	4.64	.025	.051	.205	98	116	0	.025	.051	.205
BOD-5	lbs/day	2,600	2,840	200	0.9	1.8	11.8	2,940	3,160	0	0.9	1.8	11.8
Total Suspended Solids	lbs/day	321,000	408,000	200	0.9	1.8	1,800	390,000	477,000	0	0.9	1.8	1,800
Orthophosphate Phosphorus	lbs/day	107	120	50	0.03	0.06	0.34	64	77	0	0.03	0.06	0.34
Ammonia Nitrogen	lbs/day	560	680	0	0.12	0.57	1.7	510	630	0	0.12	0.57	1.7
Nitrate Nitrogen	lbs/day	730	790	200	0	0	1.0	490	550	0	0	0	1.0
Fecal Coliform Bacteria	Number x 10^{10} per day	26,300	17,600	2.3	153	312	137	30,900	20,000	0	153	312	137

sensitive fish species such as trout. The absence of any known thermal discharges leads to the conclusion of a natural condition brought about by two factors. Large lengths of the Rock Creek watercourse have been cleared of brush and/or trees for picnic groves and to afford a scenic view to the car traveller, thus eliminating natural shading of the stream surface. Channel bank erosion is also working to destroy this natural canopy.

The location of Rock Creek within the metropolitan D.C. area subjects the watershed to the influences of the 'urban heat island.' The large structures and paved areas of urbanized regions such as the Washington metropolitan area, in addition to the vast amount of energy consumption that goes along with it, creates an 'island' of greater temperature than the surrounding natural landscape. Temperatures in downtown Washington are typically 3 to 4°F higher than surrounding rural regions in Maryland and Virginia and Rock Creek is thus affected.

Dissolved Oxygen. The balance of dissolved oxygen in a natural stream system is a quite complex interaction of numerous variables. The DES monitoring data provided a valuable data base to define trends in the stream that necessarily, by means of calibration, are reflected within the model. Simulation results provide an extended data base to further define the instream balance and relationships. In addition, critical periods of low dissolved oxygen concentration are predicted, a function that periodic grab sample monitoring cannot perform.

There are two sets of criteria that are used to judge dissolved oxygen levels; a minimum level of 4.0 mg/l at any time and a daily average minimum of 5.0 mg/l. Table 9-18 presents a comparison of model simulation results of dissolved oxygen for existing and ultimate conditions. It can be seen that only in the upper reaches of Rock Creek is there violation of standards. The 4.0 mg/l level was breached twice under existing conditions with an expected duration of 8 hours and five times under future conditions with an expected duration of only 3.5 hours. As discussed in Chapter 8, reaeration along the fall line apparently replenishes any oxygen depletion from this point on. Indications of existing and future land use simulation results are; average dissolved oxygen concentrations are unaffected but frequency and duration of D.O. sags are changed.

Table 9-19 presents a comparison of storm events for existing and future conditions. Because of increased imperviousness, the flows and BOD concentrations are higher under future land use conditions. Resulting minimum dissolved oxygen concentrations are mixed, but it can generally be seen that an additional sag of 0.2 to 0.3 mg/l is the result. Note

TABLE 9-18

MINIMUM DAILY DISSOLVED OXYGEN EXCURSIONS - EXISTING VERSUS FUTURE CONDITIONS

	Reach 8 (Near Md.-D.C. Line)		Reach 40 (Peirce Mill)		Reach 80 (Mouth)	
	Existing	Future	Existing	Future	Existing	Future
Average Dissolved Oxygen (mg/1)	9.2	9.3	10.2	10.2	10.2	10.2
Minimum Dissolved Oxygen (mg/1)	3.3	3.6	4.4	4.7	4.3	4.0
Minimum Dissolved Oxygen for Continuous 24-Hour Period	6.1	5.9	7.5	7.3	6.7	6.3
Number of Days with Minimum Dissolved Oxygen Less than 4.0 mg/1	2	5	0	0	0	0
Number of Days with Minimum Dissolved Oxygen Less than 5.0 mg/1	14	22	1	2	6	18
Expected Length of Duration of Dissolved Oxygen Less than 4.0 mg/1 (hours)	8.0	3.5	0	0	0	0
Expected Length of Duration of Dissolved Oxygen Less than 5.0 mg/1 (hours)	7.0	7.3	6.0	1.5	3.5	4.5

TABLE 9-19
COMPARISON OF STORM EVENTS - EXISTING VERSUS FUTURE CONDITIONS
AT REACH 20 (SHERRILL DRIVE)

Date	Daily Flow (cfs)		Maximum BOD (mg/l)		Dissolved Oxygen (mg/l)	
	Existing	Future	Existing	Future	Existing	Future
3/3/78	160	202	8.6	10.8	12.6	12.9
3/10/78	175	220	8.7	9.9	11.7	11.5
3/26/78	1111	1241	13.1	17.0	10.1	10.4
4/19/78	178	234	19.6	23.9	8.6	8.5
5/4/78	262	365	7.4	9.3	9.3	9.3
6/4/78	68	73	12.7	18.8	5.4	4.9
6/13/78	121	153	13.7	15.7	7.4	7.3
6/21/78	98	125	9.8	13.2	4.6	4.2
7/8/78	61	67	12.3	14.2	5.0	4.5
7/16/78	89	112	12.4	14.3	6.1	5.8
7/31/78	344	491	16.4	18.2	4.7	4.2
8/28/78	79	101	17.5	21.5	4.3	4.0
8/31/78	319	474	5.8	6.0	5.6	5.6
9/13/78	146	203	17.8	18.2	5.9	5.6
9/22/78	41	44	16.2	17.1	4.6	4.3
10/4/78	55	64	22.3	27.4	7.4	7.0
11/17/78	101	134	20.6	24.0	8.7	8.5
11/27/78	221	311	15.0	18.0	13.0	12.9
12/20/78	41	47	18.9	21.0	10.9	10.8
12/31/78	101	126	11.1	14.4	11.7	11.8
1/20/79	319	397	9.1	10.6	12.2	12.6
2/7/79	229	257	11.2	15.4	12.4	12.6

that the minimum levels recorded here were obtained from computer printout of 6-hour intervals of simulation results; hence, the levels here may not be the actual minimum concentrations. This is the reason that some D.O. concentrations actually increase under future conditions. Simulation results indicate that, although sags are more pronounced under future conditions, the duration is much shorter. Apparently, increased reaeration and dilution in the later stages of the storm hydrograph as a result of higher velocity and flow effects a more rapid recovery of D.O. levels.

Storm events are only a small part of the hydrologic regime of Rock Creek. Low flow conditions can also present depleted dissolved oxygen concentrations in a natural stream, especially when point source discharges are significant. A comparison of two separate days of low flow simulation for existing and ultimate land use conditions is presented in Tables 9-20 and 9-21. The first, a summer low flow condition in late July, shows slightly lower minimum and daily average dissolved oxygen in the upper reaches of Rock Creek near the Maryland-D.C. border for existing conditions (with Rock Creek IAWTP). Below this point, however, the increased amount of flow and velocity apparently reaerates the natural streamflow at a faster rate and D.O. levels are significantly higher. Model results indicate that the discharge from the IAWTP of BOD effects a sag of dissolved oxygen in the Maryland reach that is almost entirely recovered by the time flow reaches the District.

A more extreme low flow period is illustrated in Table 9-21 which depicts a fall day in mid-October. Comparison of D.O. concentrations confirms the conclusions reached from inspection of the summer condition. Slight differences are noted here, however, due to a variance in water temperature. The treatment plant discharge serves as a slight thermal discharge to Rock Creek during late fall and winter. This promotes lower dissolved oxygen levels by reduction of D.O. solubility. This condition is not critical since at these temperature levels D.O. is never near criteria levels in the stream.

Biochemical Oxygen Demand. As might be inferred from previous discussion, the increased imperviousness of the Montgomery County portion of the watershed not only increases the streamflow of Rock Creek during storm events, but concentrations and mass loads of oxygen-demanding organics are also significantly modified. Table 9-17 shows BOD mass delivery to the District to increase 13% from 2600 to 2940 pounds per day from existing to future conditions. Average concentrations decrease from 2.92 to 2.78 mg/l, however. One must consider the impact of discharge of 200 lbs/day by the Rock Creek IAWTP when reviewing these figures. The increase of total BOD load is even greater since this discharge is not included in future conditions.

TABLE 9-20
WATER QUALITY CONSTITUENT AVERAGE CONCENTRATIONS
LOW FLOW CONDITION - JULY 27, 1978

Water Quality Constituent	Units of Concentration	Reach: 8 (Near Md.-D.C. Line)		10 (West Beach Dr.)		20 (Sherrill Dr.)		30 (Missouri Rd.)		40 (Peirce Mill)		60 (Calvert St.)		80 (Mouth)	
		Existing	Future	Existing	Future	Existing	Future	Existing	Future	Existing	Future	Existing	Future	Existing	Future
Flow	cfs	23.4	18.1	23.6	18.3	23.9	18.7	24.7	19.4	25.8	20.6	26.6	21.3	26.9	21.8
Temperature	°C	23.8	23.9	24.2	24.2	24.2	24.3	24.2	24.3	24.2	24.3	24.4	24.5	24.7	24.8
Average Daily Dissolved Oxygen	mg/l	6.7	6.7	6.4	6.2	6.6	6.1	6.7	6.2	7.3	6.9	7.5	7.1	6.3	5.5
Minimum Daily Dissolved Oxygen	mg/l	5.7	5.8	5.2	5.3	5.5	5.0	5.7	5.2	6.1	5.8	6.2	5.9	5.1	4.6
BOD-5	mg/l	4.8	4.5	4.5	4.2	4.4	3.9	4.2	3.7	4.1	3.4	4.1	3.3	4.0	3.0
Orthophosphate Phosphorus	mg P/l	0.28	0.02	0.27	0.02	0.25	0.02	0.24	0.02	0.24	0.02	0.23	0.02	0.23	0.02
Ammonia Nitrogen	mg N/l	0.64	0.78	0.64	0.76	0.72	0.87	0.72	0.85	0.71	0.83	0.71	0.82	0.70	0.81
Nitrate Nitrogen	mg N/l	1.93	0.28	1.86	0.25	1.79	0.23	1.72	0.22	1.58	0.21	1.47	0.18	1.43	0.16
Fecal Coliforms	MPN/100ml	3800	6200	2200	3400	1400	2100	1000	1500	1300	1700	1800	2200	1500	1800
Chlorophyll a	ug/l	13.9	16.8	13.8	16.5	13.5	15.7	13.2	15.1	12.5	13.9	12.3	13.4	12.8	13.2
Benthic Algae	mg/m^2	593	593	591	590	591	591	591	591	592	592	590	590	448	449

TABLE 9-21
WATER QUALITY CONSTITUENT AVERAGE CONCENTRATIONS
LOW FLOW CONDITION - OCTOBER 18, 1978

Water Quality Constituent	Units of Concentration	Reach 8 (Near Md.-D.C. Line)		10 (West Beach Dr.)		20 (Sherrill Dr.)		30 (Missouri Rd.)		40 (Peirce Mill)		60 (Calvert St.)		80 (Mouth)	
		Existing	Future	Existing	Future	Existing	Future	Existing	Future	Existing	Future	Existing	Future	Existing	Future
Flow	cfs	13.6	8.6	14.0	9.0	14.5	9.6	15.0	10.2	15.5	10.6	15.8	10.7	16.0	10.8
Temperature	°C	8.2	7.3	7.6	6.9	7.3	6.8	7.1	6.7	7.0	6.6	6.6	6.4	6.6	6.5
Average Daily Dissolved Oxygen	mg/l	10.2	10.7	10.2	10.6	10.7	10.9	11.1	11.0	11.4	11.4	11.6	11.6	11.1	10.9
Minimum Daily Dissolved Oxygen	mg/l	9.8	10.1	9.7	9.9	10.2	10.2	10.5	10.3	10.8	10.5	10.9	10.7	10.2	9.7
BOD-5	mg/l	2.7	2.4	2.1	1.8	1.8	1.5	1.5	1.3	1.3	1.2	1.2	1.2	1.0	1.0
Orthophosphate Phosphorus	mg P/l	0.50	0.05	0.50	0.05	0.49	0.05	0.48	0.04	0.47	0.04	0.47	0.05	0.47	0.05
Ammonia Nitrogen	mg N/l	0.45	0.60	0.45	0.60	0.61	0.78	0.59	0.76	0.59	0.75	0.63	0.76	0.65	0.78
Nitrate Nitrogen	mg N/l	3.28	0.80	3.25	0.80	3.18	0.79	3.13	0.78	3.01	0.76	2.97	0.75	2.95	0.74
Fecal Coliforms	MPN/100ml	4600	7000	3300	4900	2600	3800	2200	3100	3300	4600	4800	6700	4700	6500
Chlorophyll a	ug/l	5.9	8.6	5.6	8.2	5.3	7.7	5.1	7.3	4.7	6.7	4.6	6.5	4.5	6.4
Benthic Algae	mg/m^2	153	108	108	87	93	82	86	81	83	83	82	87	186	207

The principle source of BOD during storm events is urban impervious surfaces. Higher concentrations are noted during short intense storms that are preceded by long dry weather periods of pollutant buildup. During the initial flush of such events, concentrations of over 20 mg/l are common in model simulations. Such high levels have not been monitored by DES personnel, primarily because wet weather monitoring is performed after the initial flush or even after the hydrograph peak. Large storms result in dilution of BOD and lower concentrations. Table 9-19 demonstrates these relationships. It can be seen that the small summer storm events which comprise solely impervious surface runoff result in the lower and most critical dissolved oxygen sags.

Relatively high BOD concentrations can also be observed during dry weather conditions. The decay of phytoplankton and periphyton (benthic algae) can produce a significant source of oxygen demanding organics in a lake and stream system. The effect of these sources of BOD can be seen in comparison of Tables 9-20 and 9-21. Summer concentrations average 4.8 mg/l at the Maryland-D.C. line compared to 2.7 mg/l during the fall with its small amount of algae. The decrease in concentration from the upstream to downstream end of the District reach shows the primary source of BOD during low flow to be the upper watershed. This relationship was observed in discussion in Chapter 8. Also to be seen in the tables is the impact of the Rock Creek IAWTP discharge. Dilution and decay in the Maryland reach reduce the total impact to an increase of 0.3 mg/l of BOD at the District line.

Nutrients. The mass loads and concentrations of the various forms of nitrogen and phosphorus are significantly reduced when comparing existing and future land use conditions. The main reason for this relationship, as can be seen in Table 9-17, is the presence of the Rock Creek Interim Advanced Wastewater Treatment Plant in the base run of existing conditions. The discharge of 50 lbs/day of orthophosphate phosphorus and 200 lbs/day of nitrate nitrogen comprise 47% and 27%, respectively, of the total delivery to the District. Average concentrations of the nutrient forms are:

	Reach 8 (Md.-D.C. Line)		Reach 80 (Mouth)	
	Existing	Future	Existing	Future
Orthophosphate Phosphorus (mg P/l)	0.12	0.06	0.12	0.07
Ammonia Nitrogen (mg N/l)	0.63	0.48	0.68	0.54
Nitrate Nitrogen (mg N/l)	0.82	0.46	0.79	0.47

Natural instream concentrations of orthophosphate phosphorus are significant as a limitation to aquatic plant growth. The discharge of 50 lbs/day of phosphorus by the Rock Creek IAWTP results in sufficiently available phosphorus in Rock Creek such that there is no such limitation. Dramatic increases can be observed in the low flow concentrations in Tables 9-20 and 9-21. There is also a more than adequate supply of nitrogen for aquatic growth. Despite the abundance of available nutrients, model simulation results indicate no significant difference in the population of phytoplankton or benthic algae for existing and future conditions. Other factors apparently serve to limit the proliferation of aquatic growth. Phytoplankton require still water to reach any significant concentrations. Pools in the stream and Lakes Needwood and Frank act as sources of algae. However, the velocities and short travel time of Rock Creek apparently serve by advection to limit the maximum concentrations that can be attained.

The model representation of benthic algae was accomplished by engineering judgement and experience as there is no quantitative information available to determine instream relationships and factors. Substrate suitability, nutrients, turbidity, and stream velocities all can act as limitations to growth. Simulation and sampling results show that the growth of benthic algae is limited not by nutrients but by substrate factors and high streamflow velocities which scour the bottom growth.

Nitrogen concentrations and loads are not appreciably affected by the increased urbanization of the upper watershed under future conditions. In fact, when the IAWTP discharge is discounted, dilution during storm events results in a decrease of existing ammonia and nitrate loads and concentrations. The higher levels of nitrogen occur during low flow conditions when lake, groundwater, and point sources have their maximum impact.

High concentrations of nitrate nitrogen occur during fall low flow when algal uptake is minimal. Typical concentrations in excess of 3.0 mg N/l are not critical, however, as they pose no oxygen demand, are below criteria level, and are not a potential limitation to excessive aquatic plant growth. Ammonia nitrogen, however, exerts a significant oxygen demand and can reach possibly toxic concentrations in Rock Creek as discussed in Chapter 8. Model results are insufficient as indication of causal factors due to limited and unreliable data. The principle sources of ammonia in the District reach of Rock Creek are Montgomery County, which has no monitoring data available for ammonia nitrogen, and a suspected point source on Fenwick Branch.

Fecal Coliform Bacteria. Fecal coliform bacteria, as an indicator of microbiological integrity and health safety of a water body, is a chronic and pervasive problem of Rock Creek during all flow regimes. Model results show that at no time does the D.C. reach of the creek attain the District criteria of 200 MPN per 100 ml for contact recreational use. In fact, simulations predict concentrations less than 2000 MPN/100 ml for only 20% of the total time period.

During storm events, concentrations throughout the entire D.C. reach, as a rule, exceed 100,000 MPN/100 ml and there is no noticeable difference in levels from the upstream to downstream end, combined sewer overflows notwithstanding. It takes approximately 1 to 2 days for concentrations to recede to antecedent concentrations after each event. During dry weather, the point sources documented in Chapter 8 exert their maximum influence to maintain fecal levels in the range of 500 to 10,000 MPN/100 ml. Once again, this condition is observed throughout the entire length of the D.C. watercourse. Point sources from sewer leakage, failing septic systems, and other illegal discharges in Montgomery County are estimated to contribute 153×10^{10} fecal coliform bacteria per day to the District (see Table 9-17). The approximate 312×10^{10} bacteria per day contribution of illegal District sources maintain and further increase the resulting high concentrations. Interestingly, low flow concentrations are less in the existing condition base simulation compared to future conditions simply as a consequence of dilution by the Rock Creek IAWTP discharge (see Tables 9-20 and 9-21).

Suspended Solids. Although there is no District of Columbia standard for suspended solids concentrations in District water bodies, the levels observed in Rock Creek, with the associated turbidity, BOD, and nutrients, have been a source of concern since colonial times. Simulation results of existing conditions, portrayed in Table 9-17, indicate that a yearly average sediment delivery of 150 tons per day originates at the Maryland-District of Columbia border and results in an average concentration of 360 mg/l. District sources are estimated to add 44 tons per day or 21% of the watershed total. Urbanization of the upper watershed will increase sediment delivery 21% in the future, but average concentrations will remain essentially at the same level.

Note that the model representation of the watershed under future conditions does not attempt to evaluate the effectiveness of construction, urban and agricultural sediment control measures envisioned in the Draft Functional Master Plan for Conservation and Management in the Rock Creek Basin by M-NCPPC. Simulation results predict conditions on the basis of continuation of present source control practices.

It can be seen that the problem of sediment is a pervasive one that is an inherent product of urbanization. Concentrations commonly exceed 1000 mg/l during storm events and it typically requires 1 to 2 days for levels to recede below 100 mg/l. Dry weather simulation results are inadequate due to model limitations of lake and instream simulation (see previous calibration discussion). DES monitoring results indicate, however, that concentrations are more frequently below 100 mg/l in the lower D.C. reaches:

Station	Location	Percent of Samples Less than 100 mg/l
1	Md.-D.C. Line	50%
2	West Beach Drive	45%
3	Sherrill Drive	50%
4	Missouri Road	55%
5	Peirce Mill	60%
6	Calvert Street	65%

Conclusions of this analysis are that settling in the District reaches of suspended sediment of Maryland origin during dry weather flow results in reduction of load from the upstream to downstream end.

If a typical criterion of 80 mg/l of suspended solids is used for evaluation, it can be seen that the concentrations in Rock Creek are a chronic and severe problem that poses a significant limitation to aquatic biota.

Not easily addressable is the turbidity and pollutants associated with sediment particles. It is not within the context of this study to evaluate the extent and impact of this aspect of suspended sediment and very little data is available. However, turbidity is the most visible of pollutants in Rock Creek and constitutes a major element of the suspended sediment problem. Lakes Needwood and Frank and the source control management practices of Montgomery County can effectively mitigate the delivery of the major sediment load to Rock Creek. However, turbidity is produced by the fine silt and clay particles that do not settle out in lakes or sedimentation ponds. Consequently, although total suspended solids concentrations may be reduced to acceptable levels during storm events, turbidity is evident for several days and presents a significant impact to the aquatic biota.

<u>Combined Sewer Overflows</u>. The Washington, D.C. areas of combined sewers in the Rock Creek basin have long been

maligned and accused of all the pollution problems of Rock Creek Park. Monitoring and simulation results present evidence to the contrary. Table 9-17 lists the total yearly mass contribution of combined sewer overflow to Rock Creek as a result of model simulation. It is noted that model predictions are necessarily low due to time step limitations in simulation (see calibration discussion). Only two overflow events (August 13 and 30, 1978) were simulated, whereas O'Brien & Gere flow monitors recorded seven such events at the Piney Branch overflow from May through December 1978. Despite this limitation, simulation results provide a valuable representation of the order of magnitude of the problem of combined sewage. On a yearly basis, CSO contributes approximately 0.1% of the total flow of Rock Creek. Average concentrations of this contribution are:

Biochemical Oxygen Demand	10.7 mg/l
Orthophosphate Phosphorus	0.31 mg P/l
Ammonia Nitrogen	1.5 mg N/l
Nitrate Nitrogen	0.9 mg N/l
Fecal Coliform Bacteria	273,000 MPN/100 ml

When compared to the instream storm concentrations of pollutants, as previously discussed, these levels are no different than those of the urban runoff delivered at the Maryland-D.C. boundary. This could be expected since the Rock Creek combined sewer overflows must be diluted approximately 100 times with urban runoff to operate. Indeed, since CSO necessarily requires a large event to discharge to the watercourse, higher dilution results in smaller concentrations of pollutants (such as BOD) than those observed instream during small storm events when there is no CSO. It may be argued that the combined sewer system serves to mitigate urban runoff impact in Rock Creek by performing the function of diverting urban runoff into combined sewers and out of the basin during the smaller events.

The main and more severe impact of CSO is perceived to occur not during storm events, but during dry weather conditions. It is during this time that the malfunction of combined sewer overflow regulator structures and incomplete sewer separation programs contribute raw sewage to the lower reaches of Rock Creek and maintain the fecal coliform concentrations at an unsanitary level. Table 9-17 shows that the yearly contribution of the District point source discharges of fecal coliform bacteria exceeds that of all overflows during storm events.

REFERENCES

1. Hydrocomp International, Inc., Hydrocomp Simulation Programming Operations Manual, Palo Alto, California, 1976.

2. Cotsonis, A. and Howard, W., Sewer System Diversion, Intercepting, and Overflow Structures, D.C. Dept. of Sanitary Engineering, 1967.

3. Metcalf & Eddy, Inc., Wastewater Engineering: Collection, Treatment and Disposal, McGraw Hill, 1972.

4. O'Brien & Gere Engineers, Combined Sewer Overflow Study Potomac-Anacostia River System, Department of Environmental Services, Government of the District of Columbia, 1979.

CHAPTER 10
WATER QUALITY MANAGEMENT STRATEGIES AND RECOMMENDATIONS

WATER QUALITY MANAGEMENT STRATEGIES

Various concepts or alternatives to managing water quality are presented for the following general pollution abatement strategies: urban runoff, agricultural activities, instream controls, construction site erosion, and combined sewer overflows. Many of the concepts previously discussed as flooding and channel erosion management strategies are applicable to several of the pollution sources and are just briefly reviewed. The following section shall deal with recommendations of specific strategies that will mitigate the water quality problems identified in Chapter 9.

URBAN RUNOFF

Urban runoff controls can be broadly classified into best management practices (BMP) or storage and treatment. Possible BMP strategies are discussed in this section while storage and treatment options are summarized in the section on combined sewer overflows.

The object of Best Management Practice (BMP) is to prevent or reduce urban runoff pollution in order to protect or achieve a desired water quality. No single control measure discussed here is sufficient to control urban runoff, rather a combination of control measures is required. The control options to be discussed can be viewed in terms of the physical processes involved in urban runoff as discussed in Chapter 8. Figure 10-1 presents a schematic of the urban runoff process and shows appropriate control points.

Source control measures are designed to reduce or prevent the generation of pollutants. They include chemical application restrictions, proper refuse pick-up, improved automobile maintenance, illegal storm sewer discharge prevention, and anti-litter programs. After the pollutants have built up on the impervious land surface, they may be removed prior to a runoff event, thus reducing the pollutant load. Such measures include street sweeping and animal waste control. Reducing the peak flow and total volume of urban runoff decreases the transport capacity of the runoff and generates a smaller pollution load. Other runoff controls include diverting flow from highly erodable areas and preventing runoff from entering sensitive waters. Catch basins and ponded ditches can be periodically cleaned to help reduce the pollution load from these sources. Collection system controls are those devices and measures that are used in or utilize the stormwater runoff conveyance system. They include swirl concentrators, polymer injections, in line storage, and improved maintenance of the collection system. Storage and treatment of the collected runoff may also be considered. This could involve physical/chemical treatment, land disposal, biological treatment and disinfection.

TABLE 10-1
SUMMARY OF BEST MANAGEMENT PRACTICES FOR URBAN RUNOFF

Source Controls

- Litter
- Fertilizer and Pesticide Application
- Commercial and Industrial Stockpiles
- Road Maintenance
- Vegetative Debris
- Illegal Storm Sewer Discharges
- Refuse Pickup
- Industrial Spills
- Animal Control

Air Pollution Control

Accumulated Pollutant Removal

- Street Sweeping
- Private Parking Lot Sweeping

Runoff Control

- Natural Drainage
- Contour Landscaping
- Swale Drains
- Urban Land Management
- Onsite Detention/Retention Ponds

- Parking Lot Storage
- Rooftop Storage
- Recreational Area Storage
- Dutch Drains
- Porous Pavement
- Grass-lined Ditches
- Infiltration Basins and Seepage Beds

Conveyance System Cleaning

- Catch Basin Cleaning
- Ditch Cleaning

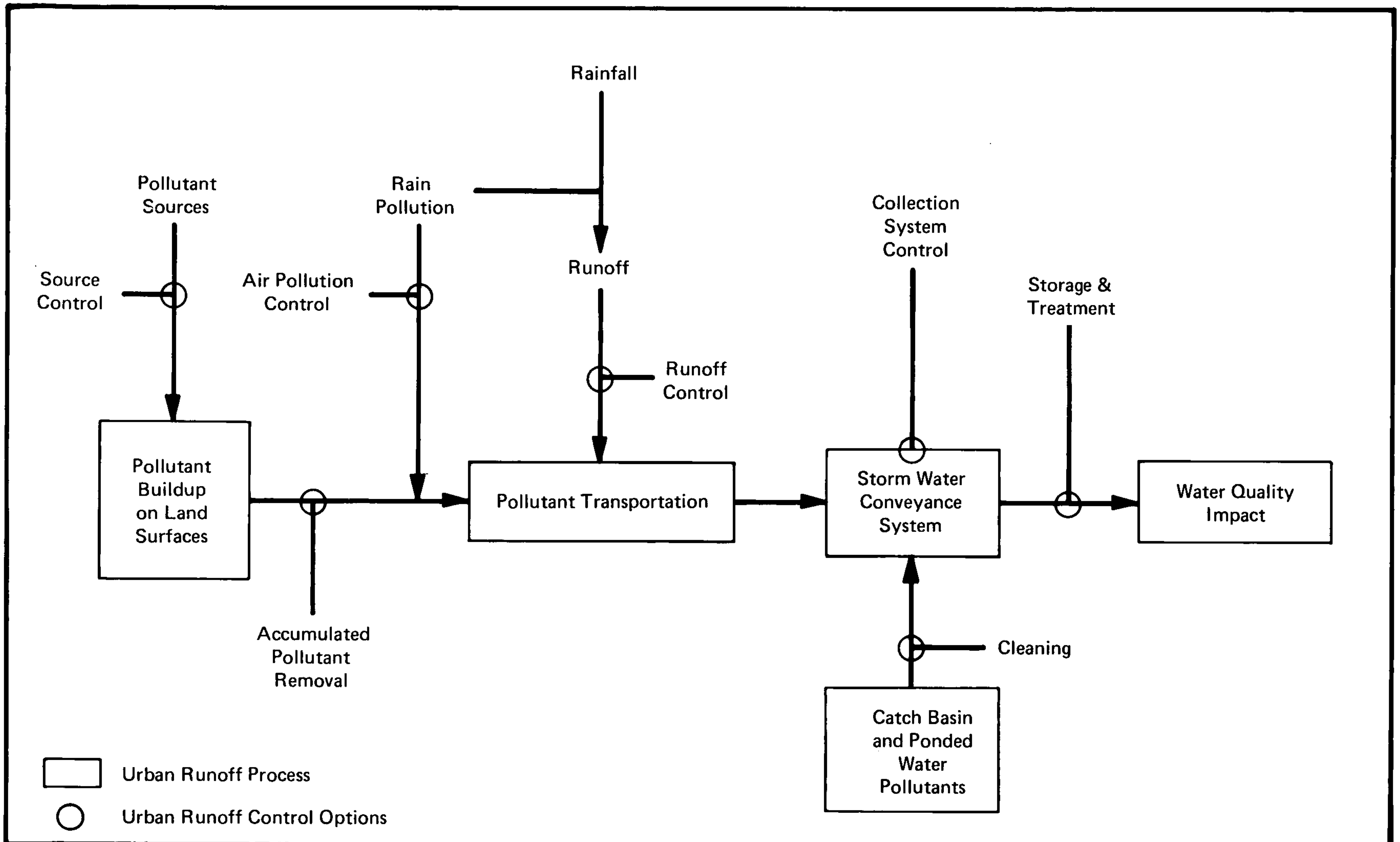


FIGURE 10-1: Urban Runoff Process & Control Schematic

In addition to considering the process of urban runoff, attention must be given to whether the urban catchment to be considered is an established or developing area. Established urban areas are generally unable to implement runoff control measures while newly developing areas can incorporate the controls in their basic plans. Established areas may also be so space limited that storage and treatment facilities would be impractical.

Table 10-1 summarizes the BMP options considered.

Source Control

An obvious way to reduce urban runoff pollution is to reduce or prevent the generation of the pollutants that accumulate on the urban land surfaces. The following sections discuss possible means to achieve this goal for several common sources.

Litter. Litter is responsible, in part, for the build-up of pollutants in urban areas. Public education plus effective and enforceable regulations and ordinances on street and property cleanliness are the most effective means to reduce the amount of litter. The Clean Community Program, sponsored by Keep America Beautiful, is an excellent means to educate the public, not only about litter as an eye sore, but also as a source of water pollution. The placement of easily identified, accessible litter containers that are properly maintained and frequently emptied can decrease littering and demonstrate the interest local governments have in reducing litter. Well advertised public clean-up campaigns can also help motivate citizens to keep the area cleaner and reduce future potential litter. The Clean Community Program would be very helpful in this endeavor.

General anti-litter ordinances that describe improper littering practices and establish fines for violations are needed, as well as specific ordinances for:

- Garbage and refuse collection
- Open trucks
- Public litter receptacles
- Refuse dumping
- Building construction and demolition
- Street construction
- Sidewalk sweeping
- Vacant lots
- Parking lots and garages
- Drive-in restaurants
- Trailer courts and campgrounds
- Sports stadiums

- Auditoriums and exhibition halls
- Theaters
- Food handling establishments
- Pet control
- Distribution of handbills
- Posting of notices and political posters
- Street vending
- Garden refuse
- Scavengers
- Weed control
- Dead animals
- Produce markets
- Direct discharges into storm sewers

Litter control is one of the most easily implemented and strongly recommended control measures.

Fertilizers, Herbicides and Pesticides. Many of the landscapes in urban areas could not be maintained without the use of fertilizers, herbicides and pesticides. Unfortunately overapplication of the chemicals is quite common, resulting in a readily transportable excess of the chemicals. Improper timing of application can result in a rain storm washing off most of the chemicals. Fertilizers result in overenrichment of nutrients in the receiving water, while pesticides are a major cause of concern due to their toxicity and persistence in the environment.

Control of fertilizers, herbicides and pesticides can be achieved by education of the public and commercial firms of the limited use of these chemicals, how to apply them, how much to apply, when to apply, and the proper storage of the chemicals. Another, less implementable, option is a professional licensing system for handlers of the chemicals, particularly commercial firms. A license would be awarded only to those who demonstrated competence in the handling of such materials, and could be revoked for failure to comply with applicable regulations designed to prevent surface or groundwater pollution. Public education through posted notices at major pesticide and fertilizer dealers is the recommended control option for these chemicals.

Stockpiles. Commercial, industrial, and municipal stockpiles that are unprotected can erode and present a water quality problem. This is especially true of stockpiled salt and other easily dissolved chemicals. Because of increasing concern regarding water quality, it is anticipated that this control would be implementable. The control would involve some public costs for inspection, but this is anticipated to be minimal. Stockpile protection would not necessarily have to involve the actual development of a structure, but could involve simple measures that trap eroded materials and prevent them from entering a water course. This control measure should be adopted, especially for stockpiles located near receiving waters.

Road Salting and Sanding. Salt and sand are used extensively during the winter months to improve driving conditions. Salt melts ice on streets and highways, and sand improves traction on ice and snow. Chloride is the commonly used indicator of water quality problems related to salting, and total suspended solids or turbidity are the commonly used indicators for water quality problems related to sanding.

Cyanide and other potentially harmful chemicals are often mixed with road salt as an anticaking agent to prevent cohesion of stockpiled salts. The type and concentration of these chemicals varies. Cyanide is generally used as an anticaking agent. However, the concentration of cyanide in the salt is not presently known, nor is its effect on water quality.

Road Maintenance. Roads that are poorly maintained experience a much higher pollutant build-up than those that are in good condition. This is principally due to the additional sediments common to deteriorating road surfaces.

Vegetative Debris. Leaves and grass clippings are a significant contributor of BOD, phosphates, and ammonia. A major problem with vegetative debris is that they are deposited in gutters and storm sewers where they decompose. During heavy rainfall, these materials are then washed to a nearby water course. Vegetative debris also increases the cost of catch basin maintenance.

Vegetative debris is typically collected once a week or less, and although encouraged, bagging of the debris is generally not required. It is quite possible for loose vegetative debris to lie in a gutter for over a week awaiting pickup. This practice can significantly add oxygen demanding and nutrient sources to runoff occurring prior to pickup. Regulations requiring debris to be bagged, bundled or put out for pickup no more than one day in advance would benefit water quality. Also more frequent pickups during certain times of the year (spring, early fall) should be implemented.

Illegal Dischargers. The purpose of this control is to assure that sanitary and other wastes are not discharged to the storm sewer system and that sanitary sewers do not leak or overflow to the stream system. In some areas, gas stations, swimming pools, vehicle washing operations and laundromats are connected to the storm sewerage system, rather than to the sanitary system. Consequently, wastewaters that should receive treatment are discharged without it. Enforcement of sanitary codes involves an aggressive inspection program which identifies illegal dischargers and requires them to connect to the sanitary system or treat their own discharges. Similarly, regular maintenance and inspection of sanitary lines is imperative to ensure proper function and transport of sewage without contamination of surface and ground waters.

Another common storm sewer discharge is oil wastes from individual automobile users and vehicle maintenance and cleaning operations. It may be possible to reduce illegal discharges of waste oil through recycling programs encouraged by public education, and by strict enforcement of the sanitary and litter ordinances. The principal problem of encouraging a recycling program is that it is difficult to provide the necessary incentive to recycle. The value of waste oil is not currently high enough to encourage individual users, such as those who maintain their own automobiles, to properly dispose of the oil and allow the development of a self-supporting program. Similarly, the use of punitive measures for discouraging the illegal discharge of oil is not anticipated to be effective because of the difficulty of catching violators.

Recent studies have shown that illegal discharges can have a predominant effect on stream biota and may be more important than pollutants that accummulate on the urban land surfaces.

Refuse Pickup. Present refuse pickup practices are often a source of litter and pollutants particularly in commercial and densely populated urban areas. Requirements for the use of covered trash cans and heavy duty plastic bags are needed. The bags should not be used for food wastes since dogs, birds, and other animals frequently break into them.

Proper training and emphasis must be given to the pickup of the refuse so that all the refuse is picked up and not left in the wake of the pickup truck.

Industrial Spillage. Immediate clean up of industrial spills of chemicals, oils, and other potential pollutants is required to prevent these substances from being washed off during a rainstorm. Education of industrial and commercial leaders to the potential water quality problems that can result from spills, and publicity of positive actions are good control practices for this problem. This should also apply to commercial activities such as car washes, gas stations, and similar operations.

Animal Control. It is expected that most of the fecal coliform contamination found in urban runoff is from the manure of urban animals, both domestic and wild animals. Animal control ordinances that require cleanup of pet manure in public areas are very difficult to enforce and typically unpopular. Again, public education is the prime control factor and should be implemented.

Advantages of Source Control Measures

The advantages of source control measures are:

- The pollution reduction is direct and occurs prior runoff.
- The majority of the controls are inexpensive
- Less litter, improved aesthetics, better feeling about one's community, etc.
- Other organizations have similar goals and interests.
- The control measures apply to both developing and developed areas.
- The controls are common sense measures.

Disadvantages of Source Control Measures

- The impact on water quality after the implementation of the control measures is not easily quantifiable.
- The controls require widespread inspections for enforcement and identification of offenders is difficult.
- Animal control ordinances are difficult to enforce.
- The measures require citizen involvement and changes in attitudes which may be difficult to achieve.

Air Pollution Control

Reducing the amount of air pollution will reduce the build-up of particulate fallout and entrappment of pollutants by falling raindrops. The concentrations of pollutants in precipitation were previously discussed in Chapter 8. Air pollution control may be costly and the source of the pollutants may not originate in the Rock Creek area so that control can not be exercised over all of the pollutant sources. EPA estimations show that air pollution control is generally less expensive than sweeping the accumulated pollutants off of the street.

Accumulated Pollutant Removal

Even with complete implementation of all the previously mentioned control measures, a buildup of pollutants on the urban land surfaces and particularly the streets is inevitable. If the pollutants can be removed prior to a runoff event then reductions in pollutant loads would be realized. Street sweeping and private parking lot maintenance are the primary control measures.

Street Sweeping. Historically street sweeping has been done for urban beautification, not water quality. However, even with present practices water quality benefits are realized.

The most common types of street sweeping are: mechanical broom sweepers; manual; vacuum sweepers; and combined mechanical and vacuum. Mechanical sweepers are the most commonly used by municipalities. The effectiveness of mechanical sweeping depends on: particle sizes to be swept; how often an area is swept; the number of passes made in an area; sweeper speed; and pavement conditions. Mechanical street sweeping is ineffective for fine solids, which account for only 5.9 percent of total solids, but 25 percent of oxygen demand. The following removal efficiencies have been estimated: total solids, 25 percent; BOD, 45 percent; COD, 30 percent; nitrates, 45 percent; phosphates, 20 percent; heavy metals, 50 percent; and total pesticides, 45 percent.

Vacuum sweepers with the vacuum action over the entire path of the sweeper can remove 90 percent of the dust and dirt compared to 50 percent for brush sweepers. Therefore, vacuum sweepers are much more effective as a pollutant removal device.

The accumulation of street surface contaminants may be minimized by increasing the frequency of street sweeping operations. Commercial areas generally need to be swept more often than other land use areas. The effectiveness may also be improved by sweeping an area more than once. Repeated passes over the same area sometimes can effectively reduce the amount of pollutants remaining. Improving present street sweeping practices may also result in a decreased pollutant buildup. The speed of travel of the street sweepers should be determined not by the speed necessary to cover a given area in a days work but rather by the speed that gives the optimum removal efficiency.

Next to street surfaces, parking lots are thought to be one of the largest contributors of non-point source pollution. As a result, frequent cleaning of parking lots would benefit water quality. An actively used parking lot should be swept six times a week.

Some of the advantages of street sweeping are:

- Primary control measure in existing urban areas.
- Programs already underway for aesthetic reasons.
- Highly visible control measure.
- Vacuum sweepers can have multiple uses: unclogging porous pavement, limited catch basin cleaning.
- Estimates of pollutant removal available.

Certain disadvantages associated with street sweeping are:

- Control of parked and abandoned cars is required.
- More expensive than source controls.
- Additional street sweepers may be required.
- Operator training for water quality control, rather than litter control required.
- Only feasible in highly urbanized areas with curbed streets.
- Vacuum sweepers required for best pollutant removal.
- Parking controls are unpopular.

Advantages of Built-up Pollutant Removal

- Removes pollutants before they are waterborne.
- Easily implemented.
- Major control measure for established urban areas.
- Can improve aesthetics of streets, parking lots and parks.

Disadvantages of Built-up Pollutant Removal

- Does not reduce sources of pollutants.

- Requires public education and street sweeper operator training.

- More expensive than source control measures.

- Parking control regulations are unpopular.

Runoff Control

Runoff control is designed to reduce the pollutant load of a runoff event by reducing the peak flow or total volume of the event, or by directing the runoff away from highly erodable or environmentally critical sites. This type of control is primarily applicable to developing areas although some of the control options may be practical for developed regions. The general approaches to this type of control are: delay of runoff on-site; increased infiltration on-site; large impoundments; using natural hydrology; and using diversion structures.

The concepts mentioned here are similar in nature and theory to those discussed in Chapter 6 for channel erosion and flooding control. Reduction of the flow rates will decrease the potential of the runoff to transport urban pollutants while reductions in the runoff volume will reduce the total pollutant load.

Natural Hydrology and Urban Land Management. These control methods are designed to use the existing hydrologic conditions to the maximum possible extent.

> Natural Drainage - maximize the use of the predevelopment drainage system; natural drainageways can be lined with vegetation or slightly modified in other ways to increase infiltration and retention. The principal advantage of natural drainage is that by eliminating the need for catch basins and storm sewers, significant cost savings can be realized by the developer. The major problem with this control is the requirement for maintenance. Because of possible multiple ownership, coordination of maintenance may be difficult.

> Contour Landscaping - involves grading the surface so that infiltration is increased and runoff is reduced; also involves the use of vegetation, so that runoff is discharged to vegetated areas for infiltration and storage.

> Swale and Ditch Storage - small grass-lined depressions that can either be natural or manmade, which collect storm runoff; infiltration and storage can be increased by maintenance of lush vegetation in the swale.

Urban Land Management - methods by which the effects of impervious surfaces can be minimized; encourage efficient use of land through open space planning, cluster-type development, and density control.

Some of the advantages of using natural hydrology and urban land management are:

- Open area concept is aesthetically pleasing.
- Requires low capital costs.
- Can reduce costs of storm sewer systems.
- Reduces hydrograph peak and total volume, thus decreasing erosion and pollutant load.
- Use of grass in systems can filter out some sediment.
- Infiltration recharges groundwater.

The disadvantages of using natural hydrology are:

- Possibility of flooding is increased due to less effective drainage.
- Swales and ditches may erode significantly if high runoff flows occur.
- Ponding can cause mosquito problems.
- Open ditches and swales attract children who may play in poor quality water.
- Vegetation requires maintenance.

Onsite Detention or Retention. Onsite detention involves the temporary storage of water from its runoff source while onsite retention involves the indefinite storage of stormwater runoff. Onsite detention/retention may be accomplished by a number of approaches:

- Storage in permanent ponds having provision for variable depth.
- Temporary ponding on parking lots and other paved areas.
- Temporary ponding on roofs of buildings.
- Temporary ponding on recreational areas.

These control measures can be effective, economical means of urban stormwater management. Besides controlling local flooding and water pollution, onsite detention may also provide aesthetic benefits, recreational opportunities, and reduced erosion and sedimentation hazards.

Onsite Detention/Retention (Storage) Ponds - onsite ponds are effective as a means to provide flood storage as well as to trap and control sediment and collect debris. They are simple to design and construct and are adaptable to the natural drainage pattern. One of the most desirable features of onsite ponds is that they can help to eliminate stormwater run-off problems before they occur. However, onsite impoundments will require periodic maintenance to remove sediment deposits and debris accumulation. Strict supervision of ponds is required to prevent accidents.

Parking Lot Storage - parking lots in commercial, industrial, and high density residential areas may be used to detain runoff. The runoff is stored in depressions constructed at drain locations. The stored water is slowly drained into the storm sewer system by reducing the size of the storm drain or increasing the spacing between the inlets at remote areas of the parking lot. If properly designed, the ponded areas could be located to cause as little inconvenience to the users as possible.

Rooftop Storage - stormwater may be temporarily stored on a flat or slightly sloping roof equipped with a controlled release drain. The drain is designed to allow a slow release of the stormwater so that if the rainfall rate exceeds this release rate, ponding occurs. The use of overflow scuppers prevents the water from ponding to an unacceptable level and overflowing along the roof.

Recreational Area Storage - recreational areas such as tennis courts, parks, ballfields, and ponds may be used for stormwater storage, since these facilities are generally not in use during rain events. Pervious areas will allow for increased infiltration, further reducing the flow peak. The areas should be designed for quick and thorough drainage.

Increased Onsite Infiltration. These control options are designed to increase infiltration on a site that has already been developed or to maintain the infiltration of a site undergoing development. The purpose of these techniques is as follows:

1. To maintain runoff volumes and peaks from areas undergoing urban development at or near natural conditions.

2. To maintain sufficient infiltration to shallow groundwater in order to to ensure that there is no appreciable decrease in the dry weather flow of streams.

3. To maintain recharge of major aquifers at a level equivalent to those under natural conditions.

4. To improve surface water quality.

<u>Dutch Drains</u> - dutch drains are gravel-filled ditches with an optional drainage pipe in the base that intercept the runoff prior to its getting to the stormwater conveyance system.

<u>Porous Pavement</u> - porous pavement includes asphalt, asphalt-concrete mixtures and precast lattice blocks and bricks that allow water to soak through the pavement and infiltrate.

<u>Grass-lined Ditches</u> - these are small grassed drainageways that can be used to replace storm sewers. Infiltration of runoff can be increased through ditch losses, and the roughness in the channel provided by the vegetation reduces water velocities and peak discharge. In addition, the grass in the ditch aids in filtering out many of the pollutants carried by the runoff.

<u>Infiltration Beds and Seepage Basins</u> - an infiltration bed or seepage basin is an excavated area of land that has been filled with rocks and gravel and overlies a soil with a high infiltration capacity. Stormwater runoff is directed to the bed or basin through an inlet screen or sediment trap which catches leaves, debris and heavier sediment particles.

Among the advantages of onsite infiltration are:

- Can reduce peak flows, thereby reducing erosion and particulate transport.
- Can reduce total volume of runoff.
- Can reduce costs of stormwater conveyance systems.

- Can be included in site development plans.
- Recharges groundwater supply.

The disadvantages include:

- Effectiveness is difficult to determine and depends on soil properties.
- Most of the techniques require maintenance.
- Limited to areas without seasonal high groundwater tables; otherwise, groundwater pollution may occur.
- Can increase the cost of development.

Advantages of Runoff Control Measures

- Can reduce peak flows thereby reducing erosion and particulate transport.
- Can reduce total volume of runoff thereby reducing the total pollutant load.
- Can reduce costs of storm water conveyance systems.
- Can be included in site development plans.

Disadvantages of Runoff Control Measures

- Does not directly reduce sources of pollutants.
- Can increase costs of developments.
- Storage/detention devices can result in mosquito, algae, and user inconveniences.
- Improperly designed systems can result in structural damages, groundwater pollution, and flooding problems.
- Determination of pollution reduction is difficult.
- Most control options require routine maintenance.

Conveyance System Cleaning

Catch basins and ponded water in ditches can trap organics which decay in the quiescent water and can result in a large oxygen demand for a subsequent runoff event. Catch basin and ditch cleaning is one of the most discussed non-structural pollution control measures. The amount of pollution removed by this method, however, would probably be small.

Historically, the role of catch basins was to minimize sewer-clogging by trapping coarse debris and to reduce odor emanations from the sewers by providing a water seal. In early sewer systems, catch basins were important because of the number of impaired streets, the use of flat grades, inefficient means of sewer-cleaning, and low flows in the sewer systems. With improvements in street surfacing, design for self-cleaning velocity in sewers, and the advent of street sweeping and improved sewer-cleaning techniques, the benefits of catch basin cleaning have been reported as being marginal.

It is recommended that where possible self-cleaning sewers be designed and catch basins eliminated. Designing ditches to minimize the amount of ponding is similarly recommended.

AGRICULTURE CONTROL PRACTICES

There are two basic strategies for controlling agricultural nonpoint sources. The first is to manage the application of wastes and chemicals to the cropland while the second involves the management of soil and water movement. The amount of water pollution caused by agriculture is more dependent on production and waste management practices than on the volume of wastes involved.

While the management of waste and chemical applications may appear to be an inherently efficient strategy, this is not necessarily true. It requires a high level of farm management skills and generally consumes substantial labor and machine time which is in short supply during the planting and growing seasons. As a result these practices are often not economically advantageous to the farmer. Also, they are very difficult to monitor.

Because of its nutrient value, manure should be considered a resource rather than a waste, and, when possible, use of all waste as fertilizer or soil conditioner should be evaluated and incorporated into an owner's management plan. The land provides a natural treatment system for animal wastes, and land spreading is a very effective means to prevent water pollution. Proper land spreading can reduce pollutants entering streams by more than 99 percent.

Management of soil and water movement from agricultural land can be greatly influenced by differences in watershed characteristics such as slope, soil permeability, surface culture, drainage pattern, degree of erosion, and other hydrogeologic factors. This requires individually tailored control systems for different watersheds.

Soil and Water Movement Control

Soil and water movement control practices have several advantages. They serve to maintain or improve agricultural productivity, and certain practices can be cost-shared with the Federal government. In addition, monitoring of the practices can be relatively straightforward. The practices are not without drawbacks, however. Many farmers have been reluctant to implement soil and water conservation programs since the benefits to agricultural productivity are generally realized in the long run. The immediate benefits are seldom obvious. The practices may also aggravate certain water quality problems. The retention of runoff water on the field may result in increased movement of water and soluble pesticides and nitrate to groundwater aquifers. Minimum tillage, which is an effective means of erosion control, generally requires increased use of pesticides for weed control and insect control.

Table 10-2 describes techniques to control nonpoint pollution from agricultural activities. The most important of these techniques are following standard soil and water conservation practices and limiting livestock access to streams.

INSTREAM CONTROL PRACTICES

Once pollutants have reached a natural stream system, there are certain strategies that can be employed to mitigate the damaging and undesirable impacts created. Although instream control techniques can accelerate the recovery of a stream when used alone, they are much more effective when used with control measures that reduce the external loads to the system. Instream controls alone generally provide only temporary relief from the effects of uncontrolled urban and agricultural runoff.

The following techniques to improve water quality are considered: impoundments, treatment of flow, nutrient inactivation/precipitation, chemical controls, sediment dredging, and aeration/circulation.

TABLE 10-2
TECHNIQUES TO CONTROL NONPOINT POLLUTION
FROM AGRICULTURAL ACTIVITIES

1. Non-Structural Control of Agricultural Runoff and Erosion

   No-till planting in prior crop residues
   Minimum tillage techniques
   Sod based rotations
   Meadowless rotations
   Winter cover crops
   Improved field operations timing
   Plow-plant systems
   Contouring
   Contour strip cropping
   Narrow row cropping
   Ridge planting
   Change in land use

2. Structural Methods to Control Agriculture Runoff and Erosion

   Construction of ponds
   Terracing
   Diversions
   Grassed outlets
   Subsurface drainage systems
   Reforming land surface

3. Practices to Control Nutrient Loss From Crop Raising Activities

   Eliminating excessive application of nutrients
   Timing fertilizer application
   Crop rotations
   Plowing under green legume crops
   Slow release fertilizers
   Control of nutrient effectiveness

4. Practices to Control Pollution From Confined and Pasture Animal Feeding

   Prevent direct discharge of manure to streams.
   Provide runoff collection systems for livestock holding areas having bare soil.
   Apply livestock wastes to cropland.
   Apply wastes uniformly.
   Govern rate, time, and frequency of application for maximum nutrient utilization by plants.
   Select disposal areas with low erosion potentials.
   Do not apply waste on grassed waterways or other drainage paths.

TABLE 10-2 (CONTINUED)
TECHNIQUES TO CONTROL NONPOINT POLLUTION
FROM AGRICULTURAL ACTIVITIES

Do not apply manure to frozen or water-saturated soils.
Plow waste under on barren fields.
Locate livestock holding areas away from unvegetated or sparsely vegetated slopes leading directly to streams.
Provide at least 100 feet of vegetated area between confinement areas and resting areas from streams or drainage paths.
Pasture animals away from streams and drainage paths.
Fence them out unless stream banks prevent direct access to water.

5. Practices to Control Pesticide Loss From Agriculture Activities

Controlled application methods
Using alternative pesticides
Optimizing pesticide formulation
Eliminating excessive treatment
Optimizing time of day for pesticide
Optimizing date of pesticide application
Controlling pesticide application rates
Managing aerial applications
Biological control
Crop rotation
Growing resistant plant varieties
Mechanical control methods
Optimizing crop planting time

6. Practices to Maintain or Create Proper Water Temperatures for Fish

Minimum tillage
Grassed waterways
Streambank protection from livestock
Maintain buffer vegetation along streams

Impoundments

Similar to the concept of onsite detention/retention of runoff, impoundments within the natural stream system act to provide storage of flood waters and trap sediment and debris that would otherwise be transported downstream. Size of the structure can vary from a small silt and debris trap to a large lake. Size, to a great degree, dictates the efficiency of sediment removal. Maintenance problems, compared to onsite ponds, are reduced since large impoundments have more available storage, control greater drainage areas, and all sediment and debris is collected in a centralized location. Significant flood control, erosion, recreation, and water pollution benefits can also be realized by construction of large impoundments. Of disadvantage is the large capital expenditure and land area required to construct the facility. For this reason, less expensive silt and debris traps that do not have the flood control and recreation benefits may be preferable. Some of the ensuing instream control practices can be incorporated in conjunction with a large impoundment to augment the effectiveness of water pollution control and/or improve the quality within the impoundment for recreation and fish and wildlife usage.

Treatment of Streamflow

The treatment of all or a substantial portion of the streamflow has potential as a way of controlling sediment, bacteria and/or nutrient concentrations. Techniques of treating streamflow include aeration, flocculation, disinfection and full scale wastewater treatment. High capital and operation costs and the potential ecological damage are serious limitations to the use of this control technique.

Nutrient Inactivation/Precipitation

Nutrient inactivation/precipitation involves the addition of specific chemical substances to stream or lake waters to: (1) alter the form of a nutrient to render it unavailable for use by plants and algae, (2) prevent the release or recycling of nutrients within a lake, or (3) remove nutrients from the photic zone so that it is less likely to be utilized.

Chemical Controls

Historically, chemical treatments have been the most widely used control techniques in eliminating nuisance algal blooms. The use of chemicals has the greatest justification and utility in highly eutrophic lakes where nutrient sources cannot be effectively controlled, and other management alternatives are infeasible.

Sediment Dredging

Inasmuch as bottom sediments represent a potential nutrient, metal, organic and pesticide source, sediment removal is often advocated as a means of reversing or retarding anaerobic, toxic, or eutrophic conditions. Although it is typically undertaken simply as a cosmetic approach to stream and lake improvement, dredging may also improve the status of the system by uncovering a stratum that does not contain or release appreciable quantities of pollutants and provides adequate biologic habitat.

Aeration and/or Circulation

Circulation and aeration by mechanical means is a common method of increasing the use potential of streams and lakes. The basic objective behind virtually all aeration projects is improved dissolved oxygen conditions for fishery or water quality management purposes.

CONSTRUCTION SITE EROSION AND SEDIMENTATION

Erosion and the resulting sedimentation is probably the most severe water quality problem in the Rock Creek watershed. Other pollutants associated with the sediment can impose an even greater impact. A brief description of the erosion process will provide a further understanding of the control measures considered.

Overland flow erosion, which includes sheet, rill and gully erosion, occurs during rainfall events. The impact of raindrops hitting the soil dislodges and breaks up the soil particles. The soil can be moved several feet by the rainfall, and larger soil particles are broken into smaller particles which are easier to remove by overland flow. The small particles can also fill voids between the larger soil grains and decrease the infiltration capacity of the soil. As the rainfall event continues, overland flow begins and transports soil from the land surface. The transported soil comes from soil particles loosened by rainfall impact, soil that is loose as a result of a soil-disturbing activity (plowing, digging, scraping, etc.), and soil that has been loosened by the hydraulic lift of the overland flow. The amount of soil that can be transported depends on the depth and velocity of the flow and the size, density, and shape of the soil particles. Small, light particles are more easily transported than large heavy particles. Therefore, the smaller particles are the first particles to be picked up by the overland flow and the last to be deposited.

Control measures will be briefly discussed for construction sites. To a great degree the strategies are similar to those previously discussed for urban areas, agricultural areas, and stream channel erosion. A point to keep in mind is that before any man-induced changes occur in the watershed, biological factors are typically the primary erosion control. For this reason, emphasis is given to maintaining or reestablishing vegetation.

Construction sites are prime candidates for significant erosion. Clearing of vegetation, slope modifications, digging and scraping of the soil, and other elements of the construction process allow rainfall and the resulting overland flow to remove considerably more soil than under natural conditions. The control measures considered are planning, land surface protection, runoff diversion, grade control, sediment traps, detention basins, and energy dissipators. Figure 10-2 is a schematic of the erosion process and shows where various controls can interact with the course of movement.

<u>Planning</u>

Proper planning of developments and construction can have a large impact on reducing the amount of erosion. The potential for erosion-causing rainfall events is greatest from June through October. If most grading and earth moving operations were scheduled for other than this period the potential for erosion would be reduced. Planning the site to avoid steep slopes and highly erodible soils would be beneficial. Phased construction rather than large-scale denuding of vegetation could be coordinated with low erosion potential periods to greatly limit erosion. Some elements of planning include the timing of land disturbance, erosion control implementation, reduction in the area denuded of vegetation, proper compaction, and environmentally sensitized design of the construction project.

Advantages of planning construction are:

- Reduces potential for erosion.
- Reduces area subject to erosion.

- Maintains the natural conditions as long as possible.

Disadvantages include:

- Requires more thoughtful site plans.
- Once erosion does occur there are no other controls.

Land Surface Protection

If the land surface can be kept covered as much as possible, erosion can be reduced by decreasing the disruptive force of rainfall, slowing down and decreasing overland flow, and requiring higher flow velocities to transport the soil. Land surface protection can consist of vegetation, mulches, plastic linings, and other covers. A protective covering should be used as soon as possible after an area has been stripped of its vegetation. This is the primary preventive control for surface erosion. Land surface protection can utilize vegetation covers, mulches, mats, chemical stabilization, gobi blocks and aggregate covers.

Advantages of land surface protection include:

- Prevents increased erosion from occurring.
- Can be aesthetically pleasing.
- Can reduce stormwater runoff.
- Permanent vegetation can be used.

Some of the disadvantages are:

- May require frequent maintenance.
- Soils may require fertilization or irrigation.
- Does not remove sediment once it has eroded.

Runoff Diversion

Diversion structures such as diversion berms and ditches can be used to direct runoff from highly erodible sites or environmentally sensitive areas. This measure can also be used to direct runoff to areas that have a high infiltration capacity. Included among diversion structures are diversion ditches, berms, channels, dikes, and toe drain ditches.

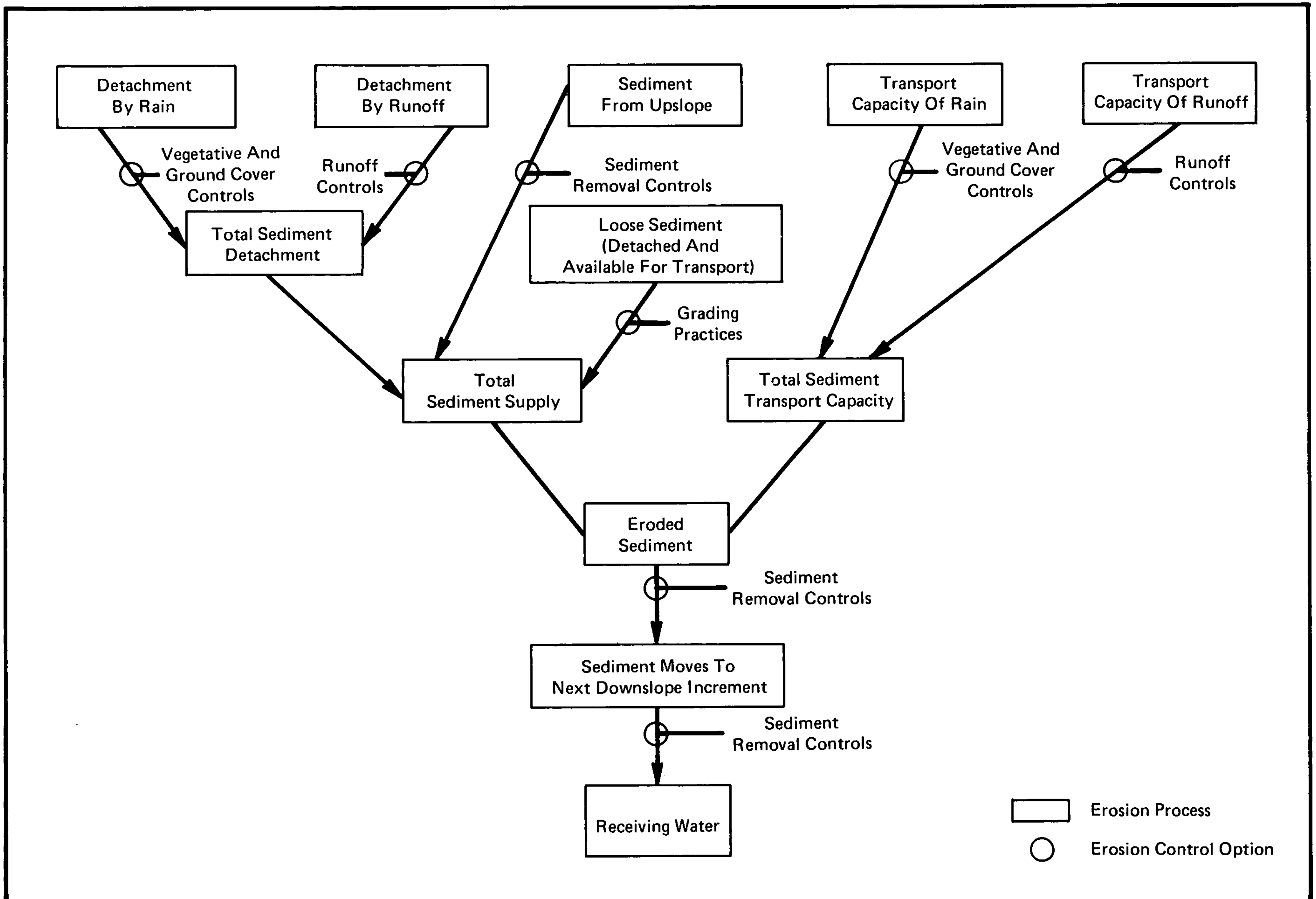


FIGURE 10-2: Erosion Process and Control Schematic

- Reduces high velocity flows which could be hazardous to children.

Among the disadvantages are:

- Does not effectively remove eroded sediment.
- Acts as a partial cure, not a prevention.
- Can be unsightly.
- May require maintenance.

Sediment Traps and Filters

Eroded soil can be kept onsite and out of the receiving waters through the use of filters and sediment traps. This helps reduce sedimentation problems by settling the larger sized soil particles. This method is one of the most widely misused erosion control alternatives, particularly the use of straw bales. Improper placement of straw bales can channel the flow and result in higher erosion rates than if the bales were not present. Straw bales should not be used where the flow is concentrated and the velocity is high. They must be maintained to be of practical use.

Some of the advantages are:

- Removes eroded sediment.
- Can decrease peak flows.
- Easily installed.

A few of the disadvantages include:

- Does not stop or significantly reduce erosion, i.e., a cure rather than prevention.
- Requires frequent maintenance.
- Generally ineffective for small sized particles.
- If improperly used, may worsen the problem.

Detention and Settling Basins

Detention or settling basins may be used onsite or offsite. They are larger than sediment traps, and with the use of flocculants and coagulants, can remove the smaller particles. The effect on the timing of runoff

Certain advantages are:

- Erosion from highly susceptible soils can be diminished.
- Runoff flows can be reduced.
- Vegetation on steep slopes can be allowed to grow.

Included among the disadvantages are:

- Does not reduce erosion from nondiverted areas.
- Does not remove sediment once it has eroded.

Grade Control

Avoidance of long lengths of steep grades will significantly reduce erosion, as will limiting the angle of grades. The angle should not be so great that vegetation or other surface protection measures can not be employed.

Some of the advantages include:

- Reduction in erosion (steep slopes are highly erodible).
- Allows use of land surface protection.
- May allow removal of eroded sediment on deposition planes.

A few of the disadvantages are:

- May require extensive earth moving.
- Requires careful site planning.

Energy Dissipators

If the velocity of overland flow can be reduced, the capacity of the flow to transport sediment will be reduced and less erosion will occur. This is an effective control measure for both surface erosion and stream channel erosion.

The advantages include:

- Reduces surface and stream channel erosion.
- Protects downstream culverts and manmade channels.

and stream hydrographs should be considered for impoundments, as discussed previously.

Included in the advantages are:

- Removes eroded sediment.
- Can decrease storm flows and channel erosion.
- Can improve water quality.
- Can be designed into detention/retention structures or flood control impoundments.
- Estimates of removal efficiencies can be made easily.

The disadvantages include:

- Does not stop or reduce upstream land surface erosion.
- May increase downstream peak flows and channel erosion.
- Requires land areas.
- Requires periodic maintenance.
- May create water quality problems.

Fine Grained Sediment and Water Quality

Fine grained sediment is the most easily eroded, the hardest to remove, and generally contains most of the water quality pollutants. The best control measures for fine grained sediment are proper planning of construction, maximum use of surface protection measures, silt fences, and adding flocculants and coagulants to settling basins. Whenever possible, it is better to avoid erosion than to require the extensive use of expensive chemical additions.

COMBINED SEWER OVERFLOWS

There are many viable technological alternatives available for control of pollution from combined sewer overflow. There is, however, no single "best alternative" which can be applied to all cases. The least cost solution in a given case is a function of the degree of pollution removal required and the physical and hydrologic characteristics of the combined sewer service area. Each situation requires individual planning and analysis.

CSO problems are unique to the given collection system. The first objective of any combined sewer overflow pollution control project should be to obtain an understanding of how the existing collection system operates, including an investigation of the existing regulator system. Collection systems will not perform as designed unless they are operated and maintained properly. If not maintained properly, overflow of raw wastewater can occur during dry weather on a nearly continuous basis.

The strategies for CSO abatement considered here are broadly grouped into source controls, collection system controls, and storage and treatment. Only brief descriptions of the alternatives will be given. A detailed CSO study for Washington, D.C. that will evaluate these control strategies is presently being conducted by the D.C. Department of Environmental Services.

Source Controls

Source controls of CSO include streetsweeping, catch basin cleaning, and sewer flushing. Streetsweeping and catch basin cleaning were previously described in this chapter as urban source control strategies.

Combined Sewer Flushing. The major objective of combined sewer flushing is to resuspend deposited sewage solids and transmit these solids to the dry-weather treatment facility before a storm event flushes them to a receiving water. Combined sewer flushing consists of introducing a controlled volume of water over a short duration at key points in the collection system. This can be done using external water from a tanker truck with a gravity or pressurized feed or using internal water detained manually or automatically. A recent feasibility study of combined sewer flushing (Reference 23) indicates that manual flushing using an external pressurized source of water is most effective. Combined sewer flushing is most effective when applied to flat collection systems. It may also be applied in conjunction with upstream storage and downstream swirl concentrators, followed by disinfection.

Advantages of source controls include:

1. Source controls may be less expensive than other controls.

2. Aesthetically better living conditions are provided.

3. Controls are labor intensive and can stimulate local employment.

4. The controls are flexible to the needs of a specific site.

5. Sewer flushing increases the sewer transport and storage capacity.

6. Implementation of sewer flushing requires a detailed knowledge of the existing sewer system.

Among the disadvantages are:

1. Streetsweeping is applicable only to streets with curbs and gutters and does not reduce domestic sewage sources.

2. Sewer flushing requires a continuous operation and maintenance program and large scale applications have been limited.

Collection System Controls

Existing System Management. The major objective of collection system management is to implement a continual remedial repair and maintenance program to provide maximum transmission of flows for treatment and disposal while minimizing overflow, bypass, and local flooding. It requires an understanding of how the collection system works and patience to locate unknown malfunctions of all types, poorly optimized regulators, unused in-line storage, and pipes clogged with sediments in old combined sewer systems.

The first phase of analysis in a sewer system investigation is an extensive inventory of existing data and mapping of flowline profiles. This information is then used to conduct a detailed physical survey of regulator and storm drain performance. This type of sewer system inventory and study should be the first objective of any combined sewer overflow pollution abatement project.

Flow Reduction Techniques. The major objective of flow reduction techniques is to maximize the effective collection system and treatment capacities by reducing extraneous sources of clean water. Infiltration is the volume of ground water entering sewers through defective joints; broken, cracked, or eroded pipe; improper connections; and manhole walls. Inflow is the volume of any kind of water discharged into sewerlines from such sources as roof leaders, cellar and yard drains, foundation drains, roadway inlets, commercial and industrial discharges, and depressed manhole covers. Combined sewers are by definition intended to carry both sanitary wastewater and inflow. Therefore, flow reduction opportunities are limited. Typical methods for reducing sewer inflow are by discharging roof and areaway drainage onto pervious land, use of pervious drainage swales and surface storage, raising depressed manholes, detention storage on streets and rooftops, and replacing vented manhole covers with unvented covers.

Sewer Separation. Sewer separation is the conversion of a combined sewer system into separate sanitary and storm sewer systems. Separation of municipal wastewater from storm water can be accomplished by adding a new sanitary sewer and using the old combined sewer as a storm sewer, by adding a new storm sewer and using the old combined sewer as a sanitary sewer, or by adding a "sewer within a sewer" pressure system.

Swirl and Helical Concentrators. The major objective of swirl and helical concentrators is to regulate both the quantity and quality of storm water at the point of overflow. Solids separation is caused by the inertia differential which results from a circular path of travel. The flow is separated into a large volume of clear overflow and a concentrated low volume of waste that is intercepted for treatment at the wastewater treatment plant. In addition to regulation of combined sewer flow, they can provide high-rate primary treatment for solids removal.

Remote Monitoring and Control. The major objective of remote monitoring and control on a combined sewer collection system is to remotely observe the sewer and treatment capacities so that the most effective use of inline storage is obtained with a minimum of severe overflow. A prerequisite for this alternative is a large collection system with the potential for inline storage. Three components are generally added to the existing collection system: a data gathering system for reporting rainfall, pumping rates, treatment rates, and regulator positions; a central computer processing center, and a control system to remotely manipulate gates, valves, regulators, and pumps. The capital costs, operation and maintenance costs, and effectiveness depend on the hydraulic characteristics of the system of concern and thus are very site-specific.

Fluidic Regulators. The major objective of fluidic combined sewer overflow regulation is to provide dynamic control at the site of overflow without a complex operational system. They are self-operated by using a venturi pressure gradient which senses the dry-weather interceptor sewer capacity before allowing combined storm water to overflow.

Polymer Injection. The primary objective of polymer injection to sewer flow is to increase the flow capacity of an existing sewer by reducing the turbulent friction. It is most applicable as an interim solution to infiltration problems of sanitary sewers since they respond slowly over a long period to rainfall-induced infiltration. A rapid short duration flow increase, such as that occurring in combined sewers, will generally exceed the capacity of polymer friction reduction.

Included among the advantages of collection system controls, are:

1. A thorough analysis of the existing sewer system is required which will result in an understanding of how the collection system operates before control alternatives are chosen.

2. Most alternatives are very flexible to site-specific conditions.

3. By using existing systems, the alternatives can be very cost effective.

4. Sewer separation solves combined sewer overflows.

Some of the disadvantages are:

1. No general cost-effectiveness data are available since the results are very site-specific.

2. Some of the controls are very expensive.

3. Some controls require construction that would disrupt traffic in the highly populated inner city.

4. Settled solids may not be removed.

Treatment Facilities

Off-Line Storage. The major objective of off-line storage is to contain combined sewer overflow for controlled release into treatment facilities. Off-line storage provides a more uniform constant flow and thus reduces the size of treatment facilities required. Off-line storage facilities may be located at overflow points or near dry-weather or wet-weather treatment facilities. A major factor determining the feasibility of using off-line storage is land availability. Operation and maintenance costs are generally small, requiring only collection and disposal costs for sludge solids, unless input or output pumping is required.

Sedimentation. The major objective of sedimentation is to produce a clarified effluent by gravitational settling of the suspended particles that are heavier than water. It is one of the most common and well-established unit operations for wastewater treatment. Sedimentation also provides storage capacity, and disinfection can be effected concurrently in the same tank. It is also very adaptable to chemical additives such as lime, alum, ferric chloride, and polymers which provide higher suspended solids, BOD, nutrients, and heavy metals removal.

Dissolved Air Flotation. The major objective of dissolved air flotation (DAF) is to achieve suspended solids removal in a shorter time than conventional sedimentation by attaching air bubbles to the suspended particles. The principal advantage of flotation over sedimentation is that very small or light particles that settle slowly can be removed more completely and in a shorter time. Capital costs for DAF are moderate; however, operating costs are relatively high due to the energy required to compress air and release it into the flotation basin and due to the greater skill required by operators. Chemical additives are also useful to improve process efficiencies of BOD and SS removals and to obtain nitrogen and phosphorus removals.

Screens. The major objective of screening is to provide high-rate solids/liquid separation for combined sewer particulate matter. Four basic screening devices have been developed to serve one of two types of applications. The microstrainer is a very fine screening device designed to be the main treatment process of a complete system. The other three devices, drum screens, rotary screens, and static screens, are basically pretreatment devices designed to remove coarse materials. BOD removal efficiencies are approximately 15% for pretreatment screens and up to 50% for microstrainers.

High-Rate Filtration. The major objective of high-rate filtration (HRF) is to capture suspended solids and other pollutants in a fixed bed dual media filter (a bed of anthracite coal is usually above sand filter media). Filtration is one step finer than screening. Solids are usually removed by one or more of the following mechanisms: straining, impingement, settling, and adsorption.

High Gradient Magnetic Separation. The major objective of high gradient magnetic separation (HGMS) is to bind suspended solids to small quantities of a magnetic seed material (iron oxide called magnetite) by chemical coagulation and then pass them through a high gradient magnetic field for removal.

Chemical Additives. The major objective of using chemical additives is to provide a higher level of treatment than is possible with unaided physical treatment processes (sedimentation, dissolved air flotation, high rate filtration, and high gradient magnetic separation). Chemicals commonly used are lime, aluminum or iron salts, polyelectrolytes, and combinations of these chemicals.

Carbon Adsorption. The major objective of carbon adsorption is to remove soluble organics as part of a complete physical-chemical treatment system that usually includes preliminary treatment, sedimentation with chemicals, filtration, and disinfection. Carbon contacting can be done using either granular activated carbon in a fixed or fluidized bed or powdered activated carbon in a sedimentation basin.

Biological Treatment. The major objective of biological treatment is to remove the nonsettleable colloidal and dissolved organic matter by biologically converting them into cell tissue which can be removed by gravity settling. Several biological processes have been applied to combined sewer overflow treatment including contact stabilization, trickling filters, rotating biological contactors, and treatment lagoons.

Disinfection. The major objective of disinfection is to control pathogens and other microorganisms in receiving waters. The disinfection agents commonly used in combined sewer overflow treatment are chlorine, calcium or sodium hypochlorite, chlorine dioxide, and ozone. They are all oxidizing agents, are corrosive to equipment, and are highly toxic to both microorganisms and people.

Certain advantages of CSO treatment strategies are:

1. The processes are familiar to design engineers and operators.

2. Some of the alternatives are simple to design and operate.

3. Pollutant removal can be easily measured, controlled and predicted.

Among the disadvantages are:

1. High land requirements.

2. Some alternatives have high capital and operating costs.

3. Sludge disposal is required.

ECOLOGICAL PROBLEM ASSESSMENT AND RECOMMENDATIONS

The impacts of flooding, sedimentation, and water pollution to the ecology are difficult at best to evaluate quantitative except under controlled monitoring. Unfortunately, there is a limited amount of data on Rock Creek to establish natural conditions prior to colonization and during subsequent development and urbanization over the years. It is equally difficult to isolate any single factor that, as a result of urbanization, has promoted a decline or shift in aquatic population and diversity.

The review of literature and additional sampling performed under the auspices of this study have served to define the present status and temporal trends, to a limited degree, of the Rock Creek ecology. Detailed analysis was presented in Chapter 8 and generalized conclusions can be drawn when reviewed in conjunction with the water quality assessment. Ecological quality of Rock Creek within the District of Columbia is of a degraded nature. LaBuy, in a biological survey of the watershed in 1966, reported evidence of pollution from near the District of Columbia-Maryland boundary to the confluence with the Potomac. Results of this study support this conclusion. Similarly, the present study supports the conclusions of O'Brien & Gere that conditions are the same or slightly degraded since LaBuy's survey. Fish surveys by Dietemann (1974) and Medford (1950) resulted in the same conclusion of decreased fish population and species diversity in the lower District portion of Rock Creek when compared to the middle and upper reaches in Maryland.

Within the District reach of Rock Creek, a significant variation is noted between the macroinvertebrate and aquatic macrophyte sampling locations which gives indication of causal factors of ecological degradation. The upper station at Candy Cane City near the Maryland-D.C. border exhibits the most diverse and abundant populations of both macroinvertebrate and aquatic macrophyte species of all stations sampled (see Chapter 8). Those species collected were indicative of fair to good water quality and ecological suitability. Immediately below this station, however, at both West Beach and Sherrill Drives, a significant decline in abundance and quality of these indicator species was noted. Keeping in mind that there is no appreciable change in water quality constituent concentrations between these stations, one must look to other causal factors of habitat insuitability. The most obvious and immediate difference between the referenced stations is that of substrate. The watercourse from the Maryland-D.C. line to the beginning of the fall line at Military Road is marked by large and frequent sand bars and silt deposits that have originated from the upper watershed in Maryland. The sluggish velocity of Rock Creek in this reach allows for deposition of these sediments during storm events. Since Lakes Needwood and Frank effectively trap all but the smallest silt and clay particles from the predominantly agricultural upper basin, the source of these deposits is assumed to be of urban and construction site origin. The high organic nature and relatively high metal content of these sediments, as measured in sample analysis (see Chapter 8), provide an undesirable habitat for aquatic life in both chemical and physical quality.

The high velocities of the fall line provide a natural gravel, cobble and boulder substrate that is more suitable for aquatic life. Also, natural reaeration improves dissolved oxygen levels in this reach from Military Road to below Peirce Mill. The high velocities may also scour out aquatic macrophytes and macroinvertebrates that are unable to anchor themselves sufficiently to the substrate. Conditions are generally improved along this reach and it is assumed that the turbulence of flow is the main limiting factor to aquatic growth.

Below the fall line, Rock Creek once again slows down and the sediment and silt deposits again dominate the watercourse. The biological sampling station results at the National Zoological Park and at P Street indicate degraded conditions with little or no aquatic macrophytes in evidence. The population and diversity of macroinvertebrates at the P Street location were severely limited. Literature has traditionally cited combined sewer overflow as the main causal factor of degraded conditions in this portion of Rock Creek. Conclusions of this study refute this argument. The water quality conditions at this segment of the stream do not greatly differ from those of the upper District of Columbia reach, as determined in Chapter 9, and the periodic discharge of combined sewage cannot be assigned the guilt as it imposes a relatively minor impact in the stream. Rather, one must look once again to the quality of habitat in this reach. Here the sediment sampling survey indicates a very high organic and metal content. Bottom substrate consists of finer sand and silt deposits than observed in the upper reaches. Accumulations of these sediments date back to colonial times when the mouth of Rock Creek once was wide and deep enough to support a wharf; a far cry from present dimensions. Original siltation of the mouth was assumed to be of agricultural origin, but today the sediments exhibit urban source attributes. It can be presumed that the origin of these deposits is both the upper watershed and the urban areas of the District.

The decreased population and diversity of fish species in the District segment can be attributed to a number of factors. The decline in macroinvertebrate population as a result of unsuitable habitat will directly impact the fish community which utilize it as a food source. Siltation of habitat also interferes with the fish reproductive cycle and other functions.

Although the general water quality conditions are not of a critical nature in the District reaches, storm events and subsequent urban runoff will result in short periods of depressed oxygen levels below the 4.0 mg/l standard (see Chapter 9). Such levels and durations are not of a nature that would prove toxic to the fish population, but chronic and repeated stress may lead to a shift in species distribution.

Additional factors that may limit the abundance and diversity of fish in Rock Creek are those of predation by fishing and physical barriers to migration. A survey of fishing habits on Rock Creek was performed by the Park Service during the spring of 1978. The principle catch of those surveyed were Alewife, Blueback Herring, Channel Catfish, Yellow Perch, Carp, and Smallmouth Bass. The majority of people used nets or double and triple snag hooks; very few used baited hooks. A significant portion of the people interviewed claimed to fish for food or to sell the catch. By far the most popular location for fishing is the old Q Street stream gaging station. At one time a drainage pipe through this 3-foot high barrier allowed water to flow through the structure and presumably, passage of fish upstream. This pipe is completely silted in now and fish passage is not possible. The fish congregate at this location and are at the mercy of the fishermen. Very few fishermen were observed above this point in the stream and none on tributaries. The survey noted that, in many instances, large scale and indiscriminant fishing practices were employed. The Park Service does not require fishing permits for Rock Creek and catches of 30 to 40 fish were noted by the observer at this point.

Similarly, the 6-foot high dam at Peirce Mill effectively prohibits any upstream migration of fish. There is no provision at this site for passage. The impact of these barriers can only be assumed, but reasoning dictates that spawning runs of anadromous fish species are effectively arrested. It is also reasonable to assume that, during storm events with high flows and velocities, some portion of the fish population will be swept downstream and over these barriers. With subsequent upstream migration impeded, fish populations may be impacted. Alternately, it may be the case that upstream migration is possible only <u>during</u> high flows and such events are beneficial.

The Park Service goal of returning the Rock Creek ecology to its former, natural status is a task that would be impossible in the true sense within the urban environment that now surrounds the park. This does not mean that a certain level of protection and recovery cannot be achieved by a more concentrated and carefully monitored program of resource management. With this objective, the following recommendations are offered to enhance the aquatic ecological resources of Rock Creek.

Instream Silt and Debris Trap

The large sediment load of Rock Creek has been observed, documented, and bemoaned ever since the colonization of the area. Clearing and cultivation at this time, with little or no soil conservation practices employed, rapidly filled in the harbor at the mouth of Rock Creek. Continued agricultural practice and urban development has maintained the status quo ever since then. Unfortunately, all the publicity given to the subject has not resulted in rectifying the situation.

Ideally, control of sediment sources is the most desirable strategy and the Maryland-National Capital Parks and Planning Commission has been instrumental in formulating policies for implementation of best management practice techniques for such. The construction of Lakes Needwood and Frank have produced noticeable improvements by effectively trapping the larger silt and sand particles of agricultural and construction site sources in the upper watershed. The finer silt and clay particles still are carried downstream, however, and contribute turbidity long after storm events. Ordinances for control of sediment sources below the lakes is an important element of the proposed policies of the M-NCPPC Functional Master Plan for Conservation and Management in the Rock Creek Basin. Such ordinances, when effectively enforced and implemented, should greatly reduce the sediment loads observed at the Maryland-D.C. boundary. However, political and economic realities often supercede policy statements and inspection and maintenance funding is generally lacking or the first to go in budget cutting. Similarly, enforcement powers are generally limited to ineffective handslapping and rarely used to their fullest extent. The Park Service is equally guilty of such in enforcement of sediment control plans for new construction within its park areas.

Rather than continued reliance upon marginally effective programs of source control that the Park Service has absolutely no power or control of, it is recommended that a positive step be taken to mitigate the sediment loads delivered to the District. The Park Service is therefore encouraged to undertake construction of one or a series of silt and debris traps on the main stem of Rock Creek. Initially only one such project should be installed and subsequent monitoring of its performance and effectiveness will determine the need or advisability of additional construction. The initial site is recommended to be above the Maryland-D.C. line where the beginning of siltation is evident. The Baltimore and Ohio Railroad bridge crossing provides an excellent opportunity for such a project. Here there is already a natural constriction in the flood plain and, as a result of previous analysis (see Chapter 7) the adverse impacts of inundation of roads and facilities would be minimized. The political feasibility and ramifications of the use of this site are subjects not within the scope of this study.

Detailed design of a silt and debris trap at the B&O Railroad bridge is not attempted here. However, a cursory analysis is presented to determine the trap efficiencies that could be expected for certain sizes of the facility. The trap efficiency, or that portion of the sediment load of a given storm event that would be retained within the impoundment, is dependent upon a number of factors including impoundment characteristics (length, area, depth, volume of available storage, shape, etc.), storm characteristics (volume, peak, duration), size distribution of suspended sediment particles, and the impoundment discharge rule curve.

The basin characteristics at the B&O Railroad bridge site are listed below:

Elevation	Depth (feet)	Area (acres)	Storage Volume (acre-feet)
185	5	6	15
190	10	29	102
195	15	111	452
200	20	192	1210
205	25	259	2338

Three storms of record were selected to demonstrate a range of characteristics of peak volume and duration to evaluate the range of expected trap efficiencies of a given size impoundment.

Date	Peak flow (cfs)	Recurrence Interval (Years)	Volume (acre-feet)	Duration (hours)	Average Flow (cfs)
9/14/66	5060	4.5	2235	17	1591
8/10/69	3020	1.6	1431	12	1443
8/27/71	1950	1	1071	14	926

This procedure is preferrable to selecting a 'design storm' since it provides a feel for the variability of performance of the impoundment over a range of different flow and operational control variables.

The size distribution of suspended sediment is a critical factor that determines exactly how much of the total load will settle out in a detention basin over a given retention time. Data collected by the U.S. Geological Survey (Reference 20) and Yorke and Herb (Reference 3) of sediment particle size distributions during storms in Rock Creek and adjacent watersheds led to formulation of a typical size distribution. Note that the percentages indicated can vary over a wide range depending on sediment source, size of storm, and location.

	Particle Size (microns)	Percentage of Sediment Load Less than Indicated Size
Clay	2	30
	4	35
Silt	8	50
	16	65
	31	80
	62	87
Sand	125	93
	250	97
	500	100

The estimation of the performance of the proposed B&O Railroad site sedimentation pond was conducted using a procedure of Haan and Barfield (Reference 18). Results of the analysis are presented below for two sizes of impoundment. The storms are assumed to utilize the maximum amount of available storage.

Maximum Elevation: 195 feet NGVD

Maximum Storage: 452 acre-feet

Surface Area: 111 acres

	9/14/66	Storm 8/10/19	8/27/71
Peak Inflow (cfs):	5060	3020	1950
Volume of Runoff (ac-ft):	2235	1431	1071
Duration of Inflow (hours):	17	12	14
Peak Outflow (cfs):	3540	1330	580
Detention Storage Time (hours):	4	5	6
Trap Efficiency (%):	17	32	42

Maximum Elevation: 200 feet NGVD
Maximum Storage: 1210 acre-feet
Surface Area: 192 acres

	9/14/66	Storm 8/10/69	8/27/71
Peak Inflow (cfs):	5060	3020	1950
Volume of Runoff (ac-ft):	2235	1431	1071
Duration of Inflow (hours):	17	12	14
Peak Outflow (cfs):	1530	*200	*200
Detention Storage Time (hours):	9	10	16
Trap Efficiency (%):	45	76	80

* Assumed Peak Outflow

It can be seen that there is a big difference in trap efficiency to be expected depending on the storm and size of the impoundment. For such a structure to realize a significant reduction of sediment load that is delivered to the District reach of Rock Creek, it will be necessary to design the stormwater detention basin to the 200-foot contour level. It is estimated that such a structure, on a yearly basis which incorporates numerous smaller events than analyzed here, would effectively trap 75-85 percent of the annual sediment yield. Previous analysis of large impoundment alternatives for flooding and channel erosion problem mitigation resulted in a similar size impoundment that would be required to reduce the mean annual (2.33-year) flood of 3760 cfs to the predevelopment level of 1620 cfs. It was concluded that such a structure could not be recommended solely on the basis of flooding damages. The main benefits that would be realized would be reduction of excessive channel bank erosion that is a chronic condition of the increase in dominant flood discharge resulting from urbanization.

On the basis of analysis herein, the additional benefits of sediment load reduction warrant reconsideration of such a project. It is judged that a sediment control facility is a necessity for the ecological enhancement of Rock Creek in the District of Columbia. The B&O Railroad site impoundment, designed to an elevation of 200' feet NGVD, is recommended. The combined benefits of flood and channel erosion control, debris and sediment trapping, stormwater pollutant load reduction, and possible recreational benefits (if a permanent pool were provided for) warrant such endorsement.

There are other considerations that should be evaluated in design of the sediment and debris trap. Maintenance of the facility can pose a significant cost and must be an important element of the project. Model simulation results predict an annual sediment load of approximately 71,200 tons for the period March 1978 through February 1979 for ultimate land use conditions (note that this was a higher than average flow period). This agrees fairly well with the M-NCPPC average sediment yield calculation of 53,600 tons per year (Reference 1). As designed, the sediment trap should effectively retain approximately 75 to 85 percent of the annual sediment yield or 42,000 to 48,000 tons of sediment per year depending on hydrologic conditions during the period. At a unit weight of 125 pounds per cubic foot, this corresponds to an accumulation of 25,000 to 28,300 cubic yards or 15.4 to 17.5 acre-feet of sediment that eventually would have to be removed and disposed of each year. The cost of this activity is a major consideration that makes the B&O Railroad site even more attractive. The access of a railroad should facilitate economical removal and transport of sediment. The nearby agricultural areas of Montgomery County provide an abundance of possible sites for disposal of the dredge material where it can serve a beneficial use. Removal of the deposits can best be facilitated by design of a forebay at the head of the impoundment where the majority of material can settle out.

The level of turbidity in Rock Creek during low flow will not be reduced by this sediment and debris basin and may actually be increased depending on the size of permanent pool, if any. It is recommended that flocculation of suspended fine clay and silt particles during dry weather be considered by polymer injection at the silt trap forebay to reduce turbidity.

Fisheries Management Recommendations

The reduction of sediment loads in Rock Creek will greatly enhance the suitability of habitat for its fish population. However, the Park Service is somewhat remiss in management of this resource and the following recommendations are offered.

Fish Ladders. The mobility of fish in Rock Creek is greatly impeded by man-made barriers, primarily the Q Street and Peirce Mill dams. The Park Service should provide an avenue for passage of anadromous and indigenous fish species upstream by construction of fish ladders at both of these sites. In this way, mobility to avoid adverse environmental conditions (including fishermen) is facilitated and spawning runs can be carried further upstream to more acceptable stream reaches and tributaries.

Fishing Regulations. The Park Service presently does not enforce its legal authority, 'to prevent overuse by fishermen of waters open to fishing in areas administered by the National Capital Region (NCR), the Superintendent, in his discretion may close to fishing all or any part of such open waters for such periods of time as may be necessary.' The park is advised to exert its regulatory and enforcement powers to prevent overfishing of its waters. Issuance of permits and catch limitations are some ways to regulate the amount and time of fishing that takes place. Limitation of sites where fishing is allowed can protect fish in locations where they are easy prey to indiscriminant, unsporting fishing techniques. Banning the use of nets and multiple snag hooks is another way to eliminate large scale fishing operations. Any or all of these methods can be easily adopted and enforcement can be managed by the park police with its mounted and vehicular patrols of the park. For guidance in development of its fishing regulation program, the Park Service is referred to the Virgnia or Maryland State fishing statutes, since the District of Columbia has no such regulations.

Fish Stocking. At one time, Rock Creek was of a nature suitable for support of such fish species as Brook Trout, Trout-Perch, Smallmouth and Largemouth Bass, and several others that are now scarce or absent in the lower watershed reaches. With implementation of the other previous recommendations, it is felt that Rock Creek could once again be made suitable for some of these presently rare species. The goal of reestablishment of these populations can most expeditiously be accomplished by a program of stocking of these and other previously indigenous species. Such a program was tried in the 1960's with some success. In addition, stocking of anadromous fish species in the upper reaches and/or tributaries could establish, in due time, a sustained yearly spawning run.

It may be overly ambitious and optimistic to assume improvement of Rock Creek to the degree that it could support a native trout population. These species are highly sensitive to silt and turbidity, depressed oxygen levels, and high temperatures. General criteria for trout waters (established by the Maryland Department of Natural Resources) are;

Dissolved Oxygen	- not less than 4 mg/l at any time or 5 mg/l for daily average
Temperature	- not greater than 24°C
Turbidity	- not greater than 150 JTU at any time or 50 JTU monthly average

Even with the control strategy recommendations presented herein, it is anticipated that Rock Creek will still exhibit excessively high turbidity and temperature and short periods of low dissolved oxygen. Hence, stocking of trout is not recommended until significant improvement can be demonstrated in the limiting factors. Initial stocking of the hardier species of Bass, Bluegill, and Sunfish is suggested. Monitoring of survival rates of the initial stocking efforts will be required to determine the advisability of continuance and trial of more sensitive species.

Anadromous fish species presently constitute a large portion of the fish catch in Rock Creek as determined by the 1978 fishing survey. Physical barriers limit the spawning run and the installation of fish ladders could allow for a significant increase in this element of the fish population. Stocking could speed up the process. Presently, water quality conditions in the Potomac River limit the extent that some more sensitive anadromous species such as Rockfish and Striped Bass can migrate upstream. However, limited tests of stocking efforts in Rock Creek may produce surprising results in future years with spawning runs of these species.

The stocking program will greatly enhance the recreational potential and use of Rock Creek Park. Strict enforcement of the previously recommended fishing regulation program will be required, however, in conjunction with the plantings, to ensure a certain survival rate.

Monitoring and Analysis. Effective fisheries management requires comprehensive monitoring and analysis of fish species numbers, habitat, mortality, food sources, and fish catch. Regular yearly surveys of points along the entire length of Rock Creek should be instituted using a harmless electrical shocking technique. Spawning runs should also be monitored in a similar fashion. Analysis of the gut content of fish collected in these surveys will provide valuable evidence of the organisms and materials the fish are utilizing for food sources and serve as indication of the overall ecological quality of the stream. As conditions are improved, quality and diversity of food sources such as aquatic insects in the gut samples should also improve.

Periodic sampling of other elements of the aquatic biota is also recommended as an indicator of trend of ecological integrity of Rock Creek. Monitoring the abundance and diversity of macroinvertebrate and macrophyte species similar to that performed in this study is an invaluable tool in assessment of the aquatic ecology.

WATER QUALITY MANAGEMENT RECOMMENDATIONS

The water quality conditions under existing and future land use conditions were presented and evaluated within the context of Chapter 9. A different set of problems within the the stream are encountered depending on the flow regime therein. Point sources of pollution create adverse water quality circumstances during dry weather flow conditions. During storm events, nonpoint sources of pollution dominate the instream constituent concentrations. Water quality management recommendations are presented in these broad classifications.

POINT SOURCE POLLUTION RECOMMENDATIONS

The impact of point source discharges of pollution is observed primarily during dry weather conditions in Rock Creek. Since this weather situation constitutes the vast majority of recreational usage of the park, the chronic condition of bacterial contamination by the point sources presents one of the principal limitatons to park utilization. Bacterial contamination is the major impact of point source discharges to Rock Creek, but other types of pollution such as nutrients, BOD, and suspended sediment can have equally damaging consequences.

District of Columbia Point Sources

The field reconnaissance, outfall inventory, and dry weather monitoring program conducted under the auspices of this study accomplished much in the way of identification and quantification of point sources within the District. Recommendations for the correction of these discharges basically call for location and elimination of the illegal sources of pollution and are presented below. Methods for enforcement and responsibility for costs are not within the scope of this study. The D.C. Department of Environmental Services is responsible for maintenance activities of the sanitary and combined sewer system. Illegal connections to the storm and/or sanitary system should be prosecuted to the full extent of legal authority granted to the Park Service and disconnection costs should be borne by the violators. It is essential that the Park Service adopt a hardline stance in mitigating the sources of point source pollution of its waters.

RC 7. The combined sewer overflow structure should be modified to eliminate splash of sewage over the diversion dam. In addition, the source of contaminated seepage behind the outlet structure should be investigated and eliminated.

RC 33. The combined sewer overflow has been a trouble spot to DES personnel for a long time because of the diversion of natural streamflow into the sewer system near the mouth of Normanstone Branch. The chronic problems created by this practice can and should be eliminated by completion of the sewer separation program in this district and sealing off the overflow of storm runoff into the West Rock Creek Diversion Sewer. Not only will this mitigate the problems of this structure at a nominal cost (separation of approximately 56 connections) but additional flow capacity of the WRCDS will be provided.

RC 43. The discharge of Washington Metropolitan Area Transit Authority tunnel seepage water of such high turbidity into Rock Creek is in direct violation of the permit granted by the EPA and the Park Service. If the park authorities are genuinely concerned as to water quality status of its streams, it must demonstrate a commitment to this goal and actively inspect and monitor all such construction activities within park bounds. All permits should include stringent provisions for large penalties for violations. It is also recommended that the Park Service enforce such penalties, even to the extent of injunctions to cease all construction activities, to the maximum. A hardline stance must be taken to mitigate the blatant abuse of construction, and economics is usually the only effective tool for such.

RC 52. Indications of an illegal industrial or commercial discharge to this storm sewer lead to recommendation of regular inspection and monitoring of flow, BOD, COD, nutrient and metal concentrations to assess impact and source.

RC 57. The seepage at the CSO diversion structure should be investigated and monitored occasionally to determine source and impact. Full survey and testing results were inconclusive.

RC 58. The National Zoological Park has demonstrated a true concern for the quality of Rock Creek in its past activities to control contaminated runoff and sewage from its premises. The flow at RC 58 should be investigated thoroughly as to source (it is suspected to originate from overflow of the waterfowl pond) and routed to one of the contaminated sewer systems that discharge to either the Rock Creek Main Interceptor or the Piney Branch Interceptor.

RC 75. The reportedly completely separated sewer system at Klingle Road is suspected of being one of the major sources of bacterial contamination in the lower reaches of Rock Creek in the District. Elimination of the sources of fecal contamination is imperative and will require intensive field work, monitoring, and testing to discover and separate.

RC 117. Another outfall with indication of industrial or commercial input, RC 117 should be regularly inspected during dry weather and monitored, similar to RC 52, to assess source and impact of this discharge.

FW 1, FW 2, P 1, BB 1, NS 1, and MH 1. The headwater outfalls of the major tributaries to Rock Creek drain extensive areas of urban area served by separated storm and sanitary sewer systems. Tracing the source of contamination to any one of these outfalls would be a formidable task that, as a consequence of the limited monitoring results, is not advised. The high COD levels of Fenwick, Normanstone and Portal Branches invariably contain contaminated water of commercial and/or industrial nature with high organic, metal and exotic pollutant levels. Much more extensive dry weather sampling of these outfalls is required to truly assess the source and impact of drainage and discharge to these storm sewer systems. It was noted in Chapters 8 and 9 that DES monitoring data indicates a significant ammonia nitrogen source on either Fenwick or Portal Branch. An immediate sampling program of all outfalls on these tributaries is recommended to locate the origin of this discharge and eliminate the source. Sampling should be performed during dry weather with analysis of all nitrogen forms at all flowing outfalls, instream on the tributaries, and both upstream and downstream of the confluence of Fenwick Branch and Rock Creek. In addition, analyses of BOD, COD, phosphorus, coliform bacteria, and metals may provide valuable data.

The headwaters of Broad Branch and Melvin Hazen Branch contain high fecal coliform concentrations that probably can be attributed to sanitary connections. Once again, further monitoring of dry weather flow is recommended to assess feasibility of the extensive chore of discovery and elimination of sanitary connections.

LZ 4. Sanitary connections to the storm sewer drainage system of this outfall should be located and separated. In addition, it is recommended that completion of the separation program of the previously combined sewer system of Luzon Valley be accomplished. This will be addressed subsequently in discussion of combined sewer overflows.

PB 4. The source of discharge at this outfall, suspected of containing high surfactant concentrations, should be located and eliminated.

SV 2. Sanitary connections in this storm sewer outfall drainage area should be located and separated from the storm sewer system.

SV 3. Similar to RC 43, the Park Service must enforce the permits for discharge that it grants for Metro construction sites. The tools and powers have been granted to park authorities and it is up to them to use them.

Summary. The problem of illegal point source discharges in an urban environment is a pervasive one that will require extensive field work, monitoring and inspection to discover and mitigate. Nevertheless, it is a principal element of the water quality problems of Rock Creek and elimination will be imperative for conditions to be improved. The monitoring and investigation performed as a part of this study is essentially only the beginning of a necessary program of regular dry weather inspection and monitoring of all outfalls within the basin. The intermittent nature of illegal discharges and the continued deterioration of sewer systems that causes breaks, blockage and seepage mandates that such a program should be instituted by the Park Service. It cannot be iterated enough that a handslapping approach to pollution mitigation will be totally ineffective in control of these pollution sources. Past experience has demonstrated this. The Park Service has the power and right to demand immediate cessation of all identified sources of pollution to Rock Creek and is urged to use all legal authority to accomplish such. The primary problem is the identification of these sources. For this, the dry weathering monitoring is essential. The D.C. Department of Environmental Services has been quick to respond to complaints in the past of sewage discharges. However, there is no longer a regular inspection of the sewer system and the Park Service will, by necessity, be forced to perform this function to protect Rock Creek waters from contamination.

Montgomery County Point Sources

Results of monitoring and simulations indicate that, for Rock Creek in the District to attain the desired fecal coliform criteria for contact recreational usage during dry weather, it will be necessary to control the sources of contamination within Montgomery County (see Chapter 9). Very little has been done to date to identify and eliminate these sources. Maintenance of the sanitary sewer system in Montgomery County is the responsibility of the Washington Suburban Sanitary Commission who presently pursue a 'find it, fix it' program, simiar to DES, of identifying and correcting leaks, overflows and exfiltration problems in sewer lines. The effectiveness of this program can be judged by bacterial concentrations in Rock Creek. Similar to the District, it can be expected that illegal sanitary connections to the storm sewer system also contribute. Areas of failing septic systems also may be an important source of contamination during dry weather. The Park Service cannot rely on other agencies to perform the needed inspection and maintenance functions if past performance is to be judged typical.

It will thus be necessary to inspect, identify and monitor these sources of pollution before correction is possible. A carefully planned program, similar to that initiated within this study, will be required and the following recommendations are offered.

Inventory of Outfalls. A complete inventory of all outfalls discharging to Rock Creek and its tributaries in Montgomery County should be compiled. The entire length of watercourse on both banks should be walked during dry weather, preferrably in the late fall when vegetative cover is minimized, and notations recorded of size, location, descriptions, condition, flow if any, and any indications of pollution.

Dry Weather Monitoring. After completion of the outfall inventory, a detailed plan for monitoring those that were observed to be flowing should be developed. Ideally, this sampling should be accomplished entirely within a one day period of an extended dry weather period. Conjunctive measurements of instream concentrations should be performed to help in assessment of impact of the measured point source discharges. Each outfall should be analyzed for flow, temperature, pH, BOD, COD, and fecal coliform bacteria. Results of the analyses will indicate which flow sources are contaminated and will pinpoint the need for additional investigation and monitoring. At this point, personnel of the WSSC should be brought in to mitigate the identified problem areas.

Similar to the District sources of contamination, control of point sources must assume the form of a continual program of inspection and monitoring if it is to be effective and produce the desired results. Rock Creek cannot achieve the desired water quality goals without control of these sources. Ideally, the sanitary sewer system of Montgomery County should be inspected weekly for blockages and leaks. The Park Service cannot and should not be responsible for such. Endorsement of WSSC inspection programs is recommended with Park Service cooperation extended. This does not, however, mitigate the need for the previously recommended program that the Park Service should institute on its own behalf.

Ammonia Nitrogen Point Source. As discussed in Chapters 8 and 9, the ammonia nitrogen levels in Rock Creek reported by D.C. DES monitoring frequently exceed possibly toxic levels. The validity of some of this data is questionable as these levels are uncommon in natural stream systems. It is recommended that the Park Service conduct a series of instream sampling surveys throughout the entire watershed (Montgomery County and the District of Columbia) of ammonia nitrogen concentration to truly determine the magnitude of this problem. Samples should be collected during dry weather from the lakes, the mouths of all tributaries, and several locations along the Rock Creek watercourse. Subsequent to the results of this sampling survey, it may be necessary to find and eliminate point source discharges of ammonia to the stream. It has already been mentioned that there is a suspected source discharging to Fenwick or Portal Branch in the District.

Rock Creek Interim Advanced Wastewater Treatment Plant.

Model simulation results are inconclusive as to the impact of the Rock Creek Interim Advanced Wastewater Treatment Plant since comparable base simulation runs were not performed. The change in land use pattern from existing to future conditions makes direct comparison invalid. It can be inferred, however, that the primary impact of the discharge of this effluent in the District reach of Rock Creek is realized during low flow periods.

As a result of BOD discharge, dissolved oxygen concentrations are lowered by approximately 0.2 to 0.3 mg/l in the upper D.C. reaches. The increase in streamflow, however, results in higher levels in the lower sections. Apparently, the major D.O. sag is imparted in the Montgomery County watershed. Dissolved oxygen levels during low flow do not reach critical levels according to model simulations.

Significant increases in the concentrations of phosphorus and nitrate nitrogen are major impacts of the IAWTP discharge. As a result, neither of these nutrients will serve to limit aquatic plant growth in Rock Creek. Phytoplankton growth may become excessive in the small pools of Rock Creek, but on the whole, velocities and flow will effectively flush algal growth from the stream before it can reach nuisance levels. Similarly the growth of rooted aquatic plants (benthic algae) can be expected to blossom to the extent that suitable substrate and scouring velocities will allow.

General conclusions and recommendations are that the IAWTP serves a beneficial purpose by augmentation of streamflow during periods of low flow. The reduction of dissolved oxygen concentrations is not a major impact in the District. Nutrient concentrations pose the primary problems and regular monitoring of algal concentrations and visual inspection of pools and channel banks during late spring through summer is recommended to assess the potential problem of excessive aquatic growth. It is additionally recommended that, during these potential problem periods, monitoring of the diurnal cycle of dissolved oxygen be performed during dry weather periods to document the regular photosynthesis-respiration processes of the aquatic plant populations.

NONPOINT SOURCE POLLUTION RECOMMENDATIONS

Model simulation results (see Chapter 9) and ecological assessment have concluded that the principle problem of nonpoint source pollution in Rock Creek is directly associated with the amount of suspended sediment delivered to the stream system during storm events. Agricultural, construction site, and urban sediment sources contribute BOD, nutrients, organics, and metals that are tied up in the sediment particles and generate deleterious water quality conditions within the stream. Ecological assessment has determined that the physical and chemical properties of the sediment that is deposited in District reaches poses the principle limitation to aquatic biota.

Model simulation results indicate that instream concentrations of pollutants in Rock Creek do not reach critical levels that would be toxic to aquatic life. Occassional infractions of minimum dissolved oxygen criteria (4.0 mg/l) occur but are not of sufficient magnitude or duration to seriously impact the stream biota. Fecal coliform levels during storm events will exceed 100,000 MPN/100 ml frequently and remain in excess of 10,000 MPN/100 ml for one to two days thereafter. A severe health hazard is presented by such high concentrations. Instream concentrations of suspended solids commonly exceed 1,000 mg/l during storm events and excessive turbidity is evident for several days.

Montgomery County, Maryland Nonpoint Sources

Within the scope of this study it is not possible to truly evaluate the sources of nonpoint pollution to Rock Creek Park. It would be unrealistic to recommend certain control practices on the basis of investigations and model results performed on such a limited amount of data. It would be equally unrealistic to assume that there is all that much that the Park Service can accomplish to control the diffuse sources of pollution that are contributed outside the limits of its jurisdiction. Instead, efforts of the Park Service should be guided towards promotion and active participation in the programs of the appropriate jurisdictional entities and identification of the pollution sources that, hitherto, are largely undocumented. Evidence of these sources must be gathered before the Service can hope to spur responsible agencies into action.

The subject of nonpoint source control is an integral element of the Functional Master Plan for Conservation and Management in the Rock Creek Basin as proposed by the M-NCPPC for adoption in Montgomery County. The Park Service is recommended to urge approval of all nonpoint source control policies in the upper watershed and play an active role in their development and implementation even to the extent of offering assistance and subsidization of the more desirable items. It is only in this fashion that the Park Service can hope to attain any appreciable input or accomplish water quality objectives on its own behalf. Included within the proposed policies are the following control strategies. Additional recommendations are offered of ways that the Park Service may contribute input.

Erosion, Sediment Control and Stormwater Management. A policy of onsite retention or combined stormwater management facilities for control of the 2-year storm runoff to control erosion from all industrial, commercial, and residential development more dense than 3 units per acre is probably the most important element of the Functional Master Plan and immediate endorsement is recommended. It has been previously pointed out, however, that provisions for control of existing nonpoint sources as a result of uncontrolled past development is ignored in this kind of program.

Public Maintenance of the Stormwater Management System. Maintenance of existing stormwater facilities is, throughout the entire watershed, one of the most evident deficiencies in stormwater and nonpoint pollution source control. The Plan points to private maintenance neglect as a sore spot, citing budgetary limitations as the prime cause. Unfortunately, public maintenance programs also suffer from lack of funding and this policy can only be effective if sufficient budgetary provisions are provided for.

Monitoring Programs. Only with sufficient synotic monitoring programs of storm events and sources of nonpoint pollution can an effective control program be established. Existing monitoring data throughout the watershed is generally devoid of wet weather samples of sufficient spatial and temporal coverage. The Functional Master Plan advocates establishment of a synoptic water quality monitoring program for the Rock Creek watershed. The Park Service is ardently urged to coordinate with the County to encompass the entire watershed in such a program to evaluate the stream system as an integral continuous medium of transport of pollutants. Diurnal variations, the effect of point and nonpoint sources, instream processes and the effect of stream hydraulics can be evaluated with this type of sampling program. Seasonal variations and longterm trends may be discerned by subsequent similar intensive sampling programs during like and/or diverse hydrologic conditions. Included in the plan are provisions for regular monitoring of identified sources of pollution such as landfills and NPDES permitted discharges.

Control of Failed Septic Systems. An accelerated inspection program is recommended to eliminate the reported failing septic systems which contribute human fecal contamination to the stream system. In addition, operation permits, licensing, and public educational programs are key items of the program which is judged to be imperative to attain bacterial integrity in Rock Creek during dry weather periods.

Litter Control. The Plan strongly recommends litter control ordinances but there is no provision for additional public litter control programs. Sponsorship of litter pickup campaigns is endorsed for addition to the functional master plan.

Fertilizer and Pesticide Control and Road Chemical Protection. The policy statements advocate control of these sources of pollution with strict ordinances. However, the vehicle for identification, inspection, and enforcement is not defined within the policy. The Park Service should require more detail for implementation or this program may suffer from neglect.

Prevention of Illegal Discharges and Oil Dumping and Clean-up of Chemical Spills. Once again, there is no vehicle for implementation of the policies to control these sources. A definite program of identification and enforcement of the ordinances promoted here is necessary. An ordinance is ineffective if there is no one to enforce it.

Street and Parking Lot Cleaning. An increased frequency of street and parking lot sweeping is recommended in the Functional Master Plan with gradual replacement of broom sweepers to vacuum equipment. In addition, it is recommended that curb sweeping be implemented and much more frequent sweeping of commercial areas and parking lots be required. Two to three times a week is a realistic frequency that will greatly reduce pollutant loads delivered to the creek.

Animal Control. Animal control laws are recommended in the Plan but are extremely difficult to effectively enforce and such a program is deemed unrealistic.

Control of Agricultural Runoff. There are no provisions, programs or strategies for control of agricultural runoff within the Functional Master Plan. The Park Service should request a program of inspection, monitoring, and enforcement of best management practices in the agricultural areas of the upper Rock Creek basin to control sediment, fecal coliform bacteria, BOD, nutrients, insecticides, and herbicides. Coordination with present Soil Conservation Service programs is the most effective way to accomplish this goal.

Lakes Needwood and Frank. The water quality of Lakes Needwood and Frank is a significant factor that determines conditions in the downstream D.C. reaches. The Rock Creek Functional

Master Plan advocates a monitoring program, dredging, and flocculation. These strategies are all heartily endorsed to define the role of the lakes in determining downstream quality and reduction of turbidity during dry weather. The Park Service should play an active role in such programs and keep track of activities.

Sewer System Inspection. It has been noted in Chapters 8 and 9 that one of the major problems of nonpoint source pollution is that of bacterial contamination during storm events. Recorded concentrations at the Maryland-D.C. line far exceed the expected levels of typical urban runoff. There is indication of an additional source of contamination that contributes a load comparable to that of combined sewage. Literature points to the possibility of sanitary sewer surcharges and overflow in the separated sewer system of Montgomery County as the source of this contamination. The Washington Suburban Sanitary Commission reflects this by its statement in "Rock Creek - A Test of Intentions" (Reference 21). It is recommended that, in conjuncton with the dry weather outfall survey of the Maryland reaches of Rock Creek and tributaries previously recommended, inspection of sanitary sewer lines and manholes of the WSSC be performed. Main interceptor lines and trunk lines should be followed and observations noted of broken lines, blockage, cracked or leaking manholes, displaced manhole covers, and physical evidence of overflow such as toilet paper, fecal remnants, and an eroded flow path to the stream. Such an inspection is necessary to provide initial evidence of surcharge and overflow occurrences. The compilation of results should be presented to the WSSC and, if warranted, a program developed to monitor the problem locations to determine the frequency and magnitude of surcharge overflows. This will also indicate whether the problem is chronic or the result of blockages. It will be imperative for the Park Service to initiate and promote this program to identify the problem locations and provide the necessary evidence in order to mitigate this suspected source of contamination. Recommendations of the M-NCPPC Functional Master Plan do not include any such provisions beyond the present WSSC programs.

Instream Sediment and Debris Trap. The sediment and debris trap that has been previously recommended for the purpose of ecological enhancement, channel erosion mitigation, and flooding control will have equally beneficial consequences of stormwater pollution reduction that may far outweigh the effect of proposed programs for control of nonpoint sources of pollution delivered to the District. Suspended sediment comprises a significant portion of the BOD and nutrient loads that are transported in stormwater. Reduction or trapping of the sediment load will correspondingly reduce pollutant loads. A summary of model simulation of annual pollutant loads for future land use conditions is presented in Table 10-3 with estimated fractions, based on literature values, that are associated with certain particle sizes of suspended sediment. Note that annual loads are based on the simulation span of March 1978 through February 1979 which was a higher than average flow period.

It can be seen that the removal of nutrients is very small since a large portion of the load is either soluble or associated with the fine sediment particles. Removal of BOD is estimated to be 25 to 40 percent of the annual load. A good part of this reduction is realized simply by biodegradation within the impoundment during the detention of stormwater volume. Programs proposed by M-NCPPC in the Functional Master Plan are estimated to reduce BOD loads at the source by approximately 40 percent from impervious surfaces and 20 percent from pervious areas. As a cumulative result significant improvement of instream dissolved oxygen in lower Rock Creek during storm events can be expected.

District of Columbia Nonpoint Sources

The control of nonpoint sources of pollution within the District of Columbia (outside of Rock Creek Park bounds), similar to Montgomery County, cannot realistically be accomplished to any significant degree by the Park Service. Once again, the Park personnel must become involved and active in the plans and programs of the appropriate jurisdictional entities whose responsibilities include such activities. Without such continual input, park concerns will not receive the desired consideration that is required to further the watershed conservation goals.

The Metropolitan Washington Council of Governments is in the process of development and implementation of a Metropolitan Washington Water Quality Management Plan (Reference 16) that encompasses the entire Rock Creek watershed in both Maryland and the District. Control of nonpoint pollution sources is a major element of this plan and the subject has received much more extensive review than is possible within the limits of this study. A synopsis of the major findings and recommendations of this plan is presented with additional elements and endorsements that the Park Service may present for consideration to the COG and the Metropolitan Washington Water Resources Planning Board.

Critical Watersheds Approach. In recognition of the range of variation of water quality problems related to the different aggregate watersheds, it has been proposed that critical watersheds be identified to receive first priority attention for pollution abatement efforts and intensified management of future growth. Criteria for selection of these watersheds are under review and it is recommended that the Park Service promote Rock Creek for such designation on

TABLE 10-3
ESTIMATED POLLUTANT TRAP EFFICIENCY OF PROPOSED SEDIMENT AND DEBRIS TRAP

Water Qual. Constituent	Annual Load At MD-DC Line (Tons)	M-NCPPC Estimated Annual Pollutant Load (Tons)[1]	Estimated Fraction of Pollutant Load In Dissolved (Soluble)[2] Form	Estimated Size Distribution of Particulate Fraction of Pollutants			Comments	Estimated Yearly Pollutant Trap Efficiency of Sediment Trap
				43 microns	43-104 microns	104 microns		
Suspended Sediment	71,200	53,600	0	83%	10%	7%	Primarily silt & clay; most sand from street surf.	75-85%
BOD-5	540	560	N/A	90%	8%	2%	Will settle out first; high fraction in urban runoff of coarse st. surface particles.	25-40%
Orthophospate Phosphorus	11.7	14.3	35-55%	96%	4%	0%	Tied up in smaller particles; very little settles.	5-10%
Nitrate Nitrogen	89.4	169	55-75%	91%	8%	1%	Similar to BOD	10-20%

NA = No Data Available

[1] References 1 and 6.

[2] Reference 2.

[3] Adapted from Reference 13.

the basis of its invaluable natural resources and problems that have been identified within this study. The natural intrinsic environmental, historical, and recreational assets of the Park merit designation for special consideration and study.

Post Development Runoff. The Water Resources Planning Board has adopted an option for control of excess postdevelopment runoff volumes that calls for control of runoff volumes in excess of predevelopment peak flows for the two-year design storm. This policy was modeled after the Montgomery County program and, as previously discussed, does not mitigate the effects of past uncontrolled development. The Park Service should petition for ammendment to the plan which would provide for incorporation of additional storage volume in new facilities to accommodate at the publics expense, excess runoff from existing development.

Gross Allotments for Nonpoint Sources and Margin for Safety. The plan calls for gross allotments and target reductions for nonpoint sources for watersheds identified as being critical and sufficiently detailed analyses are available. Rock Creek qualifies on this count on the basis of sediment and fecal coliform concentrations.

Comprehensive and Site Planning for All and Critical Watersheds. The WRPB adopted options which call for assessment of the impacts of land use changes, especially in critical watersheds, and to refine and recommend use of the regional growth policy as a guideline for local modifications of land use changes. In addition, completion of an urban nonpoint source control measure best management practices handbook is called for with required local jurisdictional use of BMP's once adopted. Once again, Rock Creek must be designated as a critical watershed and the Park Service must actively involve itself in land use planning and BMP's within the watershed to promote its concerns.

Maintenance and Education Programs. Maintenance activities such as streetsweeping, storm sewer maintenance, waste materials collection, and animal waste control, and education-related BMP's are recommended in the plan. Implementation and enforcement of BMP's by the local jurisdictions is not provided for and will be a necessary element of the plan if it is to be successful. The Park Service should require such provisions. Maintenance activities of catch basin cleaning and sewer system inspection in the District of Columbia are irregular and grossly lacking due to budgetary constraints. Adequate funding provisions are a necessary element of an implementable plan.

Structural Control Measures for Previously Developed Areas. The use of BMP's is the only measure called for developed areas by the WRPB. This basically means no additional controls. No provisions for retrofitting existing developme[nt] or the use of runoff quality controls in areas of redevelopment are incorporated in the plan. The status quo should not be accepted by the Park Service.

Agricultural Nonpoint Pollution Source Control. Elements of the WRPB adopted plan for control of agricultural nonpoint pollution sources include:

1. Agricultural sediment and erosion control by identifying and prioritizing agricultural best management practices in accord with water quality benefits provided, increased education, technical assistance and tax incentives to support water quality improvement, identification of critical agricultural watersheds, and preparation of specific erosion and sediment control elements in farm conservation plans with an emphasis on water quality,

2. Increased education and technical assistance programs to improve efficiency and reduce the negative water quality impacts of agricultural application of fertilizers,

3. Encourage BMP use and preparation of animal waste management elements of farm conservation plans with emphasis on water quality, and

4. Provide increased education, technical assistance, research for herbicide and pesticide management and enforcement of herbicide and pesticide controls.

The adopted resolutions carry very little weight to enforce implementation of best management practices. The Park Service should petition for the more strict options which call for mandatory preparation of agricultural control elements for all farms.

Construction Site Nonpoint Source Control. Within the recommended water quality management plan, the WRPB noted that current state and local ordinances already require sediment control plans prior to land disturbance, application of fairly uniform criteria for specific practices, and enforcement of plans. A policy was elected to increase the number of trained inspectors to implement and enforce the already existing programs. Results of the study have concluded similarly that existing ordinances for nonpoint and point source control, in addition to best management practice technology, are quite adequate. The primary deficiency in the Rock Creek Watershed is observed in the inspection and enforcement programs of the jurisdictional entities. It is unrealistic to expect BMP implementation without an adequate vehicle for inspection and enforcement. The WRPB is commended in this reality and the Park Service should applaud all such efforts. It is anticipated, however, that a great deal of this inspection will still have to be carried out by the Park Service where it affects park grounds. It is imperative that enforcement penalties be levied to their fullest extent to mediate the abuse of contractors in this regard.

Rock Creek Park Nonpoint Sources

It is essential that the Park Service demonstrate its strong commitment to improving Rock Creek by exhibiting best management practice controls of nonpoint source pollution within its bounds. Without such a show of sincerity, it is highly unlikely that any serious consideration would be given to Park Service petitions for control of nonpoint pollution from its neighboring jurisdictional entitites. In other words, you must clean up your own backyard before criticizing that of your next-door neighbor.

The recommendations proposed herein will serve as models and demonstrate to Montgomery County and the District that such programs can be effectively implemented and enforced.

Litter Control. The Park Service supports a regular maintenance staff of 50 to 60 employees, with special summer hiring programs, whose duties include collection of trash and debris along roads and picnic areas. Litter pickup within the stream channels is not performed on any regular basis. The control of trash and debris is one of the most visible and easily implemented strategies for nonpoint source control. Presently, park maintenance staff cannot handle the volume of trash deposited on Park grounds. The problem is a pervasive one that requires stringent enforcement of anti-litter ordinances. It is recommended that the Park adopt a set of ordinances that are to be strictly enforced by Park Police with fines to be levied, without exemption, on all violators. Anti-littering signs which espouse the penalties for violation should be posted. All picnic permits should require a deposit that is refundable only after inspection of the picnic area afterwards. Littering and abuse should result in confiscation of the deposit. Alternately, the Service may opt to control the volume of generated refuse by limiting the use of Park recreation areas. Alternately closing picnic areas for periods of two weeks or more will mitigate the deleterious effects of overuse and reduce maintenance requirements, leaving time for staff to perform other needed tasks. Picnic reservations are made by the D.C. Recreation Department. The Park Service may want to assume this role to assure adequate protection of facilities.

The construction of numerous instream debris traps in the park is not recommended. It would not necessarily lessen the accumulation of litter in pockets along the channel and banks. Maintenance would still be required and eyesores would be developed. In addition, barriers to fish migration would result and the traps would present potential health and safety hazards. Such structures are also highly susceptible to frequent flood damage.

The control of trash and debris in the stream channels will necessitate a regular maintenance program by the Park staff that can be performed in conjunction with other instream inspection and maintenance programs recommended by this study. Such a program, which entails walking the entire stream length, should become a monthly maintenance activity and should include all tributaries where a great deal of the needed cleanup is noted.

The problem of trash and debris is a controllable one that simply requires the implementation and strict enforcement of ordinances. The public will continue to abuse the privilege provided by Rock Creek until such intent is made known and evidenced.

Animal Control. Animal sources of bacterial contamination is a difficult problem that cannot realistically be controlled by pet ordinances. Leash laws do not mitigate the defecation of pets on park grounds and, in fact, result in the concentration of waste on or near paths where it creates a more obvious nuisance. For these reasons, mandatory animal control is not advocated for park visitors.

However, signs requesting that owners clean up after their pets for the mutual enjoyment of all Park users may have limited effectiveness.

Some of the more obvious sources of animal waste in the Park originate from the horses that use the trails and paths. Control of horse manure has been successfully demonstrated in numerous cities such as Charleston, South Carolina, by means of a "diaper" that is strapped to the horse to catch droppings. The use of such devices is recommended for the Park Police mounts and the recreational stables for all horses that use the Rock Creek trails.

Within the stable areas, as previously documented in Chapter 8, the drainage of manure pits and stables must be collected and routed to the sanitary sewer system. The Park Service should require immediate modifications of all such pits in the Park stables to do so. Grading around the pits will suffice to provide collection of seepage and drainage. Routing to the nearest sanitary line may require extensive piping and it may be more desirable to relocate pits nearer to existing lines. Inspection of stable areas should be performed on a monthly basis to assure conformance to control requirements and adequate operation of facilities. It should be positively ascertained that drain lines are routed to sanitary sewers and not storm lines.

Vegetation Management. The practice of maintaining vegetation can have a significant impact on nonpoint sources of pollution and instream water quality. The Park Service presently maintains picnic and recreation areas and road shoulders by mowing, tree planting and pruning, fertilizing, and occasional tilling, composting and reseeding. Previous analysis and recommendations for channel erosion and flood damage mitigation have called for reestablishment of a natural diverse growth of vegetation in park recreational areas, road shoulders, and stream banks. The practices of mowing and clearing near the stream channel should be discontinued and extensive planting of natural vegetative species instituted. A thick vegetative growth will stabilize channels, flood plain, and road shoulders from erosion, effectively filter nonpoint source pollutants, and mitigate damaging flood velocities. In addition, measures must be adopted to reestablish a natural canopy of tree shading over the main stem of Rock Creek to lower the extreme water temperatures during the summer. Some scenic roadside views of the park must be sacrificed on the behalf of instream temperatures and stabilization of the channel. Once a natural vegetation is established, the maintenance programs previously listed would be minimized and the Park goal of a "natural" setting could be approached. Bank and flood plain stabilization measures by grass seeding is only a quick and temporary technique to establish immediate protection. Ideal management would allow a subsequent natural cover to establish and grow without interference. Cleared and mowed picnic areas do not conform with the management philosophy espoused herein. But then, such areas are in compliance with the goal of a natural setting. The Park Service must evaluate its true goals and assess its maintenance capabilities to achieve these goals. The recommendations here would eventually mitigate some maintenance activities and enhance Park resources at the sacrifice of recreational value and use. Picnic groves constitute one of the major uses of park grounds, but also comprise one of the major problems, abuses, and maintenance needs. Reduction of these problems could be a boon to the Park in numerous ways.

Other Park Maintenance Activities. Additional park maintenance activities include: fertilizer and pesticide applications on the public golf course; leaf and manure stockpiles are composted and applied in vegetation plantings; logs and stumps brought in by tree crews are ground into chips and sawdust for landscaping use, under bridges, and on trails; roads and trail maintenance; quarterly catch basin cleaning by vacuum unit; weekly street and parking lot flushing; monthly streetsweeping of roads by brush sweeper; yearly turf fertilization; irregular flood mop-up, stream debris removal, and outfall inspection. Several recommenations relevant to these activites are offered.

The seepage and drainage from all stockpiles of leaves, manure, wood chips, and compost can contain very potent concentrations of BOD and ammonia. It is recommended that grading around these stockpiles be provided to collect drainage and seepage and prevent entry to the stream system. It is also suggested that the Park provide areas for public disposal of vegetative debris (leaves, grass cuttings, fallen trees, etc.) on park ground that could be used in its composting operations. This could mitigate illegal dumpings of such debris on park grounds in undesirable locations.

Controlled and limited use of fertilizer and pesticide applications is advocated for both the golf course and turf areas. Compost application is preferable as a natural fertilizer and soil stabilization medium, along with wood chips.

The Park is urged to upgrade its streetsweeping practice to include all parking lot surfaces, replace the mechanical brush unit with a vacuum sweeper, increase the frequency of sweeping to a weekly schedule, and discontinue its street flushing activities. The present programs do very little to reduce the load delivered to the stream systm. The mechanical sweeper basically just pushes debris to the curbside where heavy items are manually picked up and the finer sediment is flushed into the nearest storm drain, thence to Rock Creek. Hence, this practice actually <u>contributes</u> pollution to the creek. A vacuum sweeper will <u>do more to remove</u> the accumulations and mitigate the need for manual <u>pickup</u> and flushing.

Throughout the discussions of this report, notations of the lack of regular inspection and maintenance of storm and sanitary sewer system outfalls and facilities, the stream channels, construction activities, and other park activities have been made. If there is any one program that the Park Service should promote, it is a regular inspection of all these facilities to ensure that adequate environmental protection is provided by the use of best management practice technology. It is reiterated that the willingness to strictly enforce ordinances and powers to control adverse impacts of neglect in these activities <u>must</u> be demonstrated. Adequately maintained sewers, stream channels, and construction sites can and will enhance the Park resources to an invaluable degree.

<u>Combined Sewer Overflows</u>

The subject of combined sewer overflow discharge to Rock Creek could not be broached in any great detail within the contect of this study. The District of Columbia Department of Environmental Services is in the process of developing a Combined Sewer Overflow Study of the Potomac-Anacostia River System which will provide a much more comprehensive data base and analysis than could be produced herein for cost-effective alternatives to mitigate combined sewer overflow impact.

The water quality model simulation results were concluded to undersimulate the frequency and magnitude of combined sewer overflow to Rock Creek during the base year of simulation. However, it was determined that the impact of this overflow volume was not a serious water quality problem, contrary to past literature. The concentrations of pollutants of this overflow do not differ significantly from instream water quality constituent concentrations that come from upstream urban sources during storms of Montgomery County and the District of Columbia. This is not a startling conclusion considering that dilution of sewage by 100 times as much urban runoff is required prior to an overflow occurrence at Piney Branch. Less dilution of approximately 30 parts is provided at downstream overflow points.

Table 9-17 has indicated that, on a yearly basis, less than 0.1 percent of the flow and 0.4 percent of the BOD load at the mouth of Rock Creek is generated by combined sewers. No dissolved oxygen violations were predicted and the duration of bacterial contamination during storm events is the same with or without combined sewer overflows. Combined sewer overflow in Rock Creek is not a sewage problem but an urban runoff problem at the noted dilutions. It may be argued that the combined sewer system serves a beneficial purpose in Rock Creek by preventing the majority of urban runoff from reaching the stream and allowing only the larger, more diluted storms to overflow.

Conclusions of this study are that the most severe adverse impact of combined sewers is not during storm events, but during dry weather. The most beneficial strategies and controls for combined sewer overflow would be those that provide for more inspection, monitoring, and maintenance of the existing system and modifications of its regulators.

Rock Creek does not meet fecal coliform bacteria criteria for body contact recreational use during wet <u>or</u> dry weather conditions. To attain standards during dry weather (the most desirable and attainable), it will require the elimination of bacterial contamination from the sources documented in Chapter 8. The great number of these sources all can be correlated to one basic factor, lack of adequate inspection and maintanance of the sanitary and combined sewer systems. Previous recommendations have dealt with the individual sources identified in dry weather sampling conducted under this study. The chronic problem lies with the D.C. DES deficiency of its own inspection program to identify these problems. Such a program should be mandated by the Park Service in compliance with permits for discharge to Rock Creek. The DES has exhibited prompt and decisive action to mitigate identified problems in the past and is commended for such. However, the problems should be addressed before the fact. Research of several of the point sources identified herein have been known to DES personnel for several years as chronic problems. Yet, they have not been corrected.

Several recommendations are presented for consideration in the combined sewer overflow study of the DES on behalf of the interests of Rock Creek Park.

Completed Separation of Partially Separated Sewer Districts. Review of the historical literature of the combined sewer system tributary to Rock Creek and discussions with D.C. DES personnel has disclosed that several previously combined sewer districts underwent separation programs that, due to cost and implementation difficulties, were incomplete. It is estimate that 111 residences and other buildings remain connected to the combined sewer trunks in these districts, all located on the west side of Rock Creek. The resulting system comprises a separate sanitary sewer system that discharges to either the West·Rock Creek Diversion Sewer on the Rock Creek Main Interceptor, and a combined sewer system with 111 connections that also discharges to the major interceptors via combined sewer regulators with storm overflows to the creek. It is recommended that all sanitary connections in the Connecticut Avenue, Normanstone, 28th Street-Cleveland Avenue, Massachusetts Avenue, Whitehaven Street, and Montrose Districts be disconnected from the old combined sewer system. The major impact of this action is that the trunk line dry weather flow connections of these districts (overflow structures #76, 77, 78, and 79) could be disconnected from the interceptors and provide an additional flow capacity of approximately 186 mgd for transport of more highly concentrated combined sewage. The majority of this capacity can be realized at the Normanstone overflow structure (#77), which has historically been a problem spot to DES and may already have been modified.

The results of dry weather monitoring have revealed that other supposedly complete separation programs in other sewer districts were not totally consummated. The Klingle Road District is one such area that is suspected of contributing a major fraction of the bacterial contamination that has been observed in the lower D.C. reaches of Rock Creek during dry weather. Sewage services on Luzon Branch and Soapstone Valley Branch are also suspected of being the consequence of incomplete separation programs and must be mitigated.

Hydraulic Modifications to Operation of Combined Sewer System. A great deal of the volume of combined sewer overflow to Rock Creek during storm events can be reduced by optimal hydraulic operation of the existing sewer system and overflow regulators. The Park Service is recommended to promote investigation into the operations of the existing combined system as a part of the DES study. It has become apparent that the succession of modifications and programs in the past has resulted in confusion of the hydraulics of the D.C. sewer system. It is necessary to observe and record sewer flows and hydraulic gradients in the interceptors during storm events to develop a scheme for optimal use of avialable capacities. The presence of large sediment deposits in the West Rock Creek Diversion Sewer indicates that storm flows are not sufficiently high enough to scour these deposits out and full capacity is probably not being utilized. Hydraulic analysis in Chapter 9 resulted in a similar conclusion. It is recommended that either of two methods be implemented to utilize this capacity. The dry weather trunk line connections to the WRCDS can be replaced by larger connections to allow more wet weather flow to enter the interceptor. Alternatively, a pressure-sensitive flow regulator can be installed at CSO structure #82. Present operational setting of a static sluice gate at this structure routes all flow in the east partition of the WRCDS to the Rock Creek Main Interceptor. A variable float-type regulator that senses flow conditions on the downstream WRCDS could be set to route sufficient flow to maximize the flow utilization in this interceptor. Flow to the RCMI and all downstream overflows would subsequently be reduced.

Similar replacement of all statically set overflow structures with fluidic sewer overflow regulators (or regulators of similar principle) is recommended to optimize the dynamic hydraulic operation of the combined sewer system. This would also afford the opportunity for the appropriate structural modifications to mitigate chronic problems of sedimentation, blockage, and seepage at these overflow structures which contribute a large source of the contamination during dry weather. The present overflow regulators are antiquated and warrant such rehabilitation.

It is noted that the recommendations offered here are presented on the basis of mitigating combined sewer overflow impact on Rock Creek. The DES study is concerned with additional considerations of impact to the Potomac and Anacostia Rivers whose interests may be adversely impacted by the strategies herein. The Park Service must promote its interests and encourage intensive investigation into the hydraulic works of the combined sewer system of Rock Creek.

REFERENCES

1. Maryland-National Capital Park and Planning Commission, "Draft Functional Master Plan for Conservation and Management in the Rock Creek Basin, Montgomery County, Maryland," 1979.

2. Metropolitan Washington Council of Governments, Land Use/Runoff Quality Relationships in the Washington Metropolitan Area, Northern Virginia Planning District Commission, 1978.

3. Yorke, T.H. and Herb, W.J., Effects of Urbanization on Streamflow and Sediment Transport in the Rock Creek and Anacostia River Basins, Montgomery County, Maryland, 19621974, Geological Survey Professional Paper 1003, 1978.

4. District of Columbia Department of Environmental Services, Unpublished Stream Water Quality Monitoring Data, May 1978 to March 1979 at Six Stations on Rock Creek, D.C. Bureau of Wastewater Treatment Laboratory Division.

5. O'Brien and Gere Engineers, Combined Sewer Overflow Study Potomac-Anacostia River System, Department of Environmental SErvices, Government of the District of Columbia, 1979.

6. Maryland-National Capital Park and Planning Commission, Stormwater and Water Quality Management Study-Rock Creek, CH2M HILL, 1978.

7. Chen, C.N., "Evaluation and Control of Soil Erosion in Urbanizing Watershed," Proceedings of the National Symposium of Urban Rainfall andRunoff and Sediment Control, University of Kentucky, Lexington, Kentucky, 1974.

8. Colston, N.V., Jr., "Characterization and Treatment of Urban Land Runoff," EPA 670/12-74-096.

9. Dalyrmple, R.J., et al, "Physical and Settling Characteristics of Particulates in Storm and Sanitary Wastewaters," EPA 670/2-75-011.

10. Cowen, William F. and F.G. Lee, "Phosphorus Availability in Particulate Materials Transported by Urban Runoff," Journal WPCF, Vol. 48, No. 3, pp. 580-591.

11. Cowen, William F., et al, "Nitrogen Availability in Urban Runoff," Journal WPCF, Vol. 48, No. 2, pp. 339-345.

12. American Public Works Associaton, "Water Pollution Aspects of Urban Runoff, January 1969.

13. Sartor, J.D., and G.B. Boyd, "Water Pollution Aspects of Street Contaminants," EPA-R2-72-081, November 1972.

"Storm Water Pollution from Urban Land Activity," FWQA 11304 FKL 07/70, July 1970.

14. Amy, Gary, et al, "Water Quality Management Planning from Urban Runoff," EPA 440/9-75-004.

15. "Areawide Assessment Procedures Manual," EPA 600/9-76-014, July 1976.

16. Metropolitan Washington Council of Governments, Metropolitan Washington Water Quality Management Plan, 1978.

17. Commonwealth of Virginia State Water Control Board, Best Management Practices Handbook - Urban, 1978.

18. Haan, C.T. and Barfield, B.J., Hydrology and Sedimentology of Surface Mined Lands, 1978.

19. Curtis, D.C., and R.H. McCuen, "Design Efficiency of Stormwater Detention Basins," Journal of the Water Resources Planning and Management Division, ASCE, Vol. 103, No. WR1, Proc. Paper 12938, May 1977, pp. 125-140.

20. U.S. Geological Survey, Water Resources Data For Maryland and Delaware, Water Years 1970-1978.

21. Rock Creek Watershed Association, "Rock Creek - A Test of Intentions," Interstate Commission on the Potomac River Basin, 1967.

22. McCuen, R.H., "Water Quality Trap Efficiency of Stormwater Management Basins," Unpublished Paper.

23. U.S. Environmental Protection Agency, Report to Congress on Control of Combined Sewer Overflow in the United States, EPA 430/9-78-006, October 1978.

APPENDIX A
ECOLOGICAL INVENTORY

(THIS APPENDIX HAS BEEN COMPILED FROM LITERATURE SEARCHES AND WAS NOT FIELD VERIFIED AS PART OF THIS PROJECT.)

TABLE A-1
FUNGI, LICHENS AND RELATED GROUPS
OF THE ROCK CREEK PARK, MARYLAND
(REFERENCE 35)

Species Name	Common Name
Agaricus compestris	Field Mushroom
Amanita storbiliformis	Fir-Cone Amanita
A. phalloides	Deadly Amanita
A. parcivolvata	Slight-Volvate Amanita
A. muscaria	Fly Agaric
A. cothurnata	Booted Amanita
A. solitaria mellea	Honey Mushroom
Armillariella tabescens	Honey-Colored Clitocybe
Boletus miniatò-olivaceus	Bolete
B. separans	Separating Boletus
Bondarzewia berkelei	Berkeley's Polyporus
Cantharellus cinnabarinus	Red Chantrelle
C. cibarius	Chantrelle
Chlorophyllum esculentum	Green-Gill Lepiota
Clitocybe nuda	Blue Cap
Clitopilus prunulus	Plum Clitopilus
Coltricia perennis	Coltricia
Coriolus biformis	Coriolus
C. versicolor	Many-Colored Polypore
Cortinamius cinnamoneus	Cinnamon-Colored Cortinarius
Craterellus cornucopioides	Death Trumpet
Crepidotus crocophyllus	-
Cryptoporus volvatus	-
Daedalea quercina	Oak-Loving Bracket Fungus
D. confragosa	Curry Comb Fungus
Fistulina hepatica	Beefsteak Fungus
Fomitopsis annosa	-
Geastrum limbatus	-
Gloeophyllum trabeum	-
Helvella queletii	-
H. crispa	-
H. macropus	-
H. elastica	-
H. lacunosa	-
Hygrophorus miniatus	Vermillian Hydrophorus
H. borealis	-
Inocybe rimosellus	-
Irpex lacteus	-
Laccaria amethystea	Amethyst Laccaria
Lactarius indigo	Blue Milky-Cap
L. piperatus	Peppery Milky-Cap
Lenzites betulina	Birch Polypore
Lepiota procera	Parasol Mushroom
Lycoperdon umbrinum	-
L. molle	Puffball
L. subincarnatum	Pink Puffball

TABLE A-2
MOSSES AND LIVERWORTS COLLECTED
FROM ROCK CREEK PARK, MARYLAND
(REFERENCE 35)

Species Name	Common Name
Grimmia sp.	-
Hedwigia sp.	-
Conocephalum sp.	-
Sphagnum sp.	Peat Moss
Atrichum sp.	Star Moss
Brachytheciam sp.	-
Dicranella sp.	Little Broom Moss
Dicranum sp.	Big Broom Moss
Hypnum sp.	-
Leucobryum	Pincushion Moss
Mnium sp.	-
Pogonatum sp.	-
Polytrichum sp.	Hair Cap Moss
Thuidium sp.	Fern Moss

TABLE A-1 (CONTINUED)
FUNGI, LICHENS AND RELATED GROUPS
OF THE ROCK CREEK PARK, MARYLAND
(REFERENCE 35)

Species Name	Common Name
Marasmius minutus	-
Morchella esculenta	Beefsteak Morel
M. augusticeps	Morel
M. semilibera	Morel
M. deliciosa	Morel
Mycorrhaphium adustum	-
Phellinus rimosus	Cracked Fomus
P. pomaceus	-
Pholiota adiposa	Fatty Pholiota
Pleurotus ostreatus	Oyster Mushroom
Polyporus sulphureus	Chicken Fungus
P. tephroleucus	-
P. robiniophilus	Locust Polypore
P. dichrous	-
Ramaria aurea	Cauliflower Fungus
Russula adusta	Smoky Russula
Scleroderma geaster	Earth Star
S. cepa	-
Simblum sphaerocephalum	Chambered Stinkhorn
Steccherinum ochraceum	Ochrey Hydnum
Stereum complicatum	-
S. ostrea	-
Tylopilus indecisus	Undecided Boletus
T. fellens	Bitter Boletus
Xeromphalina campanella	Bell Omphalia
Xylaria polymorpha	Blackfinger Mushroom
X. oxyacanthae	-

TABLE A-3
FERNS AND FERN ALLIES REPORTED AND OBSERVED FROM
ROCK CREEK PARK, WASHINGTON, DC AND MARYLAND
(REFERENCES 22, 28, and 35)

Species Name	Common Name
Lycopodium lucidulum	Shining Clubmoss
L. obscurum	Ground Pine
L. complanatum	Running Pine
Equisetum arvense	Common Horsetail
E. hiemmale	Scouring Rush
O. claytoniana	Interrupted Fern
O. regalis var. spectabilis	Royal Fern
Polystichum acrostichoides	Christmas Fern
Onoclea sensibilis	Sensitive Fern
Polypodium virginianum	Polypody
Thelypteris noveboracensis	New York Fern
T. hexagonoptera	Broad Beech Fern
Athyrium filix-femina asplenoides	Southern Lady Fern
A. thalypteroides	Silvery Spleenwart
Dryopteris spinulosa	Spinulose Wood Fern
Dennstaedtia punctilobula	Hay-scented Fern
Asplenium platyneuron	Ebony Spleenwart
Botrychium dissectum	Cut-Leaved Grape Fern
B. virginianum	Rattlesnake Fern
Adiantum pedaturm	Northern Maidenhair Fern
Pteridium aquilinum	Bracken Fern

TABLE A-4
FLOWERS FOUND IN ROCK CREEK PARK, WASHINGTON, DC
(REFERENCES 22, 28, and 42)

Species Name	Common Name
Symplocarpus foetidus	Skunk Cabbage
Epigaea repens	Trailing Arbutus
Hepatica americana	Hepatica
Draba verna	Whitlow-Grass
Cardamine bulbosa	Spring Cress
Dicentra cucullaria	Dutchman's Breeches
Barbarea vulgaris	Yellow Rocket
Podophyllum peltatum	May-Apple
Sedum acre	Mossy Stone Crop
Dentaria laciniata	Toothwart
Claytonia virginica	Spring Beauty
Ranunculus abortivus	Kidney Leaf Buttercup
Stellaria pubera	Star Chickweed
S. media	Common Chickweed
S. longifolia	Long-Leaved Stitchwort
Taraxacum officinale	Dandelion
Lamium amplexicaule	Henbit
Corydalis flavula	Yellow Corydalis
Senecio aureus	Golden Ragwort
Ranunculus ficaria	Lesser Buttercup
Viola pubescens	Yellow Violet
Erythronium americanum	Adder's Tongue
Duchesnea indica	Indian Strawberry
Sanguinaria canadensis	Bloodroot
Arabidopsis thaliana	Mouse-Ear Cress
Alliaria officinalis	Garlic-Mustard
Jeffersonia diphylla	Twinleaf
Thalictrum dioicum	Early Meadow Rue
Glechoma hederacea	Ground-Ivy
Mertensia virginica	Virginia Bluebell
Saxifraga virginiensis	Saxifrage
Osmorhiza claytoni	Sweet Cicely
Amemonella thalictroides	Blue Anemone
Trillium sessile	Toadshade
Houstonia caerulea	Common Bluets
Zizia aurea	Golden Alexanders
Lepidium campestre	Field Peppergrass
Arisaema triphyllum	Jack-in-the-Pulpit
Ornithogalum umbellatum	Star-of-Bethlehem
Erigeron pulchellus	Robin-Plantain
Vinca minor	Periwinkle
Geranium maculatum	Wild Geranium
Tussilago farfara	Coltsfoot
Berberis thunbergi	Japanese Barberry
Galium aparine	Catchweed Bedstraw
Cardamine pensylvanica	Pennsylvania Bittercress
C. bulbosa	Springcress
Galanthus nivalis	Snowdrop

TABLE A-4 (CONTINUED)
FLOWERS FOUND IN ROCK CREEK PARK, WASHINGTON, DC
(REFERENCES 22, 28, and 42)

Species Name	Common Name
Viola papilonacea	Common Blue Violet
Veronica officinalis	Common Speedwell
Polygonatum biflorum	Solomon's Seal
Similacina racemosa	False Solomon's Seal
Dioscorea glauca	Wild yam
Ranunculus bulbosus	Bulbous Buttercup
R. recurvatus	Hooked Buttercup
Asarum canadense	Wild Ginger
Rumex acetosella	Sour Grass
Erigeron annuus	Daisy Fleabane
Lamium purpureum	Purple Henbit
Viola spp.	White Violet
Senecio vulgaris	Common Groundsel
Antennaria plantaginifolia	Plantain-Leaved Everlasting
Potentilla argentea	Silvery Cinquefoil
Smilax nerbacea	Carrion Flower
Fragaria virginiana	Wild Strawberry
Medeola virginiana	Indian Cucumber
Potentilla recta	Rough-Fruited Cinquefoil
Calycanthus floridus	Carolina Allspice
Malva neglecta	Cheeses
Orobanche uniflora	Cancer-root
Chaerophyllum procumbens	Wild Chervil
Smilax rotundifolia	Greenbriar
Salvia lysata	Lyse-Leaved Sage
Allium vineale	Field Garlic
A. canadense	Spring Wild Onion
Heuchera americana	Alum-Root
Vicia americana	Purple Vetch
Tradescantia virginiana	Spider Wort
Oxalis stricta	Yellow Wood-Sorrel
Capsella bursa-pastoris	Shepard's Purse
Orchis spectabilis	Showy Orchis
Chrysogonum virginianum	Chrysognum
Sisymbrium officinale	Hedge Mustard
Lychris alba	Evening Lychnis
Hypoxis hirsuta	Star Grass
Scutellaria serrata	Showy Skullcap
Vitus spp.	Wild Grape
Aralia nudicaulis	Wild Sarsaparilla
Toxicodendron radicans	Poison Ivy
Hydrophyllum virginianum	Virginia Waterleaf
Cryptotaenia canadensis	Hone Wort
Houstonia purpurea	Tall Houstonia

TABLE A-4 (CONTINUED)
FLOWERS FOUND IN ROCK CREEK PARK, WASHINGTON, DC
(REFERENCES 22, 28, and 42)

Species Name	Common Name
Trifolium repens	White Clover
Arisaema dracontium	Green Dragon
Uvularia perfoliata	Bellwort
Lapsana communis	Nipple Wort
Trifolium pratense	Red Clover
Prunella vulgaris	Heal-All
Crepis capillaris	Smooth Hawksbeard
Galium circaezans	Wild White Licorice
Galinsoga ciliata	Quick-Weed
Podophyllum peltatum	May Apple
Veronica filiformis	Slender Speedwell
Physocarpus opulifolius	Nine Bark
Sisymbrium altissimum	Tumble Mustard
Potentilla simplex	Common Cinquefoil
Medicago lupulina	Black Media
Penstemon digitalis	Beard-Tongue
Sanicula marilandica	Black Snakeroot
Cimicifuga racemosa	Black Cohosh
Rumex crispus	Curley Dock
Chrysanthemum leucanthemum	Ox-Eye Daisy
Apocynum medium	Intermediate Dog Bone
Melilotus officinalis	Yellow Sweet Clover
M. alba	White Sweet Clover
Polygonum spp.	Smart Weed
P. persicaria	Lady's Thumb
Solannm dulcamara	Purple Nightshade
Sisyrinchium mucronatum	Blue-Eye Grass
Oxalis violacea	Violet Wood-Sorrel
Hydrangea arborescens	Wild Hydrangea
Hieracium venosum	Rattlesnake Weed
Trifolium agrarium	Hop Clover
Commelina communis	Asiatic Dayflower
Plantago major	Common Plantain
P. rugelii	Blackseed Plantain
Nasturtium officinale	Watercress
Cinopholis americana	Squaw-Root
Lepidium virginicum	Peppergrass
Specularia perfoliata	Venus' Looking-Glass
Hypochoeris radicata	Cat's Ear
Chimaphila maculata	Spotted Wintergreen
C. umbellata	Pipsissewa
Lysimachia nummularia	Moneywart
Brassica nigra	Black Mustard
Polygonum spp.	Knotweed

TABLE A-4 (CONTINUED)
FLOWERS FOUND IN ROCK CREEK PARK, WASHINGTON, DC
(REFERENCES 22, 28, and 42)

Species Name	Common Name
Galinsoga parviflora	Gallant Soldiers
Vicia villosa	Hairy Vetch
Krigia virginica	Dwarf Dandelion
Archillea millefolia	Yarrow
Symphytum officinale	Wild Comfrey
Monotropa uniflora	Indian Pipe
Circaea quadrisulcata	Enchanter's Nightshade
Oenothera fruticosa	Sun Drops
Cicuta maculata	Water Hemlock
Coreopsis verticillata	Whorled Coreopsis
Scutellaria incana	Downy Skullcap
Lysimachia ciliata	Fringed Loosestrife
Thalictrum polygonum	Tall Meadow-Rue
Hypericum perforatum	Common St. Johnswort
Dianthus armeria	Deptford Pink
Impatiens capensis	Spotted Touch-me-not
Rudbechia hirta	Black-Eyed Susan
Verbena augustifolia	Purple Vervain
Ascelpias purpurascens	Purple Milkweed
Anthemis cotula	Mayweed
Hemerocallis fulva	Day-Lily
Aralia racemosa	Spikeweed
Silene stellata	Campion
Convolvulus sepium	Hedge Bindweed
Fagopyrum sagittatum	Buckwheat
Solanum carolinense	Horse Nettle
Saponaria officinalis	Bouncing Bet Soapwort
Cichorium intybus	Chicory
Hibiscus syriacus	Rose-of-Sharon
Daucus carota	Wild Carrot
Sonchus arvensis	Sow Thistle
Seriocarpus asteroides	White-Topped Aster
Ruellia caroliniensis	Ruellia
Monarda fistulosa	Wild Bergamot
Lilium canadense	Camada Lily
Anemone virginiana	Thimbleweed
Geum canadense	White Avens
G. aleppicum var. strictum	Yellow Avens
Alisma subcordatum	Water Plantain
Phytolacca americana	Pokeweed
Althaea rosea	Hollyhock
Hosta spp.	Plantain-Lily
Lycopus virginicus	Bugleweed
Desmodium spp.	Tick-Trefoil
Convolvulus arvensis	Field Bindweed

TABLE A-4 (CONTINUED)
FLOWERS FOUND IN ROCK CREEK PARK, WASHINGTON, DC
(REFERENCES 22, 28, and 42)

Species Name	Common Name
Centaurea jacea	Brown Knapweed
Verbascum thapsus	Mullein
Phryma leptostachya	Lopseed
Hieracium scabrum	Rough Hawkweed
Rorippa islandica	Yellow Cress
Phlox paniculata	Fall Phlox
Lobelia inflata	Indian Tobacco
Erigeron canadensis	Horseweed
Boehmeria cylindrica	False Nettle
Monarda clinopodia	Beebalm
Silene cucubalus	Bladder Campion
Eupatorium rugosum	White Snakeroot
Oenothera biennis	Evening Primrose
Polygonum cuspidatum	Japanese Knotweed
Ipomoea pandurata	Wild Potato-Vine
Acalypha virginica	Three-Seeded Mercury
Elephantopus carolinianus	Elephant's Foot
Solidago spp.	Goldenrod
Laportea canadensis	Wood Nettle
Galium asprellum	Rough Bedstraw
Verbena urticifolia	White Vervain
Hypericum punctatum	Spotted St. Johnswart
Portulaca oleracea	Purslane
Tovara virginiana	Virginia Knotweed
Datura stramonium	Jimsonweed
Lactuca scariola	Prickly Lettuce
Penthorum sediodes	Ditch Stone Crop
Goodyera pubescens	Rattlesnake Plantain
Epilobium angustifolium	Fireweed
Agrimonia spp.	Yellow Agrimony
Amphicarpa bracteata	Hog Peanut
Cirsium vulgare	Bull Thistle
Tipularia discolor	Cranefly Orchid
Aster novae-angliae	New England Aster
Mimulus ringens	Monkey Flower
Bidens aristosa	Tickseed-Sunflower
Cassia nictitans	Wild Sensitive Plant
Urtica dioica	Stinging Nettle
Euphorbia corollata	Flowering Spurge
Pycnanthemum spp.	Mountain Mint
Lactuca canadensis	Yellow Lettuce
Scrophularia lanceolata	Figwort
Eupatorium perfoliatum	Boneset
E. purpureum	Joe-Pye-Weed
Aruncus dioicus	Goat's Beard

TABLE A-4 (CONTINUED)
FLOWERS FOUND IN ROCK CREEK PARK, WASHINGTON, DC
(REFERENCES 22, 28, and 42)

Species Name	Common Name
Chenopodium ambrosioides	Mexican Tea
Gnaphalium obtusifolium	Sweet Everlasting
Verbesina alternifolia	Wingstem
Helianthus annuus	Sunflower
Ambrosia trifida	Great Ragweed
Hedeoma pulegioides	American Pennyroyal
Eupatorium coelestinum	Mistflower
Verbesine occidentalis	Crownbeard
Rudbeckia laciniata	Green-Headed Coneflower
Ambrosia artemisiifolia	Common Ragweed
Vernonia noveboracensis	Ironweed
Cuscuta gronovii	Dodder
Clematis virginiana	Virgin's Bower
Impatiens pallida	Pale Touch-Me-Not
Menispermum canadense	Moonseed
Abutilon theophrasti	Velvet Leaf
Ipomoea hederacea	Ivy-Leaved Morning-Glory
Pilea pumila	Clearweed
Xanthium chinense	Cocklebur
Ascyrum hypericoides	St. Andrew's Cross
Sicyos angulatus	Bur-Cucumber
Physalis heterophylla	Ground Cherry
Amaranthus hybridus	Pigweed
Epilobium glandulosum	Northern Willow Herb
Collinsonia canadensis	Horsebalm
Polygonum scandens	Climbing False Buckwheat
Strophostyles helvola	Trailing Wildbean
Bidens frondosa	Beggar-Tick
Lespedeza spp.	Bushclover
Artemisia vulgaris	Mugwort
Bidens bipinnata	Spanish Needles
Chenopodium album	Lamb's Quarters
Chrysopis mariana	Maryland Golden Aster
Epifagus virginiana	Beechdrops
Cypripedium acaule	Moccasin Flower
Cerastium viscosum	Sticky Chickweed
C. vulgatum	Common Mouse-Ear Chickweed
Potentilla norvegica	Norway Cinquefoil
P. canadensis	Field Cinquefoil
Trifolium arvense	Stone Clover
Strophostyles umbellata	Pink Wildbean
Pyrola elliptica	Shinleaf
Aplectrum hyemale	Adam-and-Eve
Oxalis europaea	European Oxalis

TABLE A-4 (CONTINUED)
FLOWERS FOUND IN ROCK CREEK PARK, WASHINGTON, DC
(REFERENCES 22, 28, and 42)

Species Name	Common Name
Geranium cardinianum	Carolina Geranium
Malva rotundifolia	Running Mallow
Sanicula canadensis	Canada Sanicle
Osmorhiza longistylis	Anise Root
Phlox divaricata	Wild Blue Phlox
Satureja vulgaris	Wild Basil
Verbascum blattaria	Moth-Mullein
Aureolaria virginica	Virginia Oak-leech
Plantago lanceolata	English Plantain
P. virginica	Hoary Plantain
Lobelia siphilitica	Great Blue Lobelia
Aster schreberi	Schreber Aster
A. divaricatus	White Woodland Aster
A. paternus	Summer-Aster
A. dumosus	Bushy Aster
Erigeron philadelphicus	Common Fleabone
E. strigosus	Daisy Fleabone
Sagittaria latifolia	Arrowhead
Asclepias tuberosa	Butterfly-weed
Opuntia humifusca	Prickly-pear Cactus
Lobelia cardinalis	Cardinal Flower
Typha latifolia	Common Cattail
T. angustifolia	Narrow-leaf Cattail
Ranunculus ficaria	Lesser Celandine
Dioscorea batatus	Cinnamon-Vine
Galium aparine	Cleavers
Trifolium procumbens	Smaller Hop Clover
Scrophularia marilandica	Maryland Figwort
Amianthium muscaetoxicum	Fly-Poison
Myosotis scorpiordes	Forget-me-not
Lycopus americanus	Cutleaf Water Horehound
Asclepias incarnata	Swamp Milkweed
Mentha aquatica	Watermint
M. piperita	Peppermint
Anagallis arvensis	Scarlet Pimpernel
Sabatia angularis	Rose Pink
Scutellaria laterifolia	Mad-dog Skullcap
Helenium nudiflorum	Purple-headed Sneezeweed
Stellaria graminea	Lesser Stitchwort
Duchesnea indica	Indian Strawberry
Polygonum sagittatum	Arrow-leaved Tearthumb
P. arifolium	Halberd-leaved Tearthumb
Trillium undulatum	Painted Trillium
Liparis lilifolia	Twayblade
Alisma trivale	Water-plantain

TABLE A-5
TREES, WOODY VINES, AND SHRUBS OF ROCK CREEK PARK, WASHINGTON, DC (REFERENCES 22, 28, and 42)

Species Name	Common Name
Pinus rigida	Pitch Pine
P. strobus	White Pine
P. virginiana	Virginia Pine
Tsuga canadensis	Eastern Hemlock
Juniperus virginiana	Red Cedar
Acer rubrum	Red Maple
Alnus rugosa	Common Alder
Lindera benzoin	Spicebush
Cornus florida	Flowering Dogwood
Viburnum prunifolium	Blackhaw
Vaccinum spp.	Blueberry
Robinia pseudoacacia	Black Locust
Morus alba	White Mulberry
Lonicera tatarica	Tartarian Honeysuckle
Acer negundo	Boxelder
Enonymus americanus	Strawberry-Bush
Prunus serotina	Wild Black Cherry
Rubus phoenicolasius	Wineberry
Rubus spp.	Blackberry
Cercis canadensis	Redbud
Amelanchier canadensis	Juneberry
Viburnum dentatum	Arrow-wood
Ligustrum ovalifolium	California Privet
Rubus procumbens	Dewberry
Wistaria floribunda	Japanese Wisteria
Viburnum opulus sterile	Snowball Bush
Magnolia tripetala	Umbrella Magnolia
M. Virginiana	Sweet Bay Magnolia
Viburnum acerfolium	Mapleleaf Viburnum
Rosa multiflora	Multiflora Rose
R. carolina	Dwarf Wild Rose
Kalmia latifolia	Mountain Laurel
Philadelphus inodorus	Mock-Orange
Ligustrum vulgare	Common Privet
Sambucus canadensis	Elderberry
Lonicera japonica	Japanese honeysuckle
Paulownia tomentosa	Princess-Tree
Albizzia julibrissin	Mimosa
Rhus glabra	Smooth Sumac
Chionanthus virginica	Fringe Tree
Cephalanthus occidentalis	Buttonbush
Acer saccharum	Sugar Maple
Carya ovata	Shagbark Hickory

TABLE A-5 (CONTINUED)
TREES, WOODY VINES, AND SHRUBS OF
ROCK CREEK PARK, WASHINGTON, DC
(REFERENCES 22, 28, and 42)

Species Name	Common Name
Juglans cinerea	Butternut
J. Nigra	Black Walnut
Liquidambar styraciflua	Sweet gum
Castanea dentata	Chestnut
Populus deltoides	Cottonwood
Carya cordiformis	Bitternut
C. tomentosa	Mockernut
C. glabra	Pignut Hickory
Gleditsia triacanthos	Honey locust
Corylus americana	American Hazelnut
Carpinus caroliniana	Hornbeam
Betula nigra	River Birch
Alnus serrulata	Smooth Alder
Fagus grandifolia	American Beech
Quercus alba	White Oak
Q. stellata	Post Oak
Q. prinus	Chestnut Oak
Q. phellos	Willow Oak
Q. falcata	Southern Red Oak
Q. velutina	Black Oak
Q. borealis	Northern Red Oak
Ulmus rubra	Red Elm
Liriodendron tulipifera	Tulip-Tree
Asimina triloba	Tall Paw Paw
Sassafras albidum	Sassafras
Platanus occidentalis	American Sycamore
Ulmus alatus	Winged Elm
Malus prunifolia	Apple
Nyssa sylvatica	Black Gum
Tilia americana	Basswood
Staphylea trifolia	American Bladdernut
Catalpa bignonoides	Southern Catalpa
Prunus avium	Sweet Cherry
P. virginiana	Choke Cherry
Quercus marilandica	Black Jack Oak
Diospyros virginiana	Common Persimmon
Elaeagnus angustifolia	Russian Olive
Gaylussacia baccata	Black Huckleberry
Ilex opaca	American Holly
Parthenocissus quinquefolia	Virginia Creeper
Rhododendron nudiflorum	Pinxter-Flower
Rhus copallinum	Dwarf Sumac
R. typhina	Staghorn Sumac
Hibiscus syriacus	Rose-of-Sharon

TABLE A-5 (CONTINUED)
TREES, WOODY VINES, AND SHRUBS OF
ROCK CREEK PARK, WASHINGTON, DC
(REFERENCES 22, 28, and 42)

Species Name	Common Name
Vaccinium caesariense	High-bush Blueberry
V. stamineum	Deerberry
V. vacillans	Late Low Blueberry
Gaultheria procumbens	Teaberry
Ampelopsis cordata	American Ampelopsis
Fraxinus americana	White Ash
Castanea mollisima	Asiatic Chestnut
C. pumilla	Chinquapin
Cornus amomum	Silky Dogwood
Celtis occidentalis	Hackberry
Crataegus spp.	Hawthorn
Ptelea trifoliata	Hop tree
Ostrya virginiana	Hop hornbeam
Hydrangea arborescens	Hydrangea
Magnolia acuminata	Bigleaf Magnolia
Wisteria sinensis	Chinese Wisteria
Acer platanoides	Norway Maple
A. saccharinum	Silver Maple
Quercus lyrata	Overcup Oak
Q. bicolor	Swamp White Oak
Q. coccinea	Scarlet Oak
Q. palustris	Pin Oak
Q. rubra	Red Oak
Q. imbricaria	Shingle Oak
Q. acutissima	Sawtooth Oak
Elaeagnus pungens	Oleaster
Maclura pomifera	Osage Orange
Rubus strigosus	Raspberry
Ailanthus altissima	Tree of Heaven
Campsis radicans	Trumpet Creeper
Parthenocissum quinquefolia	Virginia Creeper
Salix nigia	Black Willow
S. babylonica	Weeping Willow
Smilax rotundifolia	American Bittersweet
Celastrus scondens	Asiactic Bittersweet
Hamamelis virginiana	Witch Hazel
Arclia spinosa	Devils Walking Stick

TABLE A-6
LAND GASTROPODS FOUND IN THE
DISTRICT OF COLUMBIA AND VICINITY
(REFERENCE 1)

Species Name

Polygyra fraudulenta
P. fallax
P. denotata
P. thyroidus
P. thyroidus bucculenta
P. albolabris
P. exoleta
P. stenotrema
P. hirsuta
P. monodon
P. hirsuta nana
P. monodon fraterna
P. monodon aliciae
P. tridentata
P. tridentata juxtidens
P. edentilabris
Guppya sterkii
Euconulus chersinus dentatus
E. chersinus polygyratus
E. fulvus
Retinella electrina
R. identata
R.burringtoni
Mesomphix cupreus
Oxychilus lucidum
O. cellarium
O. alliarium
Hawaiia minuscula
Striatura meridionalis
Zonitoides arboreus
Z. limatulus
Z. nitidus
Z. ligerus
Z. demissus
Z. suppressus
Z. cerinoideus
Anguispira alternata
Helicodiscus parallelus
H. singleyanus inermis
Discus cronkhitei anthonyi
D. patulus
Punctum vitreum
P. minutissimum
Haplotrema concavum
Gastrocopta procera
G. armifera
G. contracta
G. corticaria
G. pentodon
Vertigo ovata
V. pygmaea
V. milium
V. gouldii
Pupoides marginatus
Gastrocopta tappaniana
Strobilops aenea
S. labyrinthica
S. affinis
Vallonia pulchella
V. excentrica
Cochliocopa lubrica
Carychium exiguum
C. exile
Limax maximus
L. flavus
Deroceras agreste
D. campestre

TABLE A-7
AQUATIC GASTROPODS FOUND IN THE
DISTRICT OF COLUMBIA AND VICINITY
(REFERENCE 1)

Species Name	
Lymnaea columella	Anculosa carinata
L. columella macrostoma	Goniobasis virginia
L. caperata	Cincinnatia cincinnatiensis
L. caperata umbilicata	Amnicola limosa
L. obrussa	A. limosa porata
L. humilis	A. pallida
Helisoma trivolvis	A. lustrica
H. antrosum	Somatogyrus virginicus
Gyraulus parvus	S. attilis
G. parvus walkeri	Lyogyrus granum
G. deflectus	L. lehnerti
G. dilatatus	L. pupoides
Menetus exacuous	Bulimus tentaculatus
Planorbula armigera	Pomatiopsis lapidaria
Ferrissia rivularis	Valvata bicarinata
F. kirklandi	V. tricarinata
F. diaphana	Campeloma decisum
F. fusca	C. rufum
Physa heterostropha	Viviparus contectoides
P. ancillaria	V. viviparus
P. gyrina	Lioplax subcarinatus

TABLE A-8
PELECYPODS FOUND IN THE
DISTRICT OF COLUMBIA AND VICINITY
(REFERENCE 1)

Species Name

Sphaerium stamineum
S. solidulum
S. modestum
S. occidentale
S. striatinum
S. secure
S. partumeium
S. truncatum
S. transversum
Pisidium virginicum
P. cruciatum
P. compressum
P. abditum
P. punctatum
P. trapezoideum
P. walkeri
P. fraudulentum
Lampsilis cariosus
L. radiatus
L. ochraceus
L. ventricosa
L. nasutus
Anodenta cataracta
Strophitus undulatus
Alasmidonta undulata
A. heterodon
A. marginata
Elliptio complanatus
E. productus

TABLE A-9
CRUSTACEA FOUND OR PRESUMED TO OCCUR
IN ROCK CREEK PARK
BASED ON HABITAT DISTRIBUTION SIMILARITY
(REFERENCES 2, 3, 4, 5, 6, 10, 11, and 12)

Copepoda -	*Cyclops exilis*
	Paracyclops fimbriatus
	Bryocamptus zschokkei alleganensis
Ostracoda -	*Potamocypris bowmani*
Amphipoda -	*Gammarus fasciatus*
	G. minus
	Crangonyx serratus
	C. shoemakeri
	Synurella chamberlaini
	Stygobromus kenki
	S. pizzinii
	S. tenuis potomacus
	S. hayi
Isopoda -	*Asellus communis*
	A. forbesi
	A. kenki
	A. racovitzai racovitzai
	Lirceus brachyurus
	L. lineatus
Decopoda -	*Orconectes limosus*
	Cambarus bartoni
	C. diogenes
	C. montanus acuminatus

TABLE A-10
A PRELIMINARY LIST OF BUTTERFLIES WHICH
MAY OCCUR IN ROCK CREEK PARK, WASHINGTON, DC
(REFERENCE 43)

Species Name	Common Name
Panoquina ocola	Long-winged Skipper
Amblyscirtes vialis	Roadside Skipper
Euphyes conspicua conspicua	Black Dash
Poanes hobomok	Northern Golden Skipper
P. zabulon	Zabulon Skipper
P. aaroni aaroni	Aaron's Skipper
Atalopedes campestris	Sachem
Pompeius verna verna	Little Glassy Wing
Wallengrenia egeremet	Northern Broken Dash
Polites coras	Peck's Skipper
P. themistodes	Tawny-edged Skipper
P. origines origines	Cross Line Skipper
Hesperia leonardus	Leonard's Skipper
Hylephila phyleus	Fiery Skipper
Thymelicus lineola	European Skipper
Ancyloxypha numitor	Least Skipper
Lerema accius	Clouded Skipper
Nastra lherminier	Swarthy Skipper
Pholisora catullus	Common Sooty Wing
Pyrgus communis communis	Checkered Skipper
Erynnis icelus	Dreamy Dusky Wing
E. brizo brizo	Sleepy Dusky Wing
E. persius persius	Persens' Dusky Wing
E. zarucco zarucco	Zarucco Dusky Wing
E. martialis	Mottled Dusky Wing
E. horatius	Horace's Dusky Wing
E. juvenalis juvenalis	Juvenal's Dusky Wing
Staphylus hayhurstii	Southern Sooty Wing
Thorybes bathyllus	Southern Cloudy Wing
T. pylades	Northern Cloudy Wing
T. confusis	Confused Cloudy Wing
Achalarus lyciades	Hoary-edged Skipper
Epargyreus clarus clarus	Silver-spotted Skipper
Battus philenor philenor	Pipevine Swallowtail
Papilio polyxenes asterius	Black Swallowtail
P. cresphontes cresphontes	Giant Swallowtail
P. glaucus glaucus	Tiger Swallowtail
P. troilus troilus	Spicebush Swallowtail
Graphium marcellus	Zebra Swallowtail
Pieris protodice protodice	Checkered White
P. rapae	Cabbage Butterfly
C. eurytheme eurytheme	Alfalfa Butterfly
C. philodice philodice	Clouded Sulfur
Eurema lisa	Little Sulfur
E. nicippe	Sleepy Orange
Anthocaris midea	Falcate Orange Tip

TABLE A-10 (CONTINUED)
A PRELIMINARY LIST OF BUTTERFLIES WHICH
MAY OCCUR IN ROCK CREEK PARK, WASHINGTON, DC
(REFERENCE 43)

Species Name	Common Name
Satyrium calanus falacer	Banded Hairstreak
Calycopis cecrops	Red-Banded Hairstreak
Callophrys henrici henrici	Henry's Elfin
C. niphon niphon	Pine Elfin
C. gryneus gryneus	Olive Hairstreak
Panthiades m-album	White on Hairstreak
Strymon melinus humuli	Northern Gray Hairstreak
Feniseca tarquinius tarquinius	Harvester
Lycaena phlaeas americana	American Copper
Everes comyntas comyntas	Eastern Tailed Blue
Celastrina argiolus pseudargiolus	Spring Azure
Libytheana bachmanii bachmanii	Snout Butterfly
Asterocampa celtis celtis	Hackberry Butterfly
A. clyton clyton	Tawny Emperor
Limenitis arthemis astyanax	Red Spotted Purple
L. archippus archippus	Viceroy
Vanessa atalanta rubria	Red Admiral
Cynthia virginiensis	Painted Beauty
C. cardui	Painted Lady
Junonia coenia coenia	Buckeye
Nymphalis antiopa antiopa	Mourning Cloak
Polygonia interrogationis	Question Mark
P. comma	Comma
Phyciodes tharos tharos	Pearl Crescent
Speyeria idalia	Regal Fritillary
S. cybele cybele	Great Spangled Fritillary
Euptoieta claudia	Variegated Fritillary
Daneus plexippus plexippus	Monarch
Lethe appalachia leeuwii	Northern Grass Nymph
Euptychia cymela cymela	Little Wood Satyr
Cercyonis pegala alope	Wood Nymph

TABLE A-11
FISH COLLECTED IN PREVIOUS STUDIES
FROM ROCK CREEK PARK*, WASHINGTON, DC
(REFERENCES 37, 38, 39, 40 and 41)

Species Name	Common Name
Salmo fontinalis	Brook Trout
Rhinichthys altratulus	Blackmose Dace
R. cataractae	Longnose Dace
Clinostomus funduloides	Rosyside Dace
Semotilus atromaculatus	Creek Chub
Exoglossum maxillingua	Cutlips Minnow
Notemigonus crysoleucas	Golden Shiner
Notropis rubellus	Rosyface Dace
Semotilus croporalis	Fallfish
Notropis procue	Swallowtail Shiner
N. analostanus	Satinfish Shiner
Pimephales notatus	Bluntnose Minnow
Notropis cornutus	Common Shiner
N. hudsonius	Spottail Shiner
Catostomus commersoni	White Sucker
Hypentelium nigricans	Hogsucker
Ictalurus natalis	Yellow Bullhead
Noturus insignis	Margined Madtom
Ambloplites rupestris	Rock Bass
Lepomis auritus	Redbreast Sunfish
L. cyanellus	Green Sunfish
Micropterus dolomieui	Smallmouth Bass
Lepomis macrochirus	Bluegill Sunfish
Percopsis omiscomaycus	Trout-Perch
Etheostoma olmstedi	Tessellated Dace
Percina peltata	Shield Darter
Cottus bairdi	Mottled Sculpin
Ictalurus punctatus	Channel Catfish
Cyprinus carpio	Carp
Anguilla rostrata	American Eel
Lepomis gibbosus	Pumpkinseed Sunfish

*Table does not include anadromous fish species since they are residents of the Potomac River and migrate into Rock Creek.

TABLE A-12
AMPHIBIANS AND REPTILES OF
ROCK CREEK PARK, WASHINGTON, DC

Scientific Name	Common Name
Ambystoma maculatum*	Spotted Salamander
Eurycea bislineata bislineata*	Northern Two-Lined Salamander
Plethodon cinereus cinereus*	Red-Backed Salamander
Pseudotritan ruber*	Northern Red Salamander
Bufo americanus americanus	American Toad
H. crucifer*	Spring Peeper
Rana catesbeiana*	Bullfrog
R. clamitans*	Green Frog
R. sylvatica*	Wood Frog
Carphophis amoenus*	Worm Snake
Diadophis punctatus*	Ring Neck Snake
Opheodrys aestivus*	Rough Green Snake
Elaphe obsoleta*	Black Rat Snake
Lampropeltis getulus*	Eastern Kingsnake
Natrix sipedon*	Northern Water Snake
Storeria dekayi*	Northern Brown Snake
T. sirtalis*	Garter Snake
Agkistrodon contortrix	Northern Copperhead
Chelydra serpentina*	Snapping Turtle
Terrapene carolina*	Eastern Box Turtle
Chrysemys picta*	Painted Turtle
C. rubriventris	Red-Bellied Turtle

*Species noted on unpublished list "Amphibians and Reptiles of Rock Creek Park".

TABLE A-13
BIRDS OF ROCK CREEK PARK, WASHINGTON, DC

Species Name	Common Name
Setophaga ruticilla	American Redstart
Hirundo rustica	Barn Swallow
Agelaius phoeniceus	Redwinged Blackbird
Colinus virginianus	Bobwhite
Bucephala albeola	Bufflehead
Passerina cyanea	Indigo Bunting
Richmondena cardinalis	Cardinal
Dumetella carolinensis	Gray Catbird
Icteria virens	Yellow-breasted Chat
Parus carolinensis	Carolina Chickadee
Fulica americana	American Coot
Molothrus ater	Brown-headed Cowbird
Certhia familiaris	Brown Creeper
Corvus brachyrynchos	Common Crow
Corvus ossifragus	Fish Crow
Zenaidura macroura	Mourning Dove
Columba livia	Rock Dove (domestic pigeon)
Aix sponsa	Wood Duck
Sialia sialis	Easter Bluebird
Hespenipnona vespartina	Evening Grosbeak
Carpodacus purpureus purpureus	Purple Finch
Coloptes auratus	Yellow-shafted Flicker
Myiarchus crinitus	Great-crested Flycatcher
Empidonax minimus	Least Flycatcher
Spinus tristis tristis	American Goldfinch
Podilymbus podiceps	Pied-billed Grebe
Quiscalus quiscula	Common Grackle
Pheucticus ludovicianus	Rose-breasted Grosbeak
Larus argentatus	Herring Gull
Buteo platypterus platypterus	Broad-winged Hawk
Accipiter cooperii	Cooper's Hawk
Buteo lineatus	Red-shouldered Hawk
B. jamaicensis	Red-tailed Hawk
Accipiter striatus	Sharp-shinned Hawk
Falco sparverius	Kestrel Hawk
Butorides virescens	Green Heron
Archilochus colubris	Ruby-throated Hummingbird
Cyanocitta cristata	Blue Jay

TABLE A-13 (CONTINUED)
BIRDS OF ROCK CREEK PARK, WASHINGTON, DC

Species Name	Common Name
Junco hyemalis	Dark-eyed Junco
Charadrius vociferus	Killdeer
Tyrannus tyrannus	Eastern Kingbird
Megaceryle alcyon alcyon	Belted Kingfisher
Regulus satrapa	Golden-crowned Kinglet
R. calendula	Ruby-crowned Kinglet
Seivrus motacilla	Louisiana Waterthrush
Anas platyrhynchos	Mallard
Progne subis	Purple Martin
Mimus polyglottos	Mockingbird
Chordeiles minor	Common Nighthawk
Sitta carolinensis	White-breasted Nuthatch
Icterus galbula	Northern Oriole
I. spurius	Orchard Oriole
Seiurus aurocapillus	Ovenbird
Strix voria	Barred Owl
Bubo virginianus	Great horned Owl
Otus asio	Screech Owl
Contopus virens	Eastern wood Pewee
Sayornis phoebe	Eastern Phoebe
Turdus migratorius	Robin
Euphages carolinus	Rusty Blackbird
Actitis macularia	Spotted Sandpiper
Sphyrapicus varius	Yellow-bellied Sapsucker
Spinus pinus	Pine Siskin
Spizella passerina	Chipping Sparrow
Passer domesticus	House (English) Sparrow
Spizella pusilla	Field Sparrow
Passerella iliaca iliaca	Fox Sparrow
Melospiza melodia	Song Sparrow
Melospiza georgiana	Swamp Sparrow
Spizella arborea	Tree Sparrow
Z. albicollis	White throated Sparrow
Sturnus vulgaris	Starling
Hirundo rustica	Barn Swallow
Stelgidopteryx ruficollis	Rough-winged Swallow
Chetura pelagica	Chimney Swift
Piranga olivacea	Scarlet Tanager
Toxostoma rufum	Brown Thrasher
Hylocichla minima	Gray cheeked Thrush
H. guttata	Hermit Thrush
H. astulata	Swainson's Thrush
H. mustelina	Wood Thrush
Parus bicolor	Tufted Titmouse

TABLE A-13 (CONTINUED)
BIRDS OF ROCK CREEK PARK, WASHINGTON, DC

Pipilo erythrophthalamus	Rufous-sided Towhee
Hylocichla fuscescens	Veery
Vireo olivaceous	Red-eyed Vireo
V. griseus	White-eyed Vireo
V. flavifrons	Yellow-throated Vireo
Coragyps atratus	Black Vulture
Cathartes aura	Turkey Vulture
Dendroica striata	Blackpoll Warbler
D. caerulescens	Black-throated Blue Warbler
D. virens	Black-throated Green Warbler
Mniotilta varia	Black and White Warbler
Vermivora pinus	Blue-winged Warbler
Dendroica pennsylvanica	Chestnut-sided Warbler
Oporornis formosus	Kentucky Warbler
Dendroica coronata	Yellow-rumped Warbler
Vermivora ruficapilla	Nashville Warbler
Dendroica palmarum	Palm Warbler
Parula americana	Parula Warbler
Dendroica pinus	Pine Warbler
Dendroica discolor	Prairie Warbler
Protonotaria citrea	Prothonotary Warbler
Dendroica petechia	Yellow Warbler
Seiurus noveboracensis	Northern Waterthrush
Bombycilla cedrorum	Cedar Waxwing
Philohela minor	American Woodcock
Dendrocopos pubescens	Downy Woodpecker
D. villosus	Hairy Woodpecker
Dryocopus pileatus	Pileated Woodpecker
Clenturus carolinus	Red-bellied Woodpecker
Thryothorus ludovicianus	Carolina Wren
Troglodytes aedon	House Wren
T. troglodytes	Winter Wren
Coccxzus amejicanus	Yellow-billed Cuckoo
Geothlypis trichas	Yellowthroat

TABLE A-14
MAMMALS OF THE DISTRICT OF COLUMBIA

Species Name	Common Name
Didelphis marsupialis virginiana	Opossum
Soret longirostris longirostris	Southeastern Shrew
Microsorex hoyi winnemana*	Pigmy Shrew
Blarina brevicanda kirtlandi	Short-Tailed Shrew
Cryptotis parva parva	Least Shrew
Scalopus aquaticus aquaticus	Eastern Mole
Condylura cristata cristata	Star-Nosed Mole
Myotis lucifugus lucifugus	Little Brown Myotis
M. keenii septentrionalis	Keen's Myotis
Lasionycteris noctivogans	Silver-Haired Bat
Pipistrellus subflavus subflavus	Eastern Pipistrelle
Eptesicus fuscus fuscus	Big Brown Bat
Lasiurus borealis borealis	Red Bat
L. cinereus cinereus	Hoary Bat
Nycticeius humeralis humeralis	Evening Bat
Sylvilagus floridanus mallurus	Eastern Cottontail
Tamias striatus fisheri	Eastern Chipmunk
Marmota monax monax	Woodchuck
Sciurus carolinensis pennsylvanicus	Gray Squirrel
S. niger vulpinus	Fox Squirrel
Tamiasciurus hudsonicus loquax	Red Squirrel
Glaucomys volans volans	Southern Flying Squirrel
Peromyscus leucopus noveboracensis	White-Footed Mouse
Microtus pennsylvanicus pennsylvanicus	Meadow Vole
Pitymys pinetorum scalopsoides	Pine Vole
Synaptomys cooperi stonei	Southern Bog Lemming
Rattus norvegicus	Norway Rat
Mus musculus	House Mouse
Zapus hudsonius americanus	Meadow Jumping Mouse
Vulpes vulpes fulva	Red Fox
Procyon lotor lotor	Raccoon
Mustela frenata noveboracensis	Long-Tailed Weasel
Odocoileus virgianus	White-Tailed Deer
Ondatra zibethics macradon	Muskrat
Vrocyon c. cinereoargentus	Gray Fox

*May occur in District of Columbia.

REFERENCES

1. Richards, H.G., 1934. 'A List of the Mollusks of the District of Columbia and Vicinity'. Amer. Midl. Nat. 25(1):85-88.
2. Meredith, W.G., and F.J. Schwartz. 1960-'Maryland Crayfishes'. Educ. Ser. No. 46, 32 pp. Maryland Department of Research and Education, Chesapeake Biological Lab, Solomans, MD.
3. Holsinger, J.R. 1967. 'Systematics of the Subterranean Amphipod Genus Stygobromus (Crangonyctidae), Part II: Species of the Eastern United States'. Smithson. Contribution to Zoology, No. 266:1-144.
4. __________. 1967. 'Systematics, Speciation, and Distribution of the Subterranean Amphipod Genus Stygonectes (Gammaridae)'. U.S. National Museum Bulletin 259:1-176.
5. Ferguson, E., Jr., 1967. 'Potamocypris Bowmani, a New Freshwater Ostracod from Washington, D.C.' Proc. Biol. Soc. Wash. 80:113-116.
6. Bowman, T.E., 1967. 'Asellus kenki, a New Isopod Crustacean from Springs in the Eastern United States'. Proc. Biol. Soc. Wash. 80:131-140.
7. Eddy, S., 1969. How to Know the Freshwater Fishes, 2nd ed. W.M.C. Brown and Co., Dubuque, Iowa 286 pp.
8. Johnson, R.I., 1970. 'The Systematics and Zoogeography of the Unionidae (Mollusca:Bivalvia) of the Southern Atlantic Slope Region'. Bull. Museum Comp. Zool., Howard University. 140(b):264-449.
9. Terrell, E.E., 1970. 'Spring Flora of the Chesapeake and Ohio Canal Area, Washington, D.C. to Seneca, Maryland'. Castanea 35:1-26.
10. Holsinger, J.R., 1972. 'The Freshwater Amphipod Crustaceans (Gammaridae) of North America'. Biota of Freshwater Ecosystems, Identification Manual No. 5. U.S. Government Printing Office, Washington, D.C. 89 pp.
11. Williams, W.D., 1972. 'Freshwater Isopods (Asellidae) of North America'. Biota of Freshwater Ecosystems, Identification Manual No. 7. U.S. Government Printing Office, Washington, D.C. 45 pp.
12. __________. 1970. 'A Revision of North American Epigean Species of Asellus (Crustacea:Isopoda)'. Smithson. Contrib. Zool. 49:1-80.
13. Harris, H.S., Jr., 1975. 'Distributional Survey (Amphibia/Reptilia): Maryland and the District of Columbia'. Bull. Md. Herpetol. Svc. 11(3):73-167.
14. Paradiso, J.C., 1969. Mammals of Maryland. Bur. Sport Fish. and Wildl., Department of Interior, North America Fauna No. 66, 193 pp. U.S. Government Printing Office, Washington, D.C.

15. Conant, R. 1975. A Field Guide to Reptiles and Amphibians of Eastern and Central North America. 2nd ed. Houghton Mifflin Co., Boston, Mass. 429 pp.
16. Fassett, N.C., 1966. A Manual of Aquatic Plants (with a revision appendix by E.C. Ogden). University of Wisconsin Press, Madison, Wisconsin, 405 pp.
17. Beal, E.O., 1977. A Manual of Marsh and Aquatic Vascular Plants of North Carolina with Habitat Data. N.C. Agric. Exp. Sta. Tech. Bul. No. 247:1-298.
18. Winterringer, G.S. and A.C. Lopinot, 1966. Aquatic Plants of Illinois. Ill. State Mus. Popular Ser. VI:1-142.
19. Mitchell, R.S., 1973. 'Effects of Radford Army Ammunition Plant Wastes on Aquatic Vegetation in the New River, Virginia', pp. 19-29. In, John Cairns, Jr. and K.L. Dickson (eds.), The Effects of Waste Discharges from Radford Army Ammunition Plant on the Biota of the New River, Virginia. Va. Water Resources Res. Ctr., Bull. 57:1-57, VPI & SU, Blacksburg, Va.
20. Rasin, V.J., Jr. and J.S. Lange, 1979. 'Potomac River Basin Water Quality 1977.' Interstate Commission on the Potomac River Basin, Rockville, Md., Tech. Publ. 79-2. 87 pp.
21. Hynes, H.B.N., 1970. The Ecology of Running Waters. Liverpool University Press, Liverpool, Great Britain. 555 pp.
22. Thomas, L.K., Jr., 1969. 'Survey of Areas for Significant Natural Values'. Ann. Prog. Report NCR-N-5a, 22 pp.
23. Jorling, T.C., 1969. 'An Analysis of the Vegetation of Rock Creek National Park, Washington, D.C.' M.S. Thesis, Wash. State University. 43 pp.
24. Grimm, W.C., 1966. How To Recognize Shrubs. Stackpole Co., Harrisburg, Pa. 319 pp.
25. Brown, R.G. and M.L. Brown, 1972. Woody Plants of Maryland. Univer. Md. Student Supply Store, Collge Park, Md. 347 pp.
26. Anderson, R.R. et.al., 1977. 'Rock Creek Park and Rock Creek and Potomac Parkway: Vegetation Community Structure'. American University, Department of Biology, Report prepared for National Park Service, National Capital Region, Washington, D.C.
27. Braun, E.L., 1950. Deciduous Forests of Eastern North America. The Blakiston Co., N.Y.
28. Johnson, R.G., 1962. 'A Checklist of Vascular Plants of the National Capital Region' Unpublished list, 61 pp.
29. Nevins, F.R., 1936. 'A Study of the Larger Invertebrate Forage Organisms in Selected Areas of the Delaware and Susquehanna Watersheds'. Rept. N.Y. State Conserv. Dept. 25 suppl., 195-204.

30. Williams, L.G., 1966. 'Dominant Planktonic Rotifers of Major Waterways of the United States'. Limnol. Oceanogr. 11:83-91.
31. Sprules, W.M.,1941. 'The Effect of a Beaver Dam on the Insect Fauna of a Trout Stream'. Trans. Amer. Fish. Soc. 70:236-248.
32. __________, 1947. 'An Ecological Investigation of Stream Insects in Algonquin Park, Ontario'. University Toronto Stud. Biol. Ser. 56:1-81.
33. O'Connell, T.R. and R.S. Campbell, 1953. 'The Benthos of the Black River and Clearwater Lake, Missouri. University Missouri Stud. 26(2):25-41.
34. Palmer, C.M, 1977. Algae and Water Pollution. Edited by R. Lewis. U.S. Environmental Protection Agency, EPA-600/9-77-036, Cincinnati, Ohio. 123 pp.
35. Shosteck, R., 1977. Rock Creek Watershed Habitat Survey and Inventory of Fauna and Flora Montgomery County, Maryland. Md.-Natl. Capital Park and Planning Commission, Silver Spring, Md. 94 pp.
36. Robbins, C.S., B. Bruun, and H.S. Zim, 1966. Birds of North America, A Guide to Field Identification. Golden Press, N.Y. 340 pp.
37. Spangler, N., 1976. 'Additions to Rock Creek Fish Survey'. Unpublished report, 3 pp.
38. Smith and Bean, 1899. 'A List of the Fishes Known to Inhabit the Waters of the District of Columbia and Vicinity', U.S. Fish Commission Bulletin No. 18, pp. 179-187.
39. Miller, 1944. Specimens Deposited with the U.S. National Museum, Washington, D.C.
40. Medford, Roy, 1950. 'A Distributional Survey of the Fishes of Rock Creek', M.S. Thesis, Department of Zoology, University of Maryland, College Park.
41. Ragan, R.M. and Dietemann, A.J., 1976. 'Characterization of Urban Runoff in the Maryland Suburbs of Washington, D.C.', Water Resources Research Center, University of Maryland.
42. Shosteck, R., 1976. 'Field Guide to Rock Creek Park', National Capital Region, National Park Service.
43. Fales, J.H., 1978. Unpublished list of butterflies.
44. Kenle, R., 1935. 'Studies on Virginian Triclads'. Jour. Elisha Mitchell Sci. Soc. 51:79-125.
45. __________. 1972. 'Freshwater Planarians (Turbellaria) of North America'. Biota of Freshwater Ecosystems, Identification Manual No. 1, U.S. Government Printing Office, Washington, D.C., 81 pp.
46. Teskey, R.O. and T.M. Hinckley, 1977. Impact of Water Level Changes on Woody Riparian and Wetland Communities, Vol. II: Southern Forest Region. Fish and Wildlife Service, U.S. Department of Interior, Biological Serv. Prog. FWS/OBS-77/59, U.S. Government Printing Office, Washington, D.C., 46 pp.

47. Fuller, S.L.H., 1974. 'Clams and Mussels (Mollusca: Bivalvia)' pp. 215-273. In, C.W. Hart, Jr. and S.L.H. Fuller (eds.), Pollution Ecology of Freshwater Invertebrates, Academic Press, N.Y.
48. Stauffer, J.R., Jr., C.H. Hocutt, an D.S. Lee, 1978. 'The Zoogeography of the Freshwater Fishes of the Potomac River Basin', pp. 44-54. In, K.C. Flynn and W.T. Mason (eds.), The Freshwater Potomac: Aquatic Communities and Environmental Stresses, Interstate Commission on the Potomac River Basin, Rockville, Maryland.
49. Frost, S., A. Huni, and W.E. Kershaw, 1971. 'Evaluation of a Kicking Technique for Sampling Stream Bottom Fauna'. Can. J. Zool. 49(2): 167-173.
50. Mason, W.T., J.B. Anderson, and G.E. Morrison, 1967. 'A Limestone-filled, Artificial Substrate Sampler-Float Unit for Collecting Macroinvertebrates in Large Streams'. Prog. Fish - Cult. 29(2):74.
51. Slack, K.V., R.C. Averett, P.E. Greeson, and R.G. Lipscomb, 1973. Techniques of Water-Resources Investigations of the United States Geological Survey. 'Methods for Collection and Analysis of Aquatic Biological and Microbiological Samples. Book 5, Chapter A4, U.S. Government Printing Office, Washington, D.C., 165 pp.
52. Weber, C.I. (ed.), 1973. Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents. U.S. EPA 670/4-73-001, National Environmental Resources Center, Cincinnati, Ohio, 157 pp.
53. Kreis, R.D., R.L. Smith, and J.E. Moyer, 1971. 'The Use of Limestone-Filled Basket Samplers for Collecting Reservoir Macroinvertebrates'. Water Res. 5:1099-1106.
54. Dickson, K.L., J. Cairns, Jr., and J.C. Arnold, 1971. 'An Evaluation of the Use of a Basket-Type Artificial Substrate for Sampling Macroinvertebrate Organisms'. Trans. Amer. Fish. Soc. 102(3): 553-559.
55. Benfield, E.F., A.C. Hendricks, and J. Cairns, Jr., 1974. Proficiencies of Two Artificial Substrates in Collecting Stream Macroinvertebrates. Hydrobiologia 45(4):431-440.
56. Mason, W.T., Jr., J.B. Anderson, R.D. Kreis, and W.C. Johnson, 1970. 'Artificial Substrate Sampling, Macroinvertebrates in a Polluted Reach of the Klamath River, Oregon'. JWPCF 42(8):R315-R328.
57. Anderson, J.B. and W.T. Mason, Jr., 1968. 'A Comparison of Benthic Macroinvertebrates Collected by Dredge and Basket Sampler'. JWPCF 40(2):252-259.
58. Fullner, R.W., 1971. 'A Comparison of Macroinvertebrates Collected by Basket and Modified Multiple-Plate Samplers'. JWPCF 43(3):494-499.

59. Van Huizen, A., 1978. 'Fishing Survey of Rock Creek Park', Unpublished Report, 9 pp.

60. Benfield, E.F., K.L. Dickson, and A.C. Hendricks, 1972. 'Macrobenthic Invertebrate Studies', pp. 9-19. In, J. Cairns, Jr. and K.L. Dickson (eds.), An Ecosystematic Study of the South River, Virginia. Va. Water Resources. Res. Ctr., Bull. 54:1-104, VPI & SU, Blacksburg, Va.

61. Parker, B.C., E.K. Obeng-Asamoa, and G.L. Samsel, 1972. 'Algal and Other Aquatic Plant Studies', pp. 45-56. In, J. Cairns, Jr., and K.L. Dickson (eds.), An Ecosystematic Study of the South River, Virginia. Va. Water Resources Res. Ctr., Bull. 54:1-104, VPI & SU, Blacksburg, Va.

62. Ross, R.D., 1972. 'Fish Studies', pp. 21-30. In, J. Cairns, Jr., and K.L. Dickson (eds.), An Ecosystematic Study of the South River, Virginia. Va. Water Resources Res. Ctr., Bull. 54:1-104, VPI & SU, Blacksburg, Va.

63. Ross, R.D., 1972. 'Effects of Radford Army Ammunition Plant Wastes on the Fishes of the New River, Virginia', pp. 43-52. In, J. Cairns, Jr., and K.L. Dickson (eds.), The Effects of Waste Discharges from Redford Army Ammunition Plant on the Biota of the New River, Virginia. Va. Water Resources Res. Ctr., Bull. 57:1-57, VPI & SU, Blacksburg, Va.

64. Sculthorpe, C.D. 1967. The Biology of Aquatic Vascular Plants. E. Arnold, London. 610 pp.

65. Palmer, M.C. 1977. Algae and Water Pollution. U.S. Department of Commerce. NTIS PB-287 128, 123 pp.

66. Yorke, T.H. 1978. Impact Assessment of Water Resource Development Activities: A Dual Matrix Approach Fish and Wildlife Serv., U.S. Department of Interior, Biological Serv. Prog., FWS/OBS-78/82, U.S. Government Printing Office, Washington, D.C. 27 pp.

67. Swift, L.W., Jr. and J.B. Messer. 1971. 'Forest Cuttings Raise Temperatures of Small Streams in the Southern Appalachians'. Journ. Soil and Water Conservation 26(3):111-116.

68. Marzolf, G.R. 1978. The Potential Effects of Cleaning and Snagging on Stream Ecosystems. Fish and Wild life Serv., U.S. Dept. Interior, Biological Serv. Prog., PWS/OBS-78/14, U.S. Government Printing Office, Washington, D.C. 31 pp.

69. LaBuy, J. 1966. 'Biological Survey of Rock Creek'. Unpublished Study, Federal Water Pollution Control Admin., Middle Atlantic Region, 14 p.

70. Aalto, J.A., N.A. Jaworski, and W.G. Schremp. 1969. 'A Water Quaity Study of the Rock Creek Watershed'. Unpublished Study, Federal Water Pollution Control Admin., Middle Atlantic Region.

APPENDIX B

FLOOD PLAN AND PROFILE SHEETS

APPENDIX C

ROCK CREEK OUTFALL INVENTORY

ROCK CREEK OUTFALL INVENTORY

Identification No.	Location	Approximate Pipe Size	Description	Source#	Flow ** Estimate	Additional Comments
			ROCK CREEK FROM THE MOUTH TO MASSACHUSETTS AVENUE			
RC 0	Immediately Upstream of Whitehurst Freeway, East Bank	16"	Circular Concrete Culvert	Storm Sewer	None (Dry)	
RC 1	Approximately 66 yards Downstream of the C&O Canal	12"	Circular Concrete Culvert Retaining Wall	GSA West Heating Plant	High	
RC 2	West Bank, Potomac Parkway Retaining Wall	48"	Flap Gate, Stone Retaining Wall	Combined Sewer Overflow (71)	None (Dry)	
RC 3	Immediately Downstream of Pennsylvania Avenue, East Bank	12"	Vitrified Clay Pipe	Combined Sewer Overflow (49)	None (Dry)	Culvert partially buried and hidden by large rocks
RC 4	East Bank, Between Pennsylvania Avenue and M Street	36"	Unknown	Combined Sewer Overflow (50)	Unknown	Culvert not found entire area covered with large rocks, strong sewage odor present
RC 5	Approximately 100 yards Upstream of M Street, West Bank	36"	Box CSO, Stone Abutment	Combined Sewer Overflow (72)	None (Dry)	Silted Outlet
RC 6	Immediately Upstream of M Street, West Bank	16"	Circular Concrete Culvert	Unknown	None (Dry)	
* RC 7	Approximately 200 yards Upstream of M Street, East Bank	24"	Box CSO, Stone Abutment	Combined Sewer Overflow (51)	Low	Partially Silted Outlet, seepage
RC8	Approximately 400 yards Upstream of M St., West Bank	48"	Crushed Remains of CSO Outfall	Combined Sewer Overflow (73)	None (Dry)	
RC 9	Approximately 400 yards Upstream of M Street, East Bank	12"	Corrugated Metal Pipe, Stone Abutment	Storm Sewer	None (Dry)	
RC 10	Immediately Downstream of P Street, East Bank	72"	Concrete Arch, Stone Abutment	Storm Sewer	Partially Submerged	
RC 11	Approximately 20 yards Downstream of P Street, East Bank	36"	Box CSO, Stone Abutment	Combined Sewer Overflow (54)	Partially Submerged	Partially Silted Outlet
RC 12	Immediately Upstream of P Street, East Bank	99"	Box CSO, Stone Abutment	Combined Sewer Overflow (55)	Completely Submerged	
RC 13	Approximately 75 yards Upstream of P St., East Bank	42"	Box CSO, Stone Abutment	Combine Sewer Overflow (56)	Submerged	
RC 14	Immediately Upstream of P Street, West Bank	Unknown	Box CSO, Stone Abutment	Combined Sewer Overflow	None (Wet)	
RC 15	Approximately 100 yards Upstream of P Street, East Bank	42"	Box CSO, Stone Abutment	Combined Sewer Overflow (57)	Partially Submerged	
RC 16	Beneath Q Street, West Bank	21"	Box CSO, Stone Abutment	Combined Sewer Overflow (74)	Moderate	
RC 17	Beneath Q Street, East Bank	12"	Circular Concrete Culvert	Storm Sewer	None (Dry)	
RC 18	Immediately Upstream of Q St., East Bank	12"	Circular Concrete Culvert	Storm Sewer	None (Dry)	

* Outfalls Sampled 6/12/79

\# Combined Sewer Overflow Identification Numbers used by A. Cotsonis & W. Howard "Diversion, Intercepting and Overflow Structures", 1967.

** FLOW ESTIMATES:
Partially Submerged: Unable to detect if flow is present.
Seepage: No Noticeable Flow
Trickle: <1/8" Flow Depth
Low: >1/8"-1/2" Flow Depth
Moderate: 1/2"-1" Flow Depth
High: >1"
None (Dry): No Flow, Dry Pipe.
None (Wet): No Flow, Wet Pipe.

ROCK CREEK OUTFALL INVENTORY
(CONTINUED)

Identification No.	Location	Approximate Pipe Size	Description	Source#	Flow ** Estimate	Additional Comments
RC 19	Approximately 200 yards Upstream of Q Street, East Bank	12"	Circular Concrete Culvert	Storm Sewer	None (Dry)	
RC 20	Approximately 250 yards Upstream of Q Street, East Bank	12"	Circular Concrete Culvert	Storm Sewer	None (Dry)	
RC 21	Approximately 260 yards Upstream of Q Street, East Bank	18"	Vitrified Clay Pipe	Storm Sewer	Completely Submerged	
RC 22	Approximately 270 yards Upstream of Q Street, East Bank	12"	Vitrified Clay Pipe	Unknown	None (Dry)	Partially Silted Outlet, Sections Eroded Away
RC 23	Approximately 280 yards Upstream of Q St., East Bank	18"	Vitrified Clay Pipe	Storm Sewer	None (Dry)	
RC 24	East Bank, Approximately 460 yards Upstream of Q Street	18"	Vitrified Clay Pipe	Storm Sewer	Partially Submerged	
RC 25	East Bank, Approximately 475 yards Downstream of Q Street	18"	Vitrified Clay Pipe	Storm Sewer	Completely Submerged	
RC 26	Above Potomac Parkway Cut Off, East Bank, Upstream of Q Street	12"	Vitrified Clay Pipe	Unknown	Partially Submerged	
RC 27	Immediately Downstream of Massachusetts Avenue, East Bank	36"	Circular Opening, Stone Abutment, Flap Gate	Unknown	Partially Submerged	Silted Opening
RC 28	Immediately Downstream of Massachussetts Avenue, East Bank	42"	Box CSO, Stone Abutment	Combined Sewer Overflow (75)	Partially Submerged	
* RC 29	Immediately Downstream of Massachussets Avenue, West Bank	24"	Vitrified Clay Pipe	Combined Sewer Overflow (76)	High	Section Eroded Away
RC 30	Beneath Massachusetts Avenue stream of Q Street, East Bank	16"	Vitrified Clay Pipe	Unknown	None (Dry)	
	ROCK CREEK FROM MASSACHUSETTS AVENUE TO PORTER STREET					
RC 31	East Bank Downstream of Normanstone Tributary	15"	Vitirfied Clay Pipe	Unknown	None (Wet)	
RC 32	East Bank Across from Normanstone Tributary	16"	Vitrified Clay Pipe	Unknown	None (Dry)	
* RC 33	West Bank 5-10 yards Upstream of Normanstone Tributary	60"x60"	Box CSO, Stone Abutment	Combined Sewer Overflow (77)	Low	Sewage Odor
RC 34	East Bank, Diagonally Across from RC/33, Upstream Side	36"x24"	Concrete Box Culvert, with Flap Gate	Combined Sewer Overflow (58)	None (Wet)	

* Outfalls Sampled 6/12/79
\# Combined Sewer Overflow Identification Numbers used by A. Cotsonis & W. Howard "Diversion, Intercepting and Overflow Structures", 1967.

** FLOW ESTIMATES:
Partially Submerged: Unable to detect if flow is present.
Seepage: No Noticeable Flow
Trickle: <1/8" Flow Depth
Low: >1/8"-1/2" Flow Depth
Moderate: 1/2"-1" Flow Depth
High: >1"
None (Dry): No Flow, Dry Pipe.
None (Wet): No Flow, Wet Pipe.

ROCK CREEK OUTFALL INVENTORY
(CONTINUED)

Identification No.	Location	Approximate Pipe Size	Description	Source#	Flow ** Estimate	Additional Comments
RC 35	East Bank, Approximately 66 yards Downstream of Parkway Bridge	12"	Cast Iron Pipe	Unknown	None (Dry)	Deteriorated Pipe
RC 36	West Bank, Approximately 50 yards Downstream of Potomac Parkway Bridge	48"	Box CSO Culvert, Concrete	Combined Sewer Overflow (78)	None (Dry)	Sewage Odor
RC 37	West Bank, 1st Tributary Downstream of Potomac Parkway	12"	Corrugated Metal Pipe	Storm Sewer	Moderate	
RC 38	East Bank, 5 yards Downstream of Potomac Parkway, East Bank	12"	Circular Concrete Culvert	Storm Sewer	None (Dry)	
RC 39	Approximately 130 yards Above Potomac Parkway, East Bank	36"x24"	Box CSO, Stone Abutment	Combined Sewer Overflow (59)	Partially Submerged	Sewage Odor
RC 40	East Bank, Approximately 120 yards Downstream of Connecticut Ave.	24"x30"	Concrete Arch Culvert	Storm Sewer	Partially Submerged	
RC 41	Approximately 5-10 yards Downstream of Connecticut Avenue, West Bank	12"	Corrugated Metal Pipe	Storm Sewer	None (Dry)	
RC 42	Approximately 5-10 yards Downstream of Connecticut Avenue, West Bank	12"	Vitrified Clay Pipe	Storm Sewer	None (Dry)	
* RC 43	Approximately 5-10 yards Upstream of Connecticut Avenue, East Bank	36"	Twin Box Culverts, Stone Abutment	Combined Sewer Overflow (60) Storm Sewer	Low (CSO Outlet)	Partially Silted Outlets
RC 44	Approximately 5-10 yards Upstream of Connecticut Avenue, West Bank	48"	Circular CSO, Brick Abutment	Combined Sewer Overflow (79)	Partially Submerged	Sewage Odor
RC 45	Approximately 25 yards Upstream of Connecticut Avenue, West Bank	24"	Concrete-Arch Culvert	Storm Sewer	None (Dry)	
RC 46	Approximately 10-15 yards Downstream of Const. Bridge, East Bank, Connecticut Avenue Metro Site	12"	Corrugated Metal Pipe	Construction Site	None (Dry)	
RC 47	Connecticut Ave. Metro Site, Under Construction Bridge, West Bank	10"	Vitrified Clay Pipe	Unknown	None (Wet)	
RC 48	Approximately 80 yards Downstream of Calvert Street Bridge, West Bank	24"	Concrete-Arch Culvert	Storm Sewer	None (Dry)	
RC 49	Approximately 100 yards Downstream of Calvert Street Bridge, East Bank	24"	Box CSO, Stone Abutment	Combined Sewer Overflow (61)	Partially Submerged	Sewage Odor

* Outfalls Sampled 6/12/79
\# Combined Sewer Overflow Identification Numbers used by A. Cotsonis & W. Howard "Diversion, Intercepting and Overflow Structures", 1967.

** FLOW ESTIMATES:
Partially Submerged: Unable to detect if flow is present.
Seepage: No Noticeable Flow
Trickle: <1/8" Flow Depth
Low: >1/8"-1/2" Flow Depth
Moderate: 1/2"-1" Flow Depth
High: >1"
None (Dry): No Flow, Dry Pipe.
None (Wet): No Flow, Wet Pipe.

ROCK CREEK OUTFALL INVENTORY
(CONTINUED)

	Identification No.	Location	Approximate Pipe Size	Description	Source#	Flow ** Estimate	Additional Comments
	RC 50	Approximately 70 yards Downstream of Calvert Street Bridge, East Bank	12"	Circular Concrete Culvert	Storm Sewer	None (Wet)	
	RC 51	Immediately Downstream of Potomac Parkway, Right Bank	24"	Vitrified Clay Pipe	Storm Sewer	None (Dry)	
*	RC 52	Approximately 5 yards Downstream of Potomac Parkway, Bridge East Bank	38"	Concrete-Arch Culvert	Unknown	Low	
	RC 53	Approximately 100 yards Upstream of Potomac Parkway Bridge East Bank	16"	Circular Concrete Culvert	Storm Sewer	None (Dry)	
	RC 54	Immediately Downstream of Old Zoo Entrance Ford, West Bank	66"	Circular Culvert, Stone Abutment, Gate	Storm Sewer	Partially Submerged	Sewage Odor
	RC 55	Approximately 150 yards Upstream of Potomac Parkway, East Bank	12"	Circular Concrete Culvert	Storm Sewer	None (Dry)	
	RC 56	Approximately 230 yards Upstream of Potomac Parkway, East Bank	16"	Corrugated Metal Pipe	Storm Sewer	None (Dry)	
*	RC 57	Approximately 200 yards Downstream of Bear Cages, West Bank	No Outfall	CSO Box Structure, Concrete	Combined Sewer By-pass Structure (81)	Seepage	Sewage Odor
*	RC 58	Directly in Front of Bear Exhibits	40"	Concrete Culvert, With Steel Flap Gate	Storm Sewer	Moderate	Disinfectant Odor, Vegetables Present
	RC 59	Approximately 30 yards Downstream of Stone Bridge in Bear Exhibits Vicinity, West Bank	18"	Corrugated Metal Pipe	Storm Sewer	None (Dry)	
	RC 60	Approximately 100 yards Upstream of Stone Bridge in Vicinity of Bear Exhibits, West Bank	10"	Corrugated Metal Pipe	Storm Sewer	None (Dry)	
	RC 61	Approximately 280 yards Upstream of Stone Bridge in Vicinity of Bear Exhibits, West Bank	16"	Circular Concrete Culvert	Storm Sewer	None (Dry)	
	RC 62	Retaining Wall Along Beach Road, East Bank, Within Zoo	12"	Circular Concrete Culverts Throughout Retaining Wall	Storm Sewer	None (Dry)	
	RC 63	West Bank, Upper End of Zoo Parking Lot	16"	Circular Concrete Culvert	Storm Sewer	None (Dry)	
	RC 64	Approximately 100 yards Downstream of Zoo Entrance Bridge, East Bank	42"	Circular CSO, Stone Abutment	Combined Sewer Overflow (62)	Partially Submerged	

* Outfalls Sampled 6/12/79
\# Combined Sewer Overflow Identification Numbers used by A. Cotsonis & W. Howard "Diversion, Intercepting and Overflow Structures", 1967.

** FLOW ESTIMATES:
Partially Submerged: Unable to detect if flow is present.
Seepage: No Noticeable Flow
Trickle: <1/8" Flow Depth
Low: >1/8"-1/2" Flow Depth
Moderate: 1/2"-1" Flow Depth
High: >1"
None (Dry): No Flow, Dry Pipe.
None (Wet): No Flow, Wet Pipe.

ROCK CREEK OUTFALL INVENTORY
(CONTINUED)

	Identification No.	Location	Approximate Pipe Size	Description	Source#	Flow ** Estimate	Additional Comments
	RC 65	Immediately Upstream of Zoo Entrance Bridge, East Bank	36"	Box CSO, Stone Abutment	Combined Sewer Overflow (63)	None (Wet)	Sewage Odor
*	RC 66	Upstream of Harvard Street Bridge, East Bank	24"	Circular Concret Culvert	Unknown	Low	
	RC 67	Approximately 15 yards Upstream of Harvard St. Bridge, East Bank	36"	Box CSO, Stone Abutment	Combined Sewer Overflow (64)	None (Dry)	Sewage Odor
	RC 68	Approximately 80 yards Upstream of Harvard Street Bridge, East Bank	16"	Circular Concrete Culvert	Unknown	None (Dry)	
	RC 69	West Bank, Directly Across From the Zoo Maintenance Buildings	21"	Box CSO, Stone Abutment	Combined Sewer Overflow (65)	Partially Submerged	
	RC 70	Bank Opposite Zoo Maintenance Buildings	16"	Concrete-Arch Culvert	Storm Sewer	None (Dry)	
	RC 71	Approximately 300 yards Downstream of Klingle Road Bridge, East Bank	30"	Box CSO, Stone Abutment	Combined Sewer Overflow (66)	None (Wet)	
	RC 72	Approximately 180 yards Downstream of Klingle Road Bridge, East Bank	16"	Concrete-Arch Culvert	Storm Sewer	None (Dry)	
	RC 73	Approximately 100 yards Downstream of Porter Street Bridge, East Bank	24"	Vitrified Clay Pipe	Unknown	None (Dry)	Silted Shut
	RC 74	Approximately 20 yards Downstream of Porter Street Bridge, West Bank	16"	Circular Concrete Culvert, Abutment Stone	Storm Sewer	None (Dry)	
*	RC 75	Approximately 10-15 yards Downstream of Porter Street Bridge, West Bank	72"x72"	Concret Box Culvert, Stone Abutment	Storm Sewer	High	Sewage Odor
	RC 76	Immediately Downstream of Porter Street Bridge, West Bank	16"	Corrugated Metal Pipe	Storm Sewer	None (Dry)	
	RC 77	Under Porter Street Bridge, West Bank	24"	Vitrified Clay Pipe	Storm Sewer	None (Dry)	
		ROCK CREEK FROM PORTER STREET TO BOULDER BRIDGE					
	RC 78	East Bank, approximately 60 yards Downstream of Piney Branch	16"	Circular Concrete Culvert	Storm Sewer	None (Dry)	
	RC 79	Approximately 150-200 yards Upstream of Piney Branch, East Bank	12"	Circular Concrete Culvert	Storm Sewer	None (Dry)	
	RC 80	Approximately 280 yards Upstream of Piney Branch, East Bank	24"	Circular Concrete Culvert	Storm Sewer	None (Dry)	

* Outfalls Sampled 6/12/79
\# Combined Sewer Overflow Identification Numbers used by A. Cotsonis & W. Howard "Diversion, Intercepting and Overflow Structures", 1967.

** FLOW ESTIMATES:
Partially Submerged: Unable to detect if flow is present.
Seepage: No Noticeable Flow
Trickle: <1/8" Flow Depth
Low: >1/8"-1/2" Flow Depth
Moderate: 1/2"-1" Flow Depth
High: >1"
None (Dry): No Flow, Dry Pipe.
None (Wet): No Flow, Wet Pipe.

ROCK CREEK OUTFALL INVENTORY
(CONTINUED)

Identification No.	Location	Approximate Pipe Size	Description	Source#	Flow ** Estimate	Additional Comments
RC 81	Approximately 150-200 yards Downstream of Park Road, East Bank	12"	Circular Concrete Culvert	Storm Sewer	None (Dry)	
RC 82	Approximately 160 yards Downstream of Park Road, West Bank	12"	Concrete-Arch Culvert	Storm Sewer	None (Dry)	
RC 83	Immediately Downstream of Park Road, West Bank	24"	Concrete-Arch Culvert	Unknown	Partially Submerged	Sound of Flow Coming From within Outfall
RC 84	Just Above Park Road, West Bank on Bike Path	24"x24"	Steel Grate Draining Bike Path	Storm Sewer	None (Dry)	
RC 85	In Retaining Wall on West Bank by Pierce Mill	12"	Circular Concrete Culvert, Stone Abutment	Storm Sewer	None (Dry)	
RC 86	Next to Pierce Mill, West Bank	36"	Channel That Provides Flow to Turn Wheel	Combination of City and Rock Creek Water	Moderate	Silted Channel
RC 87	Approximately 50 yards Above Park Road, West Bank	12"	Corrugated Metal Pipe	Storm Sewer	None (Dry)	Crushed Culvert
RC 88	Approximately 50 yards Above Park Road, East Bank	12"	Circular Concrete Culvert	Storm Sewer	None (Dry)	
RC 89	Approximately 150 yards Above Park Road, East Bank	16"	Circular Concrete Culvert	Storm Sewer	None (Wet)	
RC 90	Approximately 35 yards Upstream of Parking Lot, East Bank	10"	Vitrified Clay Pipe	Storm Sewer	None (Dry)	
RC 91	Immediately Downstream of Broad Branch Road Crossing, West Bank	12"	Circular Concrete Culvert	Storm Sewer	None (Dry)	Severe Scouring Around Culvert
RC 92	Immediately Downstream of Broad Branch Road Crossing, East Bank	72"	Circular Concrete Culvert	Storm Sewer	Moderate	
RC 93	Approximately 150 yards Upstream of Broad Branch Road Crossing, West Bank	12"	Corrugated Metal Pipe	Unknown	None (Dry)	
RC 94	Approximately 250 yards Upstream of Broad Branch Road Crossing, West Bank	19"	Circular Concrete Culvert	Storm Sewer	None (Dry)	
RC 95	Approximately 300 yards Upstream of Broad Branch Road Crossing, West Bank	12"	Circular Concrete Culvert	Storm Sewer	None (Dry)	
	ROCK CREEK FROM BOULDER BRIDGE TO MARYLAND/D.C. LINE					
RC 96	East Bank, Approximately 650 yards Upstream of Boulder Bridge	24"	Circular Concrete Culvert	Storm Sewer	Moderate	
RC 97	East Bank, Approximately 670 yards Upstream of Boulder Bridge	24"	Circular Concrete Culvert	Unknown	None (Dry)	

* Outfalls Sampled 6/12/79

\# Combined Sewer Overflow Identification Numbers used by A. Cotsonis & W. Howard "Diversion, Intercepting and Overflow Structures", 1967.

** FLOW ESTIMATES:
Partially Submerged: Unable to detect if flow is present.
Seepage: No Noticeable Flow
Trickle: <1/8" Flow Depth
Low: >1/8"-1/2" Flow Depth
Moderate: 1/2"-1" Flow Depth
High: >1"
None (Dry): No Flow, Dry Pipe.
None (Wet): No Flow, Wet Pipe.

ROCK CREEK OUTFALL INVENTORY
(CONTINUED)

Identification No.	Location	Approximate Pipe Size	Description	Source#	Flow ** Estimate	Additional Comments
RC 98	East Bank, Approximately 680 yards upstream of Boulder Bridge	12"	Circular Concrete Culvert	Unknown	Moderate	
RC 99	East Bank, Approximately 770 yards Downstream of the Park Police Station	24"	Vitrified Clay Pipe	Storm Sewer Drainage	Trickle	Partially Silted Shut
RC 100	East Bank, Approximately 580 yards Downstream of the Park Police Sta.	12"	Circular Concrete Culvert, Stone Abutment	Storm Sewer	None (Dry)	
RC 101	East Bank in Front of the Park Police Headquarters	12"	Circular Concrete Culvert, Stone Abutment	Storm Sewer	Low	
RC 102	East Bank, Immediately Downstream of Military Road Cutoff which Crosses Rock Creek	12"	Circular Concrete Culvert, Stone Abutment	Storm Sewer	None (Dry)	
RC 103	West Bank, Downstream of Military Road Cutoff which Crosses Rock Creek	24"	Circular Concrete Culvert, Stone Abutment	Unknown	None (Wet)	
* RC 104	Approximately 60 yards Downstream of Military Road, West Bank	48"	Circular Concrete Culvert, Stone Abutment	Unknown	Moderate	
* RC 105	Approximately 5-10 yards Upstream of Military Road, West Bank	24"x36"	Concrete Box Culvert, Stone Abutment	Unknown	High	
RC 106	Approximately 160 yards Upstream of Military Road, East Bank	12"	Circular Concrete Culvert, Stone Abutment	Storm Sewer	Partially Submerged	
RC 107	Approximately 25 yards Above North End of Parking Lot, West Bank	15"	Circular Concrete Culvert	Storm Sewer	None (Dry)	
* RC 108	Approximately 80 yards Above Beach Road Crossing, on East Bank, Below Picnic Grove # 7	28"	Circular Concrete Culvert	Unknown	Low	
RC 109	West Bank, at Picnic Grove #7	15"	Circular Concrete Culvert	Storm Sewer	None (Dry)	
RC 110	East Bank, Approximately 110 yards Upstream of Bingham Drive	16"	Circular Concrete Culvert	Storm Sewer	None (Dry)	
RC 111	Approximately 25 yards Above Sherrill Drive on the East Bank	16"	Circular Concrete Culvert, Stone Abutment	Storm Sewer	None (Wet)	
RC 112	Approximately 60 yards Above Sherrill Drive, West Bank	18"	Circular Concrete Culvert	Storm Sewer	None (Dry)	
RC 113	At 2nd Pulloff Above Sherrill Drive, West Bank	16"	Circular Concrete Culvert	Storm Sewer	None (Dry)	

* Outfalls Sampled 6/12/79
\# Combined Sewer Overflow Identification Numbers used by A. Cotsonis & W. Howard "Diversion, Intercepting and Overflow Structures", 1967.

** FLOW ESTIMATES:
Partially Submerged: Unable to detect if flow is present.
Seepage: No Noticeable Flow
Trickle: <1/8" Flow Depth
Low: >1/8"-1/2" Flow Depth
Moderate: 1/2"-1" Flow Depth
High: >1"
None (Dry): No Flow, Dry Pipe.
None (Wet): No Flow, Wet Pipe.

ROCK CREEK OUTFALL INVENTORY
(CONTINUED)

	Identification No.	Location	Approximate Pipe Size	Description	Source#	Flow ** Estimate	Additional Comments
	RC 114	Approximately 200 yards Above 2nd Pulloff Above Sherrill Drive	12"	Circular Concrete Culvert	Storm Sewer	None (Dry)	
	RC 115	Approximately 220 yards Downstream of the Intersection of Beach Drive and Wise Road, West Bank	16"	Circular Concrete Culvert	Storm Sewer	None (Dry)	Four Sections Eroded Away
	RC 116	Approximately 20 yards Downstream of Fenwick Branch, East Bank	48"	Circular Concrete Culvert, Iron Grate	Storm Sewer	Partially Submerged	Debris at Opening
*	RC 117	Immediately Upstream of Joyce Rd. Crossing, West Bank	6"	Cast Iron Pipe	Unknown	Moderate	
		FENWICK BRANCH					
*	FW 1	Headwaters of Fenwick Branch	10′ x 20′	Box concrete culvert	Storm sewer	High	
*	FW 2	Just below Maryland/D.C. line, right bank	60"	Circular concrete culvert, concrete abutment	Storm sewer	High	
	FW 3	Right bank, at the intersection of West Beach Terrace and West Beach Drive	24"	Circular concrete culvert	Storm sewer	None (wet)	Several sections have been exposed
*	FW 4	Right bank, approximately 100 yards from the intersection of Sycamore St. and East Branch	48"	Circular concrete culvert, stone abutment	Storm sewer	None (dry)	Orange tint to water, strong grease and oil smell
	FW 5	Left bank, at the intersection of Sycamore St. and East Beach Drive	27"	Circular Concrete culvert, Stone abutment	Storm sewer	None (dry)	
	FW 6	Left Bank, at the intersection of Redwood and East Beach Drive	16"	Vitrified clay pipe	Storm sewer	None (dry)	One section partially eroded away
	FW 7	Left bank, at the intersection of North Portal and East Beach Drive	21"	Circular concrete culvert	Storm sewer	None (dry)	Partially silted outlet
	FW 8	Right bank, at the intersection of North Portal and East Beach Drive	18"	Vitrified clay pipe, stone abutment	Storm sewer	Submerged	Four sections have been eroded away
	FW 9	Left bank, downstream of Kimia Road Bridge	48"	Brick-lined arch culvert	Storm sewer	Partially submerged	
	FW 10	Right bank, at the intersection of Plymouth Street and West Beach Drive	24"	Vitrified clay pipe, concrete abutment	Storm sewer	Partially submerged	Several sections have been eroded away
	FW 11	Right bank, approximately 10 yards above the foot bridge on Fenwick Branch	24"	Vitrified clay pipe, stone abutment	Storm sewer	None (dry)	Cinders from roadway present in culvert

* Outfalls Sampled 6/12/79
\# Combined Sewer Overflow Identification Numbers used by A. Cotsonis & W. Howard "Diversion, Intercepting and Overflow Structures", 1967.

** FLOW ESTIMATES:
Partially Submerged: Unable to detect if flow is present.
Seepage: No Noticeable Flow
Trickle: <1/8" Flow Depth
Low: >1/8"-1/2" Flow Depth
Moderate: 1/2"-1" Flow Depth
High: >1"
None (Dry): No Flow, Dry Pipe.
None (Wet): No Flow, Wet Pipe.

ROCK CREEK OUTFALL INVENTORY
(CONTINUED)

Identification No.	Location	Approximate Pipe Size	Description	Source#	Flow ** Estimate	Additional Comments
		PORTAL BRANCH				
* P 1	Headwaters of Portal	48"	Circular concrete culvert	Storm sewer	High	
P 2	Right bank, 75 yards downstream of headwaters	42"	Circular concrete culvert, concrete abutment	Unknown	Moderate	Partially filled with silt
P 3	100-150 yards downstream of headwaters, right bank	27"	Corrugated metal pipe	Storm sewer	None (wet)	
P 4	Right bank, immediately downstream of intersection Spruce and North Portal Drive	36"	Stone abutment, concrete circular culvert	Unknown	None (wet)	
P 5	Right bank, at the intersection of Birch Road Terrace and North Portal Drive	18"	Vitrified clay pipe	Storm sewer	None (dry)	Partially eroded away
P 6	Left bank, below the intersection of Birch Road Terrace	24"	Stone abutment, circular concrete	Unknown	None (wet)	
P 7	Left bank at the intersection of Primrose Road and Portal Dr.	18"	Corrugated metal pipe	Storm sewer	None (wet)	
P 8	Left bank, immediately upstream of Portal Dr.	20"	Vitrified clay pipe	Storm sewer	None (Wet)	
P 9	Left bank, downstream side of East Beach Drive	24"	Circular concrete culvert, concrete abutment	Storm sewer	None (wet)	
		PINEHURST BRANCH				
* PH 1	Headwaters of Pinehurst	10′	Oval concrete culvert, concrete abutment	Storm sewer	High	
PH 2	Right Bank, approximately 35 yards downstream of the headwaters	18′	Corrugated metal pipe	Storm sewer	None (dry)	Culvert partially filled with sediment, crushed
PH3	Left bank, approximately 50 yards downstream of the headwaters	48"	Circular concrete culvert with stone abutment, iron gate	Storm sewer	None (wet)	
PH4	Left bank, approximately 15 yards downstream from the confluence of the first major tributary	24"	Corrugated metal pipe	Storm sewer	None (wet)	
* PH5	Left bank, approximately 45 yards above the twin storm sewer lines	29"	Circular concrete culvert	Storm sewer	Moderate	

* Outfalls Sampled 6/12/79
\# Combined Sewer Overflow Identification Numbers used by A. Cotsonis & W. Howard "Diversion, Intercepting and Overflow Structures", 1967.

** FLOW ESTIMATES:
Partially Submerged: Unable to detect if flow is present.
Seepage: No Noticeable Flow
Trickle: <1/8" Flow Depth
Low: >1/8"-1/2" Flow Depth
Moderate: 1/2"-1" Flow Depth
High: >1"
None (Dry): No Flow, Dry Pipe.
None (Wet): No Flow, Wet Pipe.

ROCK CREEK OUTFALL INVENTORY
(CONTINUED)

	Identification No.	Location	Approximate Pipe Size	Description	Source#	Flow ** Estimate	Additional Comments
	PH6	Right bank, in line with Barnaby Street	24"	Twin vitrified clay pipes	Storm sewer	None (wet)	One of the two culverts is blocked with debris
	PH7	Left bank, in line with 32nd Street	27"	Circular concrete culvert, stone abutment	Storm sewer	None (wet)	
	PH 8	Left bank, in line with the cross street just below 32nd Street	24"	Concrete culvert stone abutment	Storm sewer	None (wet)	Partially silted outlet
	PH 9	Left Bank, immediately upstream of Oregon Ave.	18"	Circular concrete culvert	Storm sewer	None (wet)	Completely silted outlet
	PH 10	Right bank, immediately downstream of 24th Street	32"	Circular concrete culvert, concrete abutment	Storm sewer	None (wet)	
				LUZON BRANCH			
*	LZ 1	Headwaters of Luzon Branch (Overflow Gates)	84"	Twin gated outlets	Storm sewer/combined sewer overflow	Storm sewer (high)/CSO none (wet)	Orange tint to flow
	LZ 2	Right bank, approximately 5 yards downstream of the overflows	18"	Vitrified clay pipe, stone abutment	Unknown	None (wet)	
	LZ 3	Left bank, approximately 5 yards downstream of the overflows	18"	Vitrified clay pipe, stone abutment	Unknown	None (dry)	
*	LZ 4	Left bank, approximately 35 yards downstream of the overflow gates	24" x 36"	Oval shaped culvert, concrete/brick lined	Unknown	Low	One 6-foot section eroded away
	LZ 5	Right bank, approximately 35 yards downstream of the overflow gates	24"	Concrete arch culvert	Storm sewer	None (wet)	Filled with debris
*	LZ 6	Approximately 200 yards downstream of the overflow gates	12"	Vitrified clay pipe crossing Luzon Branch	Unknown	Low	Line broken in two places
	LZ 7	Approximately 260 yards downstream of the overflow gates	10"	Vitrified clay pipe	Unknown	None (dry)	Sections eroded away
	LZ 8	Approximately 260 yards downstream of the overflow gates	24"	Circular concrete culvert	Unknown	None (dry)	Sections eroded away
	LZ 9	Right bank, immediately downstream of Joyce Road	18"	Circular concrete culvert, concrete abutment	Storm sewer	None (wet)	
*	LZ 10	Left bank, downstream of Joyce Road, located in retaining wall	54"	Circular concrete culvert, with a concrete spillway	Storm sewer	Moderate	

* Outfalls Sampled 6/12/79
\# Combined Sewer Overflow Identification Numbers used by A. Cotsonis & W. Howard "Diversion, Intercepting and Overflow Structures", 1967.

** FLOW ESTIMATES:
Partially Submerged: Unable to detect if flow is present.
Seepage: No Noticeable Flow
Trickle: <1/8" Flow Depth
Low: >1/8"-1/2" Flow Depth
Moderate: 1/2"-1" Flow Depth
High: >1"
None (Dry): No Flow, Dry Pipe.
None (Wet): No Flow, Wet Pipe.

ROCK CREEK OUTFALL INVENTORY
(CONTINUED)

	Identification No.	Location	Approximate Pipe Size	Description	Source#	Flow ** Estimate	Additional Comments
	LZ 11	Left bank, approximately 275 yards upstream of the mouth of Luzon	24"	Corrugated metal pipe, stone abutment	Unknown	None (wet)	
*	LZ 12	Left bank, approximately 260 yards upstream of the mouth of Luzon	18"	Corrugated metal pipe, concrete abutment	Unknown	Low	Orange tint to flow
*	LZ 13	Left bank, approximately 160 yards above the mouth of Luzon	18"	Corrugated metal pipe, concrete abutment	Unknown	Low	
	LZ 14	Right bank, 150 yards above the mouth of Luzon	24"	Circular Concrete culvert, stone abutment	Storm sewer	None (wet)	
				BROAD BRANCH			
*	BB 1	Approximately 670 yards downstream of headwaters	120"x84"	Concrete box culvert	Storm sewer	High	
	BB 2	Right bank, just below 10′ x 7′ water outlet	18"	Vitrified clay pipe	Storm sewer	None (dry)	
	BB 3	Immediately below 2nd bridge crossing, right bank	18"	Corrugated metal pipe	Storm sewer	None (dry)	
	BB 4	Approximately 70 yards below 2nd bridge crossing	12"	Vitrified clay pipe	Storm sewer	Low	
	BB 5	Right bank approximately 150 yards downstream of 2nd bridge crossing	18"	Vitrified clay pipe	Storm sewer	None (dry)	
	BB 6	Right bank, in line with Fessenden Pl.	24"	Vitrified clay pipe	Storm sewer	None (wet)	
	BB 7	Right bank, immediately below the 3rd bridge crossing	36"	Circular concrete culvert, stone abutment	Storm sewer	Low	
	BB 8	Right bank, in line with Brandywine Road	24"	Vitrified clay pipe, stone abutment	Unknown	None (wet)	
	BB 9	Right bank, upstream of Albemarle Street	12"	Corrugated metal pipe, stone abutment	Storm sewer	None (dry)	
	BB 10	Right bank, directly in line with Albemarle Street	24"	Vitrified clay stone abutment	Storm sewer	None (wet)	
	BB 11	Right bank, just below Albemarle Street	12"	Vitrified clay pipe	Storm sewer	Low	
	BB 12	Right bank, approximately 150 yards downstream of Albemarle Street	24"	Vitrified clay pipe	Storm sewer	None (dry)	

* Outfalls Sampled 6/12/79
\# Combined Sewer Overflow Identification Numbers used by A. Cotsonis & W. Howard "Diversion, Intercepting and Overflow Structures", 1967.

** FLOW ESTIMATES:
Partially Submerged: Unable to detect if flow is present.
Seepage: No Noticeable Flow
Trickle: <1/8" Flow Depth
Low: >1/8"-1/2" Flow Depth
Moderate: 1/2"-1" Flow Depth
High: >1"
None (Dry): No Flow, Dry Pipe.
None (Wet): No Flow, Wet Pipe.

ROCK CREEK OUTFALL INVENTORY
(CONTINUED)

	Identification No.	Location	Approximate Pipe Size	Description	Source#	Flow ** Estimate	Additional Comments
	BB 13	Right bank, approximately midway between Albemarle Street and Audubon Terr.	18"	Vitrified clay pipe	Storm sewer	None (dry)	
	BB 14	Right bank, approximately 130 yards above confluence	16"	Vitrified clay	Storm sewer	Low	
	BB 15	Left bank, approximately 175-225 yards above confluence	16"	Concrete arch-culvert			
				MELVIN HAZEN VALLEY BRANCH			
*	MH 1	Just below 34th Street	51"	Concrete culvert, brick abutment, concrete spillway	Storm sewer	High	
*	MH 2	Approximately 350-400 yards downstream of head-water (culvert spillway), north bank	24"	Vitrified clay pipe, stone abutment	Storm sewer	Low	
	MH 3	North bank, below MH 2	12"	Circular concrete culvert	Storm sewer	None (wet)	
	MH 4	North bank, approximately 200-250 yards above Connecticut Avenue	24"	Vitrified clay pipe	Storm sewer	None (wet)	Partially filled with debris
				PINEY BRANCH			
*	PB 1	Above the overflow structures	18"	Concrete culvert	Storm sewer	Low	Buried by debris, orange flow
	PB 2	Headwaters of Piney Branch (overflow gates)	120"x120"	Box CSO overflow gates, concrete apron	Combined sewer overflow (70)	None (wet)	Coming through concrete apron
	PB 3	Left bank, approximately 50 yards downstream of the overflow gates	24"	Vitrified clay pipe, twin culverts approximately elevated 9 feet above the channel	Unknown	None (wet)	
*	PB 4	Left bank, approximately 75 yards downstream of the overflow gates	38"	Stone abutment, brick lined, with concrete spillway	Unknown	High	Milky-white colored Flow. No sewage odor present
	PB 5	Left bank, approximately 200 yards downstream of the overflow gates	12"	Circular concrete culvert	Unknown	None (dry)	

* Outfalls Sampled 6/12/79
\# Combined Sewer Overflow Identification Numbers used by A. Cotsonis & W. Howard "Diversion, Intercepting and Overflow Structures", 1967.

** FLOW ESTIMATES:
Partially Submerged: Unable to detect if flow is present.
Seepage: No Noticeable Flow
Trickle: <1/8" Flow Depth
Low: >1/8"-1/2" Flow Depth
Moderate: 1/2"-1" Flow Depth
High: >1"
None (Dry): No Flow, Dry Pipe.
None (Wet): No Flow, Wet Pipe.

ROCK CREEK OUTFALL INVENTORY
(CONTINUED)

	Identification No.	Location	Approximate Pipe Size	Description	Source#	Flow ** Estimate	Additional Comments
	PB 6	Left bank, approximately 225-250 yards downstream of the overflow gates	24"	Cast iron culvert	Combined sewer overflow (69)	None (dry)	Sewage odor present, flap gate missing
	PB 7	Left bank, between the 18" and 24" CSO outfalls	16"	Vitrified clay pipe	Unknown	None (wet)	
	PB 8	Left bank, midway between the mouth of Piney Branch and the overflow gates	18"	Cast iron pipe, with flap gate	Combined sewer overflow (68)	None (dry)	Debris around flap gate
	PB 9	Left bank, approximately 150 yards above the Park Road Bridge	12"	Vitrified clay pipe	Unknown	None (wet)	
	PB 10	Left bank, under Park Road Bridge	24"	Vitrified clay pipe, concrete housing	Combined sewer overflow (67)	None (dry)	Several sections eroded away
	PB 11	Left bank, approximately 75 yards upstream of Piney Branch mouth	18"	Circular concrete culvert	Storm sewer	None (dry)	
				NORMANSTONE BRANCH			
*	NS 1	Headwaters of Normanstone, located beneath 34th Street	48"	Vitrified clay pipe	Storm sewer	Moderate	Orange tint to flow
*	NS 2	Right bank just below the intersection of Normanstone Drive and Normanstone Terr.	48"	Circular concrete culvert, iron gate	Storm sewer	Low	
*	NS 3	Left bank, just below the intersection of Normanstone Drive and Normanstone Terr.	30"	Circular concrete culvert, stone abutment	Unknown	Low	
	NS 4	Right bank, approximately 30 yards downstream of the intersection of 30th Street and Normanstone Drive	30"	Circular concrete culvert, stone abutment, iron gate	Storm sewer	None (wet)	
	NS 5	Left bank above the Intersection of Normanstone Drive and Rock Creek Drive		CSO inlet structure iron gate			Inlet not functional, opening has been closed off
	NS 6	Left Bank, just below Rock Creek Drive	18"	Vitrified clay pipe	Storm sewer	None (wet)	Several Sections of pipe eroded away
	NS 7	Right bank, just below Rock Creek Drive	18"	Vitrified clay pipe	Storm sewer	None (wet)	
	NS 8	Left bank, midway between Foot Bridge and Rock Creek Drive	18"	Vitrified clay pipe	Storm sewer	None (wet)	
	NS 9	Right bank, midway between Foot Bridge and Rock Creek Drive	18"	Vitrified clay pipe	Storm sewer	None (wet)	

* Outfalls Sampled 6/12/79

\# Combined Sewer Overflow Identification Numbers used by A. Cotsonis & W. Howard "Diversion, Intercepting and Overflow Structures", 1967.

** FLOW ESTIMATES:
Partially Submerged: Unable to detect if flow is present.
Seepage: No Noticeable Flow
Trickle: <1/8" Flow Depth
Low: >1/8"-1/2" Flow Depth
Moderate: 1/2"-1" Flow Depth
High: >1"
None (Dry): No Flow, Dry Pipe.
None (Wet): No Flow, Wet Pipe.

ROCK CREEK OUTFALL INVENTORY
(CONTINUED)

	Identification No.	Location	Approximate Pipe Size	Description	Source#	Flow ** Estimate	Additional Comments
				KLINGLE VALLEY BRANCH			
*	KV1	Headwaters, Macomb Street, Reno Road area	48"	Circular Concrete culvert	Storm sewer	Low	Partially filled with debris, orange tint to flow
	KV2	Headwaters, Klingle Road area	48"	Corrugated metal pipe	Storm sewer	Moderate	Pipe has been washed downstream, flow is coming from ground at origin
	KV3	Left bank approximately 35-50 yards upstream of Connecticut Ave. Bridge	18"	Vitrified clay pipe	Storm sewer	None (dry)	
	KV4	Left bank, immediately upstream of Connecticut Ave. Bridge	24"	Circular concrete culvert	Storm sewer	Partially submerged	
	KV5	Left bank, beneath the Connecticut Ave. Bridge	26"	Vitrified clay pipe, concrete abutment	Storm sewer	Partially submerged	
	KV6	Left bank, approximately 80 yards downstream of Connecticut Ave.	26"	Vitrified clay pipe	Storm sewer	None (dry)	
	KV7	Right bank, approximately 100 yards downstream of Connecticut Ave.	10"	Cast iron pipe	Unknown	None (wet)	
	KV8	Left bank, approximately 120 yards downstream of Connecticut Ave.	18"	Vitrified clay pipe	Storm sewer	None (dry)	
	KV9	Left bank, approximately 145 yards downstream of Connecticut Ave.	18"	Vitrified clay pipe	Unknown	None (wet)	
	KV10	Left bank, approximately 240 yards downstream of Connecticut Ave.	18"	Vitrified clay pipe	Unknown	None (dry)	
	KV11	Left bank, approximately 210 yards upstream of the confluence	18"	Cast/iron pipe, concrete encasement	Unknown	None (dry)	
				DUNBARTON OAKS BRANCH			
*	DB1	Headwaters of Dunbarton Oaks Valley, east side of Wisconsin Ave, north of S Street.	36"	Circular concrete culvert	Storm sewer	Low	Orange tint to flow

* Outfalls Sampled 6/12/79
\# Combined Sewer Overflow Identification Numbers used by A. Cotsonis & W. Howard "Diversion, Intercepting and Overflow Structures", 1967.

** FLOW ESTIMATES:
Partially Submerged: Unable to detect if flow is present.
Seepage: No Noticeable Flow
Trickle: <1/8" Flow Depth
Low: >1/8"-1/2" Flow Depth
Moderate: 1/2"-1" Flow Depth
High: >1"
None (Dry): No Flow, Dry Pipe.
None (Wet): No Flow, Wet Pipe.

ROCK CREEK OUTFALL INVENTORY
(CONTINUED)

Identification No.	Location	Approximate Pipe Size	Description	Source#	Flow ** Estimate	Additional Comments
			SOAPSTONE VALLEY BRANCH			
* SV 1	Headwaters of Soapstone Valley, below Albemarle Street	72"	Concrete arch culvert, iron gate	Storm sewer	Moderate	Grease and oil, odor present
* SV 2	Right bank, approximately 100-150 yards downstream of the headwaters	12"	Circular concrete culvert	Unknown	Moderate	
* SV 3	Right bank, approximately 100-150 yards downstream of the headwaters	44"	Circular concrete culvert	Unknown	High	Turbid water, grease and oil, odor present
SV 4	Right bank approximately 100-150 yards downstream of the headwaters	12"	Circular concrete culvert in a concrete retaining wall	Unknown	None (wet)	
SV 5	Right bank, approximately 100-150 yards downstream of the headwaters	12"	Corrugated metal pipe	Unknown	None (dry)	
SV 6	Left bank, downstream side of 29th Street, located away from the stream channel	21"	Concrete culvert, concrete apron	Unknown	Moderate	Unable to locate in in summer due to dense vegetation

* Outfalls Sampled 6/12/79

\# Combined Sewer Overflow Identification Numbers used by A. Cotsonis & W. Howard "Diversion, Intercepting and Overflow Structures", 1967.

** FLOW ESTIMATES:
Partially Submerged: Unable to detect if flow is present.
Seepage: No Noticeable Flow
Trickle: <1/8" Flow Depth
Low: >1/8"-1/2" Flow Depth
Moderate: 1/2"-1" Flow Depth
High: >1"
None (Dry): No Flow, Dry Pipe.
None (Wet): No Flow, Wet Pipe.

APPENDIX D

FOLD-OUT FIGURES

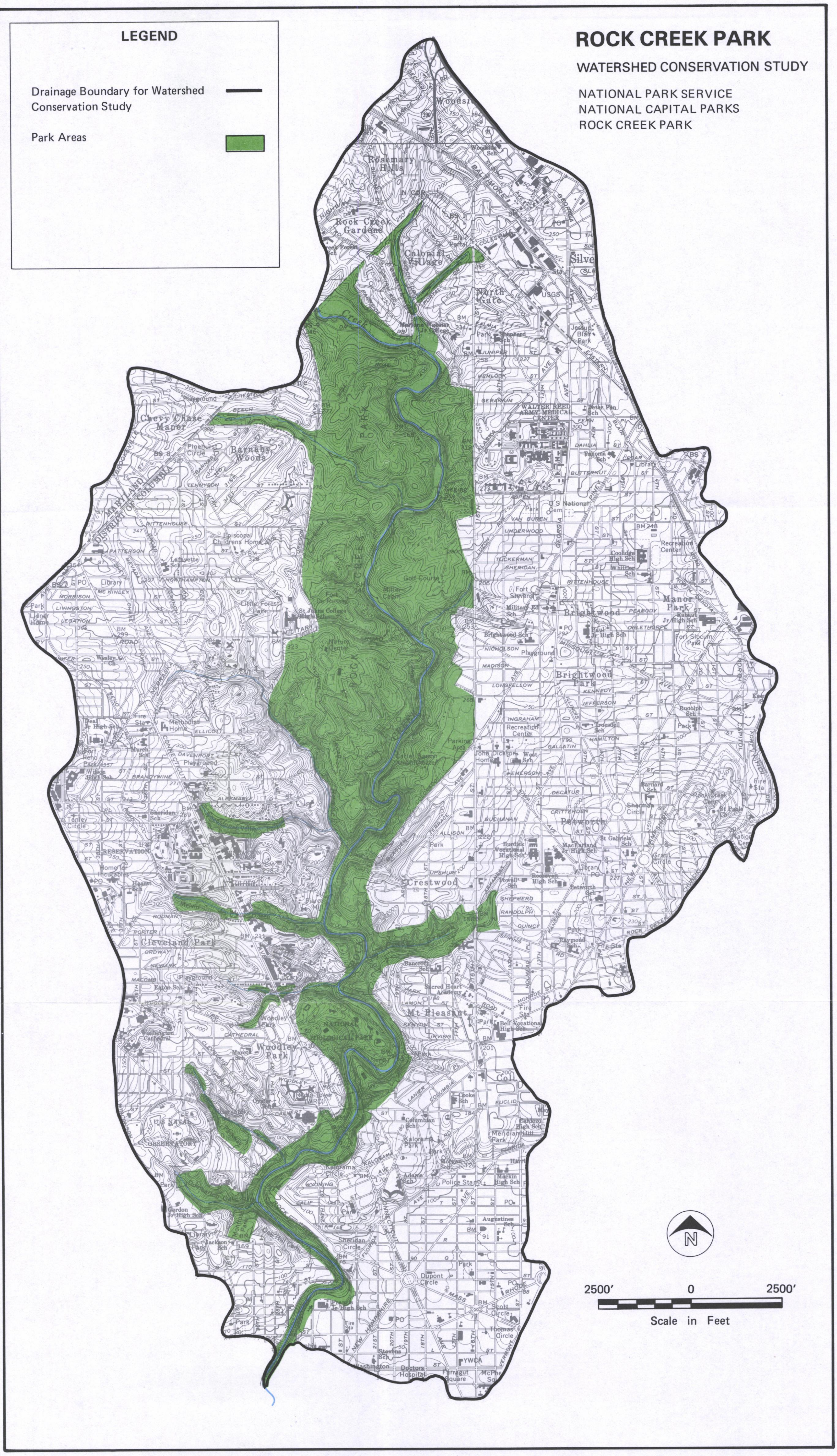


FIGURE 1-1: Rock Creek Park Study Area

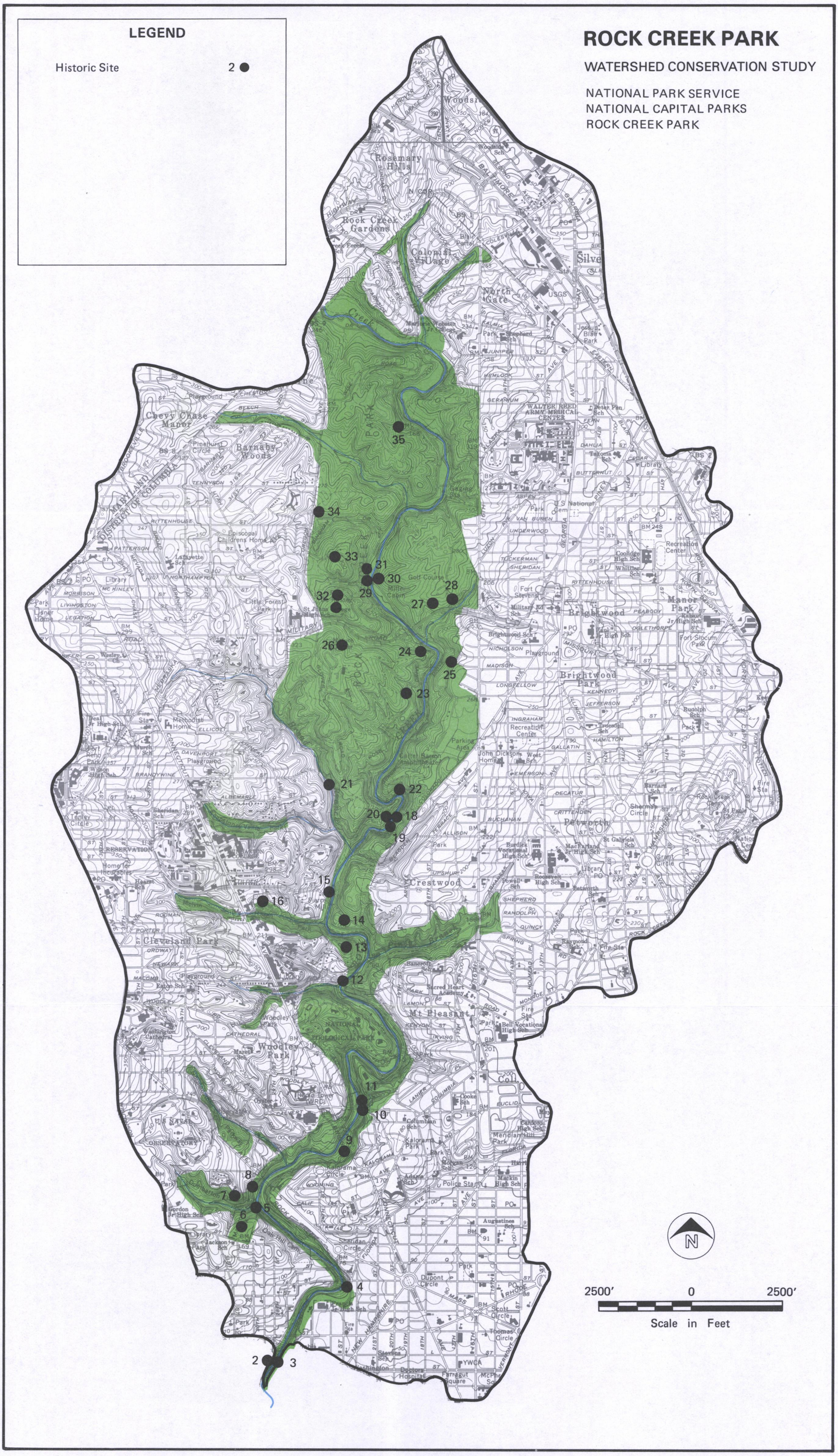


FIGURE 3-1: Historic and Archaeological Sites of Rock Creek Park

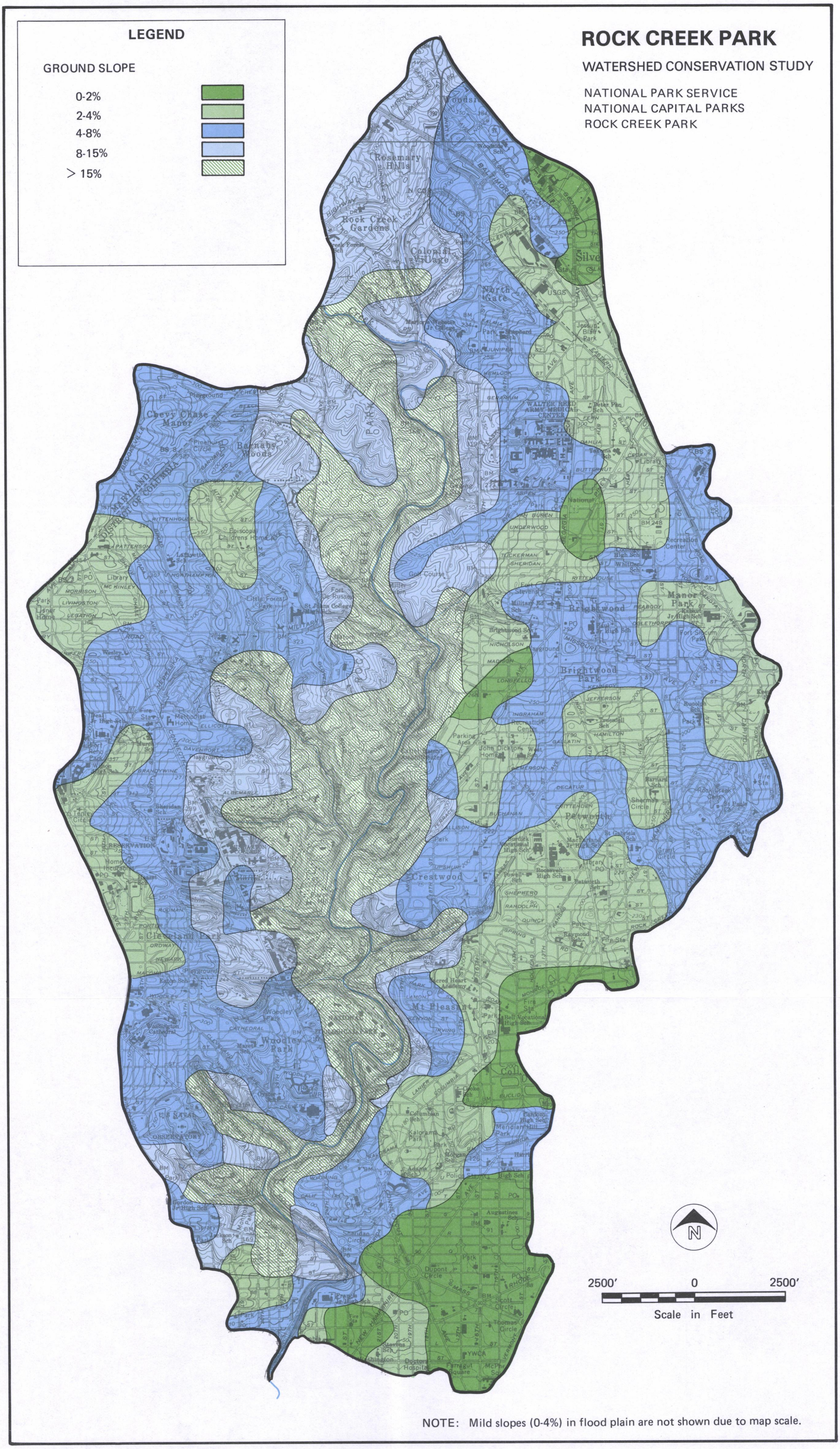


FIGURE 3-2: Overland Slope

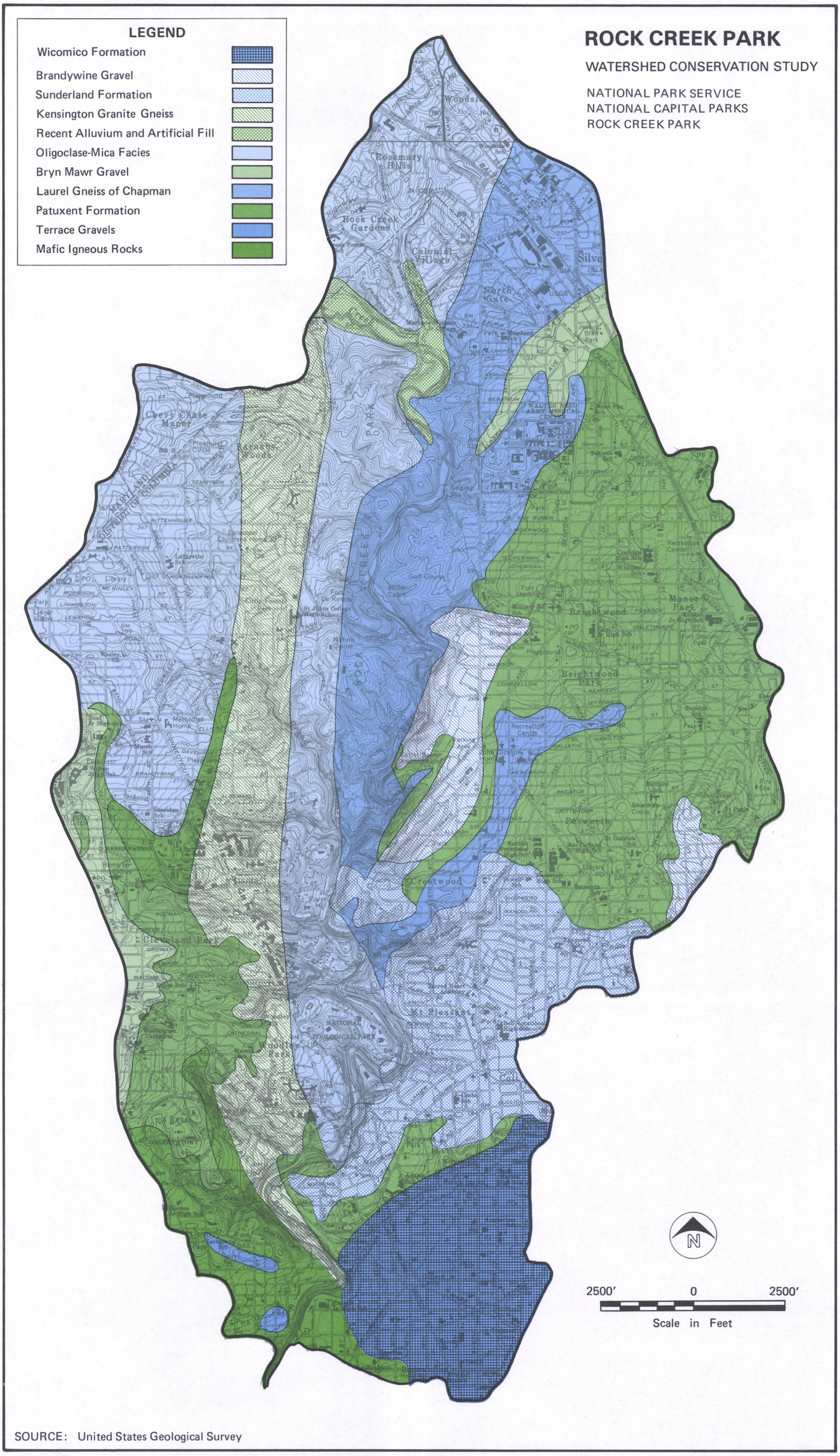


FIGURE 3-3: Geological Formations

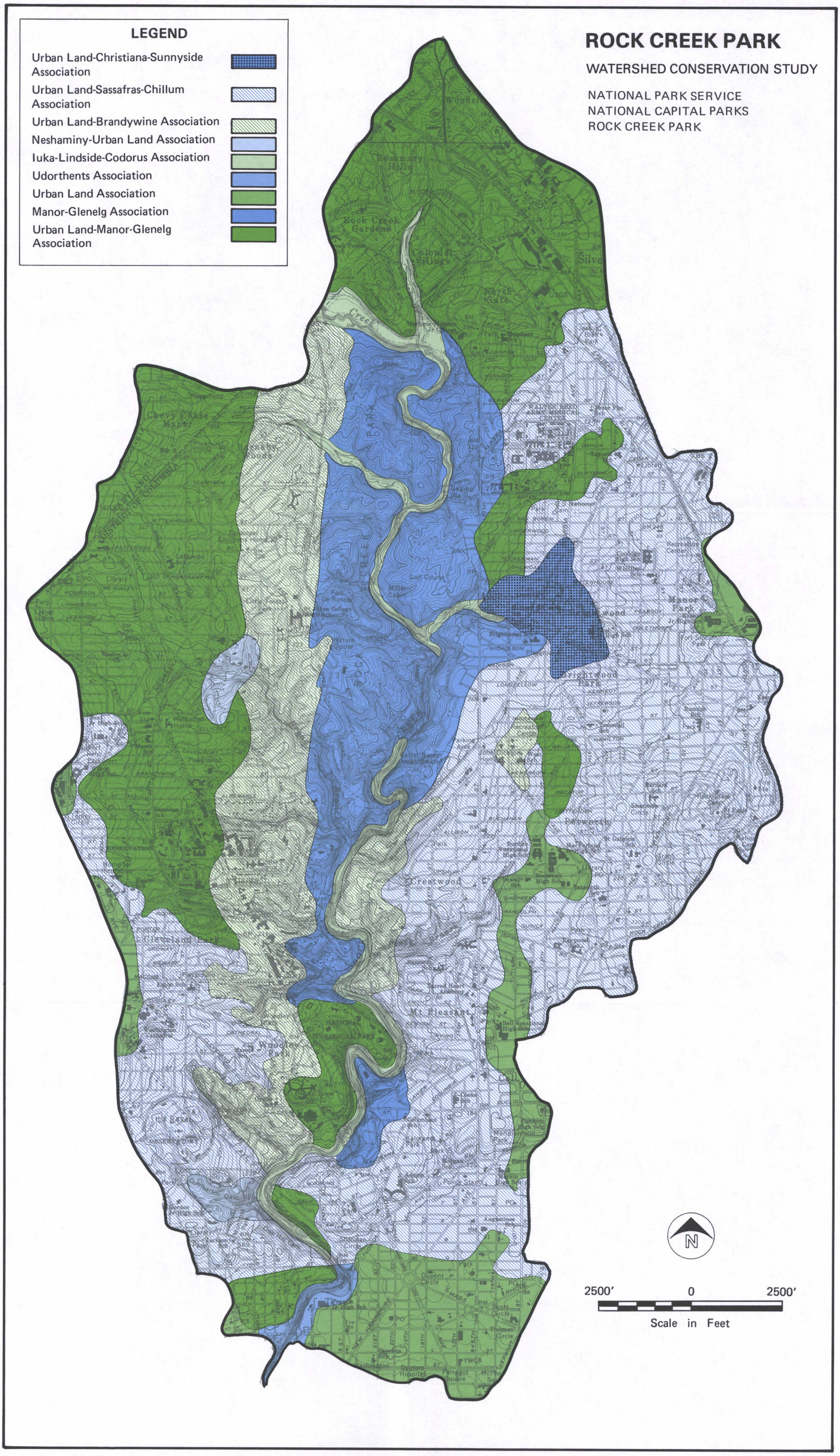


FIGURE 3-4: Soils

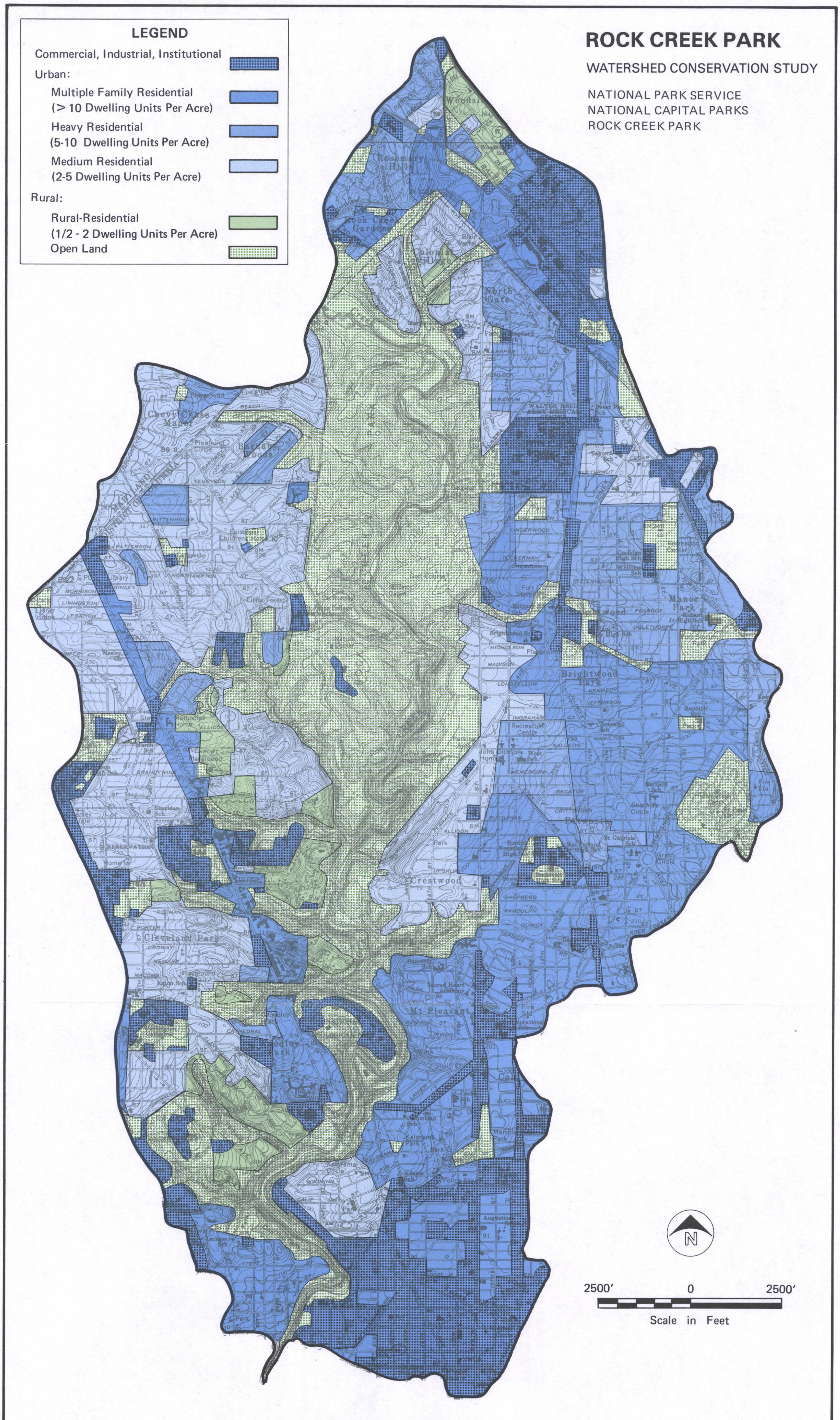


FIGURE 3-5: Existing Land Use

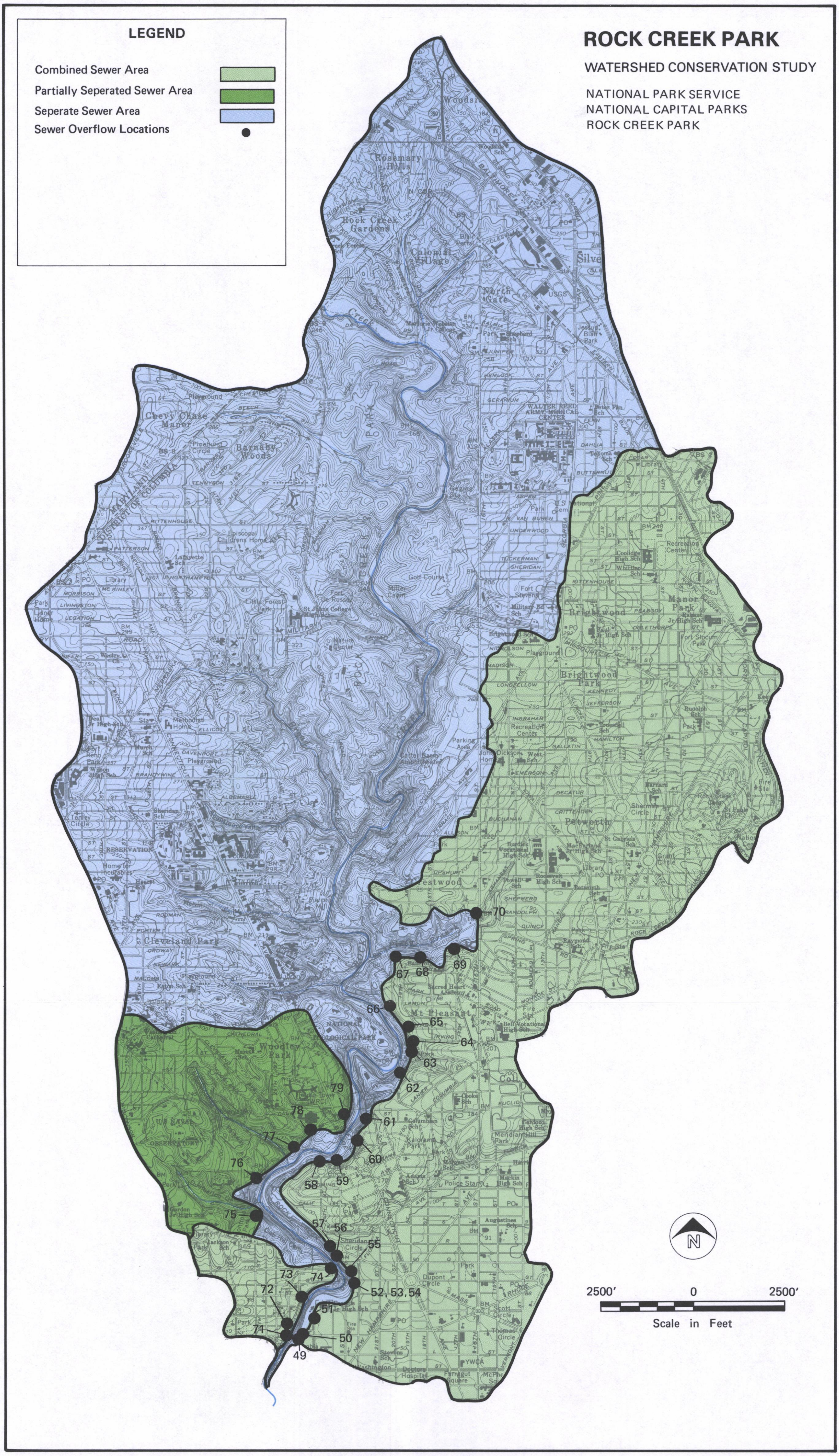


FIGURE 3-6: Sewer Boundaries and Combined Sewer Overflow Locations

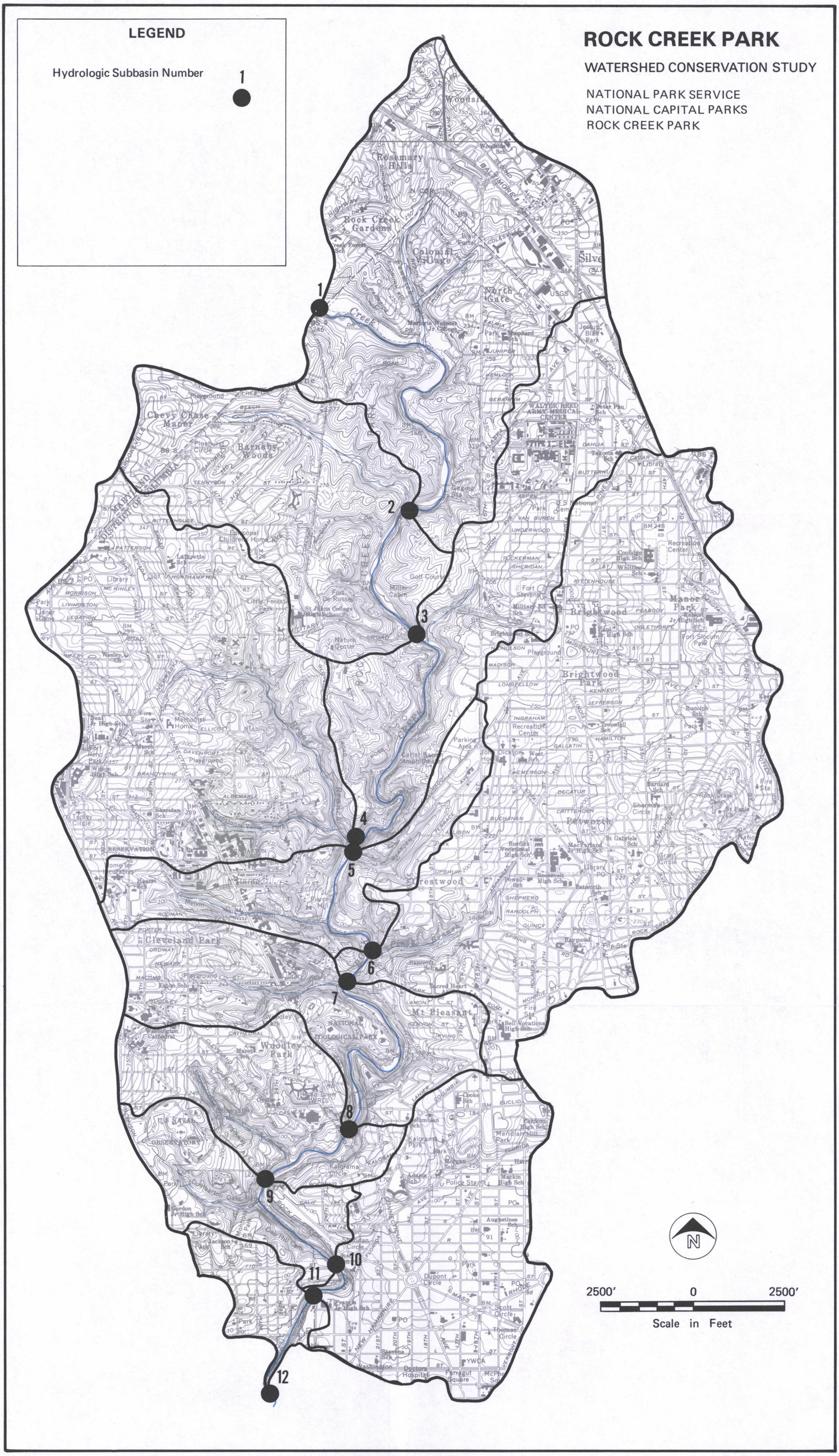


FIGURE 4-3: Hydrologic Subbasins

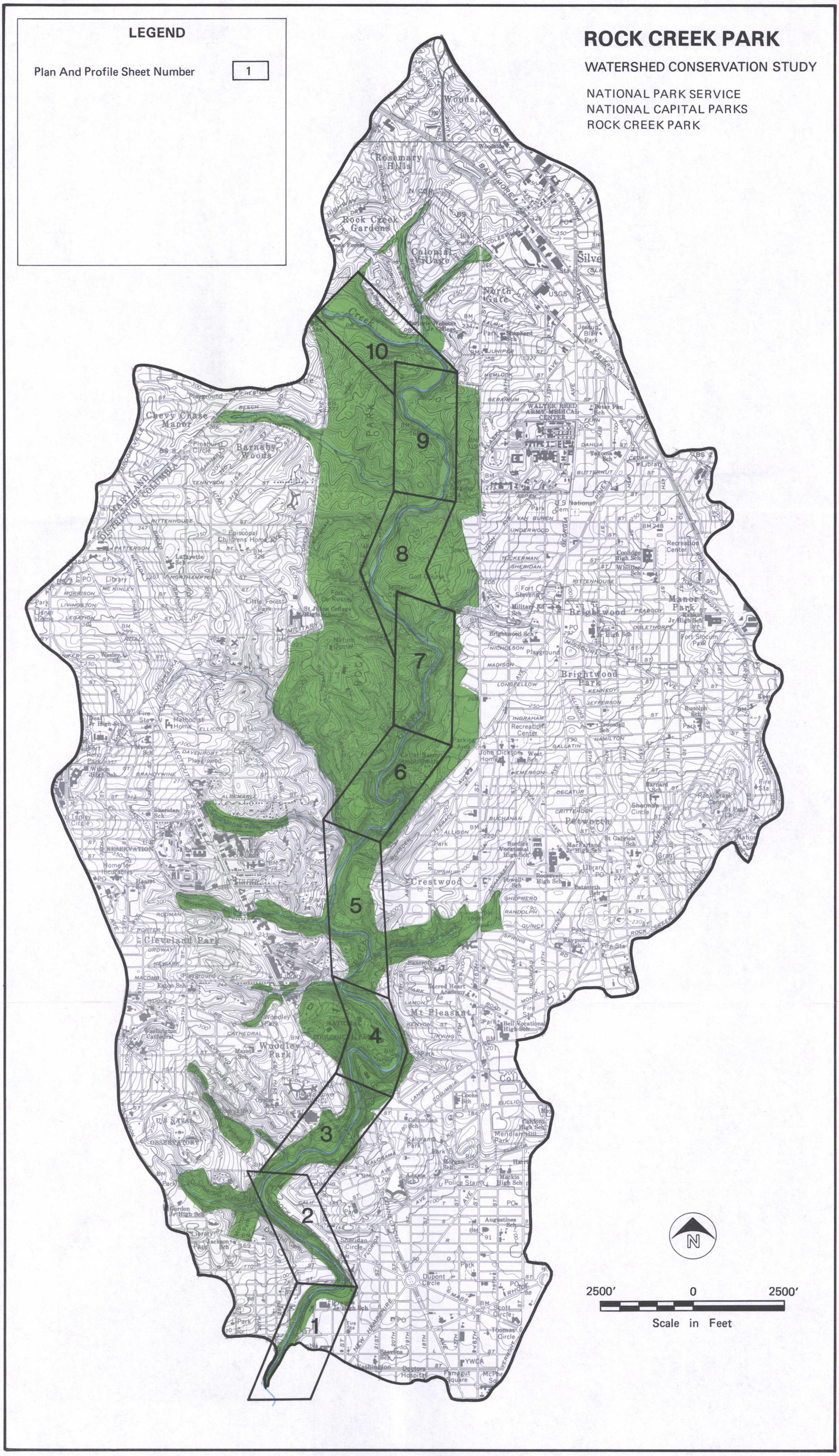


FIGURE 4-7: Index to Plan and Profile Sheets

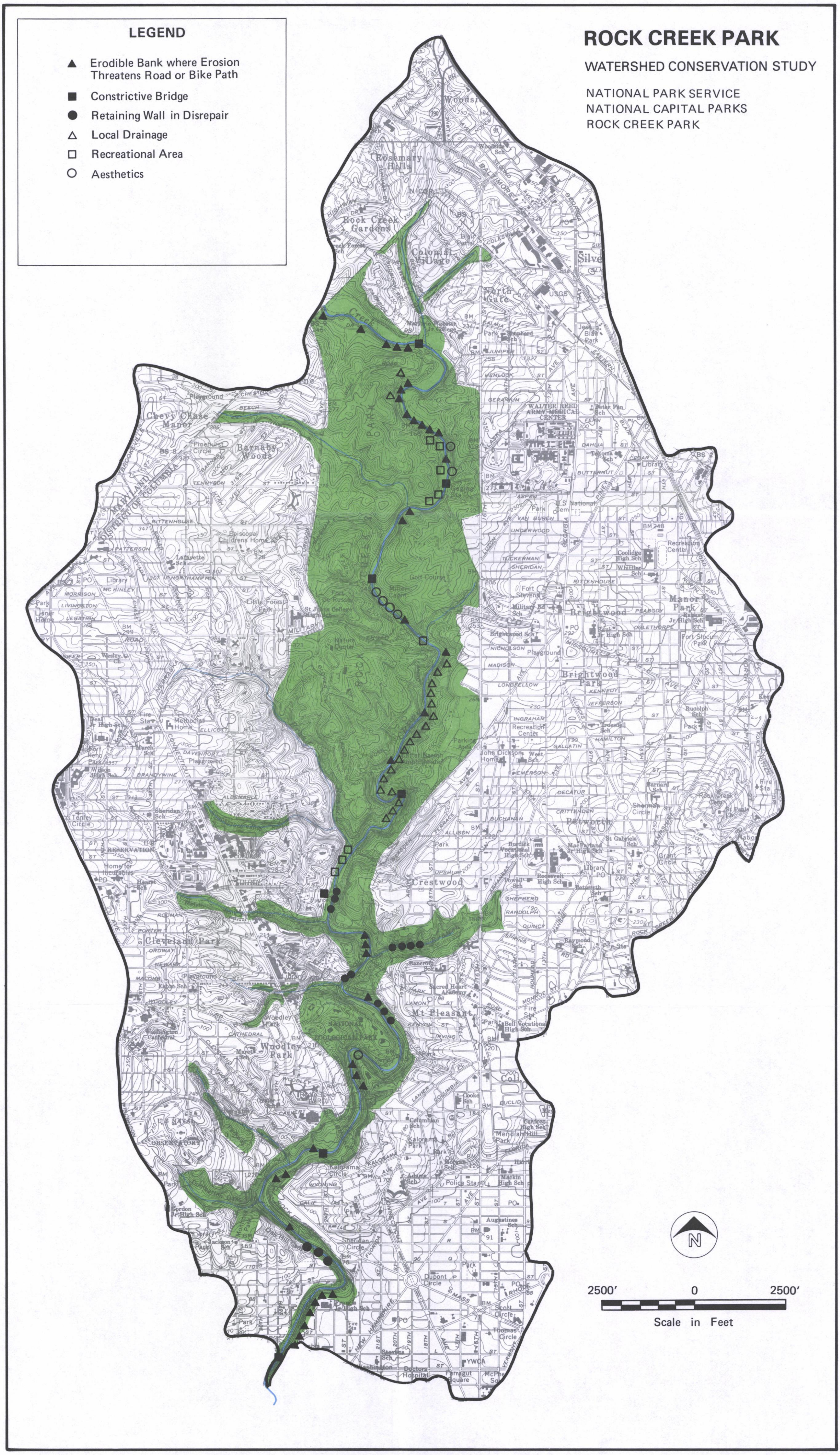


FIGURE 5-1: Erosion Problem Areas

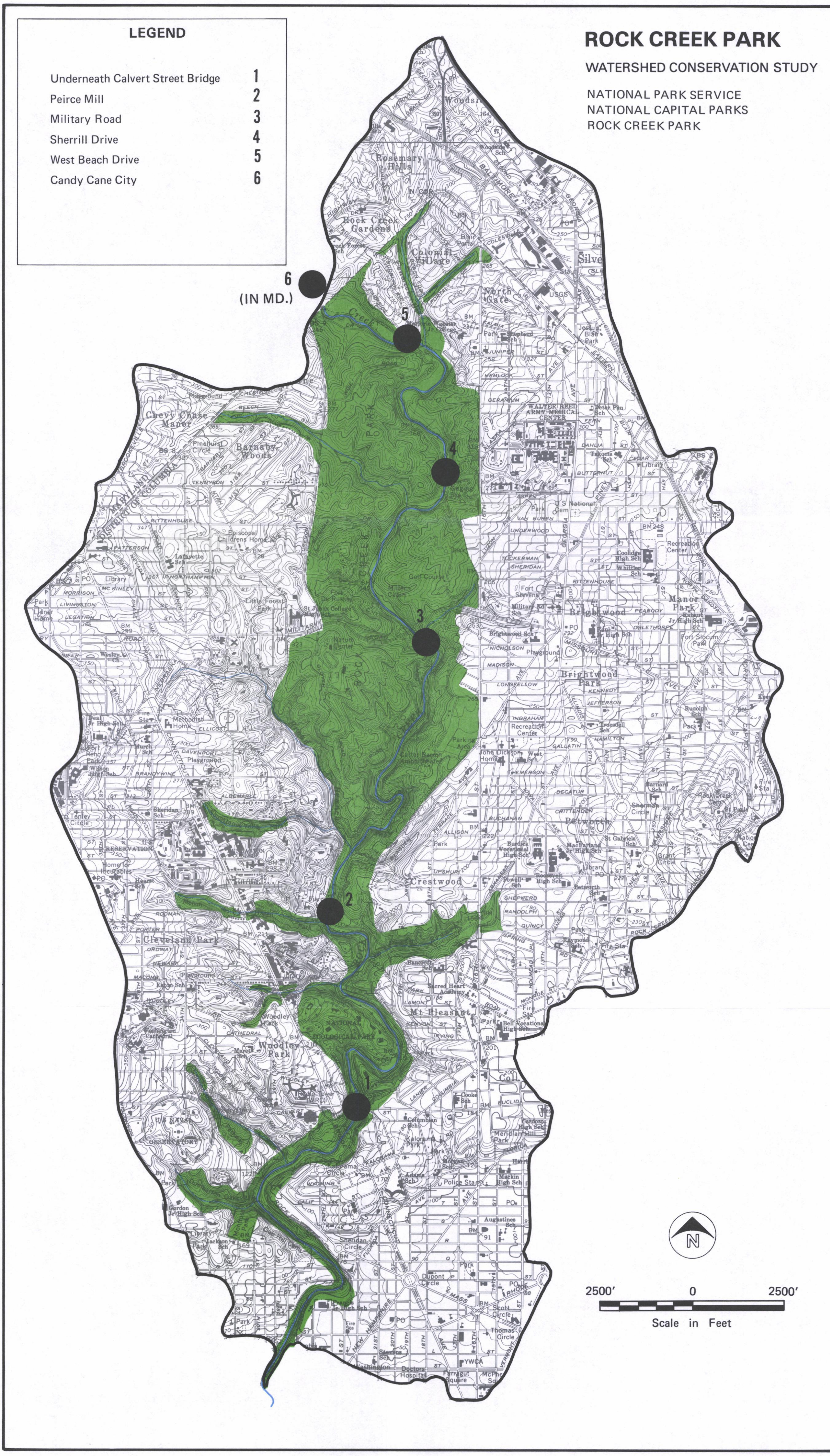


FIGURE 8-2 D.C. Department of Environmental Services Water Quality Sampling Sites

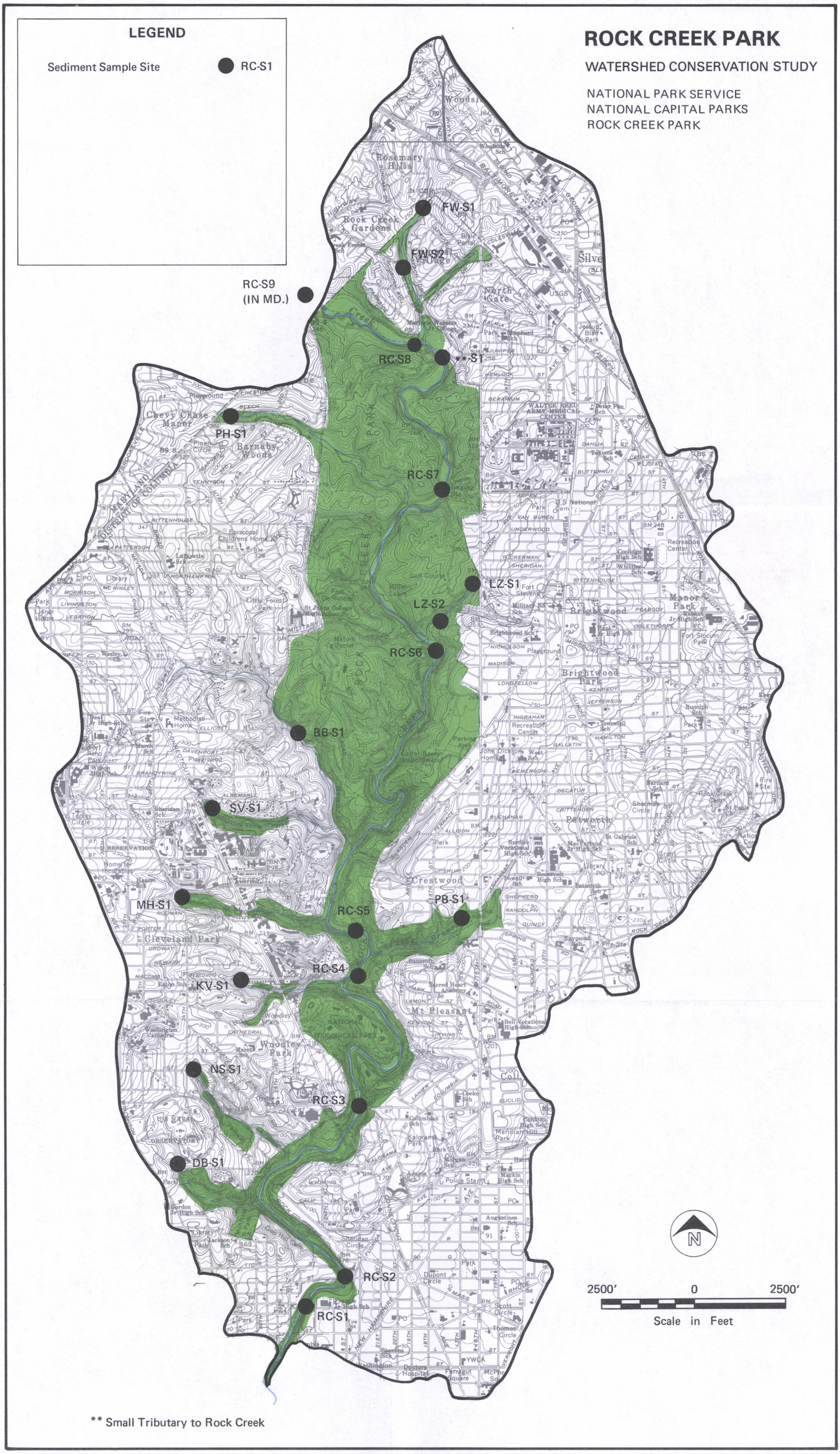


FIGURE 8-11: Rock Creek Sediment Sample Sites

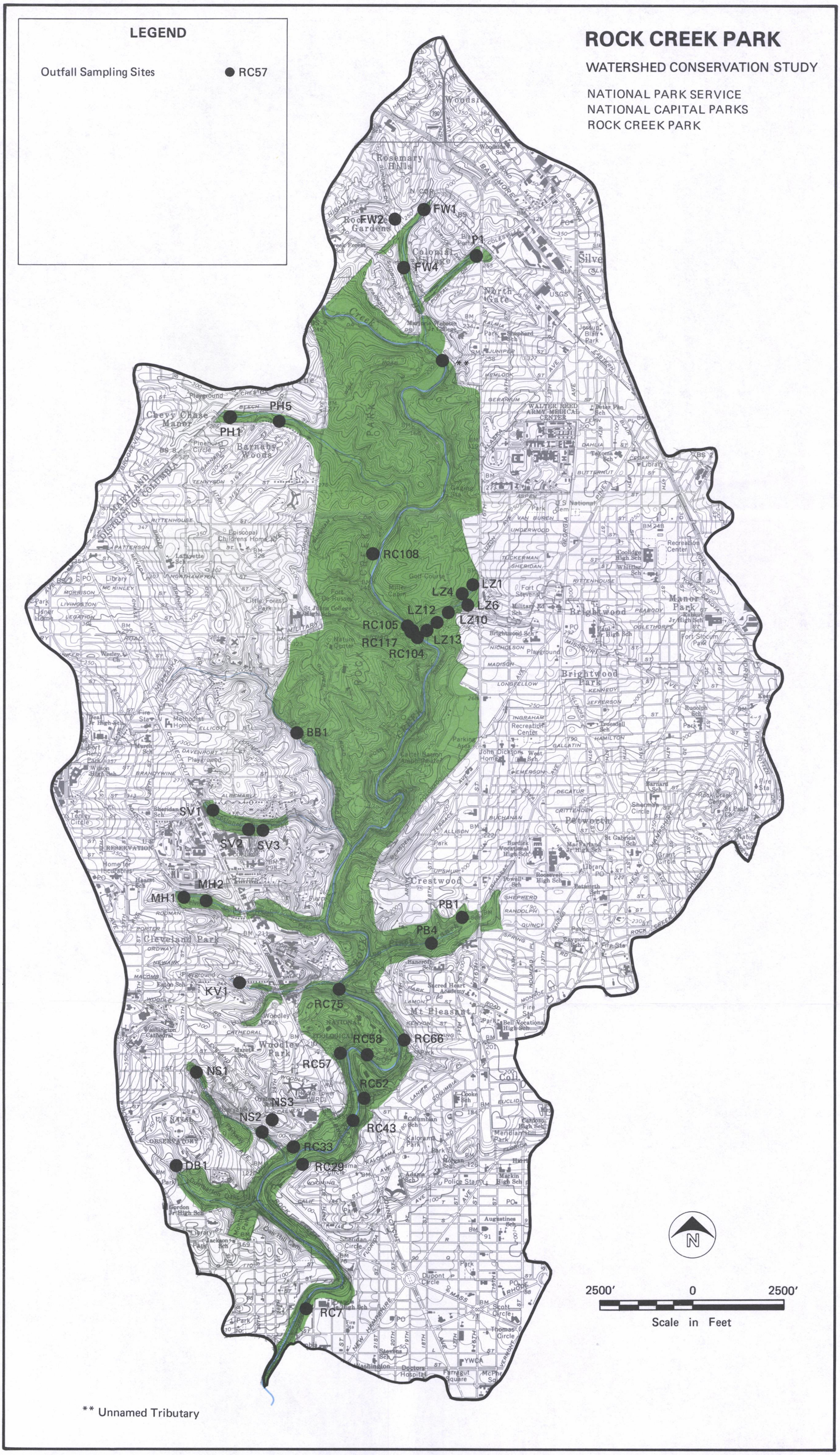


FIGURE 8-13 Rock Creek Outfall Sampling Sites

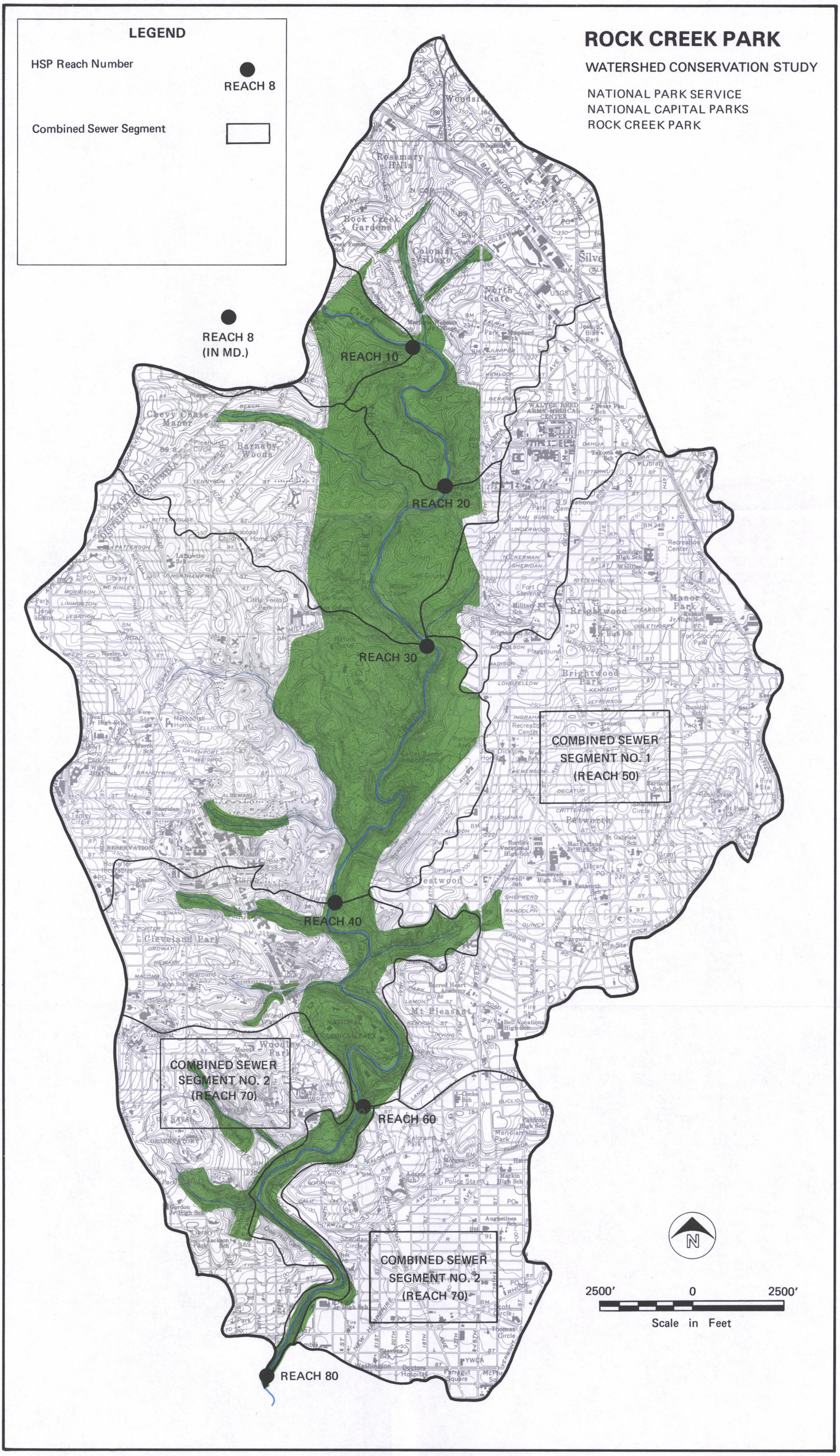


FIGURE 9-10: HSP Subbasin Segments

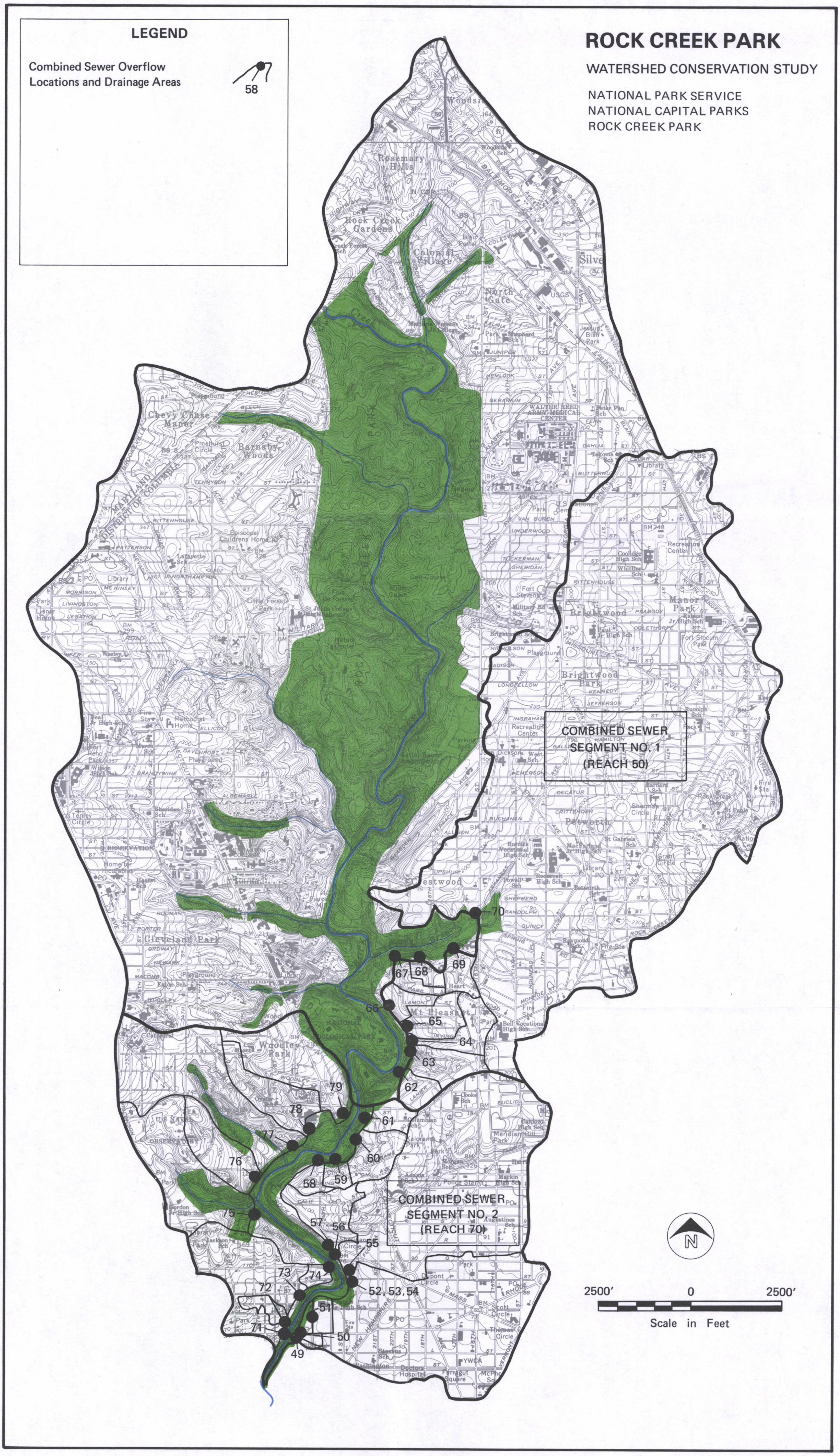


FIGURE 9-11: Combined Sewer Overflow Drainage Areas

☆ U.S. GOVERNMENT PRINTING OFFICE: 1981—335-406

MOUTH TO SECTION 12	
100-YEAR FLOOD =	17080 cfs
50-YEAR FLOOD =	14430 cfs
25-YEAR FLOOD =	11770 cfs
10-YEAR FLOOD =	8650 cfs
2.33-YEAR FLOOD =	4830 cfs

SECTION 12 TO SECTION 17	
100-YEAR FLOOD =	17060 cfs
50-YEAR FLOOD =	14410 cfs
25-YEAR FLOOD =	11750 cfs
10-YEAR FLOOD =	8640 cfs
2.33-YEAR FLOOD =	4820 cfs

NATIONAL PARK SERVICE
NATIONAL CAPITAL REGION

ROCK CREEK PARK

FLOOD PLAIN INFORMATION

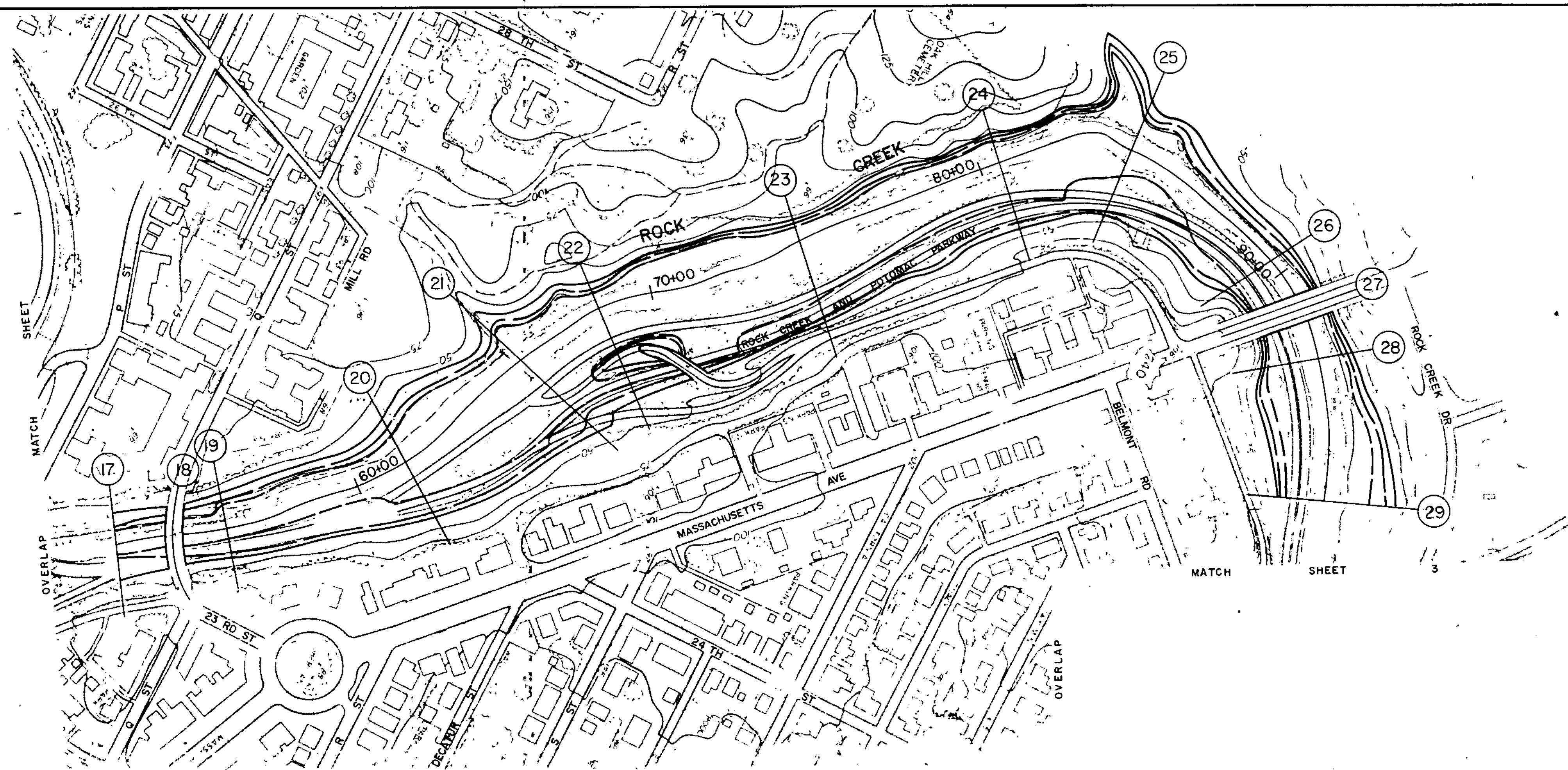
ROCK CREEK ULTIMATE LAND USE

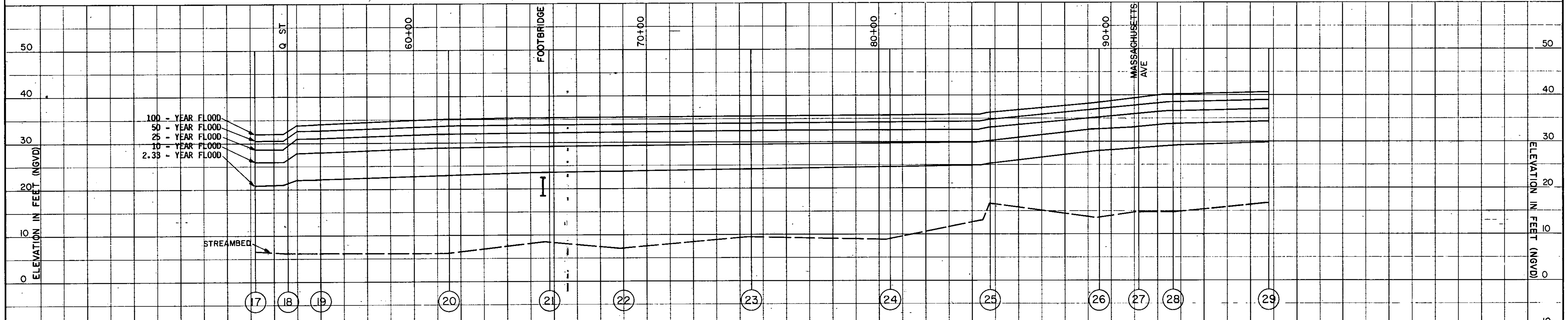
SCALE:
HORIZONTAL 1" = 200'
VERTICAL 1" = 10'

100 YEAR FLOOD
10 YEAR FLOOD
2.33 YEAR FLOOD

SHEET 1

Please See 821/80,045 for Shts 1 thru 7





SECTION 17 TO SECTION 26

100-YEAR FLOOD	=	16690 cfs
50-YEAR FLOOD	=	14070 cfs
25-YEAR FLOOD	=	11430 cfs
10-YEAR FLOOD	=	8370 cfs
2.33-YEAR FLOOD	=	4630 cfs

SECTION 26 TO SECTION 36

100-YEAR FLOOD	=	16650 cfs
50-YEAR FLOOD	=	14040 cfs
25-YEAR FLOOD	=	11400 cfs
10-YEAR FLOOD	=	8350 cfs
2.33-YEAR FLOOD	=	4620 cfs

NATIONAL PARK SERVICE
NATIONAL CAPITAL REGION

ROCK CREEK PARK

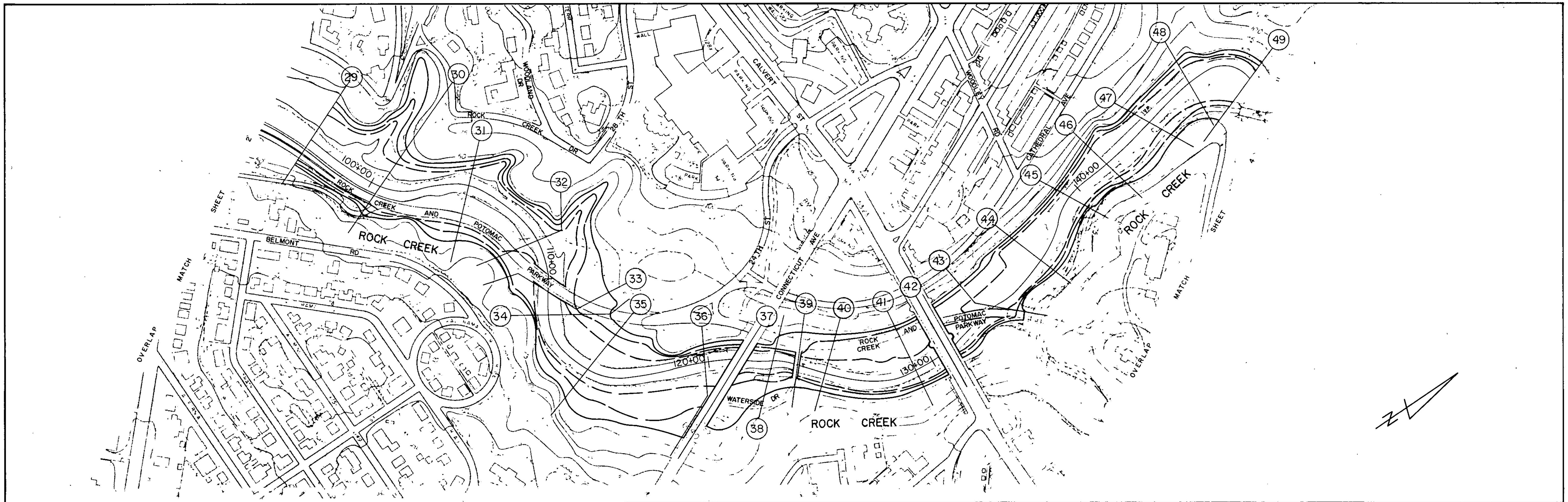
FLOOD PLAIN INFORMATION

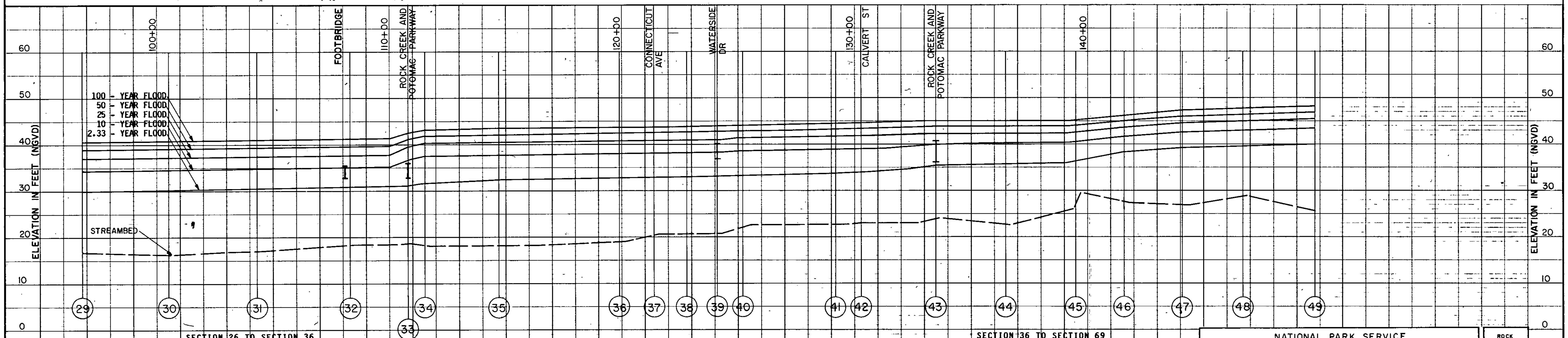
ROCK CREEK
ULTIMATE LAND USE

SCALE:
HORIZONTAL 1" = 200'
VERTICAL 1" = 10'

100 YEAR FLOOD
10 YEAR FLOOD
2.33 YEAR FLOOD

SHEET 2





SECTION 26 TO SECTION 36

100-YEAR FLOOD = 16650 cfs
50-YEAR FLOOD = 14040 cfs
25-YEAR FLOOD = 11400 cfs
10-YEAR FLOOD = 8350 cfs
2.33-YEAR FLOOD = 4620 cfs

SECTION 36 TO SECTION 69

100-YEAR FLOOD = 16480 cfs
50-YEAR FLOOD = 13890 cfs
25-YEAR FLOOD = 11290 cfs
10-YEAR FLOOD = 8270 cfs
2.33-YEAR FLOOD = 4570 cfs

NATIONAL PARK SERVICE
NATIONAL CAPITAL REGION

ROCK CREEK PARK

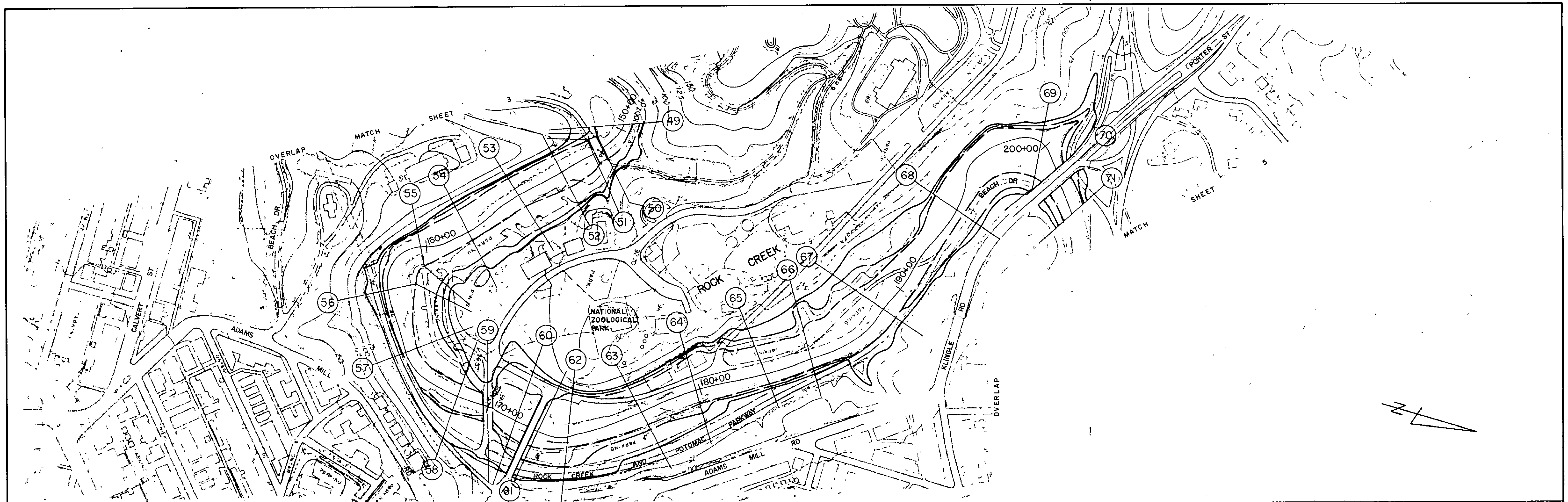
FLOOD PLAIN INFORMATION

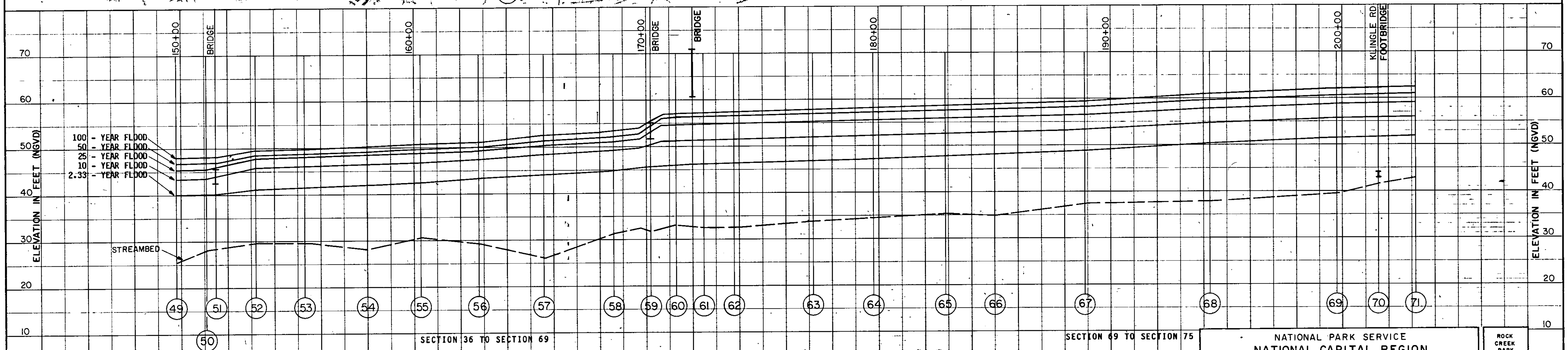
ROCK CREEK
ULTIMATE LAND USE

SCALE:
HORIZONTAL 1" = 200'
VERTICAL 1" = 10'

100 YEAR FLOOD
10 YEAR FLOOD
2.33 YEAR FLOOD

SHEET 3





SECTION 36 TO SECTION 69

100-YEAR FLOOD	= 16480 cfs
50-YEAR FLOOD	= 13090 cfs
25-YEAR FLOOD	= 11290 cfs
10-YEAR FLOOD	= 8270 cfs
2.33-YEAR FLOOD	= 4570 cfs

SECTION 69 TO SECTION 75

100-YEAR FLOOD	= 15940 cfs
50-YEAR FLOOD	= 13440 cfs
25-YEAR FLOOD	= 10930 cfs
10-YEAR FLOOD	= 8010 cfs
2.33-YEAR FLOOD	= 4420 cfs

NATIONAL PARK SERVICE
NATIONAL CAPITAL REGION

ROCK CREEK PARK

FLOOD PLAIN INFORMATION

ROCK CREEK
ULTIMATE LAND USE

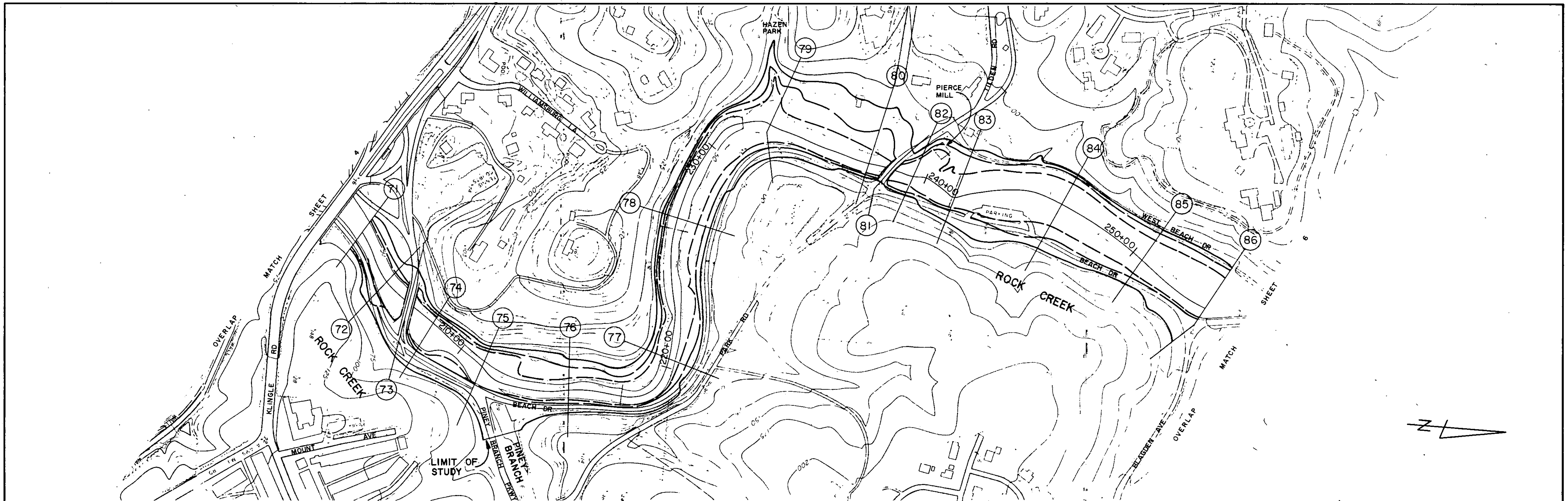
SCALE:
HORIZONTAL 1" = 200'
VERTICAL 1" = 10'

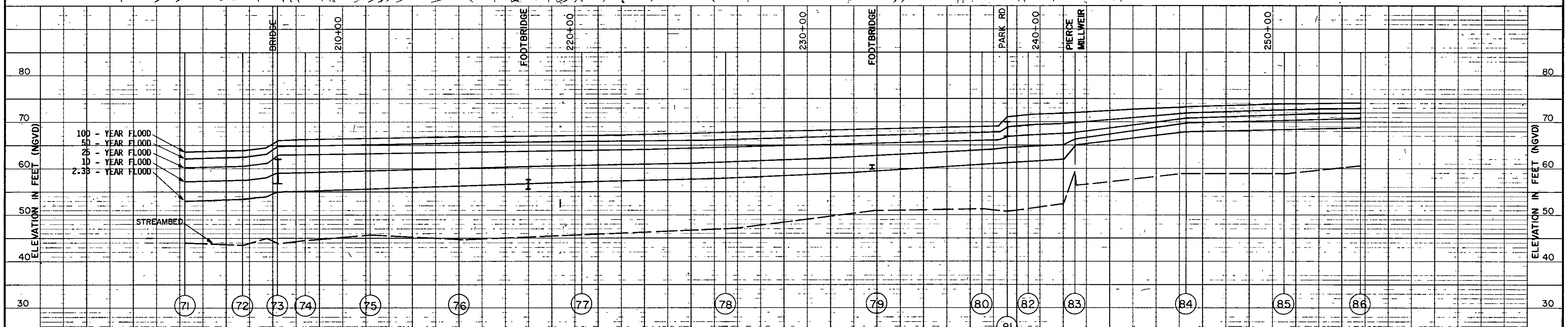
—— 100 YEAR FLOOD
— — 10 YEAR FLOOD
- - - 2.33 YEAR FLOOD

SHEET 4

Please See 844/80028 for Shts. 1 thru 3

821/80,045 1 of 7





SECTION 69 TO SECTION 75	SECTION 75 TO SECTION 84	SECTION 84 TO SECTION 87
100-YEAR FLOOD = 15940 cfs	100-YEAR FLOOD = 14760 cfs	100-YEAR FLOOD = 14640 cfs
50-YEAR FLOOD = 13440 cfs	50-YEAR FLOOD = 12430 cfs	50-YEAR FLOOD = 12340 cfs
25-YEAR FLOOD = 10930 cfs	25-YEAR FLOOD = 10090 cfs	25-YEAR FLOOD = 10010 cfs
10-YEAR FLOOD = 8010 cfs	10-YEAR FLOOD = 7390 cfs	10-YEAR FLOOD = 7330 cfs
2.33-YEAR FLOOD = 4420 cfs	2.33-YEAR FLOOD = 4060 cfs	2.33-YEAR FLOOD = 4020 cfs

NATIONAL PARK SERVICE
NATIONAL CAPITAL REGION

ROCK CREEK PARK

FLOOD PLAIN INFORMATION

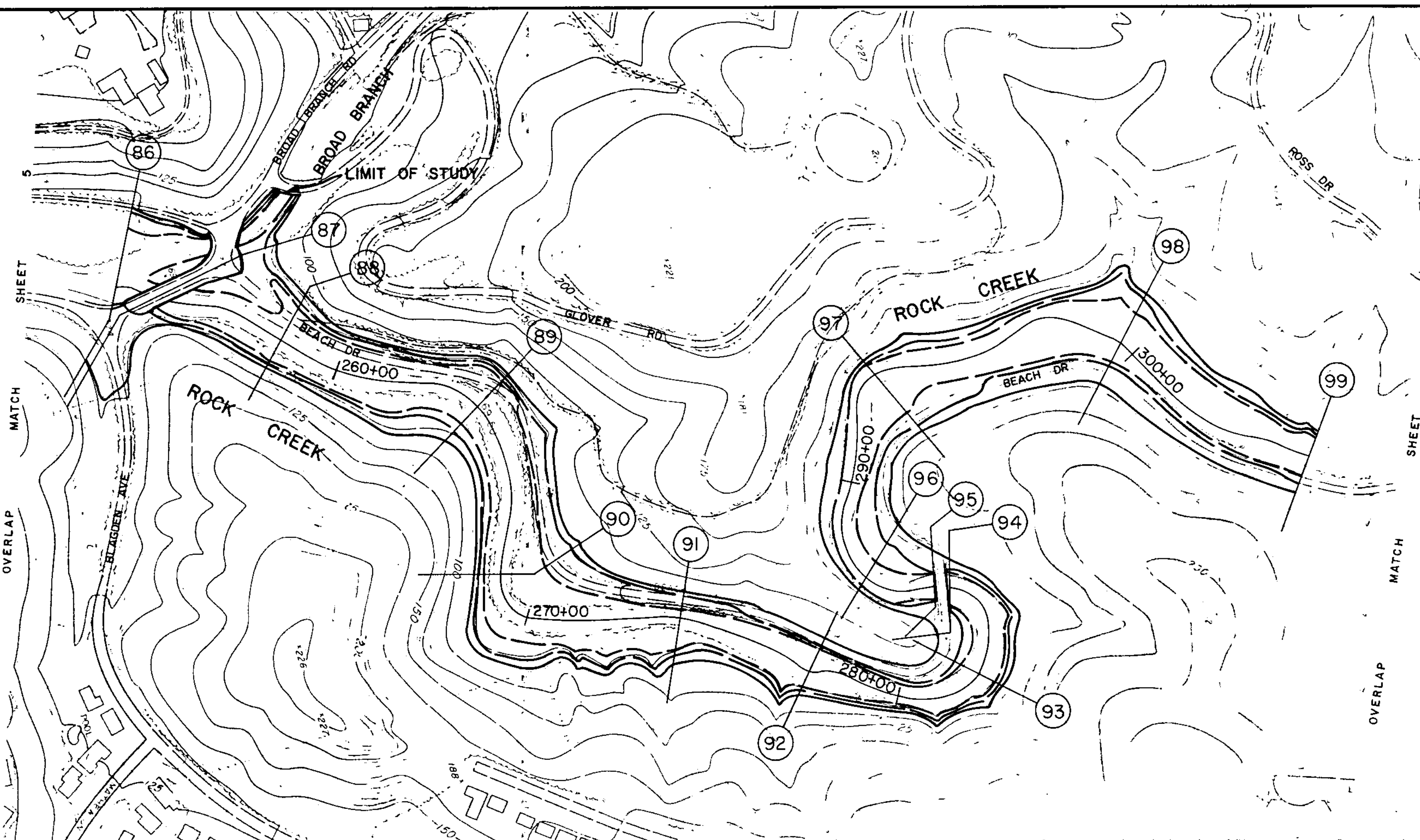
ROCK CREEK
ULTIMATE LAND USE

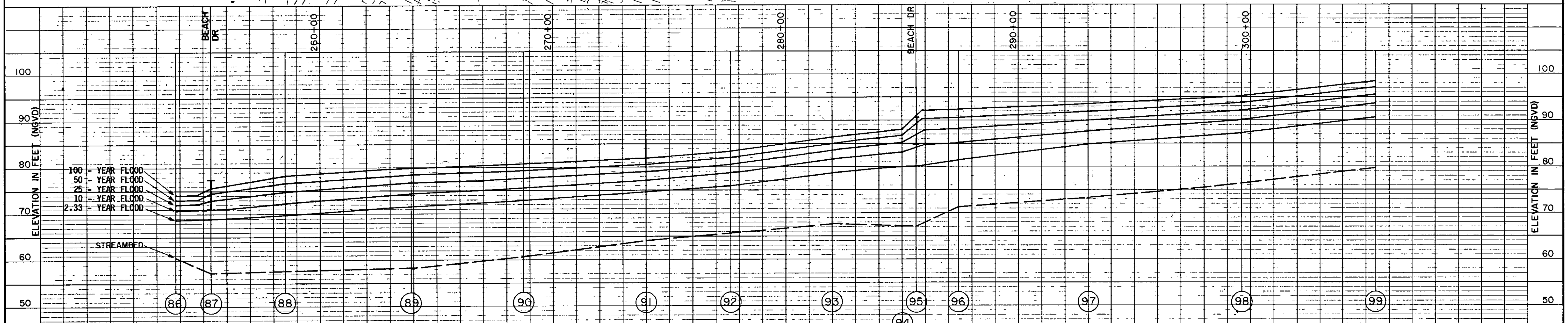
SCALE:
HORIZONTAL 1" = 200'
VERTICAL 1" = 10'

100 YEAR FLOOD
10 YEAR FLOOD
2.33 YEAR FLOOD

SHEET
5

821/80,045 2 of 7





SECTION 84 TO SECTION 87

100-YEAR FLOOD	= 14640 cfs
50-YEAR FLOOD	= 12340 cfs
25-YEAR FLOOD	= 10010 cfs
10-YEAR FLOOD	= 7330 cfs
2.33-YEAR FLOOD	= 4020 cfs

SECTION 87 TO SECTION 114

100-YEAR FLOOD	= 13920 cfs
50-YEAR FLOOD	= 11720 cfs
25-YEAR FLOOD	= 9500 cfs
10-YEAR FLOOD	= 6940 cfs
2.33-YEAR FLOOD	= 3970 cfs

NATIONAL PARK SERVICE
NATIONAL CAPITAL REGION

ROCK CREEK PARK

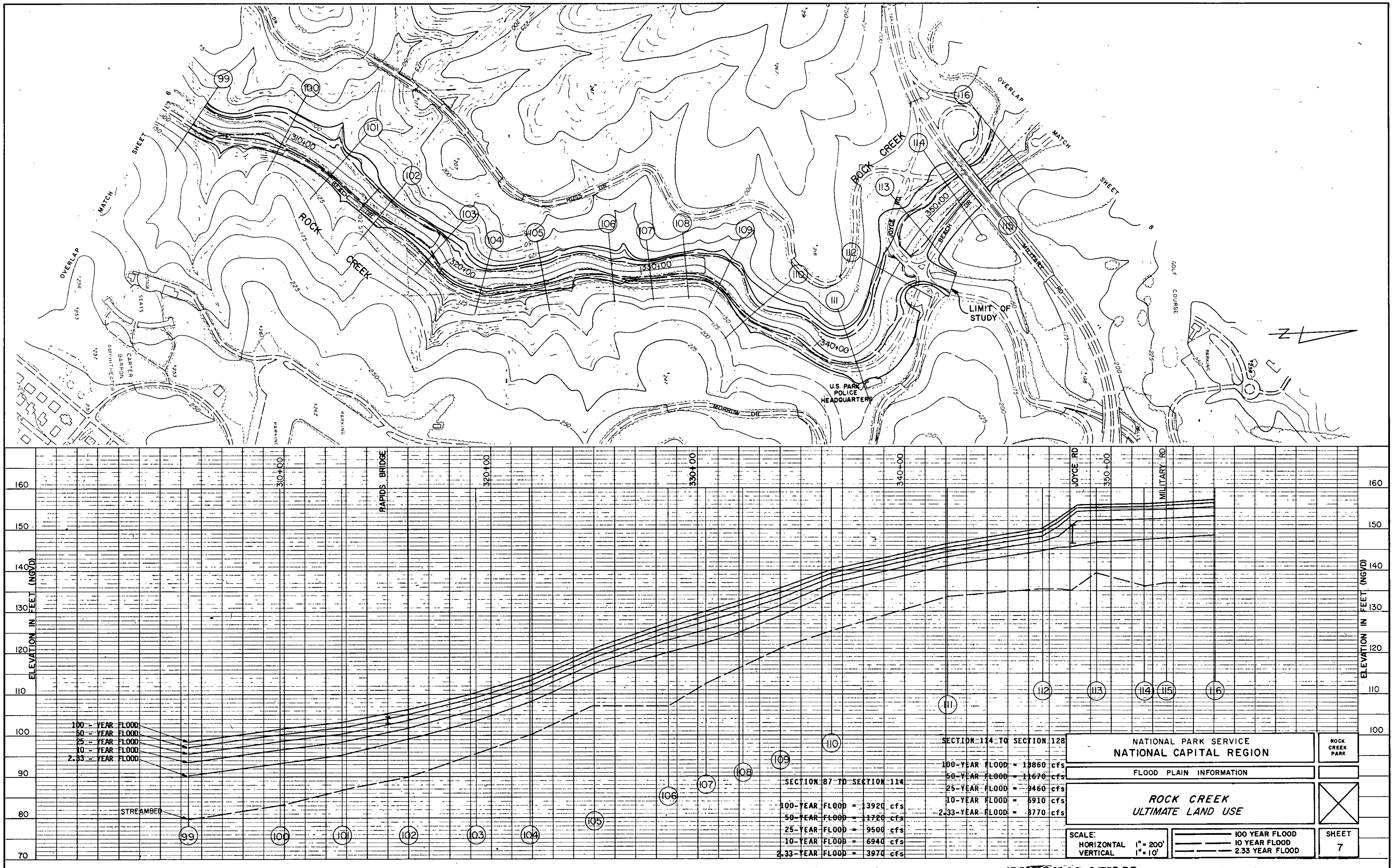
FLOOD PLAIN INFORMATION

ROCK CREEK
ULTIMATE LAND USE

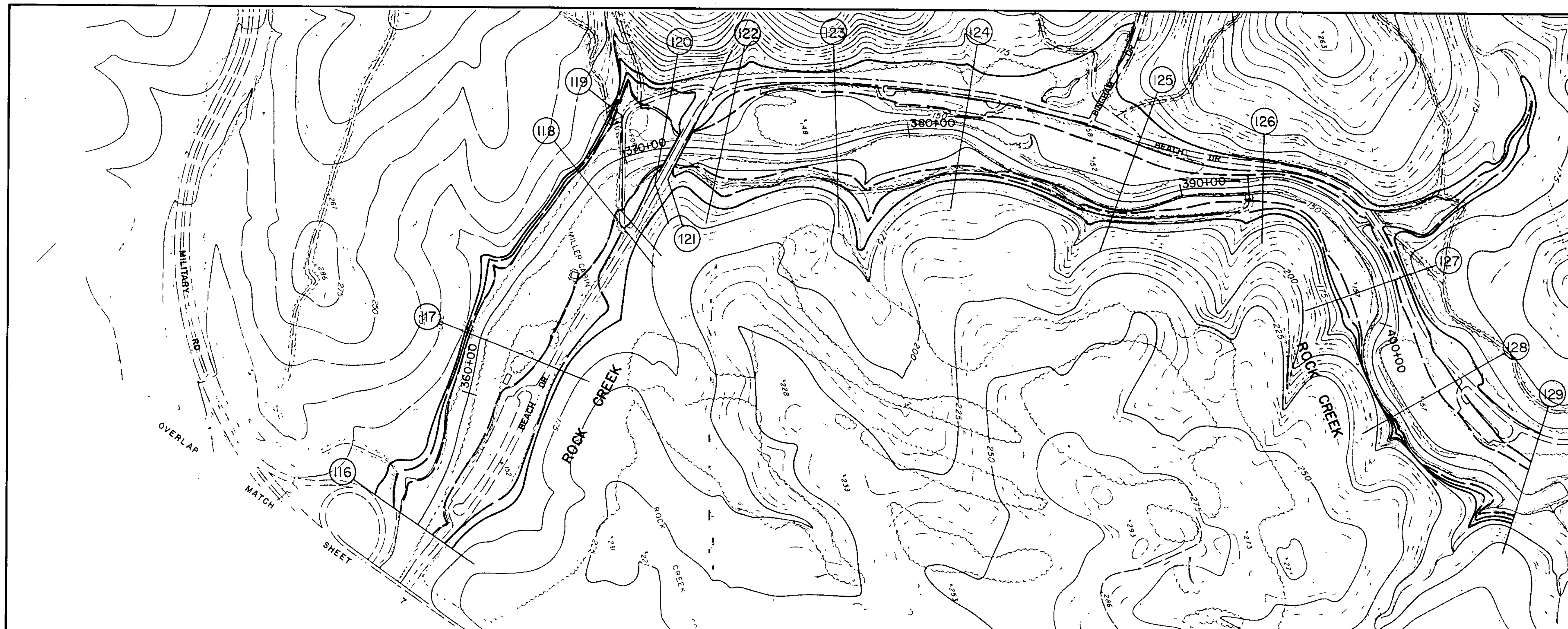
SCALE:
HORIZONTAL 1" = 200'
VERTICAL 1" = 10'

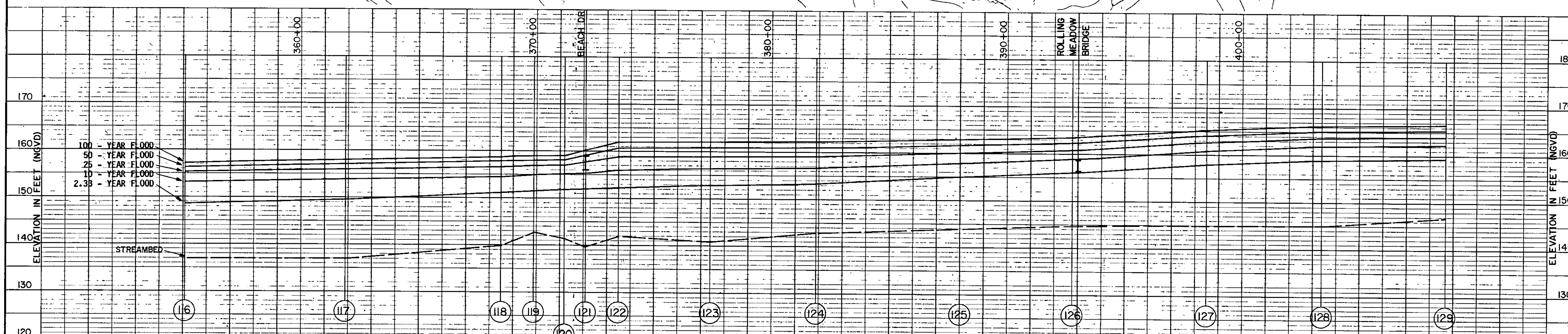
100 YEAR FLOOD
10 YEAR FLOOD
2.33 YEAR FLOOD

SHEET 6



OVERLAP MATCH SHEET 6
OVERLAP MATCH SHEET 8
ROCK CREEK
BEACH DR
ROSS DR
MORROW DR
JOYCE RD
MILITARY RD
GOLF COURSE
CARTER BARRON AMPHITHEATER
SEATS
PARKING
U.S. PARK POLICE HEADQUARTERS
LIMIT OF STUDY
310+00
320+00
330+00
340+00
350+00
RAPIDS BRIDGE
ELEVATION IN FEET (NGVD)
100 - YEAR FLOOD
50 - YEAR FLOOD
25 - YEAR FLOOD
10 - YEAR FLOOD
2.33 - YEAR FLOOD
STREAMBED
SECTION 87 TO SECTION 114
100-YEAR FLOOD = 13920 cfs
50-YEAR FLOOD = 11720 cfs
25-YEAR FLOOD = 9500 cfs
10-YEAR FLOOD = 6940 cfs
2.33-YEAR FLOOD = 3970 cfs
SECTION 114 TO SECTION 128
100-YEAR FLOOD = 13860 cfs
50-YEAR FLOOD = 11670 cfs
25-YEAR FLOOD = 9460 cfs
10-YEAR FLOOD = 5910 cfs
2.33-YEAR FLOOD = 3770 cfs
NATIONAL PARK SERVICE
NATIONAL CAPITAL REGION
ROCK CREEK PARK
FLOOD PLAIN INFORMATION
ROCK CREEK
ULTIMATE LAND USE
SCALE:
HORIZONTAL 1" = 200'
VERTICAL 1" = 10'
100 YEAR FLOOD
10 YEAR FLOOD
2.33 YEAR FLOOD
SHEET 7





SECTION 114 TO SECTION 128

100-YEAR FLOOD	= 13860 cfs
50-YEAR FLOOD	= 11670 cfs
25-YEAR FLOOD	= 9460 cfs
10-YEAR FLOOD	= 6910 cfs
2.33-YEAR FLOOD	= 3770 cfs

SECTION 128 TO SECTION 149

100-YEAR FLOOD	= 13680 cfs
50-YEAR FLOOD	= 11500 cfs
25-YEAR FLOOD	= 9370 cfs
10-YEAR FLOOD	= 6860 cfs
2.33-YEAR FLOOD	= 3760 cfs

NATIONAL PARK SERVICE
NATIONAL CAPITAL REGION

ROCK CREEK PARK

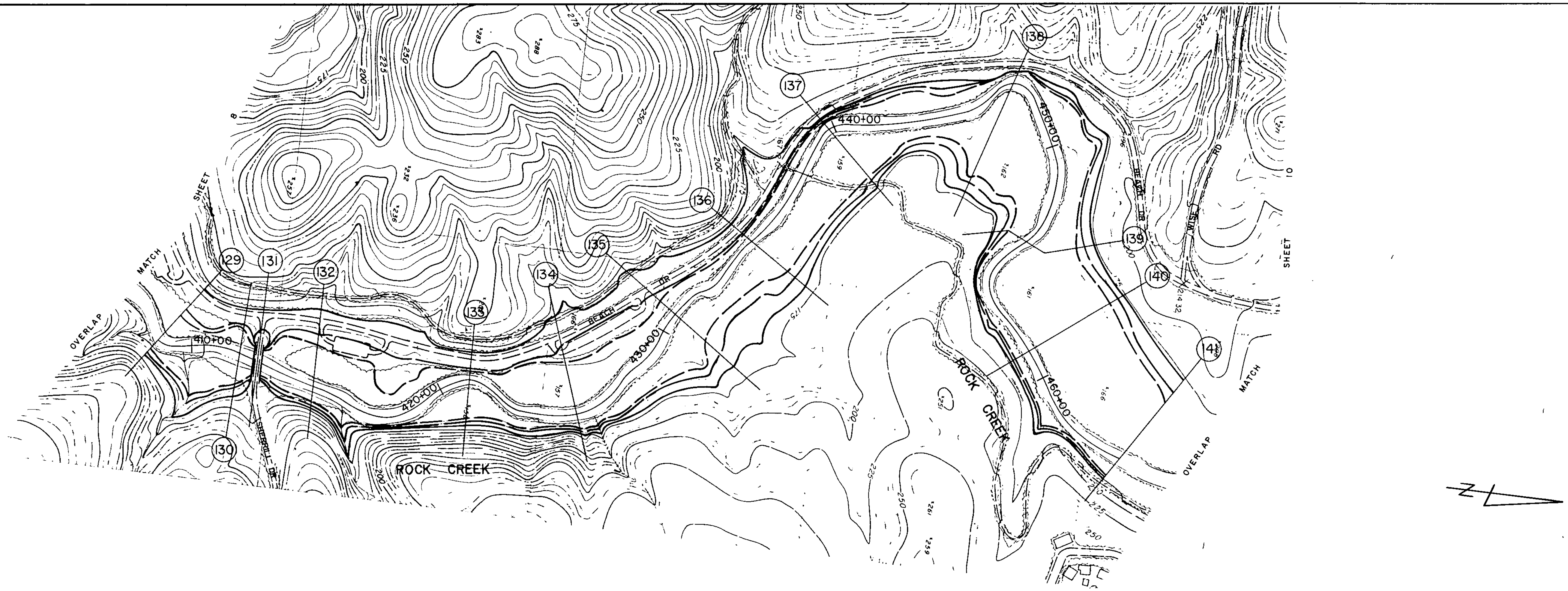
FLOOD PLAIN INFORMATION

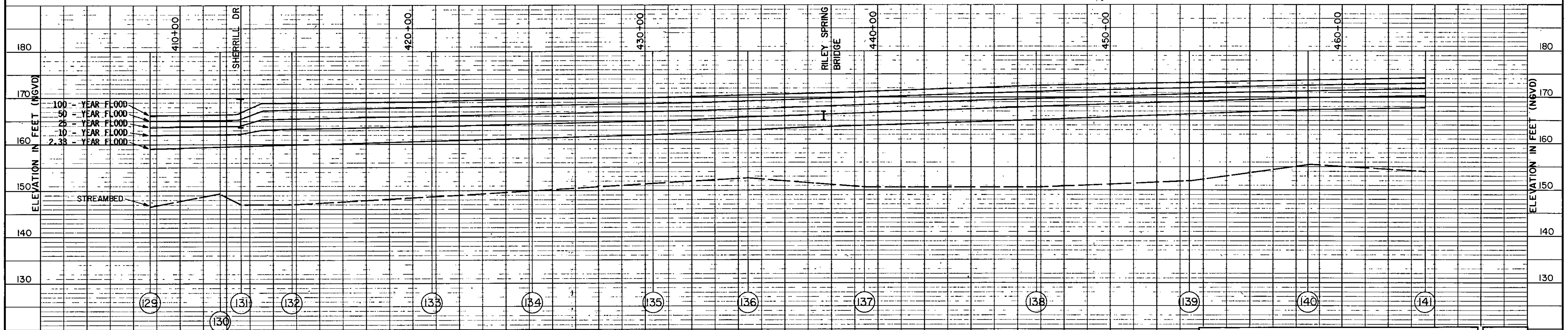
ROCK CREEK
ULTIMATE LAND USE

SCALE:
HORIZONTAL 1" = 200'
VERTICAL 1" = 10'

100 YEAR FLOOD
10 YEAR FLOOD
2.33 YEAR FLOOD

SHEET 8

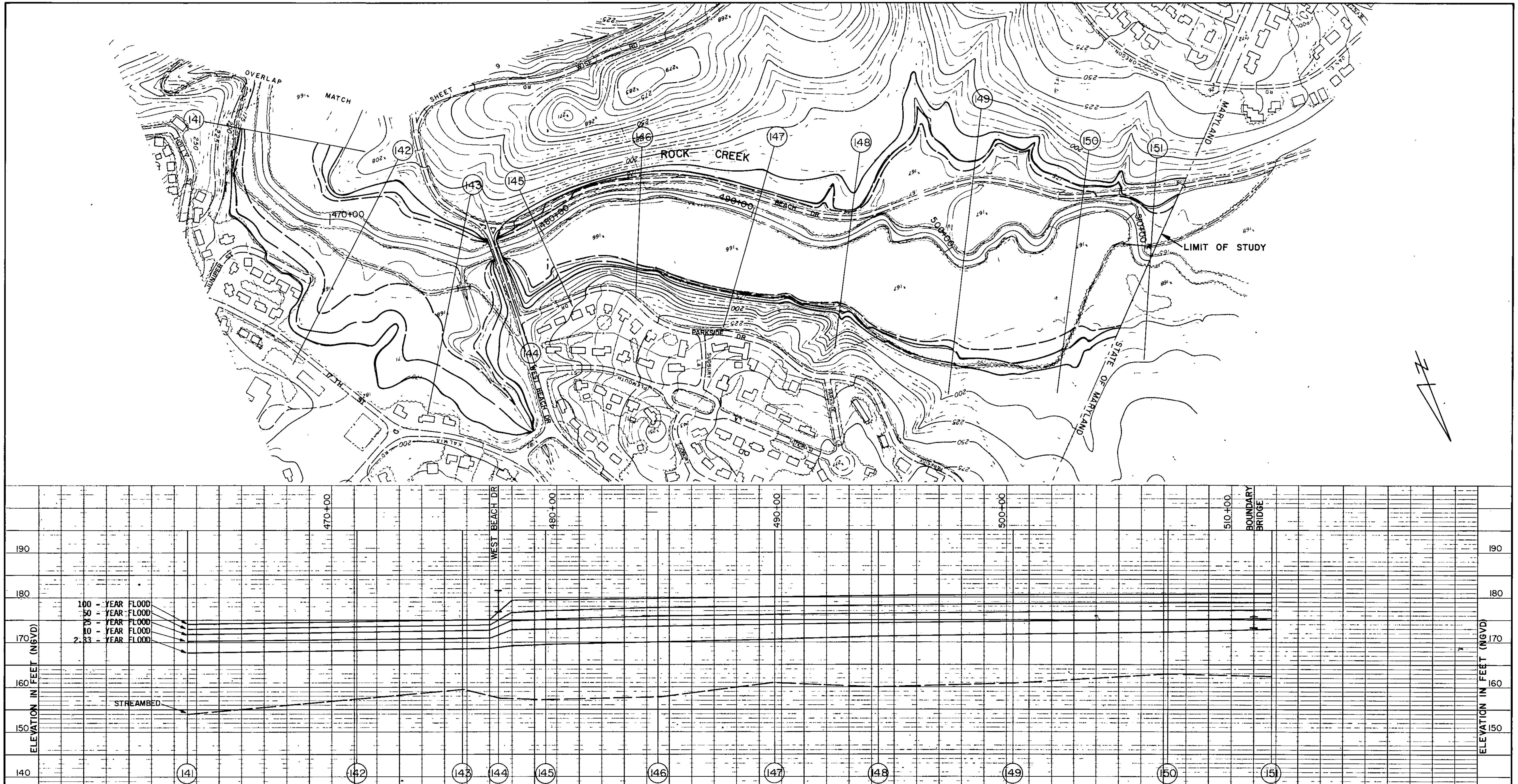




SECTION 128 TO SECTION 149

100-YEAR FLOOD = 13680 cfs
50-YEAR FLOOD = 11500 cfs
25-YEAR FLOOD = 9370 cfs
10-YEAR FLOOD = 6860 cfs
2.33-YEAR FLOOD = 3760 cfs

NATIONAL PARK SERVICE NATIONAL CAPITAL REGION	ROCK CREEK PARK
FLOOD PLAIN INFORMATION	
ROCK CREEK *ULTIMATE LAND USE*	
SCALE: HORIZONTAL 1" = 200' VERTICAL 1" = 10'	100 YEAR FLOOD 10 YEAR FLOOD 2.33 YEAR FLOOD
SHEET	9



SECTION 128 TO SECTION 149

100-YEAR FLOOD = 13680 cfs
50-YEAR FLOOD = 11500 cfs
25-YEAR FLOOD = 9370 cfs
10-YEAR FLOOD = 6860 cfs
2.33-YEAR FLOOD = 3760 cfs

SECTION 149 TO MARYLAND STATE LINE

100-YEAR FLOOD = 13730 cfs
50-YEAR FLOOD = 11570 cfs
25-YEAR FLOOD = 9400 cfs
10-YEAR FLOOD = 6880 cfs
2.33-YEAR FLOOD = 3780 cfs

NATIONAL PARK SERVICE
NATIONAL CAPITAL REGION

ROCK CREEK PARK

FLOOD PLAIN INFORMATION

ROCK CREEK
ULTIMATE LAND USE

SCALE:
HORIZONTAL 1" = 200'
VERTICAL 1" = 10'

100 YEAR FLOOD
10 YEAR FLOOD
2.33 YEAR FLOOD

SHEET 10