Bulletin 88

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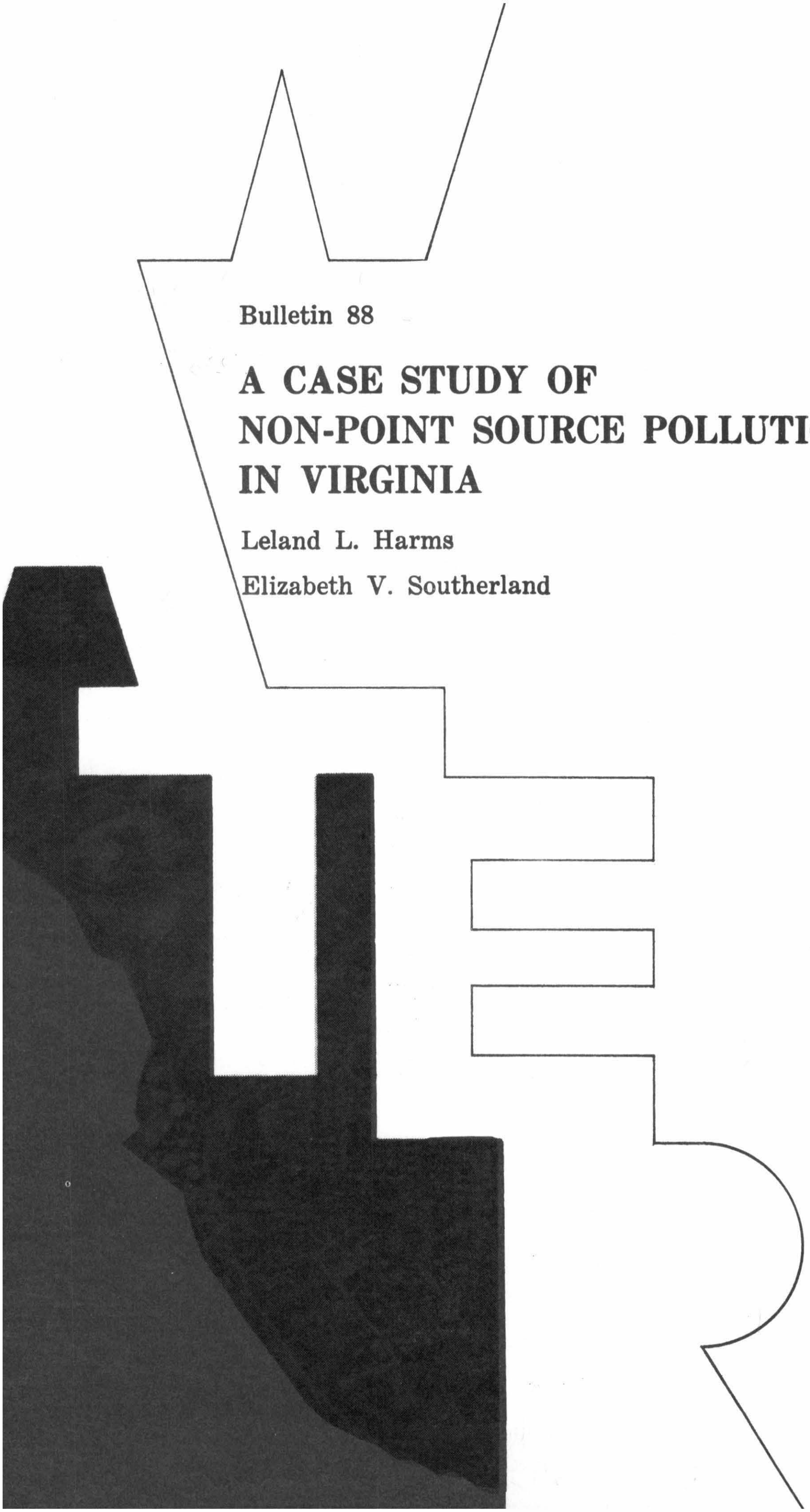

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A CASE STUDY OF NON-POINT SOURCE POLLUTION IN VIRGINIA

Leland L. Harms
Assistant Professor

Elizabeth V. Southerland
Graduate Research Assistant

Department of Civil Engineering
Virginia Polytechnic Institute and State University
Blacksburg, Virginia

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ABSTRACT

Sources of organic matter, sediment, and nutrients were investigated for the Upper South River Basin near Waynesboro, Virginia. The study period extended from the end of April until mid-September, 1974, a total of 135 days. During the study period, 156 samples were collected with the following analytical determinations being made on each sample: chemical oxygen demand, total suspended solids, turbidity, specific conductance, total kjeldahl nitrogen, and nitrate. Flow measurements were also made at the sampling stations in order that total yields of materials could be established.

Sources of organic matter, sediment and nutrients were agricultural, forest and urban land drainage in addition to domestic and industrial wastewater effluents. For each pound of phosphorus recorded in the river, about 10 pounds of nitrogen and 75 pounds of sediment were also present. Point sources accounted for an insignificant portion of the sediment, 2.1%, but were the major source of all other contaminants during the study. However, the point source contributions were overshadowed by non-point discharges during major storm events.

Agricultural land drainage was a greater source of contaminants than forest drainage. Urban runoff contributed substantial pollutant loads during runoff periods. The Waynesbore sewage treatment plant was the greatest source of phosphorus in the basin studied. Reduction of phosphorus in the Waynesboro sewage treatment plant effluent may reduce excessive algal production in the South River below Waynesboro.

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I. INTRODUCTION

The project compares the relative importance of non-point sources of pollution with known point sources of pollution in the Upper South River Basin near Waynesboro, Virginia. It is felt that the watershed chosen has problems similar to those in other areas and that the research findings will assist in understanding water quality problems elsewhere.

Non-point sources are nondiscrete, diffuse discharges such as agriculture and forest land drainage, urban runoff, and construction drainage. Point sources are those waste discharges which are collected and discharged at a single point such as the effluent from a sewage treatment plant or an industrial facility.

Both point and non-point sources contribute pollutants to a particular watershed, but in varying degrees and at different times. The phosphorus contribution from a sewage treatment plant may be substantial, for example, but this contribution may be overshadowed by the combined instantaneous discharges from non-point sources during a major storm event.

As additional emphasis is placed on reducing the pollutant loads discharged from point sources, it becomes necessary to consider the pollutants discharged from the non-point sources. It is necessary to determine their relative importance within the watershed under consideration. It would not be wise to spend large sums of money for point source control if the majority of the contaminants are from other sources, that is, unless additional controls regarding the non-point sources are also envisioned.

Crop debris, animal wastes, and forest litter are among the organic wastes transported to streams in runoff from agricultural and forest lands. Urban storm runoff also sweeps organic matter from streets and yards and transports it into receiving streams. These organic loads exert a biochemical oxygen demand in the stream and are also a source of microbial pollution.

Thermal pollution may be a problem in forests cleared by lumbering or housing development operations. Stream temperatures will be raised since removal of tree cover along streambanks exposes water to direct heating from the sun's rays.

In 1971 a report was prepared for the Council on Environmental Quality which estimated the extent of pollution contributed by non-point sources in a number of river basins throughout the country(1). The study concluded that in 80 percent of the basins reviewed non-point sources were the dominant sources of water pollution. During periods of heavy rainfall and increased stream flow, data for both rural and industrialized areas indicated that the concentrations of pollutants increased instead of being diluted, thereby reflecting a significant pollutant contribution from land runoff.

The Upper South River watershed was chosen as the study area for a number of reasons. It is a very representative watershed in that it receives agricultural, forest land, and urban runoff as well as significant industrial and municipal waste discharges. The main stem of the South River below Waynesboro has been rated a critical water quality segment by the Virginia State Water Control Board. This designation indicates that water quality in this segment does not at present meet applicable water quality standards and is not expected to meet such standards even after implementation of "best practicable control technology" for industry and secondary treatment for municipalities. In addition, there is substantial background information on water quality and land use in this watershed due to the efforts of the Interstate Commission on the Potomac, South River Watershed Development Project, Soil Conservation Service, State Water Control Board, and other federal, state, and local agencies.

The South River joins the North and Middle Rivers near Port Republic, Virginia to form the South Fork Shenandoah River. Approximately 90 percent of the South River watershed lies in Augusta County and 10 percent in Rockingham County. Except for a few relatively small feeder streams located in the Blue Ridge Mountains, the South River originates in the valley and exhibits the characteristics of a valley stream. Although flows show substantial seasonal variations, changes in flow are rather gradual. The 0.3 percent gradient of South River is low enough to cause some meandering of the stream. The stream channel of the South River is wide and shallow with a rocky or sandy bottom. Channel slope is variable giving rise to a series of millponds and free flowing areas. Above Waynesboro, the average flow is 128 cubic feet per second (cfs) with a range of 25 cfs to 990 cfs. Below Waynesboro at Harriston, the average flow is 243 cfs with a range of 60 cfs to 1,710 cfs(2).

Along its 52-mile length, South River drains 144 square miles of wooded, mountainous terrain with agriculturally developed bottom land. About 133 square miles of this drainage area lies above Waynesboro and is the source of non-point pollution from farmland and forest. The only heavily populated and industrialized segment of the river is in the city of Waynesboro. Waynesboro, with a population of 16,709, is a source of considerable urban runoff, industrial discharges, and domestic waste(2). The low level of dissolved oxygen which occurs periodically in South River is a result of the organic load imposed by these industrial, municipal, and non-point sources. Substantial algal activity stimulated by nutrient inputs further depresses dissolved oxygen levels in the absence of sunlight. The South River below Waynesboro is not able to continuously accept the wastewater load now imposed upon it without serious degradation of water quality. At the same time, pressure is being exerted to develop new residential areas and expand industrial facilities within the watershed. Before such development is undertaken, land use planners should have a thorough knowledge of both the sources and effects of non-point and point pollutant contributions.

Therefore, the primary purpose of the study was to study in detail the water quality of a stream which is fed by an area subjected to agricultural, forest land and urban runoff; and estimate the importance of the non-point sources by comparison to contributing point sources. Secondary objectives were to recommend the kinds of data to be collected for other non-point source studies and recommend possible control measures.

II. BACKGROUND

Importance of Non-point Sources and Nutrients

Information regarding the actual extent of water pollution which results from non-point sources of pollution is seriously lacking in Virginia as well as throughout the nation. Water pollution control efforts have generally concentrated on point source discharges because they are easy to locate, amenable to treatment, and the effects of these discharges are sometimes apparent by visual inspection. Non-point sources, on the other hand, are almost impossible to trace to the point of origin, do not lend themselves to treatment, and their harmful effects may not become apparent until after extensive chemical, physical, and biological monitoring.

Advanced waste treatment, tertiary treatment, is being considered for future waste treatment facilities and for upgrading existing plants by many agencies on local, state, and national levels. A major reason for utilizing advanced waste treatment methods is for inorganic nutrient removal to arrest degradation of streams and lakes, primarily lakes. Non-point sources are known to contain quantities of the nutrients which are responsible for eutrophication. It is a very real possibility that large sums of money will be committed to building tertiary treatment facilities without the anticipated improvement in water quality being realized because the non-point sources were ignored.

Inorganic nutrients are necessary for biochemical synthesis of cell material. Macronutrients are those nutrients required in relatively large quantities by an organism and include carbon, hydrogen, oxygen, sodium, sulfur, calcium, magensium, potassium, nitrogen, and phosphorus(3).

An increase in nutrient input to a lake or stream may promote the eutrophication of that body of water. The term "eutrophication" was originally coined to describe the slow, natural aging process by which a lake becomes steadily more productive through nutrient enrichment and eventually fills in with sediment and vegetative growth. Unlike a lake, a stream follows no evolutionary path of development, but it also responds to nutrient enrichment with an increase in biological productivity(4). Environmental concern is directed towards those instances where man's activities accelerate the natural process of eutrophication to the extent of creating a nuisance or interfering with a water use.

The most commonly recognized sign of advancing eutrophication is the algal bloom. A bloom exists when the productivity of a limited number of algal species produces a blomass that becomes a nuisance. Unlike studies of lakes, there have been few detailed or long continued studies of algae in American rivers. Palmer (5) reports results of a two-year study of algae in rivers of the U. S. Indications are that there are much larger numbers of algae in rivers than has generally been assumed and that seasonal fluctuation in algae is less than suspected. According to Martin and Weinberger (6) and Bauman and Kelman (7), algal growth may have the following detrimental effects on water quality:

1. Exertion of a demand on the oxygen of a lake during absence of sunlight and following death of the algae.
2. Return of inorganic nutrients to the aquatic system following degradation of dead plant cells, thereby restimulating algal growth.
3. Creation of a disturbance in the food chain, thus affecting the life cycle of higher species.
4. Increase in turbidity and suspended solids load and production of tastes and odors in the body of water.
5. Release of toxins which result in death of other life.

According to Liebig's Law of the Minimum, algal growth in a given environment is limited by that essential nutrient which is present in the lowest relative amount (8). Carbon, nitrogen, oxygen, and hydrogen are nutrients with a gaseous phase, and consequently have an atmospheric reservoir available to the aquatic environment. A nutrient such as calcium or phosphorus which does not have an atmospheric reservoir is likely to be the limiting nutrient. Phosphorus is generally considered to be the limiting factor in algal metabolism most consistent with Leibig's limiting concept.

Strategies for control of manmade eutrophication stress nitrogen and phosphorus removal since both are constituents of treated sewage and runoff waters. In Wisconsin lakes Sawyer (9) found that concentrations of 0.01 mg/1 of soluble phosphorus (0.0326 mg/1 as PO_4) and concentrations of 0.30 mg/1 inorganic nitrogen (1.4 mg/1 as NO_3) were sufficient to support algal blooms when other environmental growth conditions were optimum. Sylvester(10) reported limiting concentrations of 0.01 mg/1 P and 0.2 mg/1 N from his work on Green Lake near Seattle, Washington. For flowing streams Mackenthun(11) recommended that total phosphorus concentration should not exceed 0.1 mg/1 P (0.326 mg/1 PO_4) at any point within the stream, nor should 0.05 mg/1 P (0.163 mg/ PO_4) be exceeded where flowing water enters a lake, reservoir, or other standing water body. A study of stream quality in the U. S. by the Federal Water Pollution Control Administration reported that total phosphorus concentrations exceeded 0.05 mg/1 P at 48 percent of the stations sampled(12). A Public Health Service study also monitored stations on river systems throughout the U.S.(6). An average of 77 percent of the stations reported water samples containing at least 0.1 mg/1 PO_4 and 60 percent reported nitrate concentrations greater than 1.4 mg/1 NO_3.

Nitrogen may reach the aquatic environment by leaching through the soil to the ground-water table. Witzel indicates that nitrates appear in ground water because they are anions which are only slightly absorbed by soil(13). Nitrogen is also transported to streams and lakes through soil erosion and surface runoff. According to Holt *et al.*(14), sediment transported to surface waters carries organic nitrogen, ammonium nitrogen, nitrite, and nitrate. Sediment loses soluble nitrite and nitrate to the water and carries insoluble organic nitrogen and ammonium nitrogen to streambed deposits.

Phosphorus occurs in soil in both organic and inorganic forms. Biggar and Corey(15), state that proportions of each form have been found to range from 3 percent organic and 97 percent inorganic to 75 percent organic and 25 percent inorganic. Plant and animal remains contribute organic phosphorus. Black(16) states that most of the phosphorus that reaches streams and lakes comes from domestic sewage discharges and surface runoff. The phosphorus transported in surface runoff is primarily in particulate form, either fixed in living cells or adsorbed on particulate matter. Since much of the sediment in streams during high flow is derived from streambank erosion and streambed scour, the phosphorus concentration in these areas is an important factor affecting the concentration of soluble phosphorus in water during periods of high flow. Kramer *et al.*(17) report research findings that phosphorus is released from sediment when the following conditions prevail:

1. Oxidation-reduction potential is reduced at the sediment surface.
2. pH is above or below the range 5 to 7.
3. Calcium concentrations are out of the range 226 to 325 ppm.
4. Sediments are agitated.

Phosphorus is assimilated rapidly from flowing water. According to Keup(18), stream biota, particularly periphyton, comprise the primary mechanism of phosphorus uptake. The biological cycling of phosphorus begins with the absorption of dissolved orthophosphate by aquatic plants. The orthophosphate is used to synthesize organic compounds and is passed along the food chain until it is recycled back into the system through bacterial decomposition of excretory products and dead tissue.

Kramer *et al.*(17) reported that some species of algae can use organic phosphorus directly. These algae begin to synthesize phosphatase enzymes when inorganic phosphorus levels become low enough to limit algal growth. Kramer *et al.* warned that this phosphatase capability may prove to be of great importance to efforts to control nuisance growth of algae. Although removals as high as 95 percent of total phosphorus in wastewater are theoretically possible, the removal efficiency is frequently far greater for orthophosphate than for organic phosphorus. In addition to carrying plant nutrients into receiving streams, sediment also introduces chemicals, radioactive materials, and pathogens. Sediment has a number of detrimental effects on water quality. According to Johnson and Moldenhauer(19), sediment causes silting in reservoirs, lakes and ponds; interfering with navigation and proper drainage by clogging streams and drainageways; reducing the recreational and consumptive value of water through turbidity and discoloration; and increasing water treatment costs.

Hoak(20) describes the detrimental effects of sediment on aquatic life in streams. Suspension of sediment particles limits the growth of aquatic plants by blocking sunlight, while settling of these particles can smother benthic organisms. This interference with photosynthesis and benthic life reduces the self-purification capability of a stream. Heavy loads of sediment also damage fish directly by clogging or abrading their gills and indirectly by killing bottom fauna and covering spawning grounds.

As precipitation hits the ground and begins to concentrate in rivulets, it will pick up and transport loose particles. A particle's size determines its ability to be moved by runoff. The smaller the particle, the more likely its chance of reaching a receiving stream. Holt *et al.*(16) indicate that the selective, size-sorting nature of erosion causes sediment to be higher in silt, clay, and organic matter than the soil from which it was derived.

Most of the sediment being transported by a stream is in suspension, and most of these fine particles are derived from soil erosion and land runoff(21). Johnson and Moldenhauer(19) quote studies which show that 85 to 95 percent of the total sediment discharge is in suspension.

Summary of Related Non-Point Source Contributions

The primary non-point sources which affected the quality of the South River were agricultural land runoff, forest land runoff, and urban runoff. Obviously, during a storm event, the major fluctuations in pollutant loadings result from surface runoff. However, ground-water contributions from agricultural and forested areas which reached the South River were also included. A brief summary follows of related work regarding runoff from agricultural land, forested land, and urban areas.

Agricultural land runoff yields have been given by Weidner *et al.*(22) for small plots in Ohio, by Engelbrecht and Morgan(23) for the Kaskaskia River Basin in Illinois, by Sawyer(9) for three Wisconsin lakes, by Dornbush *et al.*(24) for seven small watersheds in South Dakota, and by Witzel *et al.*(25) for small watersheds in Wisconsin. Forest land contributions have been listed by Cooper(26) for northern Minnesota, by Sylvester(10) for three forested watersheds in Washington, by Jaworski and Hetling(27), for the Potomac River Basin, and Taylor *et al.*(28) for an Ohio forest. Pollutants present in urban runoff were reported by Soderlund and Lehtinen(29) for three urban areas in Stockholm, by Weibel *et al.*(3) for a residential and light commercial area in Cincinnati, by Colston(31) for Durham, North Carolina, and by Kluesener and Lee(32) for a residential section of Madison, Wisconsin. Information contained in these references is summarized in Table I.

The wide range in reported values would seem to indicate that the differences in climate and size of watershed radically affect the pollutional load discharged from land surfaces. This is undoubtedly true. Another factor which should be pointed out is the hazard of generalizing the data into pound/acre/year contributions. The uppermost acre of a watershed does not contribute at an annual rate which is identical to the annual contribution of an acre bordering the stream.

Related South River Basin Studies

In 1967 the Virginia Division of Water Resources(33) investigated dissolved oxygen levels in the South River. Analyses revealed wide fluctuations in dissolved oxygen due to intensive algal activity. The Division attempted to predict dissolved oxygen variations based on observed diurnal extremes. The calculated concentrations and predicted fluctuation pattern agreed with observed data. During high algal respiration at 6 A. M., the dissolved oxygen concentration 10 to 13 miles below the city of Waynesboro fell sharply to 0 mg/1. At a point 20 miles below the city, concentrations at 6 A. M. had risen to 5 mg/1. During peak algal photosynthesis at 3 P.M., dissolved oxygen at the 10-mile point rose to about 3 mg/1. Concentrations below this point fluctuated between 0 and 5 mg/1 and then rose sharply to 11 mg/1 at the 20-mile point. Algal activity and accompanying dissolved oxygen fluctuations continued downstream of the confluence of the South and North Rivers into the South Fork Shenandoah. The Division attributed this intensive algal growth to high nitrogen and phosphorus concentrations in the South River below Waynesboro.

Cairns and Dickson(34) conducted an ecosystematic study of the South River in September 1970. Sampling stations were established both upstream and downstream of the city of Waynesboro's domestic and industrial discharges. The diversity, density and distribution of fish, macroinvertebrates, algae, aquatic plants, protozoans, and bacteria were determined at each station. Chemical water quality analyses were also made. The three stations upstream of Waynesboro supported a diverse and healthy fauna and flora. The station directly below discharges from the DuPont and Crompton-Shenandoah industrial plants had a drastically reduced bottom fauna community primarily consisting of pollution-tolerant midge larvae. Downstream of this station fish diversity was reduced significantly in comparison with areas upstream of Waynesboro. Qualitative shifts in algae, higher plants, protozoans, and bacteria also occurred. Directly below the industrial discharges there was an increase in organic material, phosphorus, heavy metals, total solids, sulfates, chlorides, and total hardness. Dissolved oxygen was almost entirely depleted in areas downstream of Waynesboro at times of low flow and high temperature. Biological recovery was not complete 14 miles below Waynesboro at Harriston, Virginia.

III. METHODS

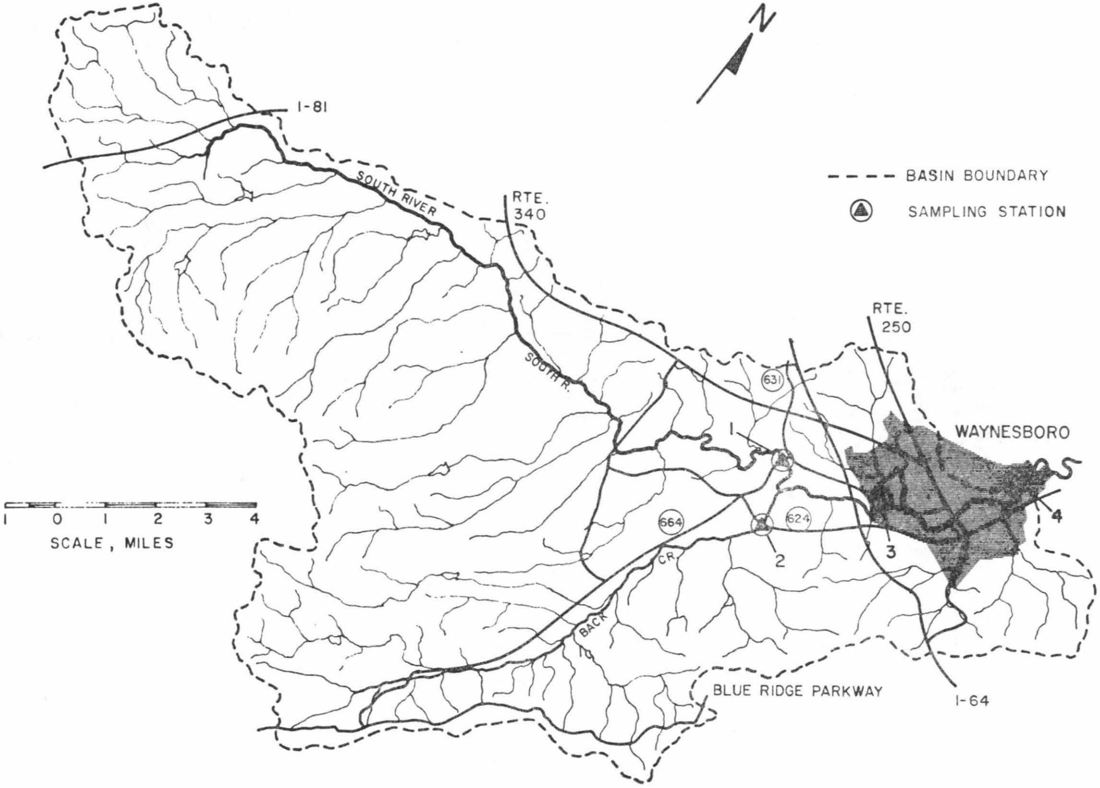
This investigation of water quality in the Upper South River Basin was conducted from April 26, 1974 until September 11, 1974. A total of 156 samples were collected and analyzed according to the procedures outlined below.

Field

A map of the Upper South River Basin is shown in Figure 1. Table II presents physical data on the entire length of South River and its major tributary, Back Creek. Four sampling sites were selected to assess the relative significance of point and non-point sources of pollution. Locations of the sampling stations are shown on Figure 1, and land use classifications of their drainage basins are presented in Table III. Drainage areas at each site were determined using United Coast and Geodetic Survey 7.5 minute Quadrangle Maps of the South River area. Land use percentages were estimated with the assistance of the Augusta County Soil Conservation Service. Chemical analyses of water samples from Sites 1, 2, and 3 measure concentrations of pollutants in groundwater and surface runoff from agricultural and forest land while analyses of Site 4 include the contributions of urban runoff and point source discharges. Site 1 is located on the South River, 1 mile above the confluence with Back Creek. Fifty-three percent of this Upper South River drainage basin is forest land, 32 percent pasture and grassland, and 13 percent cropland. The remaining 2 percent of the basin is residential, with concentrations in Stuarts Draft and Greenville. Domestic waste from the Stuarts Draft lagoon is the only significant point source discharge into this portion of the river. Site 2 is located on Back Creek 0.8 mile upstream of the confluence with South River. The drainage basin of this tributary is 88.6 percent forest and 10 percent pasture and grassland. Cropland and residential areas are small and scattered.

Site 3 is located on the South River 2.4 miles downstream of Back Creek. The South River at this point is composed of the combined flow from the upper South River and Back Creek. No point sources discharge into the South River between Sites 1 and 3. Site 4 is located on the South River below the city of Waynesboro, 5.4 miles downstream of Site 3. The drain-

Figure 1.—Upper South River Basin



age basin of the South River at this point contains all of Waynesboro as well as additional agricultural and forest land. Major point source dischargers in the city are the DuPont Company's synthetic fiber plant, Crompton-Shenandoah's dye and finishing plant, and the Waynesboro sewage treatment plant. Two new gages were established in the Upper South River Basin with the assistance of the Virginia State Water Control Board's Bureau of Surveillance and Field Studies. A continuous flow recorder was placed at Site 2 on Back Creek and a wire weight gage was located at Site 4 on the South River. The permanent digital tape recording gage operated by the U. S. Geological Survey was used at Site 3. Rating curves for each of the gages were obtained from the Bureau of Surveillance and Field Studies. Flows and chemical analyses of domestic and industrial wastewater discharges were obtained from the State Water Control Board's Regional office in Bridgewater. Data on the amount and time of precipitation were obtained from the National Weather Service rain gage at Stuarts Draft.

Samples were collected manually in acid washed glass bottles or in acid washed polyethylene containers provided by the State Water Control Board. Samples were taken at midchannel directly below the water surface. Prior to June 17, samples were collected primarily during wet weather. Samples were packed in ice as soon as collected and transported within 3 hours to the Sanitary Engineering Laboratory of Virginia Polytechnic Institute and State University. From June 17 until completion of sampling, dry weather samples were taken two or three times a week. These samples were packed in ice and transported via the Greyhound bus to Roanoke. From there they were taken directly to the Sanitary Engineering Laboratory with total time in transit averaging 8 hours. Samples were refrigerated at the laboratory until all chemical analyses were completed.

Laboratory

Chemical oxygen demand (COD) was determined by the alternate procedure for dilute samples described in "Standard Methods"(36). Using the dilute sample procedure, 10 milliliters of 0.025 N standard potassium dichromate were used to oxidize 20 milliliters of sample. Excess potassium dichromate was then titrated with 0.01 N ferrous ammonium sulfate, using ferroin as the indicator solution.

Total Kjeldahl Nitrogen (organic-N and NH_3-N) and iron concentrations were determined with a Technicon Auto Analyzer equipped with a 50 millimeter flow cell. Concentrations of nitrate (NO_3-N) were measured with an Orion Research Model 92-07 specific ion electrode. Nitrate analyses were conducted using the method of known additions with an Orion Research Model 703 digital pH/millivolt meter.

Total phosphorus (dissolved and suspended) was determined according to the tentative ascorbic acid procedures in "Standard Methods"(36). The tentative procedure was used in place of the vanadomolybdic acid and stannous chloride methods because these methods were subject to silica interferences when samples were heated. The ascorbic acid method was used to avoid interferences by the silica in sediment suspended in the samples. Samples were digested in the autoclave according to the persulfate oxidation technique presented in "Standard Methods"(36). Prior to color development, digested samples were filtered through a Whatman No. 40 filter in order to remove color interferences from suspended particles. Samples were then neutralized with 1 N NaOH to the phenophthalein endpoint; color was developed with the combined reagent; and colorimetric measurements were made with a Bausch and Lomb Spectronic 20 spectrophotometer.

A hellige turbidimeter was used for turbidity measurements, and a Barnstead Conductivity Bridge Model PM-7OCB was used for specific conductance measurements. Conductivity values were temperature-adjusted to 25° C using multiplication factors presented in "Standard Methods"(36).

Total suspended solids (SS) were measured by filtering samples through 5.5 cm glass fliber filters. In accordance with "Standard Methods"(36), filters were dried in an oven at 103° C for 60 minutes and placed in a desiccator for 30 minutes both before and after filtering. Weighing was done on a Metler Model H-32 analytical balance. The millipore apparatus used for filtering was Teflon-coated to prevent loss of filter material.

IV. RESULTS

Hydrologic Summary

The Virginia Division of Water Resources has presented a summary of South River Basin climatic data in the Comprehensive Water Resources Plan for the Potomac-Shenandoah River Basin(37). The South River Basin has a temperate climate. The average annual temperature is 51° F. The first frost occurs about mid-October and the last frost in late April. In January, the mean daily maximum temperature is 45° F and the mean daily minimum temperature is 26° F. In July the mean daily maximum temperature is 86° F and the mean daily minimum temperature is 64° F.

Prevailing winds are from the southwest at an average velocity of 10 mph. These winds generally bring moist air from the Gulf of Mexico. Polar air masses from the northwest clash with warm Gulf air to produce most of the climatological changes that occur in the Basin.

Evaporation averages 34 to 35 inches in the South River Basin from April to October, the period in which 80 to 85 percent of annual evaporation takes place. Annual rainfall averages 36 inches, with June having the highest average precipitation (3.74″) and January the lowest (2.21″). Monthly rainfall averages are greatest from April through September, which is also the period of highest evaporation. Annual snowfall in the Basin averages 20 inches.

Table IV compares monthly totals of rainfall during the sampling period for this study with monthly averages based on 14 years of records from the Stuarts Draft rain gage. The National Weather Service gage measures only total amount and hours of precipitation and does not record intensity. As Dornbush *et al.*(24) have stated, intensity of rainfall has a great effect on the quantity and quality of runoff from a given area. This lack of data precludes meaningful comparison of runoff potential from year to year.

The average discharge of the Upper South River is 128 cfs based on 20 years of U.S.G.S. records for the gage at Site 3(38). Extremes during the period of record range from a maximum discharge of 17,400 cfs during the flood of 1969 to a minimum daily discharge of 17 cfs in August 1966. Flow from 41 square miles of the 133 square miles of drainage area above the Site 3 gage is slightly regulated by twelve flood retention reservoirs. The average discharge below Waynesboro at Harriston is 243 cfs, based on 30 years of record. The increase in flow is due to contributions from an additional 79 square miles of drainage area as well as an addition of approximately 20 cfs of ground water through the DuPont Company's waste treatment system(2).

Many streams in the South River watershed are wet weather streams. The main stem gets its water during dry months primarily from several large springs. The minimum mean seven-consecutive day drought flow of the Upper South River with 10-year return frequency is 23 cfs(37). Figure 2 presents the flow duration curve devised by the Virginia Division of Water Resources(37) for the Upper South River at Site 3. Fifty percent of the time, flow at this location exceeds 70 cfs and 99.9 percent of the time it exceeds 24 cfs.

Figure 3 shows the recorded flows at Site 3 above Waynesboro for the water year October 1972 to September 1973. Total pounds of pollutants from land drainage may be greater during the winter months. However, as will be shown later, it is probable that the most rapid water quality changes in the river are brought about by short-duration, highly-intensive summer storms occurring during the lower flow periods of this study. Winter land drainage concentrations of nitrate may be higher as this nutrient is sometimes prevalent in groundwater contributions. Quite probably the phosphorus load will be less from the land runoff during the winter period because of the affinity of phosphorus for soil.

Figures 4 and 5 show the flow variations for the four sampling locations. The major runoff event occurred on May 12, early in the season when the soil surface was partially saturated and the ground covers were not well established on the agricultural lands. Small peaks from June to September are evident on Figure 5 without corresponding peaks on Figure 4. Small rainfall events do not produce significant runoff from the agricultural and forest sectors, but do have some effect on the South River because of urban drainage. This is reasonable because the runoff from an urban area with paved

Figure 2.—Flow Duration Curve for South River at Site 3

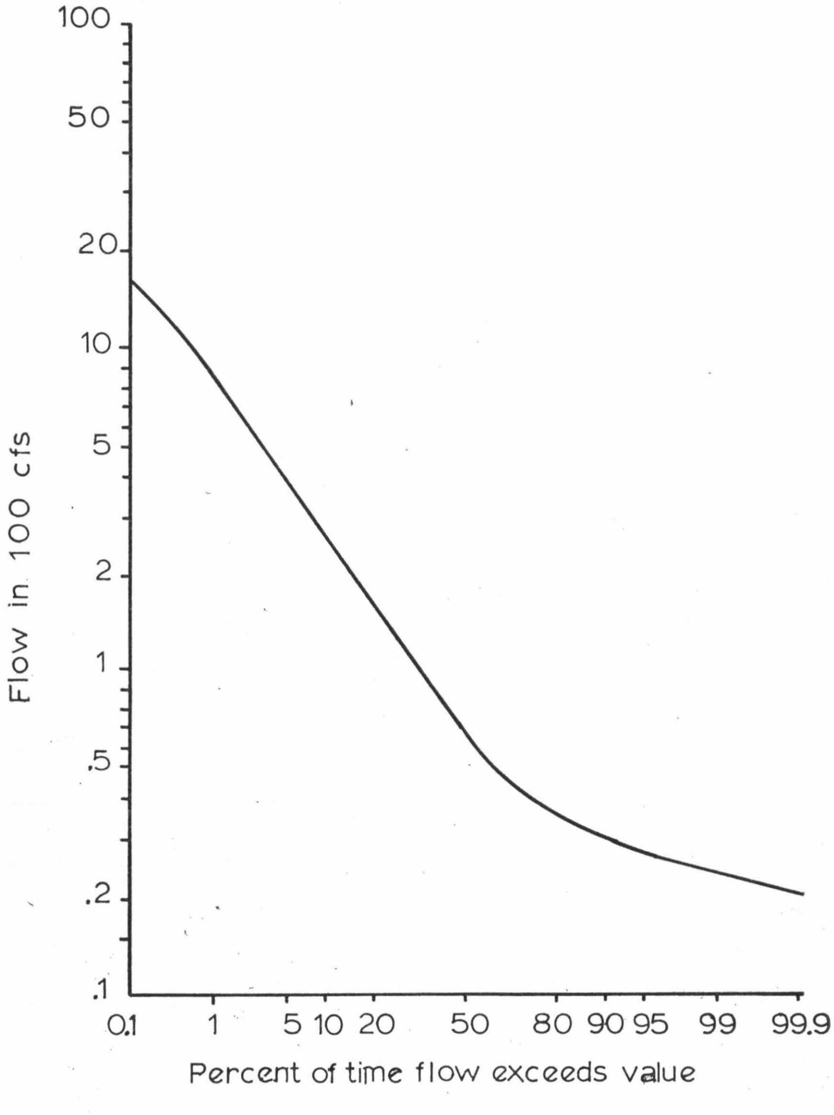


Figure 3.—Monthly Average Discharge at Site 3

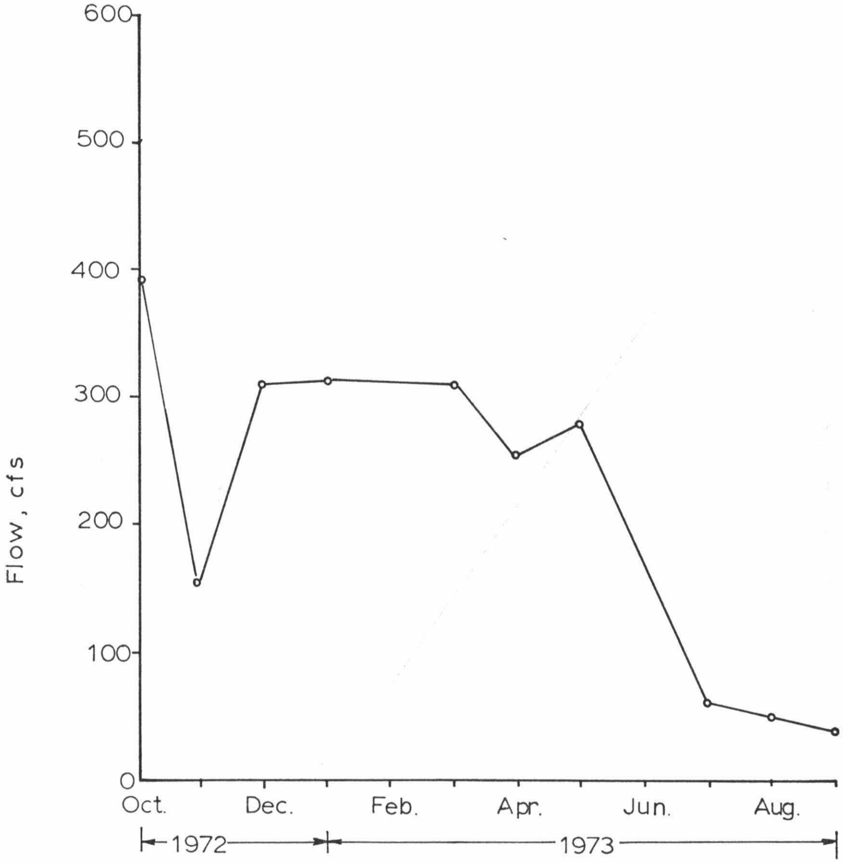


Figure 4.—Flow at Sites 1 and 2

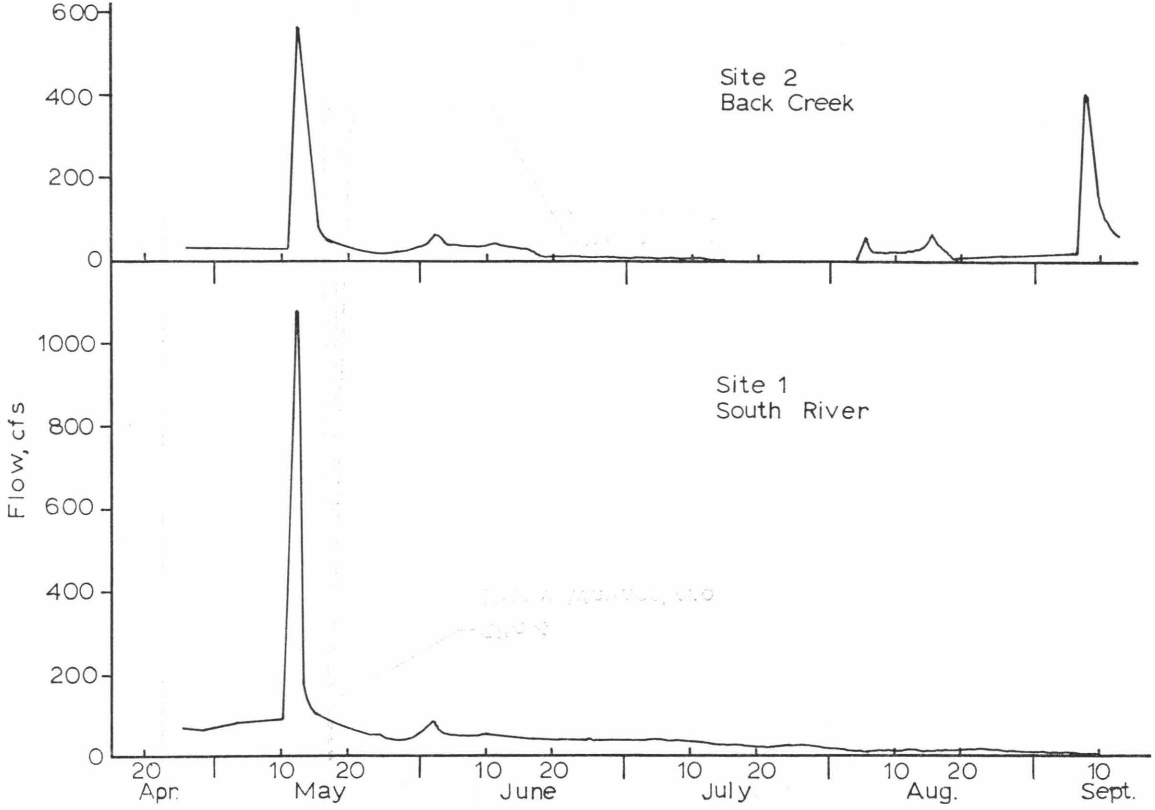
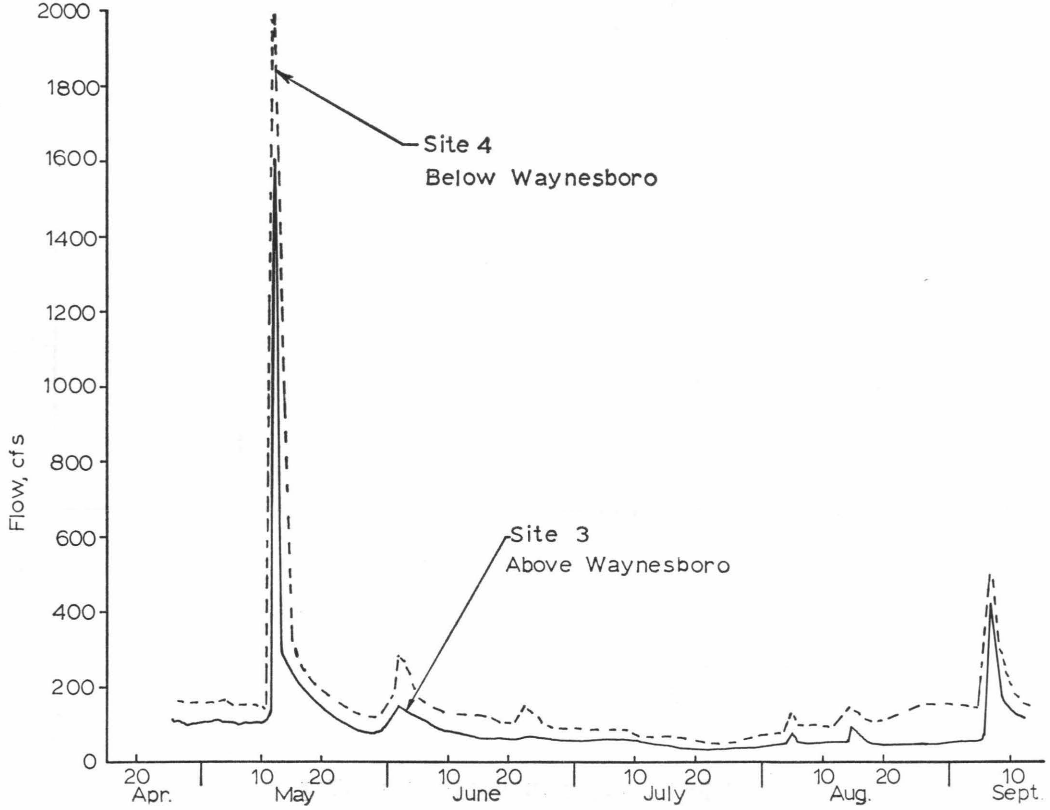


Figure 5.—Flow at Sites 3 and 4



streets and buildings should be significantly greater than the runoff from forest and agricultural lands.

Note that the hydrograph at Site 1, Figure 4, shows very little variation after June. This would seem to indicate that agricultural lands will not yield important quantities of pollutants after the crops become well established. In this situation because of the relatively steep gradient of Back Creek, forest land drainage can still play a very important role. Back Creek exhibits a "flashy" flood nature, as confirmed by local residents, and flow variations caused by land drainage from the forest are transmitted to the South River (Compare Figure 4 to Figure 5 during August and September). In fact, the majority of the increased pollutional load for the storm of September 6 is directly attributed to the forest land drainage and the urban runoff from Waynesboro.

Parameter Concentrations

Table V illustrates the differences in concentration for the various parameters during dry and wet weather flows. The averages are based on 14 sets of wet weather data and 25 sets of dry weather data. When comparing wet weather data with dry weather information, it should be kept in mind that some sedimentation probably occurred between Site 3 and Site 4 at low flows. The South River widens and meanders between these sampling locations. Also one of the industries adds about 20 cfs of ground water to the river between Sites 3 and 4. Therefore, some of the additional increases in concentrations at Site 4 may be due to the scouring of materials originally from agricultural or forest land, and they may not be from the urban runoff or the point sources. Sediment sampling to determine the influence of scour was beyond the scope of this research and was not conducted.

Referring to Table V, it can be seen that most of the parameters normally associated with sediment (i.e., COD, SS, turbidity, and phosphorus) generally increased during wet weather flow. These are mean values and are not weighted with respect to flow so they do not indicate the whole story. The organic contribution, based on COD values, was not of sufficient magnitude to cause concern. The large increase in phosphorus at Site 4 illustrates that the point sources contribute most of the phosphorus to the river.

Wet weather caused a large increase in turbidity and suspended solids concentration. A comparison of suspended solids data from other investigators (Table I) with the wet weather data of Table V indicates a lower value than expected. The sediment load is sufficient to be a water quality problem, especially during major storm events, but the impact of urban runoff on the sediment load might be higher for this location than for other watersheds.

The specific conductance determination indicates total dissolved solids in the water. As such, the best water comes from forest drainage and is recorded at Site 2. The agricultural lands contribute water with more dissolved salts, as expected. The decrease in specific conductance during wet weather at Sites 3 and 4 would seem to indicate that the urban runoff is low in dissolved solids although it may be carrying a considerable sediment load.

The agricultural drainage provides most of the nitrate, probably present in ground water which leaches through the soil mantle. Again, the surface drainage dilutes this parameter as it is of better quality with regard to this nutrient than the normal dry weather flow. As evidenced by the total kjeldahl nitrogen determination, the point sources are responsible for most of the organic nitrogen and ammonia present in the South River downstream from Waynesboro. Concentrations of all parameters except TKN and COD are significantly lower at Site 2 than at the other three sites. This agrees with studies by Taylor *et al.*(28) and Thomas and Crutchfield(39) in which concentrations in agricultural runoff consistently exceeded those in forest runoff. Both leachate and runoff from forests are low in organic matter, nutrients and dissolved ions because of the retentive capacity of the forest cover. This retentive capacity is also reflected in the fact that variations in concentrations under different dry and wet conditions are smallest at Site 2. Total suspended solids and turbidity are low at Site 2 because low creek flows have little erosive power or carrying capacity for sediment. The low concentration of sediment also results in low phosphorus concentrations since phosphorus is readily adsorbed in sediment(16).

The concentrations of nitrogen and phosphorus recorded during the study warrant additional discussion. Studies by the

Virginia Division of Water Resources(33) and Cairns and Dickson(34) have pointed out the problem of heavy algal growths and dissolved oxygen fluctuations downstream of the city of Waynesboro. The South River above Waynesboro has been found to have concentrations of nutrients in excess of the "limiting" values reported by Sawyer(9) and Mackenthun(11). For flowing streams, Mackenthun recommended that 0.1 mg/1 P should not be exceeded at any point within the stream, or that 0.05 mg/1 P should not be exceeded where water enters a standing body of water. Sawyer found that in lakes concentrations of 0.01 mg/1 of soluble phosphorus and 0.30 mg/1 inorganic nitrogen were sufficient to support algal blooms. Direct comparison cannot be made between Sawyer's soluble phosphorus value and the total phosphorus concentrations reported in this study, but nitrate values can be compared.

During the study nitrate concentrations at Site 1 were 2 to 8 times the critical value Sawyer reported. The average phosphorus concentration (0.16 mg/1 P) at this site was only slightly greater than Mackenthun's limit, but concentrations up to 3 times as great were reported on occasion. At Site 2 nitrate-N concentrations exceeded the limit in April and May but were negligible for the remainder of the study except for one sample taken during the storm of Sept. 6. Phosphorus concentrations at Site 2 sometimes exceeded Mackenthun's 0.05 mg/1 P limit but seldom exceeded the 0.1 mg/1 critical value. At Site 3 concentrations of phosphorus and nitrate usually exceeded limiting values. Nitrate concentrations were 2 to 10 times as great as Sawyer's critical value, but phosphorus concentrations only slightly exceeded the 0.1 mg/1 P limit. As expected, nutrient concentrations below Waynesboro were far in excess of the limiting concentrations. Nitrate concentrations at Site 4 were 4 to 12 times as great, and phosphorus concentrations were 2 to 6 times greater than the 0.1 mg/1 P limit.

High nitrogen and phosphorus concentrations were common at all sites during storm events. Baumann and Kelman(7) point out, however, that algal growth is not a problem during such high flows when the increased turbidity and scouring action of the flow inhibit aquatic plant growths. The fact that summer concentrations exceeded limiting values is more significant since light and turbidity conditions during those months were favorable for phytoplankton growth. During such favorable dry weather conditions, the principal source of nitrogen and phosphorus is derived from municipal and industrial wastewater discharges. It appears from upstream nitrate concentrations that nitrogen will never be limiting to algal growth even if the nitrogen in wastewater effluents is reduced. Control of phosphorus in wastewater would produce limiting concentrations some of the time since upstream phosphorus concentrations occasionally fall below Mackenthung's 0.1 mg/1 P limit.

Point Sources

Four main point sources discharge to the South River within the study area. They are municipal treatment facilities at Stuarts Draft and Waynesboro, the DuPont synthetic fiber plant, and the Crompton-Shenandoah dye and finishing plant. The Virginia State Water Control Board reports average effluent concentrations for the two main industries and city sewage treatment plant as follows:

1. DuPont synthetic fiber plant (1.77 MGD)—120 mg/1 TKN, 1.2 mg/1 Total P, 0.59 mg/1 NO_3-N, and 321 mg/1 COD.
2. Crompton-Shenandoah dye and finishing plant (1.70 MGD) —2.2 mg/1 TKN, 1.2 mg/1 Total P, 10.98 mg/1 NO_3-N, 69 mg/1 COD, and 12 mg/1 TSS.
3. Waynesboro sewage treatment plant effluent (2.15 MGD) —17 mg/1 TKN, 3.0 mg/1 Total P, 4.21 mg/1 NO_3-N, 98 mg/1 COD, and 19 mg/1 TSS.

Table VI presents the calculated wastewater loadings for the four most significant point source discharges in the Upper South River Basin. Stuarts Draft discharges an average 0.18 MGD of treated domestic waste from an aerated lagoon about 10.5 miles upstream of the Site 1 station. The Crompton-Shenandoah dye and finishing plant and the DuPont Company synthetic fiber plant are located in the city of Waynesboro, about 3.5 miles upstream of Site 4. An average 1.7 MGD of treated industrial waste are discharged from the Crompton-Shenandoah's secondary treatment system and an average 1.77 MGD from DuPont's activated sludge wastewater treatment plant. The city's high rate trickling filter plant discharges an average 2.15 MGD of treated domestic waste during June and July. Industrial waste discharges account for 75 percent of the total COD in all wastewater sources, 13 percent of the total phosphorus, 85 percent of the TKN and 67 percent of the nitrate nitrogen. The Waynesboro sewage treatment plant is the primary source of phosphorus.

Point Sources vs. Non-point Sources

The relative contributions of point sources and non-point sources with respect to sediment and the nutrients nitrogen and phosphorus are presented in this section. The data are not presented in annual weight per unit area terms (lb/acre/yr) for reasons previously discussed. Site 3 data were used as the total contribution of agricultural and forest land. During dry weather, Site 4 data represent the load present at Site 3 plus any changes because of point source discharges at Waynesboro. During wet weather, samples collected at Site 4 represent the load at Site 3 plus point sources plus urban runoff.

For purposes of this discussion, urban runoff will be considered as a non-point source. Other investigators may disagree with this designation because this discharge is usually from a pipe. However, the multiple discharge points used in a modern storm sewer system and the discontinuous nature of the discharge (only when it rains or snows) indicate that urban runoff affects the river as a non-point source and not as a point source. Values attributed to urban runoff were obtained by subtraction using data from Sites 3 and 4, and estimations of point source loads based on dry weather flow and the information presented in the previous section on point sources.

The foregoing discussion outlines the methods used to construct the figures presented in this section. It is believed that this approach is logical and provides worthwhile information. It is not entirely correct, however, and this needs to be emphasized so the figures can be properly interpreted.

A stream is a living, dynamic entity and it does not change merely because man would like to quantify its processes. Assimilation and waste discharges occurred within the stream by various aquatic organisms. Attempts were not made to determine their effects. Sediment and the compounds associated with the sediment were at times deposited in certain sections of the stream and later, possibly, resuspended during high flows. Sediment analyses were far beyond the scope of this investigation.

Also some construction activities, non-point sources themselves, may have caused some variations, particularly at Site 1. These activities were not separated but included as the non-point sources of agricultural and forest land. Also included in this last category were some urban runoff contributions which sometime occurred above Site 3 from roads and a residential area. This urban runoff was considered to be insignificant when compared with the urban discharge from the 7 square miles of Waynesboro proper.

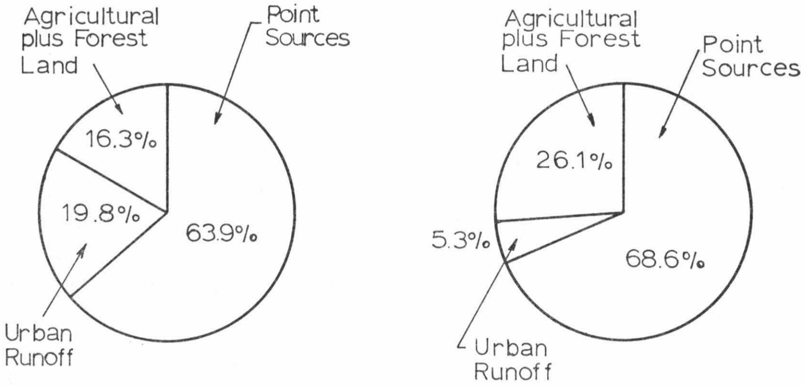
Figure 6 shows the total pounds of phosphorus, nitrogen, and sediment which passed Site 4 during the entire study period. The pie-charts have been broken into segments representing the portions attributed to point sources, urban runoff, and agricultural and forest lands by methods previously discussed. Agricultural and forest land contributions were not separated. Speculation regarding these contributions could be made by using Site 2 data as forest land contributions and Site 1 information for agricultural land. However, each site does contain a considerable portion of its drainage area in the other use.

The pie-charts clearly show that the point sources contributed the bulk of the nutrients to the South River, but only a minor portion of the sediment (2.1%). It is significant that 50% of the sediment was assigned to urban runoff. This may be slightly high because any river scour between Sites 3 and 4 because of increased flow would show up as an urban runoff contribution.

Eutrophication, sparked by increased quantities of nitrogen and phosphorus, has been a serious problem in recent years. Just how important man's activities are to this process is underscored when one considers that all the nutrients from the point sources and urban runoff, plus some of the nutrients from agricultural and forest lands, would not have entered the South River if man had not settled nearby. This amounts to something in excess of 84% of the phosphorus and in excess of 74% of the nitrogen. Pollution control measures and land use legislation become more realistic when man's activities are viewed in this regard.

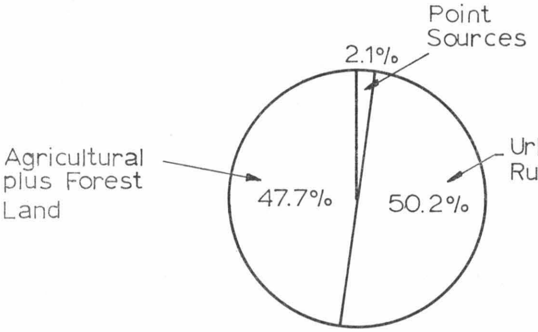
However, because of major storm-runoff events, the role that non-point sources play in nutrient supply cannot be ignored. Two major runoff events occurred on the South River during

Figure 6.—Point and Non-Point Source Total Contributions



42,260 lb P

463,800 lb N



3,169,000 lb Sediment

this study period, on May 12 and September 6. A five-day storm hydrograph was used for the storm of May 12 and a seven-day storm hydrograph was used for the event of September 6. Other minor events also occurred but they will not be discussed separately.

Table VII summarizes the sources of nutrients and sediment contributed during these two events. During the 5-day period of the May 12 storm-runoff event, for example, 74 percent of the nitrogen and 85 percent of the phosphorus came from non-point sources. Much of the nitrogen and phosphorus attributed to the non-point sources is contributed during major storm events. Clearly other years with different numbers of events will have a different segmentation than what is shown in Figure 6.

Figures 7, 8, and 9 show the daily fluctuations in stream load for sediment, nitrogen, and phosphorus, respectively. The loading rates are plotted in pounds per day so that the area under the graph represents the total pounds of constituent contributed to the river. The pie-charts pictorially present the information given in Table VII for the two most major storm events.

In each of the three figures, the loadings at both Sites 3 and 4 are shown. Site 3 data represent the non-point source load from agricultural and forest lands. Site 4 data represent the load at Site 3 plus the point source contribution during dry weather, while urban runoff is also included during wet weather.

The small difference in Figure 7 between Site 3 and Site 4 at times of dry-weather flow indicates that relatively small amounts of sediment are added by the point sources. Note that during low flow periods, the graph for Site 4 drops below the graph for Site 3. This apparent decrease in sediment load below Waynesboro is a result of some sedimentation as the river decreases velocity along with flow augmentation from groundwater pumped into the river. Subsequent higher flows may scour some of this material leading to erroneously high loads assigned to urban runoff. Point source contributions of sediment are almost negligible, and are negligible during storm runoff events.

Figure 8 shows the load rate variations for nitrogen. The point sources contributions of total nitrogen varies from about

Figure 7.—Sediment Variations

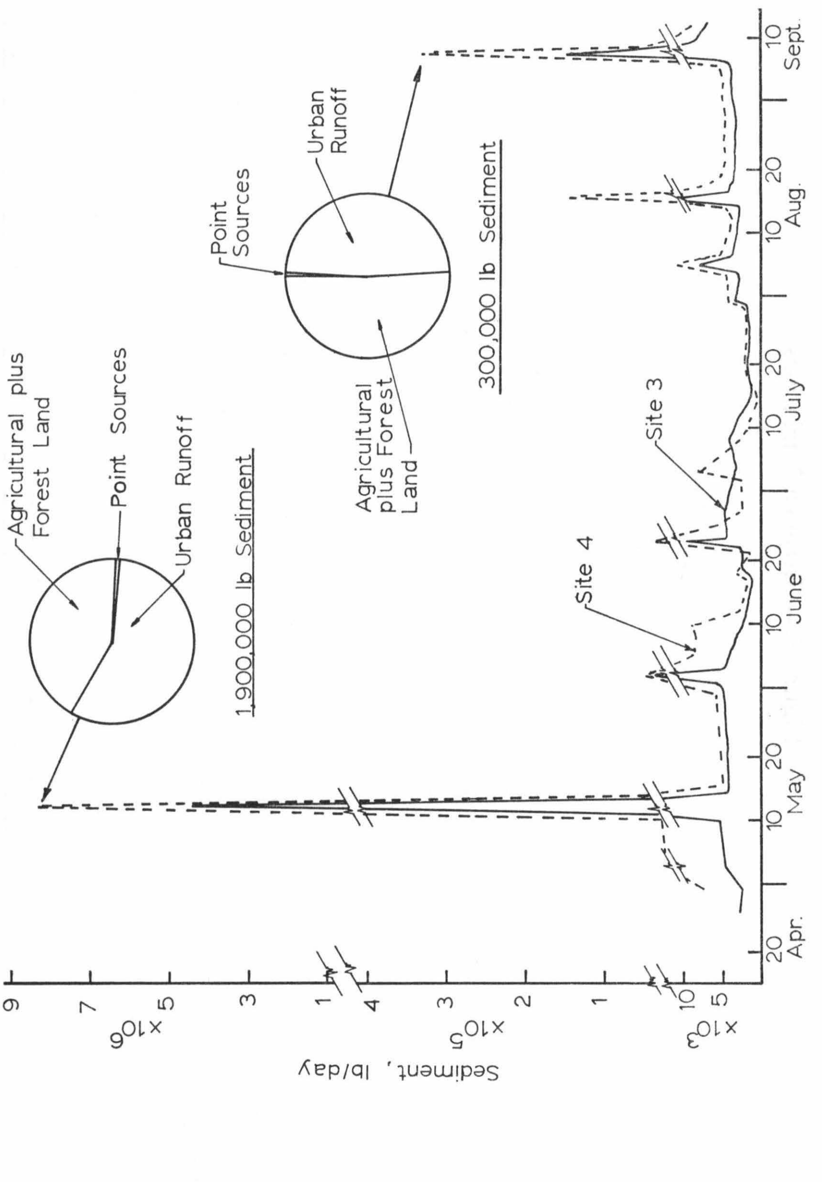


Figure 8.—Nitrogen Variations

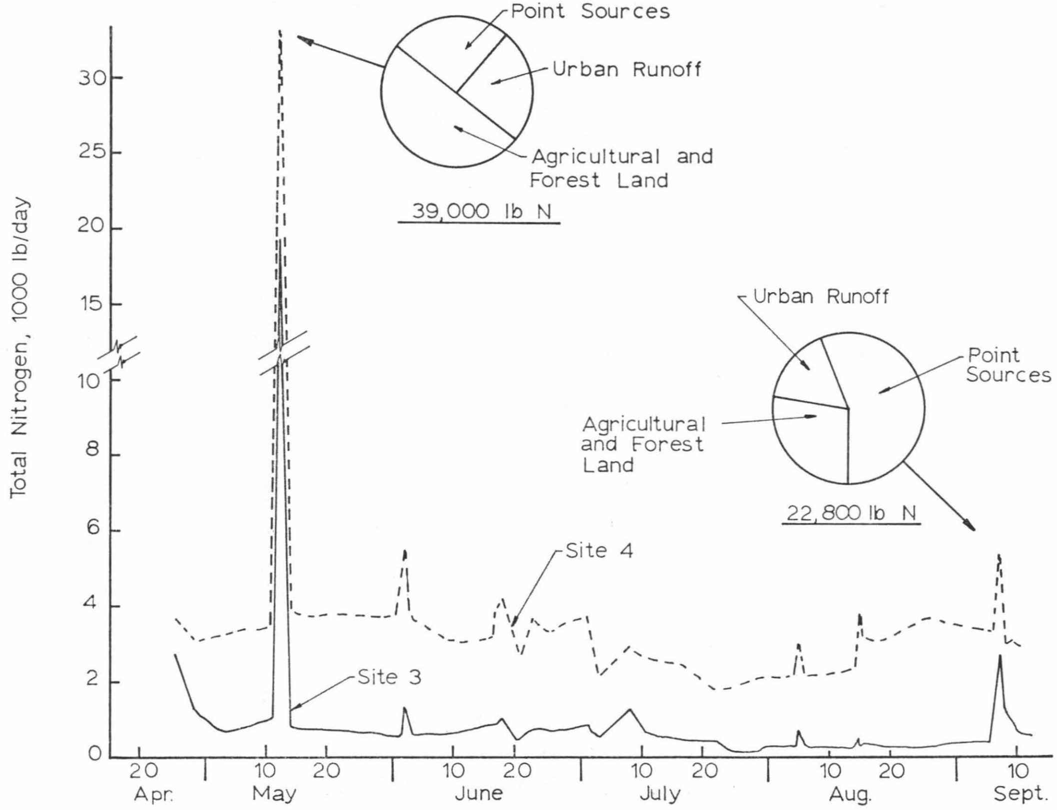
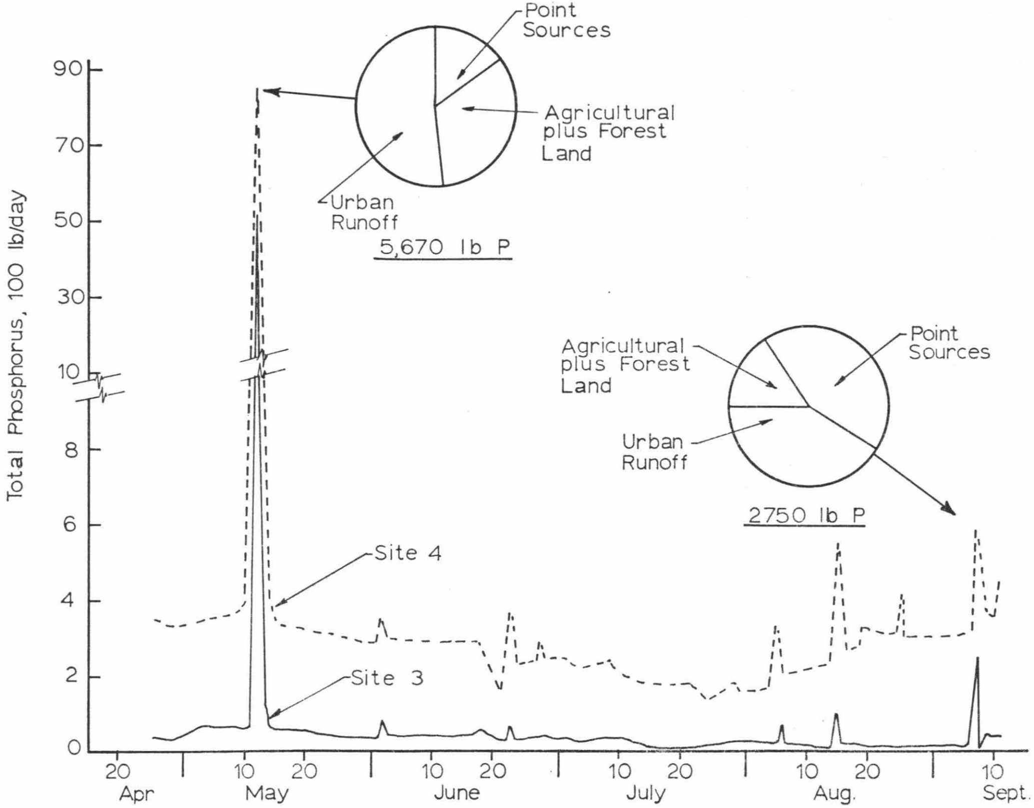


Figure 9.—Phosphorus Variations



1,500 lb/day to more than 3,000 lb/day. This contribution dwarfs the non-point source load during dry weather. Even during major storm events, the point sources contribute 25 to 55 percent of the nitrogen.

Figure 9 shows that almost all of the daily phosphorus load originates with point sources, primarily treated municipal wastewater. Clearly eutrophication control cannot be achieved without phosphorus reduction at sewage treatment facilities. Urban runoff deposits more phosphorus in the South River than was anticipated. The portion attributed to urban drainage may be somewhat high because of sediment scour (and associated phosphorus) which occurs between Site 3 and 4. The phosphorus load attributed to urban runoff, however, is not unrealistic when compared with other urban studies(30)(31).

V. SUMMARY AND CONCLUSIONS

The Upper South River Basin represented a good location for a field study to compare the relative importance of point and non-point sources of pollution. An ideal field situation is seldom found, and the data interpretation reflects uncertainties relating to changes occurring within the stream at various times, such as assimilation, sedimentation, and scour. Urban runoff contributions were calculated using limited point source loading information and were affected by the limitations mentioned.

If the study was conducted during a "normal" year, the infrequent occurrence of major storm events must be noted. Only several years of study could determine if the events of this year were normal or abnormal. Certainly as the number of major storm events decrease, the importance of the non-point sources decrease as well.

Point sources contributed only negligible quantities of sediment, but the majority of the nitrogen and phosphorus. The nitrogen and phosphorus contributions of point sources during major storm events usually were over-shadowed by the summation of the non-point source contributions.

If phosphorus is the nutrient which should be controlled to retard eutrophication, point source control should be exercised and urban runoff controls should be considered. If 90% of the phosphorus attributed to these two sources could be eliminated, it is quite probable that eutrophication can be slowed to an acceptable rate. This approach should be considered.

It would be well to reinforce the findings of this study by additional data collection either in the same location, at other locations, or both. These studies should collect similar data. However, it will probably not be necessary to attempt to define loadings from agricultural land and forest land as separate categories. The total will be sufficient. Additional data should be obtained on the urban runoff contribution and the point source variability should be defined. Information on stream waste assimilation would be useful, and special attention should be given to the effects of scour on water quality during periods of high flows.

(*continued*)

Based on this limited study, the following conclusions appear to be justified.

1. The point sources were the source of most of the organic nitrogen, ammonia, and phosphorus during the study period.
2. Agricultural drainage provided most of the nitrate.
3. Non-point sources contributed about 98% of the sediment.
4. The organic pollution resulting from non-point discharges is insignificant.
5. Phosphorus removal should be practiced at point sources.
6. Urban runoff pollution controls are necessary.

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TABLES

Table I. Nutrient Yields from Land Runoff

Land Runoff (lb/acre/year)	Weidner *et al.* (Ohio)	Engelbrecht & Morgan (Illinois)	Sawyer (Wisconsin)	Dornbush *et al.* (South Dakota)	Witzel *et al.* (Wisconsin)	Cooper (Minnesota)	Sylvester (Washington)	Jaworski & Hetling (Potomac R. Basin)	Taylor *et al.* (Ohio)	Soderlund & Lehtinen (Sweden)	Weibel *et al.* (Cincinnati)	Colston (North Carolina)	Kluesner & Lee (Wisconsin)
Agri. Runoff													
Total P	0.36–9.2	0.32	0.4	0.09–0.27	1.1			0.7	0.05				
NO_3-N				0.21–0.36				3.0					
TKN				0.65–1.00				0.4					
Total N	11–237		7.0	0.86–1.36	3.6				4.1				
SS				3.6 –255									
COD	64–1300			12–43									
Forest Runoff													
Total P						0.07–0.16	0.3–0.8	0.09	0.04				
NO_3-N						0.23–2.38		1.15					
TKN						0.95–2.08		0.23					
Total N							1.3–3.0		2.1				
Urban Runoff													
Total P								0.6		.09	2.5	4.7	.98
NO_3-N								1.5					160
TKN								0.4				6.1	
Total N										1.6	8.9	6690	
SS										196	730	938	
COD											240		

Table II. Physical Characteristics of South River and Back Creek (35)

Characteristics	South River	Back Creek
Drainage Area (sq. miles)	234.4	42
Length (miles)	52.3	13.3
Elevation at source (feet)	2,020	2,750
Elevation at mount (feet)	1,040	1,330

Table III. Land Use in Drainage Areas of South River and Back Creek

Description		Drainage Area sq. miles	 % Total (74)
Site 1	Rts. 664 bridge South River	85	100
—forest		45	53
—pasture/grassland		27	32
—cropland		11	13
—residential/industrial		2	2
Site 2	Rte. 624 bridge South River	43	100
—forest		38.1	88.6
—pasture/grassland		4.3	10
—cropland		0.4	0.9
—residential		0.2	0.5
Site 3	Rte. 664 bridge South River	133	100
—forest		86	65
—pasture/grassland		32	24
—cropland		12	9
—residential/industrial		3	2
Site 4	Hopeman Parkway bridge South River	157	100
—forest		96	61
—pasture/grassland		37	24
—cropland		14	9
—residential/industrial		10	6

Table IV. Comparison of Total Monthly Rainfall Measured at Stuarts Draft Rain Gage

Month	Rainfall (inches)
May 1974	3.40
May Average *	3.41
June 1974	4.58
June Average *	3.74
July 1974	2.22
July Average *	3.44
August 1974	5.44
August Average *	3.65

* Averages based on 14 years of record.

Table V. Dry and Wet Weather Comparison of Mean Concentrations

	Parameter *						
Site and Weather	COD, mg/1	SS, mg/1	Turbidity, mg/1 SiO_2	Specific Conductance μmhos/cm @ 25° C	Total P mg/1	Total Kjeldahl Nitrogen, mg/1	Nitrate, mg/1 N
Site 1							
Dry	5	14	8	229	0.11	0.9	1.18
Wet	16	50	29	230	0.19	0.8	0.94
Site 2							
Dry	4	2	2	34	0.04	0.8	0.08
Wet	15	38	15	64	0.07	0.7	0.11
Site 3							
Dry	6	11	7	195	0.10	0.8	1.04
Wet	20	70	29	113	0.21	0.7	0.40
Site 4							
Dry	20	9	8	376	0.45	3.2	2.05
Wet	36	139	46	215	0.39	1.7	1.05

* Mean value based on 14 dry weather samples and 25 wet weather samples.

Table VI. Calculated Wastewater Loadings to Upper South River Basin*

Parameter (lb/day)	Stuarts Draft Municipal Plant	Crompton-Shenandoah Plant	DuPont Plant	Waynesboro Municipal Plant	Total
COD	107	955	4,719	1,754	7,535
TSS	24	181	Not available	340	545
Total phosphorus (as P)	15	5	18	143	181
TKN	14	31	1,764	304	2,113
NO_3-N	4	155	9	75	243

* 24 hr. composite concentrations and MGD of effluent, provided by Virginia State Water Control Board.

Table VII. Summary of Storm Contributions

Source and	Nitrogen		Phosphorus		Sediment	
Events	Lbs.	%	Lbs.	%	Lbs.	%
Storm of 5/12						
Point	10,000	25.6	850	15.0	1,100	0.1
Urban	9,400	24.1	2,935	51.8	1,098,900	57.8
Agriculture and Forest	19,600	50.3	1,885	33.2	800,000	42.1
Total	39,000	100.0	5,670	100.0	1,900,000	10.00
Storm of 9/6						
Point	12,840	56.3	1,190	43.2	1,600	0.5
Urban	3,660	16.1	1,135	41.2	146,400	48.8
Agriculture and Forest	6,300	27.6	425	15.6	152,000	50.7
Total	22,800	100.0	2,750	100.0	300,000	100.0

APPENDIX

Chemical and Physical Quality Characteristics

Chemical and Physical Quality Characteristics

Date: April 26, 1974
Weather: Dry

Characteristic *	Site 1	Site 2	Site 3	Site 4
Flow (cfs)	78	38	116	165
COD	8	8	12	27
Total suspended solids	—	—	—	—
Turbidity (mg/1 SiO_2)	11	5	15	25
Specific conductance (micromhos/cm @ 25°C)	214	35	146	309
Total phosphorus as P	.07	.02	.07	.39
Total kjeldahl nitrogen	.4	0	1.3	1.7
Nitrate as N	1.07	.99	3.19	2.38

Date: April 29, 1974
Weather: Dry

Characteristic *	Site 1	Site 2	Site 3	Site 4
Flow (cfs)	62	38	100	159
COD	8	8	12	35
Total suspended solids	9	0.2	5	9
Turbidity (mg/1 SiO_2)	13	4	12	22
Specific conductance (micromhos/cm @ 25°C)	196	25	144	282
Total phosphorus as P	.07	.01	.07	.39
Total kjeldahl nitrogen	.4	0	.4	2.5
Nitrate as N	.85	.43	1.87	1.16

Date: May 3, 1974
Weather: Wet, 0.37″ rain over 19 hrs.

Characteristic *	Site 1	Site 2	Site 3	Site 4
Flow (cfs)	86	28	114	165
COD	20	8	20	28
Total suspended solids	10	1	8	13
Turbidity (mg/1 SiO_2)	16	4	15	18
Specific conductance (micromhos/cm @ 25°C)	205	30	156	295
Total phosphorus as P	.07	0	.11	.39
Total kjeldahl nitrogen	.4	.4	.4	2.5
Nitrate as N	.91	.43	.69	1.16

* All concentrations in milligrams per liter (mg/1) except as noted.

Date: May 12, 1974
Weather: Storm, 1.24″ rain over 6 hrs.

Characteristic *	Site 1	Site 2	Site 3	Site 4
Flow (cfs)	1080	570	1650	1985
COD	36	48	76	100
Total suspended solids	57	311	476	711
Turbidity mg/1 SiO_2)	18	76	160	180
Specific conductance (micromhos/cm @ 25°C)	206	77	42	77
Total phosphorus as P	0.16	0.33	0.58	0.79
Total kjeldahl nitrogen	1.3	1.7	1.7	2.5
Nitrate as N	0.79	0	0.48	0.57
Fe	0.28	0.67	0.79	0.71

Date: May 12, 1974
Weather: Storm, 1.24″ rain over 6 hrs.

Characteristic *	Site 1	Site 2	Site 3	Site 4
Flow (cfs)	1030	420	1450	1785
COD	28	52	60	84
Total suspended solids	39	100	136	328
Turbidity (mg/1 SiO_2)	8	22	36	76
Specific conductance (micromhos/cm @ 25°C)	223	214	57	261
Total phosphorus as P	0.10	0.13	0.21	0.46
Total kjeldahl nitrogen	1.1	1.1	1.3	1.3
Nitrate as N	0.91	0	0	0
Fe	0.21	0.38	0.49	0.68

Date: May 13, 1974
Weather: Dry

Characteristic *	Site 1	Site 2	Site 3	Site 4
Flow (cfs)	400	420	820	1150
COD	28	24	40	68
Total suspended solids	57	15	31	46
Turbidity (mg/1 SiO_2)	25	8	12	12
Specific conductance (micromhos/cm @ 25°C)	190	141	111	240
Total phosphorus as P	0.27	0	0.06	0.15
Total kjeldahl nitrogen	1.5	1.3	1.1	1.3
Nitrate as N	0.99	0	0.51	0.54
Fe	0.59	0.20	0.32	0.36

* All concentrations in milligrams per liter (mg/1) except as noted.

Chemical and Physical Quality Characteristics (Continued)

Date: June 2, 1974
Weather: Wet, 0.87″ over 7.5 hrs.

Characteristic *	Site 1	Site 2	Site 3	Site 4
Flow (cfs)	91	65	156	286
COD	14	6	8	14
Total suspended solids	47	5	40	29
Turbidity (mg/1 SiO_2)	24	2.8	22	8
Specific conductance (micromhos/cm @ 25°C)	186	36.3	121	214
Total phosphorus as P	0.2	0.03	0.1	0.23
Total kjeldahl nitrogen	1.1	0.8	0.7	1.1
Nitrate as N	2.10	0	0.91	1.68

Date: June 10, 1974
Weather: Dry

Characteristic *	Site 1	Site 2	Site 3	Site 4
Flow (cfs)	62.5	21.5	84	131
COD	2	1	2	18
Total suspended solids	14	1	5	12
Turbidity (mg/1 SiO_2)	10	1	5	17
Specific conductance (micromhos/cm @ 25°C)	214	32	172	323
Total phosphorus as P	—	—	—	—
Total kjeldahl nitrogen	1.1	0.8	0.7	1.9
Nitrate as N	1.38	0	0.91	2.38

Date: June 17, 1974
Weather: Wet, 0.23″ rain over 7 hrs.

Characteristic *	Site 1	Site 2	Site 3	Site 4
Flow (cfs)	48.5	21.5	70	122
COD	4	2	2.5	12
Total suspended solids	8	2	3	3
Turbidity (mg/1 SiO_2)	6	1	3	4
Specific conductance (micromhos/cm @ 25°C)	224	33	181	301
Total phosphorus as P	0.1	0.07	0.12	0.45
Total kjeldahl nitrogen	0.8	0.4	0.8	2.9
Nitrate as N	1.68	0	1.44	2.95

* All concentrations in milligrams per liter (mg/1) except as noted.

Date: June 18, 1974
Weather: Dry

Characteristic *	Site 1	Site 2	Site 3	Site 4
Flow (cfs)	52	18	70	110
COD	5	2	2	15
Total suspended solids	11	1	7	6
Turbidity (mg/1 SiO_2)	5	1	4	5
Specific conductance (micromhos/cm @ 25°C)	228	36	200	338
Total phosphorus as P	0.18	0.08	0.16	0.48
Total kjeldahl nitrogen	1.7	1.3	1.1	5.4
Nitrate as N	2.10	0	1.68	1.77

Date: June 21, 1974
Weather: Wet, 0.11″ rain over 14.5 hrs.

Characteristic *	Site 1	Site 2	Site 3	Site 4
Flow (cfs)	45.5	15.5	61	107
COD	4	3	3	17
Total suspended solids	18	4	8	3
Turbidity (mg/1 SiO_2)	7	1	6	5
Specific conductance (micromhos/cm @ 25°C)	241	35	205	366
Total phosphorus as P	0.13	0	0.10	0.28
Total kjeldahl nitrogen	1.3	0.4	0	2.1
Nitrate as N	1.60	0	1.52	2.74

Date: June 23, 1974
Weather: Wet, 0.85″ rain over 14 hrs.

Characteristic *	Site 1	Site 2	Site 3	Site 4
Flow (cfs)	55	17	72	148
COD	14	8	11	26
Total suspended solids	104	13	24	40
Turbidity (mg/1 SiO_2)	27	4	8	9
Specific conductance (micromhos/cm @ 25°C)	272	37	207	284
Total phosphorus as P	0.34	0.08	0.18	0.46
Total kjeldahl nitrogen	0.4	0	0.4	1.7
Nitrate as N	1.77	0	1.59	2.95

* All concentrations in milligrams per liter (mg/1) except as noted.

Chemical and Physical Quality Characteristics (Continued)

Date: June 26, 1974
Weather: Dry

Characteristic *	Site 1	Site 2	Site 3	Site 4
Flow (cfs)	51.5	12.5	64	110
COD	4	1	4	17
Total suspended solids	15	0	14	9
Turbidity (mg/1 SiO_2)	5	1	5	4
Specific conductance (micromhos/cm @ 25°C)	230	34	203	368
Total phosphorus as P	0.11	0.01	0.11	0.4
Total kjeldahl nitrogen	0.4	0	0.6	2.1
Nitrate as N	1.87	0	1.60	3.48

Date: June 28, 1974
Weather: Dry

Characteristic *	Site 1	Site 2	Site 3	Site 4
Flow (cfs)	49.5	12.5	62	94
COD	5	3	4	17
Total suspended solids	14	1	14	6
Turbidity (mg/1 SiO_2)	4	1	4	4
Specific conductance (micromhos/cm @ 25°C)	231	36	213	373
Total phosphorus as P	0.2	0.06	0.13	0.57
Total kjeldahl nitrogen	0.8	3.1	0.8	4
Nitrate as N	1.77	0	1.45	3.19

Date: July 1, 1974
Weather: Dry

Characteristic *	Site 1	Site 2	Site 3	Site 4
Flow (cfs)	49.5	12.5	62	94
COD	3	2	3	18
Total suspended solids	14	1	12	6
Turbidity (mg/1 SiO_2)	5	1	5	5
Specific conductance (micromhos/cm @ 25°C)	227	33	210	355
Total phosphorus as P	0.12	0.04	0.11	0.50
Total kjeldahl nitrogen	0.8	1	0.8	4.6
Nitrate as N	2.38	0	1.68	2.74

* All concentrations in milligrams per liter (mg/1) except as noted.

Date: July 3, 1974
Weather: Dry

Characteristic *	Site 1	Site 2	Site 3	Site 4
Flow (cfs)	56	6	62	86
COD	3	3	8	16
Total suspended solids	12	3	11	17
Turbidity (mg/1 SiO_2)	5	2	5	6
Specific conductance (micromhos/cm @ 25°C)	225	35	221	394
Total phosphorus as P	0.10	0.02	0.07	0.48
Total kjeldahl nitrogen	0.8	0.6	0.8	2.9
Nitrate as N	0.85	0	0.82	1.68

Date: July 8, 1974
Weather: Dry

Characteristic *	Site 1	Site 2	Site 3	Site 4
Flow (cfs)	52.5	9.5	62	94
COD	7	4	7	20
Total suspended solids	11	0	12	6
Turbidity (mg/1 SiO_2)	5	4	8	7
Specific conductance (micromhos/cm @ 25°C)	222	39	209	351
Total phosphorus as P	0.12	0.03	0.12	0.48
Total kjeldahl nitrogen	2.9	2.9	2.9	4.2
Nitrate as N	0.99	0	0.88	1.52

Date: July 11, 1974
Weather: Wet, 0.70″ rain over 15 hrs.

Characteristic *	Site 1	Site 2	Site 3	Site 4
Flow (cfs)	43.5	12.5	56	72
COD	2	2	5	19
Total suspended solids	13	1	10	5
Turbidity (mg/1 SiO_2)	5	2	5	5
Specific conductance (micromhos/cm @ 25°C)	233	48	196	488
Total phosphorus as P	0.12	0.06	0.12	0.52
Total kjeldahl nitrogen	1.3	1.3	1.3	5.0
Nitrate as N	1.32	0	0.82	1.77

* All concentrations in milligrams per liter (mg/1) except as noted.

Chemical and Physical Quality Characteristics (Continued)

Date: July 15, 1974
Weather: Dry

Characteristic *	Site 1	Site 2	Site 3	Site 4
Flow (cfs)	39.5	2.5	42	75
COD	3	1	2	15
Total suspended solids	4	1	6	2
Turbidity (mg/1 SiO_2)	4	1	4	5
Specific conductance (micromhos/cm @ 25°C)	233	37	224	393
Total phosphorus as P	0.07	0.02	0.07	0.44
Total kjeldahl nitrogen	1.2	1.1	1.3	3.8
Nitrate as N	0.91	0	0.91	2.38

Date: July 18, 1974
Weather: Dry

Characteristic *	Site 1	Site 2	Site 3	Site 4
Flow (cfs)	37.5	2.5	40	66
COD	3	4	4	20
Total suspended solids	9	4	7	5
Turbidity (mg/1 SiO_2)	5	1	4	4
Specific conductance (micromhos/cm @ 25°C)	237	41	229	449
Total phosphorus as P	0.10	0.02	0.07	0.51
Total kjeldahl nitrogen	1.3	1.3	1.3	4.2
Nitrate as N	0.99	0	0.72	2.38

Date: July 22, 1974
Weather: Dry

Characteristic *	Site 1	Site 2	Site 3	Site 4
Flow (cfs)	38	0	38	54
COD	1	—	2	19
Total suspended solids	10	—	9	7
Turbidity (mg/1 SiO_2)	2	—	3	4
Specific conductance (micromhos/cm @ 25°C)	228	—	236	413
Total phosphorus as P	0.15	—	0.05	0.62
Total kjeldahl nitrogen	1.3	—	1.3	3.8
Nitrate as N	0.74	—	0.74	2.38

* All concentrations in milligrams per liter (mg/1) except as noted.

Date: July 25, 1974
Weather: Dry

Characteristic *	Site 1	Site 2	Site 3	Site 4
Flow (cfs)	42	0	42	54
COD	3	—	5	28
Total suspended solids	9	—	8	6
Turbidity (mg/1 SiO_2)	4	—	3	4
Specific conductance (micromhos/cm @ 25°C)	246	—	246	583
Total phosphorus as P	0.07	—	0.09	0.47
Total kjeldahl nitrogen	0	—	0	4.2
Nitrate as N	0.67	—	0.61	2.10

Date: July 29, 1974
Weather: Dry

Characteristic *	Site 1	Site 2	Site 3	Site 4
Flow (cfs)	37.5	2.5	40	72
COD	5	5	4	22
Total suspended solids	12	3	9	6
Turbidity (mg/1 SiO_2)	5	2	5	6
Specific conductance (micromhos/cm @ 25°C)	237	43	233	428
Total phosphorus as P	0.15	0.14	0.15	0.47
Total kjeldahl nitrogen	0.4	0.4	0.4	3.4
Nitrate as N	0.54	0	0.45	1.99

Date: July 30, 1974
Weather: Wet, 0.47″ rain over 9 hrs.

Characteristic *	Site 1	Site 2	Site 3	Site 4
Flow (cfs)	36	7	43	75
COD	5	8	7	25
Total suspended solids	18	13	16	11
Turbidity (mg/1 SiO_2)	6.1	1.6	8.0	8.0
Specific conductance (micromhos/cm @ 25°C)	223	37	230	451
Total phosphorus as P	0.15	0.06	0.14	0.4
Total kjeldahl nitrogen	0.4	0.4	0.4	3.4
Nitrate as N	0.63	0	0.61	1.87

* All concentrations in milligrams per liter (mg/1) except as noted.

Chemical and Physical Quality Characteristics (Continued)

Date: August 5, 1974
Weather: Wet

Characteristic *	Site 1	Site 2	Site 3	Site 4
Flow (cfs)	21	60	81	131
COD	5	5	6	21
Total suspended solids	15	3	17	22
Turbidity (mg/1 SiO_2)	4	3	6	7
Specific conductance (micromhos/cm @ 25°C)	243	38	141	299
Total phosphorus as P	0.10	0.04	0.07	0.47
Total kjeldahl nitrogen	1.5	1.2	1.1	3.1
Nitrate as N	0.76	0	0.35	1.16

Date: August 6, 1974
Weather: Dry

Characteristic *	Site 1	Site 2	Site 3	Site 4
Flow (cfs)	27	31	58	100
COD	3	1	10	17
Total suspended solids	11	1	75**	10
Turbidity (mg/1 SiO_2)	4	1	7	4
Specific conductance (micromhos/cm @ 25°C)	251	38	177	392
Total phosphorus as P	0.08	0.02	0.22	0.40
Total kjeldahl nitrogen	0.4	0.4	0.7	2.5
Nitrates as N	0.69	0	0.36	1.52

** Bottom disturbed while sampling.

Date: August 12, 1974
Weather: Dry

Characteristic *	Site 1	Site 2	Site 3	Site 4
Flow (cfs)	37	29	56	98
COD	8	8	5	19
Total suspended solids	16	0	9	7
Turbidity (mg/1 SiO_2)	5	1	5	6
Specific conductance (micromhos/cm @ 25°C)	245	36	178	376
Total phosphorus as P	0.09	0.09	0.05	0.44
Total kjeldahl nitrogen	0.5	0.4	0.5	3.2
Nitrate as N	0.69	0	0.38	1.07

* All concentrations in milligrams per liter (mg/1) except as noted.

Date: August 14-15, 1974
Weather: Wet

Characteristic *	Site 1 11:55 pm	Site 2 12:06 am	Site 3 12:24 am	Site 4 12:45 am
Flow (cfs)	24	74	98	147
COD	8	16	6	26
Total suspended solids	26	10	23	41
Turbidity (mg/1 SiO_2)	5	4	7	39
Specific conductance (micromhos/cm @ 25°)	235	84	191	302
Total phosphorus as P	0.13	0.21	0.19	0.51
Total kjeldahl nitrogen	0.7	0.8	0.5	2.5
Nitrate as N	0.69	0	0.51	1.38

Date: August 15, 1974
Weather: Wet

Characteristic *	Site 1 1:10 am	Site 2 1:20 am	Site 3 1:35 am	Site 4 1:55 am
Flow (cfs)	25	66	91	140
COD	6	11	7	26
Total suspended solids	28	4	22	110
Turbidity (mg/1 SiO_2)	48	13	7	63
Specific conductance (micromhos/cm @ 25°C)	246	70	170	344
Total phosphorus as P	0.14	0.07	0.13	0.57
Total kjeldahl nitrogen	0.4	0.7	0.4	2.8
Nitrate as N	0.69	0	0.41	1.68

Date: August 15, 1974
Weather: Wet

Characteristic *	Site 1 2:55 am	Site 2 3:08 am	Site 3 3:25 am	Site 4 3:46 am
Flow (cfs)	29	59	88	137
COD	8	7	13	36
Total suspended solids	27	2	22	198
Turbidity (mg/1 SiO_2)	11	5	10	32
Specific conductance (micromhos/cm @ 25°C)	244	51	142	308
Total phosphorus as P	0.15	0.04	0.11	0.73
Total kjeldahl nitrogen	0.6	0.5	0.4	3.0
Nitrate as N	0.69	0	0.51	2.10

* All concentrations in milligrams per liter (mg/1) except as noted.

Chemical and Physical Quality Characteristics (Continued)

Date: August 19, 1974
Weather: Dry

Characteristic *	Site 1 11:15 am	Site 2 11:30 am	Site 3 11:45 am	Site 4 12:00 noon
Flow (cfs)	31	18	49	106
COD	8	4	6	23
Total suspended solids	25	1	13	9
Turbidity (mg/1 SiO_2)	7	2	6	8
Specific conductance (micromhos/cm @ 25°C)	255	41	209	471
Total phosphorus as P	0.12	0	0.10	0.58
Total kjeldahl nitrogen	0.4	0.4	0.4	3.1
Nitrate as N	1.17	0	0.79	2.38

Date: August 26, 1974
Weather: Dry

Characteristic *	Site 1	Site 2	Site 3	Site 4
Flow (cfs)	31	20	51	156
COD	1	0	3	20
Total suspended solids	19	1	12	6
Turbidity (mg/1 SiO_2)	21	5	15	13
Specific conductance (micromhos/cm @ 25°C)	242	40	196	378
Total phosphorus as P	0.09	0.01	0.07	0.49
Total kjeldahl nitrogen	0.7	0.2	0.4	2.7
Nitrate as N	0.79	0	0.61	1.68

Date: September 7, 1974
Weather: Storm of September 6, 1974

Characteristic *	Site 1 9:20 am	Site 2 9:35 am	Site 3 10:00 am	Site 4 10:50 am
Flow (cfs)	10	410	420	495
COD	15	11	15	32
Total suspended solids	67	28	65	127
Turbidity (mg/1 SiO_2)	52	28	41	57
Specific conductance (micromhos/cm @ 25°C)	249	32	87	165
Total phosphorus as P	0.30	0.03	0.09	0.22
Total kjeldahl nitrogen	0.9	0.8	0.6	1.3
Nitrate as N	1.07	0	0.28	0.69

* All concentrations in milligrams per liter (mg/1) except as noted.

Date: September 7, 1974
Weather: Storm

Characteristic *	Site 1 12:20 pm	Site 2 12:40 pm	Site 3 12:45 pm	Site 4 1:35 pm
Flow (cfs)	8	402	410	485
COD	27	11	16	29
Total suspended solids	128	17	57	103
Turbidity (mg/1 SiO_2)	63	16	37	47
Specific conductance (micromhos/cm @ 25°C)	222	31	89	142
Total phosphorus as P	0.29	0.03	0.10	0.22
Total kjeldahl nitrogen	1.2	0.5	0.7	1.4
Nitrate as N	0.91	0	0.36	0.65

Date: September 7, 1974
Weather: Storm

Characteristic *	Site 1 3:30 pm	Site 2 3:45 pm	Site 3 4:10 pm	Site 4 4:30 pm
Flow (cfs)	25	360	385	465
COD	18	11	10	21
Total suspended solids	58	15	53	72
Turbidity (mg/1 SiO_2)	48	13	33	36
Specific conductance (micromhos/cm @ 25°C)	229	31	84	155
Total phosphorus as P	0.21	0.06	0.12	0.23
Total kjeldahl nitrogen	0.6	0.2	0.9	1.3
Nitrate as N	0.79	0	0.35	0.61

Date: September 7, 1974
Weather: Storm

Characteristic *	Site 1 10:30 pm	Site 2 10:50 pm	Site 3 11:00 pm	Site 4 12:00 am
Flow (cfs)	5	335	340	410
COD	12	6	7	16
Total suspended solids	39	10	30	48
Turbidity (mg/1 SiO_2)	41	11	21	31
Specific conductance (micromhos/cm @ 25°C)	215	33	84	147
Total phosphorus as P	0.17	0.01	0.05	0.22
Total kjeldahl nitrogen	0.9	0.6	0.5	1.1
Nitrate as N	1.52	0	0.33	0.69

* All concentrations in milligrams per liter (mg/1) except as noted.

Chemical and Physical Quality Characteristics (concluded)

Date: September 8, 1974
Weather: Storm of September 6, 1974

Characteristic *	Site 1 11:00 am	Site 2 11:20 am	Site 3 12:00 pm	Site 4 1:00 pm
Flow (cfs)	10	260	270	323
COD	10	4	8	13
Total suspended solids	32	7	21	33
Turbidity (mg/1 SiO_2)	27	6	20	25
Specific conductance (micromhos/cm @ 25°C)	214	38	86	142
Total phosphorus as P	0.10	0	0	0.08
Total kjeldahl nitrogen	0.7	0.4	0.4	1.1
Nitrate as N	0.74	0	0.43	0.65

Date: September 9, 1974
Weather: Storm of September 6, 1974

Characteristic *	Site 1 11:20 am	Site 2 11:30 am	Site 3 11:45 am	Site 4 12:06 pm
Flow (cfs)	0	170	169	237
COD	5	3	4	16
Total suspended solids	14	1	11	18
Turbidity (mg/1 SiO_2)	20	7	11	19
Specific conductance (micromhos/cm @ 25°C)	232	30	103	198
Total phosphorus as P	0.14	0.02	0.06	0.28
Total kjeldahl nitrogen	0.5	0.5	0.5	1.6
Nitrate as N	0.79	0.35	0.57	0.85

Date: September 11, 1974
Weather: Storm of September 6, 1974

Characteristic *	Site 1 10:00 am	Site 2 10:15 am	Site 3 10:45 am	Site 4 11:15 am
Flow (cfs)	45	87	132	178
COD	4	3	3	12
Total suspended solids	20	1	10	9
Turbidity (mg/1 SiO_2)	19	2	9	11
Specific conductance (micromhos/cm @ 25°C)	243	32	128	247
Total phosphorus as P	0.11	0.02	0.06	0.47
Total kjeldahl nitrogen	0.4	0.2	0.4	1.5
Nitrate as N	0.79	0	0.45	1.52

* All concentrations in milligrams per liter (mg/1) except as noted.

VIRGINIA WATER RESOURCES RESEARCH CENTER
BLACKSBURG, VIRGINIA 24061