NON-POINT POLLUTION
IN THE
POTOMAC RIVER BASIN

by

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INTRODUCTION

NON-POINT POLLUTION IN THE POTOMAC RIVER BASIN

The headwaters of the Potomac River originate in the Allegheny plateau, an area largely of forest and rushing streams. The river remains a comparatively narrow, fast-flowing stream, with natural obstructions and rapids, as it flows some 266 miles first northeasterly then southeasterly to the fall line, near Washington, D.C. After crashing over Great Falls, the river begins to widen, entering the Potomac estuary. Here the river becomes slow-moving and relatively shallow, with a great number of tidal embayments. After entering the estuary, the Potomac River merges some 107 miles later with the waters of the Chesapeake Bay.

Despite containing a major metropolitan center, the Potomac River basin remains essentially rural in nature. Land use is currently estimated to be 55 percent forest, 40 percent agriculture and grazing land, and 5 percent urban.[32] Because of its unique distinction as the nation's capital, the major source of employment within the metropolitan area is in the field of public administration and little industry has developed. What industry has developed in the basin is concentrated in the North Branch of the Potomac near Luke and Cumberland, Maryland, and in the South Fork of the Shenandoah near Front Royal and Waynesboro, Virginia.

The Potomac River basin has a drainage area of 14,670 square miles, which encompasses portions of Maryland, West

POTOMAC RIVER BASIN
POTOMAC RIVER TRIBUTARIES
COUNTIES

Virginia, Virginia and Pennsylvania, and the whole of the District of Columbia (Figure 1). The water quality within the basin is generally good; however, wide local variations in quality do occur. Those factors which most affect water quality in the various stretches of the river include: (1) the existence of acid mine drainage, (2) the extent of urban development, (3) the degree to which municipal and industrial wastes are treated, and (4) the existence of erosion and sedimentation in urban and non-urban areas (Table 1).

POINT SOURCE AND NON-POINT SOURCE POLLUTION CONTROL

Nationally, as well as in the Potomac River basin, initial efforts to improve water quality have been directed toward the treatment of point source discharges. These discharges are typified by most industrial and municipal effluents, with wastes being transported by a confined and discrete conveyance, such as a pipe, tunnel, or channel. In the past one hundred years, control of pollutants from these discharges has advanced from removing only patently obnoxious constituents to treating pollutants which can be measured by only very precise methods and instruments. Only primary treatment was at first required of municipal and industrial discharges to alleviate the visual and odor problems associated with the release of raw wastes. Years later, as public concern with water pollution became more pronounced, secondary treatment and chlorination of some wastes were required to address the problems of low dissolved oxygen and high coliform levels.

In the 1970's, more advanced waste treatment has been

TABLE 1

SUMMARY OF WATER QUALITY CONDITIONS
IN THE POTOMAC RIVER BASIN

River or Stream Reach	Is State WQ Standard Being Met?	Major Water Quality Problems: Low DO	High BOD	High Coliform Densities	Excessive Nutrients	Pesticides	Acid Mine Drainage	Excessive Heavy Metals
North Branch	No	X	X	X			X	
South Branch	Yes (1)			X	X			
Conococheague Creek	No			X		X		
Opequon Creek	Yes (1)							
Abrams Creek	No	X	X	X	X			
Tuscarora Creek	No	X	X	X	X			
Antietam Creek	No	X	X	X	X	X		
Shenandoah River								
North Fork	No	X		X				
South Fork	No	X		X				
Main Stem	Yes							
Monocacy River	Contravened	X		X				
Main Stem Potomac	Contravened	X (1)		X	X	X		
Estuary	No (2)	X (3)	X (3)	X	X	X		X

Notes: (1) Selected areas do not meet standards
(2) Selected areas do meet standards
(3) Periodic values are within allowable limits

Source: Potomac River Basin Water Supply, An Interim Report[13] page 7.

suggested and put into operation in many treatment facilities to treat other forms of pollution, such as nutrients and toxic substances. Although this upgrading in treatment has undoubtedly improved water quality in many places, it is becoming obvious that this approach -- concentrating only on municipal and industrial point source discharges -- may not raise the water quality of the nation's rivers to that mandated by the 1972 Federal Water Pollution Control Act Amendments. It appears now that in some situations, such as in the Potomac River basin, even if all municipal and industrial point source discharges are treated to some advanced degree, water quality problems will still remain. The persistence of these water quality problems is mainly a result of huge quantities of pollution that never receive treatment before they reach waterways, known as non-point pollution.

The term "non-point pollution" implies a source of pollution that is diffuse, with the constituents of the flow originating over a large area. Storm water runoff from forested, agricultural, and urban areas is, perhaps, the most common example of this type of pollution. The concentration of pollutants in flows from non-point sources is often dilute; however, the total discharge of pollutants from these sources can be quite significant because of the huge quantities of flows involved.

Non-point pollution often presents unique difficulties in treatment not posed by conventional point source discharges. One major difficulty is their extreme variation in quantity.

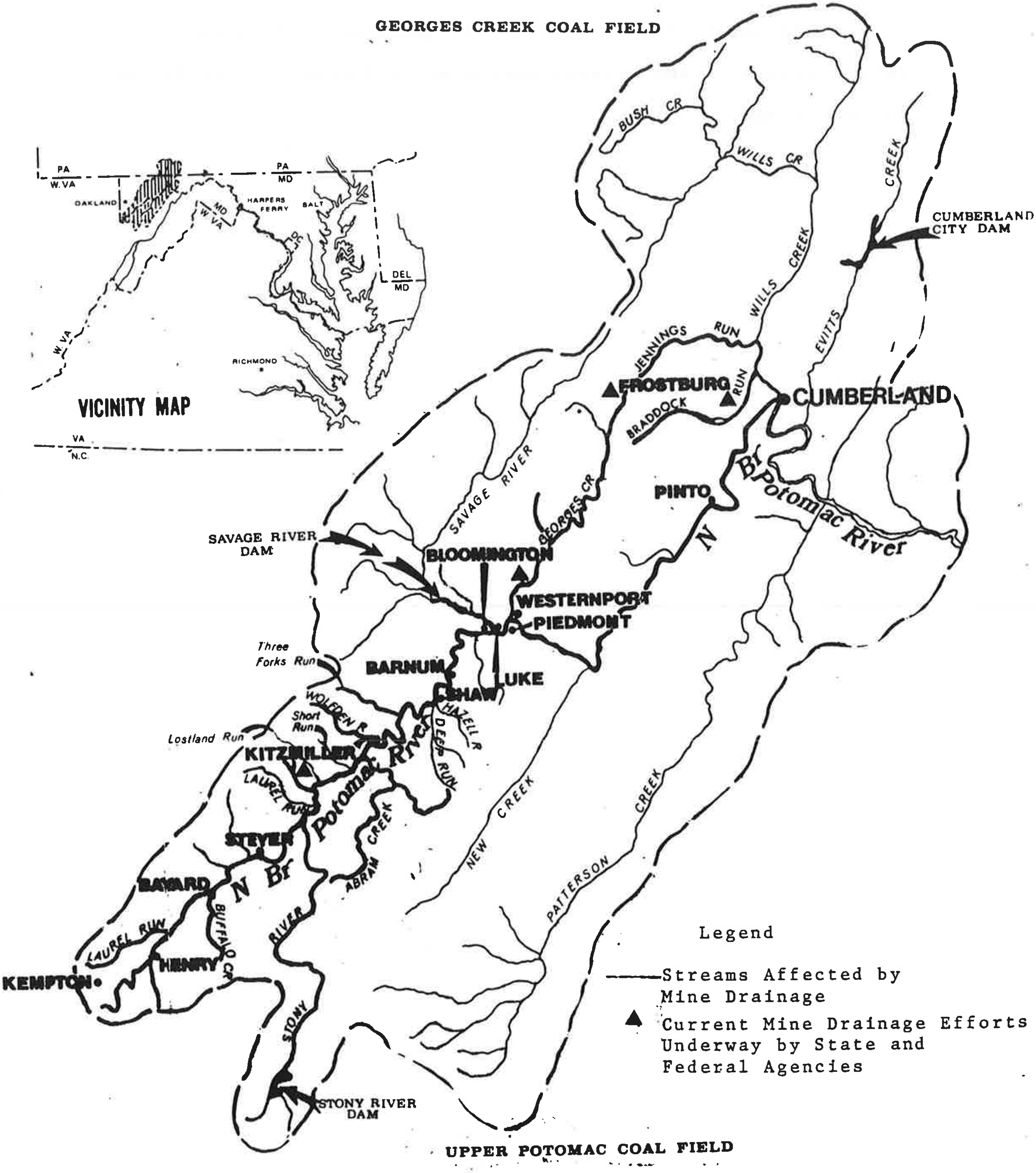
During periods of heavy precipitation non-point pollution can represent a major problem source, while during periods of low precipitation they may become minor or cease totally. This trait, coupled with their generally modest pollutant concentrations, makes conventional treatment techniques inadequate. Preventing pollution from entering non-point flows has often proven more cost-effective than treating contaminated flows.

Within the Potomac basin, two forms of non-point pollution exist in addition to simple runoff from land. Acid mine drainage in the northwestern portion of the basin represents a major pollution source which is complex in its formation and devastating in its effect. The second uncommon non-point source, combined sewer overflows in the District of Columbia and Alexandria, Virginia, impairs the recreational use of the Potomac estuary for many miles. Although both of these sources of pollution may receive National Pollutant Discharge Elimination System (NPDES) permits, a dubious honor normally restricted to discharge of point source pollution, they are included in this paper because of their close similarity to most non-point discharges.

Although the polluting constituents of non-point discharges vary, in the Potomac basin there are four types of pollution from sources which are of major significance. They are acid mine drainage, sediment, bacteria, and nutrients. Rather than examining sources of pollution (because a single non-point source may contain several of these constituents), this paper is arranged to explore the magnitude and effect of each of these pollution types and to outline abatement techniques that have been suggested previously. Though much of the data used to compile this report is historical, it is hoped that this paper will allow an accurate overview of the present non-point pollution problem in the Potomac basin.

FIGURE 2

THE NORTH BRANCH POTOMAC RIVER



Source: North Branch Potomac River Mine Drainage Study,[8] p. 7.

I. ACID MINE DRAINAGE

Acid mine drainage in the United States, almost all of which originates from the runoff of coal mines, pollutes over 10,000 miles of streams. Water quality problems in the Potomac basin due to acid mine drainage are found primarily in the northeastern portion of the Potomac basin originating along the North Branch (Figure 2). Mine drainage problems in this area result not only from active mines, but as runoff from an accumulation of debris and mines that have been inactive for as many as 150 years. These problems are accentuated by a lack of natural alkalinity in the rock formation over which the drainage travels.

EFFECTS OF ACID MINE DRAINAGE

Over 140 miles of streams and river are profoundly affected by the acid drainage -- 40 miles of main stem below Luke, Maryland, and over 100 miles of tributary streams. All of these 140 miles are devoid of fish life, and virtually no natural biological communities exist upstream of Kitzmiller. Much of this area has a ferric hydroxide slime (known as yellow-boy) covering stream beds, which destroys any benthic organisms that might be able to survive the low pH conditions. Sediment from runoff does much to increase turbidity in these streams. These detrimental characteristics are in addition to the low pH (sometimes as low as 2.0), high acidity (sometimes as high as 10,000 mg/l), and other toxic precipitates that accompany all mine drainage. The result of these synergistic impacts is a virtually sterile area, lacking even those bacteria that normally purify streams.

TABLE 2

CONSTITUENTS OF ACID MINE DRAINAGE

Parameter	Concentrations
pH, units	2 - 4.5
Acidity, mg/l	1,000 - 15,000
Ferrous Iron, mg/l	500 - 10,000
Ferric Iron, mg/l	0 - 100
Aluminum, mg/l	0 - 2,000
Sulfate, mg/l	1,000 - 20,000
Calcium, mg/l	10 - 1,000

These impacts continue to affect the aquatic life in the river until some ten miles upstream of Cumberland. This situation becomes increasingly significant in light of the five-fold increase in acidity that the North Branch received from the years 1956 to 1967[5] and the almost certain future increase in mining activity that is expected due to the rising value of coal in these areas.

In addition to the biological devastation that acid mine drainage inflicts on the streams of the basin, acid drainage also affects the industrial and municipal uses of water. Municipalities that wish to use such water for potable supplies must apply extremely high amounts of chemicals to raise its pH and are still often faced with problems in their coagulation processes. In addition, excessive amounts of iron and manganese, even after treatment, can present serious public health problems. Industries wishing to use such water must take special precautions to treat the corrosive properties of the water and often face rapid scale buildup on boilers due to the permanent hardness of the water.

CHEMICAL REACTIONS

Acid mine drainage pollution is characterized by dissolved and suspended solids, low pH, high acidity, toxic precipitates, dissolved iron, and other metals (Table 2). When discharged into a stream, these constituents can create a biological desert devoid of any but the most resistant plant and animal life.

The chemical reactions which result in acid mine drainage are neither straightforward nor completely understood. The formation of acid drainage involves the oxidation of iron sulfide or pyrite

TABLE 3

THE pH OF THE POTOMAC RIVER AND TRIBUTARIES

June 1968 - June 1969

	Ranges pH	Ranges Acidity (mg/l)	Total Acidity (lbs/day)
1. Elk Run	2.0 - 2.5	3,500 - 10,000	35,000
2. Laurel Creek	2.0 - 3.0	250 - 600	13,000
3. Buffalo Creek	2.0 - 3.0	150 - 600	15,000
4. Abrams Creek	3.0 - 4.0	10 - 180	8,000
5. Stony River	3.0 - 6.5	-20 - 30	4,500
6. Three Fork Run	2.0 - 3.5	100 - 700	3,300
7. Piney Swamp Run	2.1 - 3.0	100 - 1,000	3,200
8. Lostland Run	3.0 - 4.0	20 - 150	1,000
9. North Branch at Kitzmiller	2.5 - 5.0	50 - 225	
at Barnum	2.5 - 3.5	50 - 225	
at Beryl	3.5 - 6.5	-50 - 50	

Source: Mine Drainage in the North Branch Potomac River Basin[5] page II2, V1 - V32.

to form, in a series of reactions, sulfates, sulfuric acid, iron oxides, and other compounds. The oxidation that takes place has been shown to be biological as well as chemical in nature, involving a variety of microorganisms, and the rate-controlling reactions are believed determined by the exposure of pyrite to moist air.

WATER QUALITY

Table 3 presents a range of values found for pH and acidity levels from June 1968 to June 1969 in various streams in the Potomac basin affected by mine drainage. It should be noted that the water quality of many of these streams approaches that of raw mine drainage and that in all cases water quality standards are exceeded much of the year. In Table 3 the total acidity loads from these streams were calculated for the same time period. The streams studied account for over 72 percent of all acidity measured at Beryl, West Virginia, in an area which includes 287 square miles and virtually all mine drainage in the area. Fifty-four percent of this acid loading (63,000 pounds per day) originates in tributary streams of Elk Run, Laurel Run, and Buffalo Creek with a drainage area of only 20 square miles. From a state jurisdictional standpoint, 67 percent of the annual acidity loading originates in West Virginia (79,000 pounds per day) and 33 percent in Maryland (39,000 pounds per day).

SOURCES OF ACID MINE DRAINAGE

The sources of acid mine drainage in the basin are active and inactive surface mines and active and inactive deep mines. Unfortunately, no delineation has been made of the flows from surface or deep mines. Some attempts have been made to differentiate between the loads from active and inactive mines. A comprehensive study was conducted by the state of Maryland[20] indicating that only 22 mines had an active status and 135 mines were inactive. Of the active mines, 15 were found to be draining; of inactive mines, 71 were found draining. From these observations it was concluded that the majority of acidity was originating from inactive mines. In West Virginia, the situation was found to be the reverse. Based on visual observations and reconnaissance studies conducted by the Annapolis Science Center, it was concluded that active mine operations contribute most of the acid mine drainage. This is most probably due to its larger number of active mines. Recent studies conducted by the state of West Virginia[50] concur with the Annapolis findings and indicate a continued increase in acid loads from the years 1968 to 1972.

ABATEMENT TECHNIQUES

A variety of techniques exists for the elimination of acid mine drainage. They may be divided into either prevention techniques or treatment techniques. In the Potomac basin prevention techniques will never be 100 percent successful because of the number of abandoned mines which contribute to the acidity loadings.

PREVENTION

Preventive techniques include inundation of deep mines, the construction of stream channel diversions, the restoration and filling of surface mines, and the sealing of mines. Each of these techniques involves limiting the formation of acid by eliminating one of the three constituents needed for the reaction to proceed: oxygen, pyrite, or water. Another technique not based on these principles calls for the treatment of water entering a mine with limestone for the purpose of reducing the rate of acid formation. Still another technique requires the rapid removal of mine water by pumping, thus reducing the time allowed for the oxidation of pyrite. Of all of these methods, the two most often used for inactive deep mines are mine sealing (preventing air from entering the mine) and hydraulic controls. Unfortunately, mine sealing has proved largely unsuccessful because of the very low concentrations of oxygen necessary, and hydraulic controls have proved successful only in those cases where the hydraulic isolation of the mine is simple. For surface mines, careful backfilling and compaction is the most common treatment along with the detouring of the surface drainage around the stripping area.

TREATMENT

Treatment techniques range from the simple collection, impoundment, and chemical precipitation of drainage to exotic techniques including reverse osmosis, ion exchange, and electrodialysis. The more exotic techniques have proven unsuccessful and unreliable, unless pretreatment techniques, such as chemical precipitation, are practiced. For this reason, this discussion will examine only chemical precipitation.

Chemical precipitation requires the addition and mixing of an alkali (e.g., lime, limestone, gypsum) with the acid mine water. The result is a more neutral water and a precipitate

TABLE 4

PRELIMINARY MINE DRAINAGE ABATEMENT COSTS

North Branch Potomac Basin

	Watershed	Mean Acidity (observed) lbs/day	Design Acidity lbs/day	Preventive Measures First Cost $\$x10^6$	Preventive Measures O&M* $\$x10^6$	Preventive Measures Annual $\$x10^6$	Collection & Imp. First Cost $\$x10^6$	Collection & Imp. O&M* $\$x10^6$	Collection & Imp. Annual $\$x10^6$	Treatment First Cost $\$x10^6$	Treatment O&M* $\$x10^6$	Treatment Annual $\$x10^6$	Total First Cost $\$x10^6$	Total O&M* $\$x10^6$	Total Annual $\$x10^6$
1.	Elk Run	35,000	100,000	6.15	0.15	0.31	.00**	.00	.00	2.70	0.81	0.18	8.85	0.93	1.42
2.	Laurel Run	13,000	40,000	2.45	0.05	0.12	1.70	0.08	0.11	1.20	0.36	0.08	5.35	0.49	0.80
3.	Buffalo Cr.	16,000	50,000	3.10	0.06	0.16	1.90	0.10	0.12	1.50	0.45	0.10	6.50	0.61	0.99
4.	Stony River	4,500	20,000	1.20	0.02	0.06	1.30	0.06	0.08	0.70	0.21	0.04	3.20	0.29	0.47
5.	Abrams Creek	9,000	30,000	1.85	0.04	0.09	1.50	0.08	0.10	1.00	0.30	0.06	4.35	0.42	0.67
6.	Three Fork Run	3,300	10,000	0.06	0.01	0.03	1.00	0.05	0.06	0.50	0.15	0.03	2.10	0.21	0.33
7.	Piney Swamp Run	3,200	10,000	0.60	0.01	0.03	1.00	0.05	0.06	0.50	0.15	0.03	2.10	0.21	0.33
													32.45		5.01

* O&M = yearly operation and maintenance costs

** Since most of the mine drainage is mainly from one active operation, no massive collection system would be required.

Source: Mine Drainage in the North Branch Potomac River Basin[5] page VIII9.

containing metal salts, which in turn can be separated by filtration and settling. The metal salts precipitate because they are less soluble at higher pH's and settle out by the coagulation process resulting from flocculation of the alkali. This is by far the most reliable method currently available for the treatment of acid mine drainage, but it has not been used to great extent because of its high costs.

COST OF CORRECTIVE ACTION FOR THE NORTH BRANCH

Cost estimates for the correction of acid mine drainage in the Potomac can, at best, be called speculative because no detailed engineering study for the North Branch has ever been completed. However, in 1969 the Annapolis Science Center presented an order-of-magnitude-type estimate of one abatement alternative (Table 4). The costs for this alternative were based on a study done by Gannet, Fleming, Corddry, and Carpenter, Inc.[16] in 1968 which investigated acid mine drainage in the Susquehanna River basin. It was felt by the Science Center that the geography and degree of industrialization of these two basins were similar enough to apply those cost figures developed for the Susquehanna to the Potomac. Both preventive and treatment methods were used to design a system which would comply to standards including no acid discharge, iron concentrations not greater than 7 mg/1, and pH values between 6 and 9. The total annual cost of such a program in 1968 dollars was estimated at $5 million per year.[5]

A report co-authored by Greene Associates and Gannet, Fleming, Corddry, and Carpenter, Inc., published in January 1975, investigates acid mine drainage in northwest Allegany County and the lower Georges Creek. This report outlines abatement alternatives and costs for this sub-basin of the North Branch Potomac River. Currently the Baltimore District Corps of Engineers is involved in an intensive investigation of acid mine drainage in the entire Potomac basin.[8] The Corps investigation will attempt to define the extent and magnitude of abandoned mine drainage pollution in the North Branch, investigate alternative abatement techniques, and develop detailed design and cost estimates for one alternative.

II. SEDIMENT POLLUTION

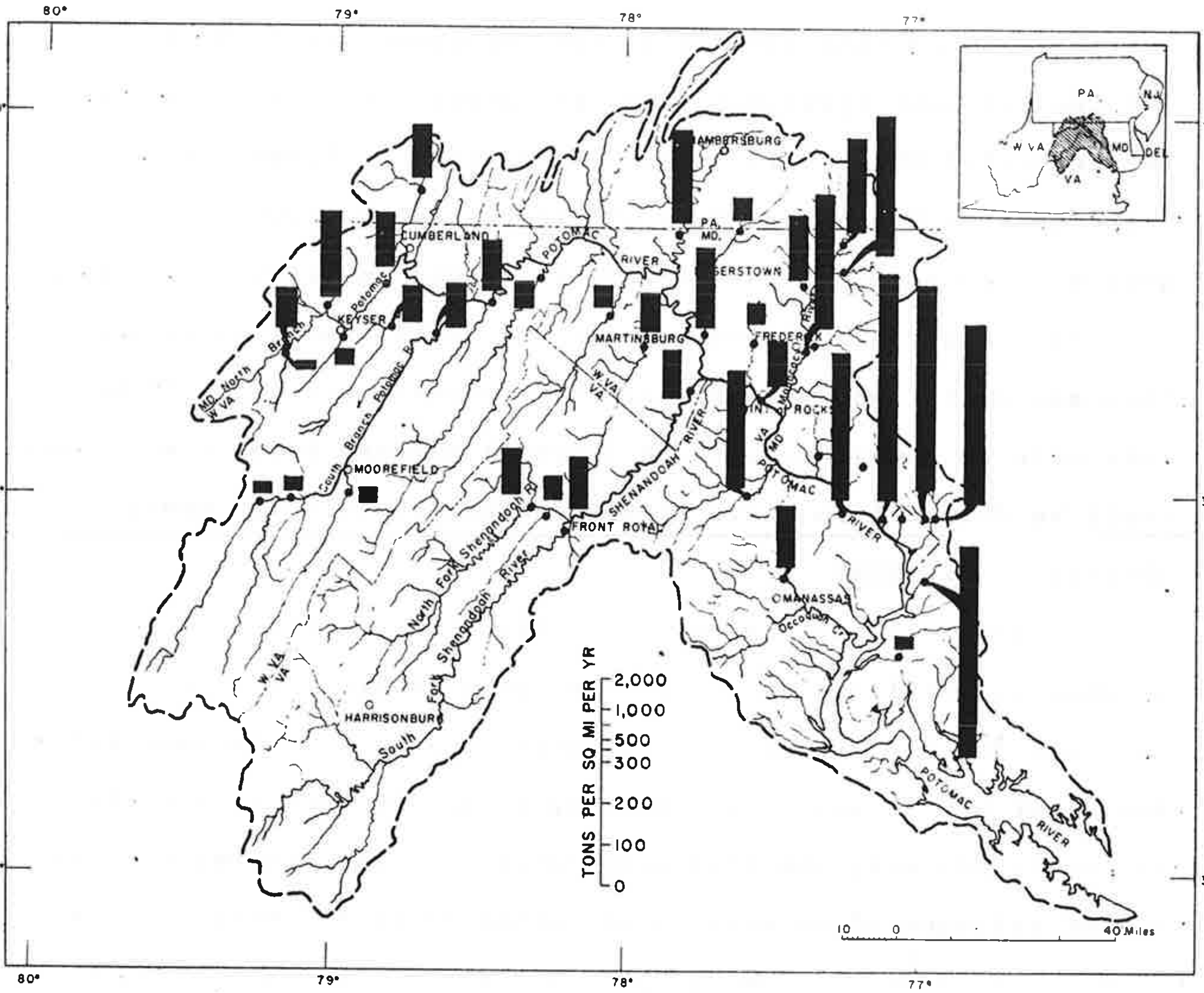
Of all the pollutants entering the Potomac River, perhaps the most noticeable to a casual observer is sediment. During periods of high water flow one may notice the river's clarity greatly reduced, and the estuary taking on a deep chocolate color. This turbidity and color is a result of erosion -- the wearing away of land surface by running water, wind, or ice -- and the sediment resulting from this process is found throughout the length of the river. A study completed by ICPRB and the United States Geological Survey[47] in the early 1960's indicated that over 50 million tons of soil is eroded annually in the basin (Figure 3 and Table 5) and between 2.5 and 2.9 million tons of this sediment finds its way into the Potomac estuary. If this rate were to continue, with no remedial efforts made, the estuary could be filled from Chain Bridge to Fort Foote in 50 years.

EFFECTS OF SEDIMENT

In almost every respect, the effect that sediment has on streams is detrimental. Excessive sediment greatly decreases the usefulness of water as a resource, requiring treatment before the water may be used. In treating water for both industrial and municipal use, the cost associated with the removal of suspended sediment often exceeds all other costs of treatment combined. Sediment can also greatly alter the natural ecology of a river. High sediment loads can cover river beds, destroying both natural benthic organisms and the eggs of spawning fish. If concentrations of sediment become great enough, fish kills

FIGURE 3

AVERAGE ANNUAL SEDIMENT DISCHARGE OF STREAMS IN THE POTOMAC RIVER BASIN



Source: Preliminary Study of Sediment Sources and Transport in the Potomac River Basin[48], p. 18.

TABLE 5

SEDIMENT LOAD IN THE POTOMAC BASIN

STATION	Area Drainage (sq. mi.)	Average Annual Sediment Discharge Tons	Tons Per sq. mi.
Abrams Creek at Oakmont, W. Va.	47.3	1,100	21
North Branch Potomac River at Kitzmiller, Md.	225	21,200	94
Georges Creek at Franklin, Md.	72.4	15,000	207
New Creek near Keyser, W. Va.	45.7	1,600	35
North Branch Potomac River at Pinto, Md.	596	78,000	130
Wills Creek below Hyndman, Pa.	146	18,500	127
Patterson Creek near Hedgeville, W. Va.	219	18,400	84
North Fork of South Br. Potomac River at Cabins, W. Va.	314	7,630	24
South Branch Potomac River near Petersburg, W. Va.	642	18,500	29
So. Fork of S. Branch Potomac River near Moorefield, W. Va.	283	9,390	33
South Branch Potomac River near Springfield, W. Va.	1,471	157,000	107
Potomac River at Paw Paw, W. Va.	3,109	383,000	123
Cacapon River near Great Cacapon, W. Va.	677	43,600	64
Back Creek near Jones Springs, W. Va.	243	12,400	51
Conococheague Creek at Fairview, Md.	494	107,000	217
Opequon Creek near Martinsburg, W. Va.	272	26,400	97
Antietam Creek near Waynesboro, Pa.	93.5	5,600	60
Antietam Creek near Sharpsburg, Md.	281	54,200	193
South Fork Shenandoah River at Front Royal, Va.	1,638	209,000	128
North Fork Shenandoah River near Strasburg, Va.	772	83,200	107
Passage Creek at Buckton, Va.	87	4,660	54
Shenandoah River at Millville, W. Va.	3,040	365,000	120
Catoctin Creek near Middletown, Md.	66.9	31,200	47
Potomac River at Point of Rocks, Md.	9,651	1,090,000	113
Monocacy River at Bridgeport, Md.	173	39,800	230
Big Pipe Creek at Bruceville, Md.	102	44,800	440
Hunting Creek at Jimtown, Md.	18.4	2,840	154
Linganore Creek near Frederick, Md.	82.3	30,500	370
Monocacy River at Jug Bridge near Frederick, Md.	817	267,000	327
Goose Creek near Leesburg, Va.	338	98,000	290
Seneca Creek at Dawsonville, Md.	101	32,300	320
Watts Branch at Rockville, Md.	3.7	1,910	516
Difficult Run near Great Falls, Va.	58	16,200	280
Little Falls Branch near Bethesda, Md.	4.1	9,530	2,320
Rock Creek at Sherrill Drive, Washington, D.C.	62.2	99,500	1,600
Northeast Branch Anacostia River at Riverdale, Md.	72.8	77,400	1,060
Northwest Branch Anacostia River near Colesville, Md.	21.3	10,000	470
Northwest Branch Anacostia River near Hyattsville, Md.	47.4	91,300	1,850
Henson Creek at Oxon Hill, Md.	16.7	36,000	2,160
Accotink Creek near Annandale, Va.	23.6	17,800	690
Bull Run near Manassas, Va.	147	21,400	146
Mattawoman Creek near Pomonkey, Md.	57.7	1,830	32

Source: Reconnaissance of Sedimentation and Chemical Quality of Surface Water in the Potomac River Basin,[48] p. 19.

can be attributed directly to the high concentrations. In the Potomac River, the cost due to sediment of maintaining navigable conditions in the estuary has been estimated to average $1.5 million per year.[38] Of all the results of sediment on the Potomac, perhaps the only positive one is the effect that sediment has on the production of algae in the estuary. Because of limited light penetration, algae are only able to grow in the first few feet below the surface. It has been suggested that if the sediment level was decreased in the estuary, the production of algae, and its associated nuisances, would increase many times.

SOURCES OF SEDIMENT POLLUTION

Sediment pollution has historically been viewed as a rural problem, caused by mismanaged farm land. Within recent years, however, it has been recognized that urban areas -- particularly those undergoing new construction -- constitute a formidable percentage of the total sediment problem. Within the Potomac basin, sediment results not only from these common causes but also from unique problems such as acid mine drainage. Thus, sediment pollution cannot be viewed as a simple problem but rather one related to a number of factors including land use, topography, climate, and rainfall. Because of the complexity of the problem, it is easiest to divide the basin into two simple categories, urban/suburban and rural, and discuss the sources of sediment found in each.

URBAN/SUBURBAN SOURCES OF SEDIMENT

Urban/suburban land use represents a situation that is highly susceptible to the erosion of soil. Most sediment results from the development, redevelopment, and use of the land including:

(1) Commercial and residential construction;

(2) Highway, road, and other public construction;

(3) Public parks and other recreational areas which receive heavy usage and insufficient maintenance; and

(4) Miscellaneous unstabilized areas which have been stripped of their natural cover and discharge into streets, roads, and storm sewers.

Although the sources listed above deal chiefly with development, it should be noted that once an area is developed the previous hydrologic conditions remain changed. The quantity of runoff associated with a storm event changes due to the increased surface areas of nonporous materials (i.e., highways, roads, parking lots, housetops), and a corresponding increase can be expected in total runoff. This increase in runoff can often increase the erosion rate of any creek, stream, or river that it enters.

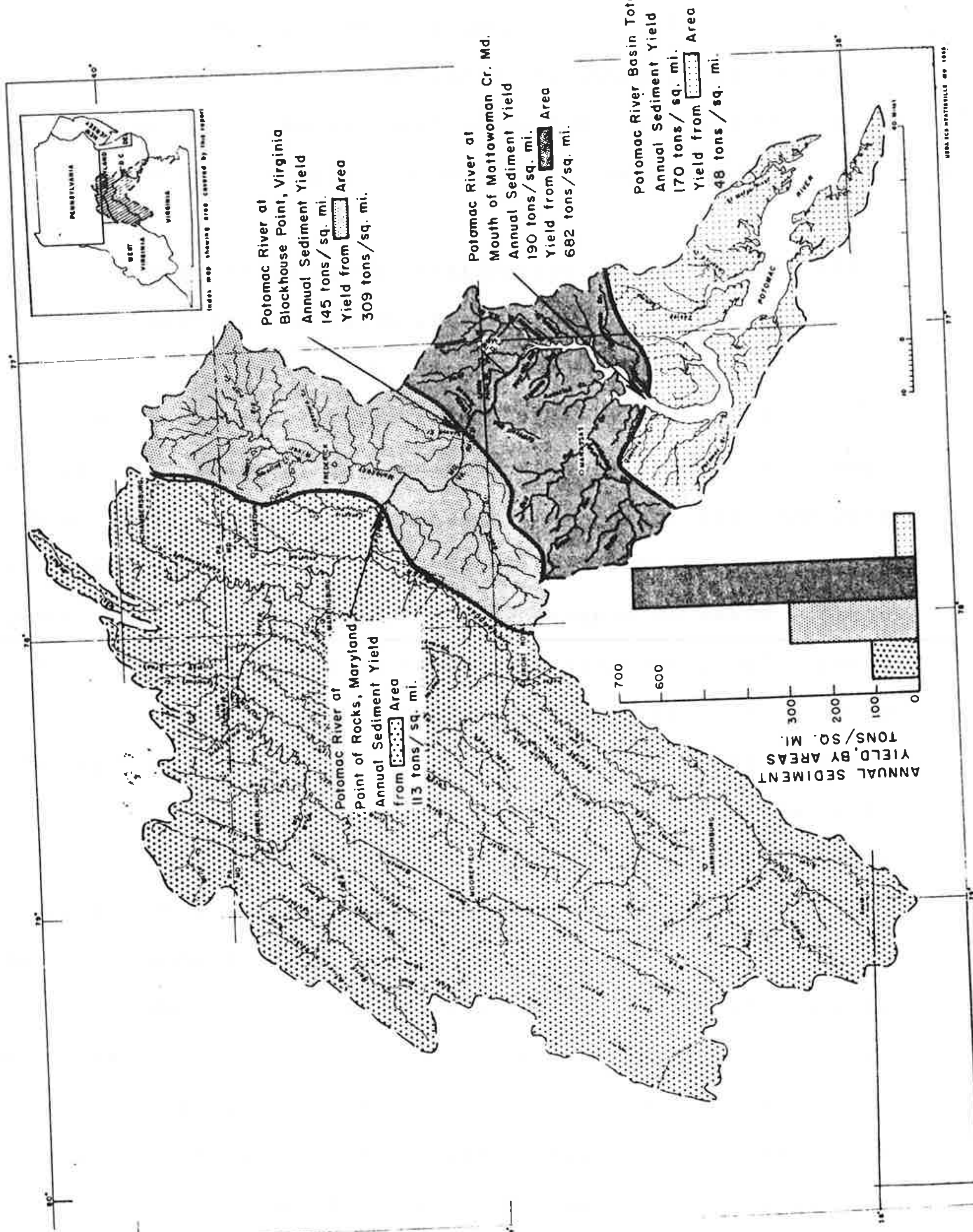
RURAL SOURCES OF SEDIMENT

The sources of sediment in rural areas are of a different nature than those of urban areas and can be described in two groups. The first group includes those sources which make up what is considered the natural or background levels of sediment. These sources are the natural runoff from land during a storm event and are quite difficult, if not impossible, to alleviate. The second group of sources includes those that result from a

FIGURE 4

ESTIMATED AVERAGE ANNUAL SEDIMENT YIELDS

AT SELECTED POINTS ON THE POTOMAC RIVER



Source: Report to the Interdepartmental Task Force on the Potomac by the Sedimentation and Erosion Sub-task Force,[43] p. 9

more obvious mismanagement of land. This mismanagement in agricultural areas can be in the form of improper plowing and planting techniques, poor drainage that cannot be corrected, or from overgrazing pasture land. In forest lands, sediment can be attributed to (1) improper lumbering techniques which allow the creation of skid roads that transport water and sediment or (2) the slow reestablishment of ground cover which results after both selective and clear cutting. All of these sources of sediment in rural areas will be discussed in the section of this paper dealing with nutrient pollution.

ANNUAL SEDIMENT YIELDS AND LOADS

Figure 4 indicates estimated average annual sediment yields for the Potomac basin when divided into four sub-basins based on the previously cited ICPRB and USGS study. From Figure 4 the variation in sediment yield from the four divisions can be seen to range from 48 to 682 tons per square mile.

What is most obvious from this figure is the areas with the highest yield per square mile are those near urban development, while agricultural land has the second highest yield and forest the smallest. For example, the annual sediment yield near the immediate Washington area is approximately 1,500 tons per square mile, while the yield for all stations in West Virginia is 57 tons per square mile. For land with a forest cover of 70 percent, the annual discharge is only 60 tons per square mile, while land with a 30 percent cover yields a 300 ton average. For crop land the effect is just the opposite, with the greater the amount of crop cover, the greater the sediment yield. Land

FIGURE 5

Total Water Discharge and Sediment Load

Potomac River at Point of Rocks

1966-1971

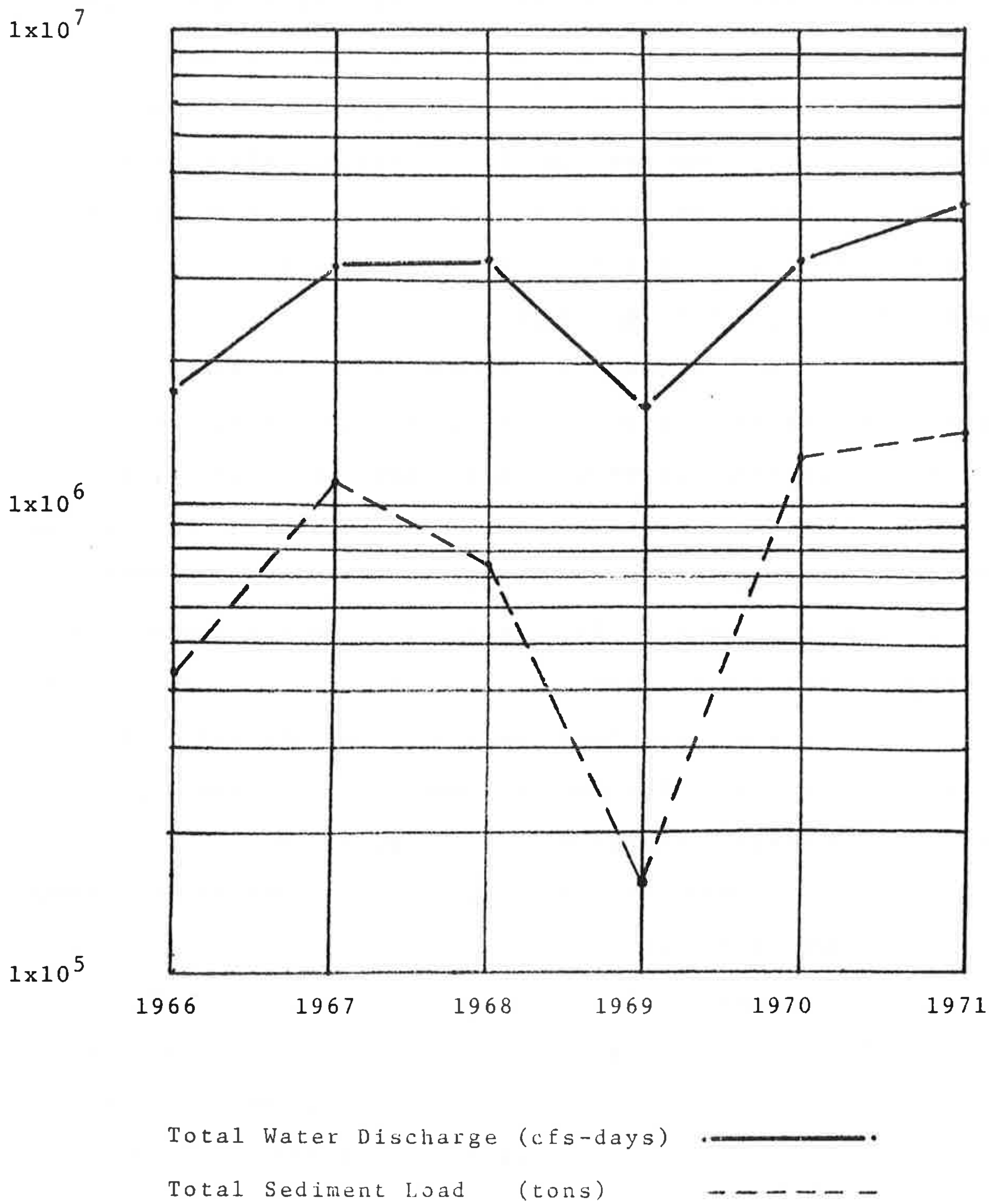
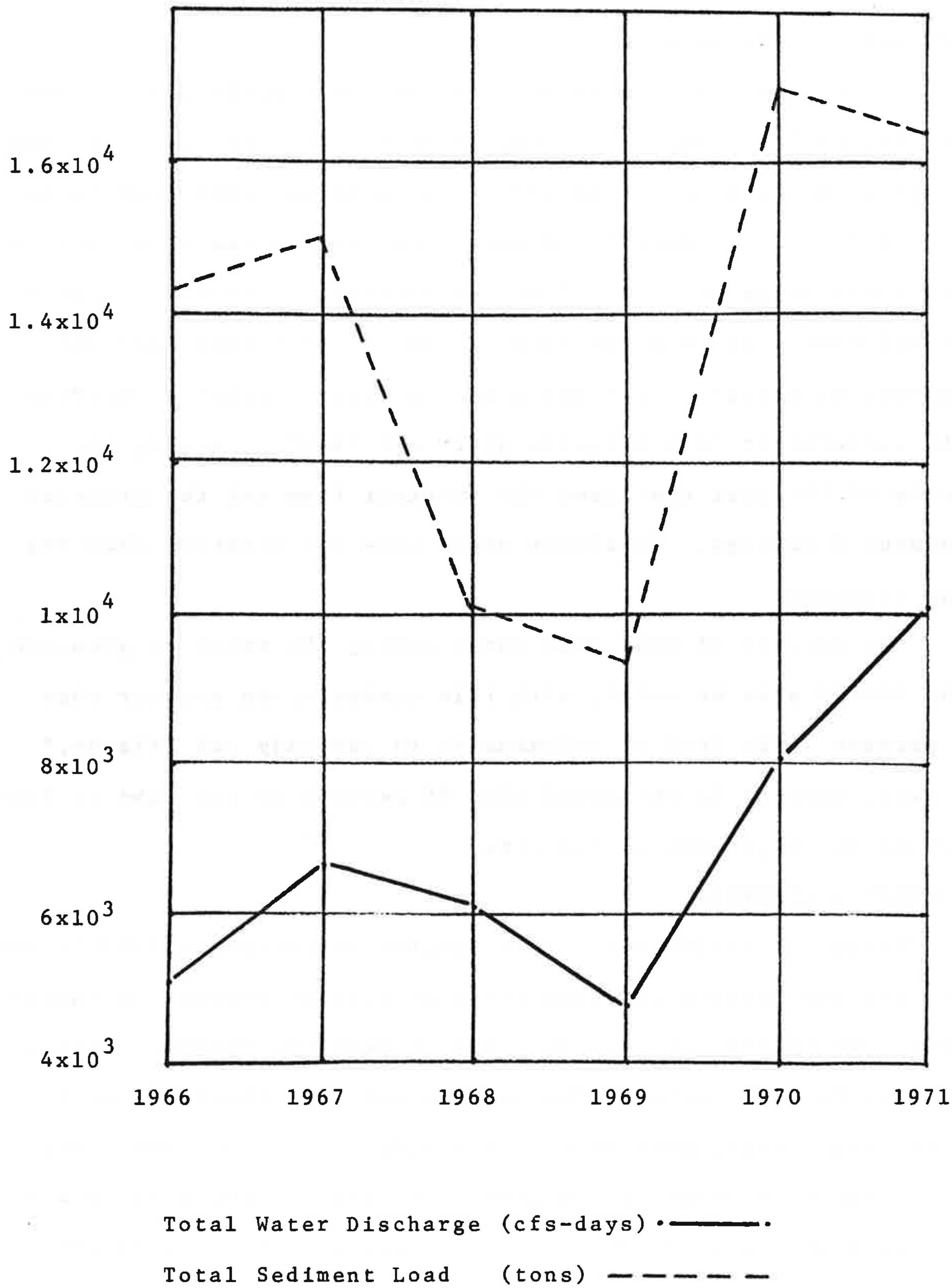


FIGURE 5 (continued)

Total Water Discharge and Sediment Load

Northwest Branch Anacostia near Colesville

1966-1971



with 15 percent crop cover has a yield of 90 tons per square mile, while land with a 50 percent crop cover has a yield of 250 tons per square mile.

In addition to the variation in sediment yield that can be seen due to land use, a variation that is essentially due to the amount of erodible material available, a second important factor is stream flow. Figure 5 indicates the correlation between total annual discharge and total flow for an essentially urban area and a rural area. In both instances it can be seen that flow and sediment discharge correspond almost exactly. Table 6 indicates this correlation in a slightly different fashion, noting the months of the year that have the greatest flow and the greatest sediment discharge. In almost every case the greatest flow and load coincide.

The percent of load that comes during the month of greatest load should also be noted, with this number often greater than 50 percent. The load of sediment is so unsteady and "flashy," in fact, that it is estimated that 90 percent of the load is discharged in 10 percent of the time.

SEDIMENT ABATEMENT

Table 7 contains a ten year program suggested in 1967 by the Sediment and Erosion Sub-Task Force of Project Potomac, a multi-level governmental program designed to make the Potomac River a showcase for the nation. The program outlined involves local, state, and federal governments in a wide variety of conservation and sediment treatment techniques. The cost of the program was estimated at $250,233,000 in 1967 dollars and the program was

TABLE 6

ANNUAL FLOWS AND SEDIMENT LOADS
1966 - 1971

Year	Annual Flow (cfs-days)	Month of Greatest Flow	Flow in Greatest Month	% Greatest Month is of Annual	Annual Sediment Load (tons)	Month of Greatest Load	Load in Greatest Month	% Greatest Month is of Annual
Potomac River at Point of Rocks								
1966	1,779,725	May	372,960	21	443,946	March	258,210	58.2
1967	3,204,350	March	973,680	30.4	1,129,158	March	948,520	84
1968	3,260,000	March	672,340	20.6	734,893	March	284,138	38.7
1969	1,593,658	August	253,220	15.9	156,864	August	69,303	44.2
1970	3,333,430	April	894,200	26.8	1,270,933	April	719,758	56.6
1971	4,342,980	Feb.	820,320	18.0	1,375,032	Feb.	499,814	36.3
Northwest Branch Anacostia at Colesville								
1966	5,137	Feb.	1,153	22.5	14,402	Feb.	4,354	30.2
1967	6,738	March	1,266	18.8	15,009	August	5,543	36.9
1968	6,188	March	989	16.0	10,498	March	2,758	26.3
1969	4,825	August	919	19.1	9,458	August	3,668	38.8
1970	8,055	April	1,559	19.4	17,269	April	3,823	22.1
1971	10,757	Feb.	2,150	20.0	16,553	Feb.	6,405	38.7

TABLE 7

TEN YEAR EROSION AND SEDIMENT CONTROL PROGRAM

Item	Federal	Non-Federal	Total
Basin-wide activities			
1. Watershed planning	$ 2,500	$ 0	$ 2,500
2. Erosion & sediment control during highway & road construction	10,000	0	10,000
3. Roadside stabilization - existing secondary roads	47,970	5,330	53,300
4. Soil Surveys	900	0	900
5. Economic evaluations	800	0	800
6. Sedimentation & erosion control evaluation and research	4,180	0	4,180
Rural activities			
Cropland			
7. Technical assistance	6,210	0	6,210
8. Cost-sharing assistance	24,000	24,000	48,000
9. Sediment detention basins	17,700	0	17,700
Pasture			
10. Technical assistance	690	0	690
11. Cost-sharing assistance	11,500	11,500	23,000
Forest			
12. Cost-sharing assistance	2,500	625	3,125
13. Cooperative State and private forestry	1,799	404	2,203
14. National forests	2,090	0	2,090
15. Forest research	1,445	0	1,445
Urban activities			
16. Technical assistance	2,640	0	2,640
17. Sediment and erosion control demonstrations	1,550	0	1,550
18. Sediment detention basins	53,910	5,990	59,900
Strip mine reclamation			
19. Technical and cost-sharing assistance	9,000	1,000	10,000
	$201,384	$48,849	$250,233

Source: Interdepartmental Task Force on the Potomac[43] p. 20.

designed to reduce the sediment load entering the Potomac estuary by 48 percent. It is interesting to note that the recommended program has devoted approximately 25 percent of its resources solely to abatement in urban areas. This expenditure is a result of the difficulty that has been found in instigating sediment conservation practices in urban areas. In rural areas, at least some land owners have instituted erosion control practices on the premise that lost soil costs them money. In urban areas, the developer and construction crew do not lose any large percentage of their investment due to soil loss, but rather a third party, somewhere downstream, must pay the price.

In very recent years, a number of state and local governments have passed laws and regulations to control erosion and sediment. The first of these in the Potomac basin was passed in Maryland on April 22, 1970, followed by Pennsylvania on September 1, 1972, and Virginia on July 1, 1974. Considerable variation exists in the laws and regulations but in general an approved erosion and sediment control plan is required of any soil disturbing activity on a land area greater than a specified minimum size. Failure to adhere to the approved plan is a violation subject to fines and/or other enforcement action by the regulatory agency. Generally, agriculture has been exempted from the plan requirements. In the Pennsylvania regulations, however, agriculture will come under the provisions of the law in 1977.

Due to the recent nature of regulatory approaches to controlling erosion and sediment, measurement of their success in terms of sediment yield reduction in the basin has been impossible.

In a conference held on November 7 and 8, 1974, by ICPRB,[25] the status of new regulatory approaches to erosion and sediment control by states within the Potomac basin was discussed. Each state representative commented on his experience with administering their laws and regulations and outlined problems that remained to be solved. It was generally felt that the new laws and regulations would prove successful in controlling sediment when more experience in administering them had been gained. The problems most often encountered in the programs included inadequate education of developers and construction workers concerning the purpose of erosion and sediment control plans and an insufficient number of inspectors.

III. BACTERIAL POLLUTION

Bacteria are microscopic, single-celled organisms that are found throughout our environment. The vast majority of bacteria have little significance from a public health or water quality control perspective. A few of these organisms, however, have been determined to be pathogenic and an extreme threat to public health, such as those bacteria causing diarrhea, typhoid fever, dysentery, gastroenteritis, or Asian cholera. Other bacteria, although not directly responsible for causing disease, have been found useful as indicators of water pollution. It is these two types of organisms that are important as non-point sources of pollution and around which this discussion is centered.

INDICATOR ORGANISMS

Unfortunately for those responsible for maintaining public health, the detection of pathogenic organisms in water has often proven difficult. Because of this difficulty, the coliform bacteria, which are found in larger quantities and are more easily detected than pathogenic organisms, have been used as indicators of pollution. The presence of coliforms in water is taken as an indication that pathogenic organisms may be present, while the absence of coliforms indicates the absence of disease-causing organisms.

Of the 256 types of bacteria that compose the coliform group, three are of particular interest from a public health standpoint. The first, *Escherichia coli* (*E. coli*) normally inhabit the intestinal tract of man and animals and are excreted

TABLE 8

TEN-YEAR COLIFORM CONCENTRATION (1962-1972)
IN THE POTOMAC BASIN

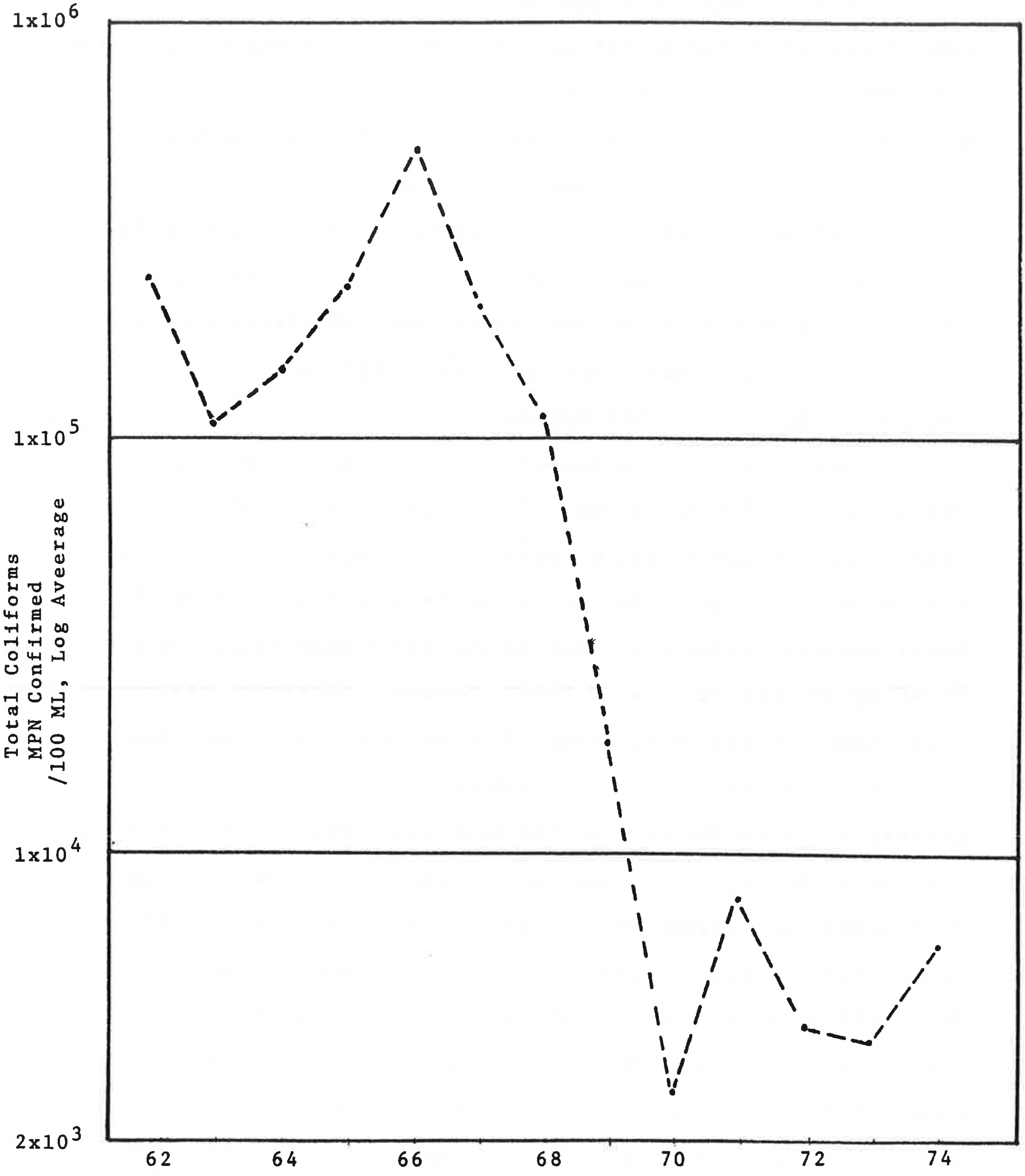
Station Location	River Mile	Ten-Year Log Average Total Coliforms Most Probable Number/100ml
Muddy Branch Creek	133.5-0.5	4,526
Potomac River Below Blue Plains	95.3	84,914
Potomac River at Marshall Hall	85	1,956
Potomac River at Indian Head	77.5	209
Anacostia River at D. C. Line	97-7.2	36,729
South Branch Potomac River Below Romney, W.V.	283-31.5	2,893
Shenandoah River at Waynesboro	171-176	3,097
Goose Creek	142-2.2	5,581
Shenandoah River at Port Republic	152.8	2,182
Monocacy River	153.5-2.0	23,007
Cabin John Creek	118-0.3	33,343
Potomac River at Great Falls	125.6	192

with feces. *Aerobacter aerogens* are more widely distributed in nature and are found on plants and in soils. *Aerobacter cloaceae* are found both in the feces of warm blooded animals and in soils. Of these coliforms, only a confirmation of *E. coli* indicates a certain contamination with human or animal feces. A test for total coliforms, or all of the coliforms, is still used to indicate a possible contamination of water with soils, plants, or feces. As a general rule, one can estimate the fecal coliform counts (*E. coli*) as one-tenth the total coliform counts.

BACTERIAL POLLUTION IN THE POTOMAC

Evidence of coliform bacteria can be found throughout the reaches of the Potomac River. The origin of this pollution includes treated and untreated sewage, some types of industrial discharges, and agricultural, silvacultural, and urban runoff. Water quality analyses in most of the river show coliforms to be of an average background level; however, bacterial pollution does become excessive in areas of relatively high population concentrations (Table 8). The existence and history of coliform contamination in the Potomac has best been documented in the Washington Metropolitan Area and for this reason the following discussion will center around this geographical area rather than examining contamination in other stretches of the river. It should be noted that the trends of coliform contamination seen in the Washington Metropolitan Area are characteristic of those trends likely to be found in developing urban areas throughout the basin. Many of the abatement alternatives suggested for the Washington area could therefore be useful in

FIGURE 6



Total Coliform Count
Below Blue Plains Sewage Treatment Plant
River Mile 95.3

examining alternative abatement schemes in other portions of the basin.

BACTERIAL POLLUTION NEAR WASHINGTON, D.C.

In 1925, when the Public Health Service first surveyed the area, it was concluded that no section of the river "could be considered free enough from pollution with sewage to permit its use for bathing without potential danger to such bathers of contracting sewage-borne diseases."[4] In 1954, an ICPRB report indicated that bacterial pollution continued "higher than desirable. Pollution mounts rapidly in the Roosevelt Island area and below. . . . Coliform counts as high as 500,000/100 ml have been reported."[1] In 1957, a U. S. Department of Interior report described "a picture of extreme bacterial contamination which renders the river hazardous to the health of those who use it for any type of recreation that involves contact with the water. At no point can it be considered safe for swimming."[22] In 1965 the maximum three-month coliform average in the estuary was 521,000 per 100 ml, which was 100 times greater than the partial body contact limit at that time and 500 times greater than the body contact limit.

In 1969 the bacterial pollution in the upper estuary was reduced by a factor of ten by chlorinating the largest point source -- the effluent from the Blue Plains Wastewater Treatment Plant. Unfortunately, as Figure 6 indicates, this effort did not relieve bacterial pollution to the point of meeting water quality standards or making water safe for contact. The cause for this continued violation of water quality standards is the discharge of non-point sources of bacterial pollution into the river.

NON-POINT SOURCES OF POLLUTION

Non-point sources of pollution in the Washington Metropolitan Area can be classified as either storm water runoff or combined sewer overflows. These two classifications arise from the type of conduit system used to transport the flows. "Separate sewer" systems have one conduit system devoted solely to the transport of storm water runoff and another system devoted solely to the transport of sewage. "Combined sewer" systems have a single conduit to transport both storm water and sewage. In the case of separate systems, storm water runoff is usually never treated, while most sewage -- even during a storm event -- receives whatever treatment is available. Combined sewers, which accept both sewage and huge quantities of storm water flow during storm events, often have points at which flows are allowed to discharge out of the system. These "overflow points" exist because the conduits are often inadequate in capacity to contain all of the flow and because the transport of all of the flows to the treatment facility would result in the facility's overloading.

Within the Washington Metropolitan Area both types of sewer systems are found, although the vast majority of the sewers are separated. The Blue Plains Wastewater Treatment Plant has some 12,000 acres of combined sewers, most of which are located in the downtown portion of Washington, D.C., and 452,000 acres of separated sewers. The Alexandria Sanitation Authority Treatment Plant is the only other facility in the area with combined sewers, with 885 acres of combined sewers and 30,865 acres of separate sewers. The remainder of the Washington Metropolitan Area is served totally by separate sewers.

The bacterial pollution concentration of these two types of sewers is quite different. Because combined sewers allow the mixing of storm water with raw sewage, overflows have extremely high coliform counts. Total coliform concentrations for these discharges often average between 100,000 and 10,000,000 per 100 milliliter sample, whereas storm water runoff from separate sewers averages between 1,000 and 20,000 per 100 milliliter sample (Table 8).

Table 9 indicates various bacterial loads that are discharged solely from the District of Columbia. From the table, it is obvious that combined sewer overflows represent the vast majority of bacterial pollution. Their load is several orders of magnitude greater than all other sources together. What is not obvious from the table is the effect on the estuary of those bacterial loads from combined sewers. As contrasted with the discharge from Blue Plains -- which is relatively continuous -- overflows and storm water runoff act more as a "slug" effect, with large loads coming within a very short time period. This characteristic, in combination with the long residence time of the estuarine waters, suggests the serious impact this pollution has on the recreational potential of the river.

TREATMENT AND CONTROL

A number of alternatives have been investigated to relieve the excessive bacterial pollution near Washington, D.C. Roy F.

TABLE 8

TOTAL COLIFORM CONCENTRATIONS
OF
URBAN DISCHARGES

Discharge	Total Coliforms per 100 ml
Raw Sewage	$5x10^6$ - $5x10^8$
Treated Effluent (Secondary Treated)	$2.8x10^4$ - $2.8x10^6$
Chlorinated Effluent	$2.4x10^1$ - $2.4x10^3$
Combined Sewer Overflows	$1x10^5$ - $1x10^7$
Street Runoff	$1x10^3$ - $2.4x10^4$

TABLE 9

ESTIMATED BACTERIAL LOADS FROM VARIOUS SOURCES
WASHINGTON, D.C.

Source	Flow	Concentration (/100 ml)	Load (Coliforms/yr.)
Blue Plains	309	$2x10^2$	$7.84x10^{14}$
Sewer Overflows			
Sanitary Sewage	2.7	$5x10^6$ - $5x10^8$	$1.71x10^{17}$ - $1.71x10^{19}$
Storm Water	30.1	$2x10^3$ - $2x10^5$	$7.65x10^{13}$ - $7.65x10^{15}$
Direct Discharge from Separated Storm Sewers	43.8	$2x10^3$ - $2x10^5$	$1.11x10^{14}$ - $1.11x10^{16}$

Weston, Incorporated, completed a study in 1969 investigating combined sewer overflows in Washington, D.C., and Greeley and Hansen Engineers completed a similar study for Alexandria in 1971. Most alternatives suggested by these two reports are in one of the following three categories: separation of combined sewers, construction of retention basins to hold storm water and overflows until they may be treated in existing facilities, or continuous treatment of storm water and combined sewer overflows during storm events.

SEWER SEPARATION

The separation of combined sewers into sanitary and storm sewers was once thought to be the most cost-effective solution to the problem of combined sewer overflows and was practiced in many cities. However, with the advent of new treatment techniques, this is often not the case. This is particularly true in densely populated areas where the construction of sanitary sewers would disrupt the activities of a large portion of a city. The separation of combined sewers also does not address the problem of storm water runoff which still persists. The cost of separating the combined sewers of Washington, D.C. was estimated at $610 million in 1969 dollars by Weston, Incorporated,[51] and the estimate by Greeley and Hansen[17] for Alexandria was $21,120,000 in 1971 dollars.

RETENTION BASINS

The construction of retention basins would allow overflows from a storm event to be stored until they can be treated in a conventional fashion. This type of alternative has the distinct advantage of treating all flows, sewage as well as surface runoff. In Washington, D.C., it was suggested that overflows be conveyed down through vertical shafts to a system of tunnels and deep mines. Such a system designed to treat a two year frequency, 24-hour storm was estimated by Weston, Incoporated,[51] to cost $210 million, while the cost of treating a similar storm with a 15-year frequency was estimated at $1.9 billion. In Alexandria, a surface retention basin designed to contain all but two storm events per year and to supply a minimum of primary treatment and chlorination to those flows which could not be retained, was estimated to cost $6,210,000 by Greeley and Hansen.[17]

TREATMENT AT OVERFLOW POINTS

With the need for the treatment of combined sewer overflows becoming more apparent, attempts have been made to create systems which handle the treatment of these wastes rapidly. Table 10 lists several of these systems along with estimated costs for applying them to the overflows at Alexandria. Weston has estimated the cost of applying one such system, high rate filtration, to overflows in Washington, D.C., and has estimated a cost of $266 million in 1969 dollars.

COMBINATION OF TREATMENT ALTERNATIVES

In addition to the abatement alternatives previously mentioned, Weston, Incorporated,[51] has investigated a treatment scheme for the District of Columbia that would include some sewer separation, mine and reservoir storage, and treatment at overflow sites. This combination would be quite effective

TABLE 10

ON-SITE TREATMENT OF COMBINED SEWER OVERFLOWS AND COST FOR ALEXANDRIA, VIRGINIA

Plain Sedimentation	3,475,000
Rotary Screens	3,063,000
Rotary Screens and Dissolved Air Flotation	3,383,000
Microstrainers	3,312,000
High Rate Filtration	7,005,000
Rotating Biological Contactor	5,773,000
Biological and Filtration	7,685,000

Source: Study on Waterway Pollution from Combined Sewer Overflows[17] p. 2.

in treating all components of non-point pollution in Washington, D.C., and the estimated cost was $318 million in 1969 dollars.

IV. NUTRIENTS

Most bodies of water, particularly lakes and estuaries, go through a natural aging process. This process, known as eutrophication, is commonly characterized by a slow transition from infertile, barren bodies of water to ones that are highly productive and teeming with life.

Eutrophication of water bodies was originially considered simply an "act of God" over which no one had control. It was not until the 1920's that the same concept of plant nutrition that had been applied to land plants a century earlier was applied to aquatic plants. Studies discovered the essential mineral nutrients required for plant growth, and among those revealed were carbon, nitrogen, oxygen, hydrogen, calcium, phosphorus, sulfur, magnesium, and potassium. As on land, if all of these nutrients were present in the proper proportions, one could expect a good "crop" of aquatic plants to be produced, along with all of the inconveniences they brought.

CAUSES OF EUTROPHICATION

In recent years the number of water bodies showing marked increase in their eutrophication rate has risen tremendously. The cause of the rapid increase in the rate of eutrophication in American waters can be directly attributed to man's activities. The transition from an agrarian economy to an urban economy, with the corresponding shift from a dispersed population to a concentrated population, has been a major factor in the overloading of water bodies located near developing urban areas. In addition, man's soil disturbing operations, including the construction of highways, agricultural pursuits, and urban construction, have greatly increased runoff and sediment, and consequently the nutrients, reaching waterways. Finally, man's habits and style of living, typified by the use of synthetic detergents and fertilizers, have also tremendously affected the quantity of nutrients discharged.

EFFECTS OF EUTROPHICATION

Regardless of the cause of eutrophication, whether it is natural or a result of man's activity, the use of eutrophic water can present difficulties to man. Among these problems are:

(1) Taste and odor in public water supplies and serious interference with water purification;

(2) A depletion of dissolved oxygen that may cause fish kills and a possibility of foul odors due to the decomposition of algae;

(3) An impediment to water-contact recreation; and

(4) A generally lower aesthetic value of the water.

EUTROPHICATION IN THE POTOMAC

Within the Potomac River basin a classical example of eutrophication is taking place. At the turn of the 20th Century the Potomac estuary had no noticeable nuisance levels of rooted aquatic plants or algal blooms. By 1920, as the Washington Metropolitan Area's population increased, an infestation of water chestnuts had appeared and had to be controlled by mechanical removal. In 1952, extensive surveys of the water near Washington revealed that normal aquatic vegetation was virtually nonexistent and that there had been an increase in the blue-green algae population, an algae associated with nuisance conditions. Between 1958 and 1963 an aquatic plant, water milfoil, developed in the Potomac estuary and created extreme nuisance conditions but dramatically disappeared in late 1965. The cause of its disappearance was uncertain but possibly it was due to a virus. During these same years, the level of blue-green algae concentration increased to the point that for every summer, from 1960 to the present, the Potomac estuary has experienced blooms of these algae.

In recent years, large populations of blue-green algae, which often form thick mats, have been observed from U.S. Rt. 301 Bridge to the Woodrow Wilson Bridge during the months of June through October. In September 1970, after a period of low flow and high temperatures, an algal mat extended upstream beyond Hains Point and included the first nuisance growth within the Tidal Basin.

The ultimate oxygen demand of algal growths such as these has been estimated to be as high as 490,000 pounds per day. Although this load is dispersed over the entire upper estuary, it is a load greater than the total oxygen demand exerted by all of the wastewater discharged into the upper estuary.

LEVELS OF NUTRIENTS ENCOURAGING EUTROPHICATION

A number of investigators have attempted to determine the concentration level of nutrients which encourage rapid eutrophication characterized by algal blooms. One of the most famous of these attempts was conducted by Clair Sawyer,[45] who, in 1947 after studying 17 lakes in Wisconsin, suggested that the levels of inorganic nitrogen and inorganic phosphorus that differentiated a well-behaved lake and a nuisance lake were 0.3 mg/l nitrogen and 0.015 mg/l phosphorus. Jaworski, et. al.,[36] in reviewing historical data for the upper Potomac estuary, suggested that when the concentrations of total phosphorus and inorganic nitrogen were 0.1 and 2.3 mg/l, respectively, nuisance algal blooms of approximately 50 μg/l of chlorophyll a could be expected.

The EPA Annapolis Science Center,[30-32, 34-36] using a variety of analyses, has developed the following nutrient criteria for preventing nuisance algal blooms in the freshwater portions of the Potomac estuary:

Parameter	Concentration Range
Inorganic Nitrogen	0.3-0.5 mg/l
Total Phosphorus	0.03-0.1 mg/l

The lower values in the ranges were intended to apply to the freshwater portion of the estuary from Indian Head to Smith Point and to the embayment portions of the estuary. The upper ranges of the criteria were applicable to the upper portion of the estuary which has a light-limited euphotic zone of less than two feet on most occasions.

SOURCES OF NUTRIENTS

Within the Potomac River basin there are many sources of nitrogen and phosphorus. These nutrients come from a wide variety of sources, including treated and untreated municipal and industrial wastes, rainfall, urban runoff, agricultural drainage, animal wastes and forestry runoff.

The greatest single source of nutrients discharged into the

Potomac basin is municipal effluents.[32] In 1972, municipalities discharged nearly 400 million gallons per day, containing 87,230 pounds per day of phosphorus and 60,016 pounds per day of nitrogen.

The non-point sources of nutrients that enter the Potomac River can be classified into three groups according to their origin: agriculture, forest, and urban runoff. The EPA Annapolis Science Center has done research on non-point sources of pollution originating from these various land usages in the Potomac basin.[28,32,36] By studying three separate sub-basins, each characterized as either urban, forest, or agriculture, estimates were made of the average nutrient runoff per day of each. As shown in Table 11, the yearly contribution of phosphorus from agriculture, forest, and urban runoff is, respectively, 7,592, 4,050, and 800 pounds per day. Nitrogen contributions from agriculture, forest, and urban runoff are, respectively, 38,836, 19,440, and 2,665 pounds per day. Tables 12 and 13 show the same breakdown of sources for the upper and lower portions of the basin, the dividing line being Great Falls.

In contrast to municipal effluents which discharge at a relatively constant rate, the flow of non-point sources is extremely variable and is determined to a great extent by land use and meteorologic conditions. Table 14 illustrates this, showing the relative contributions of nutrients from different sources during various flow conditions. Tremendous increases in loads from the upper basin and urban/suburban runoff can be noted as flows vary upward between 1,200 cfs and 34,600 cfs.

TABLE 11

ESTIMATED NUTRIENT LOADINGS
IN THE
POTOMAC RIVER BASIN

Land Use	Area (Sq. Mi.)	Total Phosphate as PO_4 (lbs/day)	$NO_2 + NO_3$ (lbs/day)	TKN* as N (lbs/day)	Total Nitrogen as N (lbs/day)
Municipal Discharge		87,230	4,344	55,672	60,016
Agricultural	5,840	7,592	35,040	3,796	38,836
Forest	8,100	4,050	16,200	3,240	19,440
Urban	730	800	2,190	475	2,665
Totals		99,672	57,744	63,183	120,957
% Municipal		87.5%	7.5%	88.1%	49.6%
% Runoff		12.5%	92.5%	11.9%	50.4%

*Total Kjeldahl nitrogen includes ammonia and organic nitrogen but not nitrite and nitrate nitrogen.

TABLE 12

ESTIMATED NUTRIENT LOADINGS
IN THE UPPER POTOMAC BASIN
(ABOVE GREAT FALLS)

Land Use	Area (Sq. Mi.)	Total Phosphate as PO_4 (lbs/day)	$NO_2 + NO_3$ (lbs/day)	TKN* as N (lbs/day)	Total Nitrogen as N (lbs/day)
Municipal Discharge		11,273	560	8,173	8,733
Agriculture	4,100	5,100	24,500	2,660	27,160
Forest	6,800	3,400	13,600	2,720	16,320
Urban	100	110	300	65	365
Totals	11,000	19,883	38,960	13,618	52,578
% Municipal		56.7%	1.4%	60.0%	16.6%
% Runoff		43.3%	98.6%	40.0%	83.4%

*Total Kjeldahl nitrogen includes ammonia and organic nitrogen but not nitrite and nitrate nitrogen.

TABLE 13

ESTIMATED NUTRIENT LOADINGS
IN THE LOWER POTOMAC BASIN
(BELOW GREAT FALLS)

Land Use	Area (Sq. Mi.)	Total Phosphate as PO_4 (lbs/day)	$NO_2 + NO_3$ (lbs/day)	TKN* as N (lbs/day)	Total Nitrogen as N (lbs/day)
Municipal Discharge		75,957	3,784	47,499	51,283
Agriculture	1,740	2,492	10,540	1,136	11,676
Forest	1,300	650	2,600	520	3,120
Urban	630	690	1,890	410	2,300
Totals	3,670	79,789 (26,074 as P)	18,814	49,565	68,379
% Municipal		95.2%	20.1%	95.8%	75%
% Runoff		4.8%	79.9%	4.2%	25%

*Total Kjeldahl nitrogen includes ammonia and organic nitrogen but not nitrite and nitrate nitrogen.

TABLE 14

SUMMARY OF CONTRIBUTIONS OF NITROGEN AND PHOSPHORUS

Loading Duration*		Upper Potomac River Basin		Urban and Suburban Runoff		Wastewater Treatment Facility Discharge		Total
		lbs/day	% of Total	lbs/day	% of Total	lbs/day	% of Total	lbs/day
5%	Total Nitrogen as N	376,000	79.99	34,300	7.29	60,000	12.75	470,300
	Total Phosphorus as P	19,300	41.41	3,300	7.08	24,000	51.51	46,600
50%	Total Nitrogen as N	36,000	35.97	4,070	4.07	60,000	59.96	100,070
	Total Phosphorus as P	4,400	15.04	850	2.91	24,000	82.05	29,250
95%	Total Nitrogen as N	6,200	9.27	660	0.99	60,000	89.74	66,860
	Total Phosphorus as P	920	3.68	90	0.36	24,000	95.96	25,010

*The percent of time for which a given loading is equaled or exceeded. The 5%, 50%, and 95% corresponds to a freshwater flow into the estuary of 34,600 cfs, 6,470 cfs, and 1,200 cfs, respectively.

Source: Water Resource-Water Supply Study of the Potomac Estuary[30] p. IV-15.

TABLE 15

NUTRIENT LEVELS AT FLETCHERS BOAT HOUSE, WASHINGTON, D.C.

Date From To		Ammonia (NH_3) as N Total MG/L	Nitrite (NO_2) as N Total MG/L	Nitrate (NO_3) as N Total MG/L	Total Kjedhal Nitrogen as N MG/L	Total Phosphate as PO_4 MG/L	Dissolved Phosphate as PO_4 MG/L	Total Phosphate as P MG/L
1969	Number	33.0000	33.0000	33.0000	33.0000			33.0000
	Maximum	1.10000	.130000	1.14000	2.82000			2.10000
	Minimum	.0000000	.0000000	.0000000	.550000			.180000
	Mean	.514848	.0167879	.369909	1.35211			.716361
1970	Number	43.0000	43.0000	43.0000	42.0000		1.00000	42.0000
	Maximum	1.10000	.0300000	1.86000	3.09000		.0699999	.770000
	Minimum	.0000000	.0000000	.130000	.610000		.0699999	.130000
	Mean	.415580	.0060465	.743484	1.30190		.0699999	.330238
1971	Number	25.0000	25.0000	25.0000	25.0000	1.00000		23.0000
	Maximum	1.99000	.0300000	1.47000	3.09000	.190000		.910000
	Minimum	.0000000	.0000000	.0200000	.770000	.190000		.120000
	Mean	.443600	.0120000	.568799	1.52120	.190000		.417391
1972	Number	32.0000	32.0000	32.0000	32.0000	17.0000	15.0000	9.00000
	Maximum	.560000	.0699999	4.82000	2.17000	.580000	.300000	.300000
	Minimum	.0000000	.0000000	.290000	.0000000	.0899999	.0000000	.0899999
	Mean	.143125	.0143750	.917183	.935935	.198823	.172000	.150000
1973	Number	42.0000	42.0000	42.0000	41.0000	20.0000	22.0000	
	Maximum	1.58000	.100000	1.82000	2.86000	1.18000	.650000	
	Minimum	.0000000	.0000000	.0300000	.540000	.0500000	.0600000	
	Mean	.398809	.0152381	.60471	1.28902	.241000	.198181	
1974	Number	14.0000		15.0000		3.00000	13.0000	
	Maximum	.880000		1.34000		.260000	.620000	
	Minimum	.0000000		.0000000		.0500000	.0500000	
	Mean	.264285		.635333		.140000	.200000	

NUTRIENT CONTROL

The control of nutrients within the Potomac River basin has centered around advanced waste treatment of point source discharges. This has been the case in spite of the observation made by several investigators that the concentration of nutrients in the Potomac River, before entering the estuary, is great enough to support nuisance levels of algae, with inorganic nitrogen levels averaging 0.95 mg/l and total phosphorus averaging 0.094 mg/l at Great Falls. Table 15 lists the nitrogen and phosphorus levels at Fletcher's Boat House, 104 miles above the mouth of the estuary. As shown, the values found are three to five times the level indicated by Sawyer to cause nuisance conditions.

NUTRIENT CONTROL OF POINT SOURCES

To control eutrophication in the estuary, the removal of both phosphorus and nitrogen from municipal discharges has been recommended by the Annapolis Science Center.[30] Limits for both of these nutrients were prescribed for several reasons. It was felt that because of the "flashy" flows of the Potomac, neither phosphorus nor nitrogen could be controlled throughout the estuary at all times. Because of the contributions of non-point sources during high flow periods, the control of phosphorus appears more feasible, while during low flows, the control of nitrogen is more feasible. In addition, the Science Center has pointed to the compatibility between wastewater treatment requirements for dissolved oxygen enhancement and the prevention of eutrophication.

One alternative for point source treatment is patterned after the "Memorandum of Understanding" presented at a special session of the Potomac River Washington Metropolitan Area Enforcement Conference held October 13, 1970. Cost estimates were developed for nine conventional secondary treatment plants and six advanced waste treatment plants. The advanced waste treatment plants would remove phosphorus and nitrogen (on a seasonal basis) and would contain the following unit treatment processes: lime clarification, carbon adsorption, biological nitrification-denitrification, and effluent aeration. The total capital cost required to construct and/or upgrade these plants from 1970 through 2020 was estimated by a computer model in 1971 at $2.271 billion.[30] However, since this estimate was made, the construction cost of treatment facilities has increased at a much faster rate than was predicted and there is every reason to believe that this value underestimates the true cost of the program outlined. For example, the cost of Blue Plains alone increased 33 percent in a nine month period in 1974.

CONTROL OF NON-POINT SOURCES

Because nutrient concentrations in the nontidal Potomac River exceed the level known to cause nuisance eutrophic conditions in the estuary, a systematic program for all controllable sources must be attempted in the upper basin as well as in the lower basin. Estimates by the Annapolis Science Center have indicated that at least 50 percent of the nutrient load entering the river must be eliminated to halt the eutrophication process. Although no detailed cost estimates have been made concerning the control of non-point sources in the upper basin, a good deal is known about the causes of this pollution and the availability of various control techniques.

NUTRIENTS FROM FOREST RUNOFF

Normally, one does not think of an area of forested land as a source of water pollution. A well-managed forest with a good stand of trees is usually quite resistant to erosion and absorbs incidental rainfall with little, if any, runoff. A forest is normally so efficient in recycling nutrients, in fact, that it is used in many places as an ideal, environmentally safe place to spray municipal effluents. It is only during those periods when the forest is disturbed in some manner, either by a natural event or harvesting of trees, that nutrient pollution becomes excessive. It is at these critical periods, between disturbance and the reestablishment of the forest, that tremendous amounts of sediments, due to increased runoff and exposed surface area, can be discharged to neighboring water bodies.

Runoff and sediment loads occurring during the harvest procedure are increased in a number of ways. The construction of roads not only loosens soils and makes them more susceptible to erosion, but also provides an area on which runoff can flow unimpeded by natural ground cover. Likewise, the cutting and dragging of trees not only exposes ground cover to direct rainfall, but creates "ruts" which act in a manner very similar to roads.

A number of techniques exist to combat these problems of detrimental impacts to the forest. In many instances, selective cutting of timber can be practiced rather than clear-cutting. If clear-cutting must be used, and conditions allow, tree limbs, tops, and other wood that remains can be allowed to act as a cover. In all cases, reforestation can be initiated immediately. In the creation of roads, special engineering care and judgment can be taken to design systems not susceptible to excessive erosion. These roads and any areas not reforested can be protected with a vegetative covering of grass and legumes. Finally, in extreme instances, physical structures can be built to collect and treat runoff before it is released.

A number of application techniques also exist for fertilization. Before any fertilizer is applied, precautions can be taken to make certain that the benefits of the application are greater than the economical costs. Frequent fertilizations at low rates are environmentally more sound than infrequent fertilizations at high rates. Care should be taken not to spray fertilizers over water courses, and buffer strips should be maintained between streams and fertilized areas. Fertilizers should not be applied when wind drift is high. Finally, in those instances when rainfall can be predicted, fertilization during periods of heavy rainfall should be avoided.

NUTRIENTS FROM AGRICULTURAL RUNOFF

As with forestry, proper land management practices in agriculture will keep soil and plant nutrients on the land rather than allow them to become part of the waterborne pollutant load. Proper agricultural management is complicated, however, by the enormous amount of nutrients that is used on agricultural land

and on the variety of soil disturbances that is inherent in the planting and harvesting of crops yearly. These problems result in making agricultural runoff a much greater discharger of nutrients than silvacultural runoff.

Phosphorus and nitrogen are lost to agricultural lands in much the same manner as in forestry, through sediment erosion and runoff. However, because of the greater accessibility of agricultural lands, the techniques of control are different. A variety of tillage techniques, including zero tillage, sweep tillage, and plow plant, has been designed to enhance the infiltration properties of soils. In addition, contouring -- tilling in a direction perpendicular to the slope of the land -- provides even more protection from water erosion. Strip cropping, the practice of planting close-growing crops or meadow grasses between tilled row cropstrips, can also be practiced as a means of reducing erosion on tilled soils. In situations where none of these techniques is sufficient, terracing can be practiced. Aside from the techniques already mentioned for proper fertilizer application in forests, slow-release fertilizers can be used to minimize possible nitrogen losses on soils subject to leaching.

V. CONCLUSION

As pollution control techniques for municipal and industrial discharges become more sophisticated, the importance of non-point sources of pollution in the Potomac basin has increased proportionately. Loads from these sources have become increasingly significant and deserve special attention as progress is made in controlling point sources. Such special attention should include consideration of an increased share of or priority for financial and technical assistance, regulatory effort, public education, and research. Until this attention is given to non-point sources of pollution, it seems doubtful that the Potomac River will realize its full potential as a source of recreation, beauty, and economic benefit throughout its entire length.

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