AGRICULTURAL AND FOREST LAND RUNOFF IN UPPER SOUTH RIVER NEAR WAYNESBORO, VIRGINIA

by

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Thesis submitted to the Graduate Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE
in
Environmental Science and Engineering

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September 1974

Blacksburg, Virginia

ACKNOWLEDGMENTS

The author wishes to express her sincere appreciation to , Director of the Bureau of Water Control Management of the State Water Control Board, and to of the South River Land and Water Conservation Association for their invaluable help in planning and executing this project.

The author wishes to thank for his guidance and supervision of this project.

The author extends thanks to of the Augusta County Soil Conservation Service for his assistance in site selection and land use estimations.

The author would like to thank of the State Water Control Board for the establishment of gages and development of rating curves. The author would also like to thank of the State Water Control Board's Valley Regional Office for his supervision of the field team.

Thanks are extended to and for their assistance in the laboratory work. The author also wishes to thank for his assistance in delineating drainage areas and in map drafting.

The author was supported by a research assistantship under Grant No. A - 053 - VA from the Office of Water Resources Research. This project was also partially supported by a grant from the Virginia State Water Control Board.

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INTRODUCTION

The U.S. Environmental Protection Agency (EPA) has described nonpoint sources of pollution as nondiscrete, diffuse processes contributing discharges to the environment that are not amenable to treatment (1). Much of man's contributions to water quality have derived from discrete, localized operations which generate point discharges capable of being treated. The major thrust of federal, state, and local water pollution control programs has always been directed towards treatment of these point source discharges. Under the 1972 amendments to the Water Quality Act, secondary treatment is required for all municipal wastes and "best practicable control technology" is required for treatment of industrial effluents. With the prospect of point sources coming under better control, water pollution from nonpoint sources has become increasingly visible. The EPA has identified sources and contributions of nonpoint pollution as follows (1). Nonpoint sources of discharge for which man must accept responsibility are agriculture; mining; construction; urban storm runoff; nonurban based recreational activity; and silviculture. Types of pollutants contributed by these nonpoint sources are classified as sediment, mineral pollutants, nutrients, pesticides, organic wastes, thermal pollution, and microorganisms.

Cropland, grassland, and commercial forests occupy 64 percent of the total land area in the U.S. and thus are potentially the greatest contributors of nonpoint pollution (1). The major nonpoint pollutant is sediment. According to the 1971 inventory of the Soil Conservation Service, total sediment yield from cropland per year was approximately 1 billion tons and comprised at least 50 percent of the sediment deposited in the country's inland waterways (1). Tree cover and forest litter deprive rainfall of its erosive force, and runoff from well managed forests is fairly free of sediment. However, soils in forests disturbed by disease, fire, or lumbering operations are erodible and add to sediment loading of waterways. Construction and surface mining activities also yield large quantities of sediment in relatively small regions of impact.

Mineral pollution includes acid drainage, salinity, hardness minerals, and toxic elements such as lead, arsenic, zinc, cadmium, and copper. These pollutants are transported by water in contact with rock formations exposed by mining activities.

The availability of nutrients, primarily nitrogen and phosphorus, in a body of water results in extensive algal growth. Detrimental effects of algal growths include lowered dissolved oxygen levels in the absence of sunlight, increased biochemical oxidation demand, increased turbidity and suspended solids, and taste and odor problems. The greatest nonpoint contribution of nutrient elements comes from fertilized cropland and feedlots. Forty-one million tons of commercial fertilizers were used during 1972 in the U.S., 75 percent of which was applied on farmland, and about 2 billion tons of livestock wastes were produced (1). A fraction of these quantities leaches through the soil to ground water or is transported in runoff to the nation's streams and lakes. A Task Group Report for the American Water Works Association estimated that agricultural runoff surpassed domestic waste discharges as the single greatest contributor of nitrogen and phosphorus to water supplies in the U.S. Agricultural runoff yields 1,500 to 15,000 million pounds of nitrogen and 120 to 1,200 million pounds of phosphorus per year as compared to domestic waste contributions of 1,100 to 1,600 million pounds of nitrogen and 200 to 500 million pounds of phosphorus per year (2).

About 70 percent of the 1 billion pounds of pesticides applied in the U.S. during 1970 was used on farms (1). An unknown amount of these pesticides reaches the country's waterways through agricultural runoff. Pesticides are used less extensively in forests, urban areas, construction sites, and mines and are also found in runoff from these areas.

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 oxidation demand in the stream and are 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 the sun's rays.

In 1971 a report was prepared for the Council on Environmental Quality which estimated the extent of pollution contributed by nonpoint sources in a number of river basins throughout the country (3). The study concluded that in 80 percent of the basins reviewed, nonpoint 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 pollutants increased instead of being diluted out, thereby reflecting a significant pollutant contribution from land runoff.

In 1973 the U.S. Environmental Protection Agency gave the States the responsibility of identifying nonpoint pollution problems within their boundaries and developing appropriate control strategies (4). This case study of the South River should aid in Virginia's development of a state strategy for the study of nonpoint source problems. The study is designed to investigate agricultural and forest runoff contributions to the South River and to estimate the importance of these nonpoint types of pollution by comparison to contributing point sources. South River 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% 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 1,720 cfs (5). The increase in flow below Waynesboro results from both increased drainage area and the addition of approximately 20 cfs of ground water through the DuPont Company waste treatment system (5).

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 nonpoint 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 16,707, is a source of considerable urban runoff, industrial discharges, and domestic waste

(5). 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 nonpoint sources. Substantial algal activity stimulated by nutrient inputs further suppresses dissolved oxygen levels in the absence of sunlight. The South River below Waynesboro is not able continuously to accept the wastewater load now imposed upon it without serious degradation in 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 nonpoint and point pollutant contributions. It is the aim of this study to contribute to such knowledge.

LITERATURE REVIEW

The three major types of pollutants analyzed in this study are nutrients, suspended matter, and organic wastes. Research on the chemistry, sources and effects of these runoff constituents will be reviewed here.

WATER QUALITY PARAMETERS

Inorganic nutrients are necessary for biochemical synthesis of cell material, and life processes depend on the quantity, nature, and rate of addition of nutrients. Macronutrients are those nutrients required in relatively large quantities by an organism and include carbon, hydrogen, oxygen, sodium, sulfur, calcium, magnesium, potassium, nitrogen, and phosphorus (6). Extremely small concentrations of other elements--micronutrients--may also be critical to the growth of living things. Such micronutrients include cobalt, manganese, iron, copper, zinc, molybdenum, vanadium, boron, chloride, and silicon (6).

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 biologic productivity (7). 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 develops when a single or limited number of algal species grow to such an extent that nuisance conditions develop. Unlike studies of lakes, there have been few detailed or long continued studies of algae in American rivers. Palmer (8) 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 (9) and Baumann and Kelman (10), stimulation of algal growth has 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 (11). Carbon, nitrogen, oxygen, and hydrogen are nutrients with a gaseous phase, and consequently have an atmospheric reservoir available to the aquatic environment. Such nutrients have more or less complete biogeochemical cycles in which there is a continuous transfer of nutrients between living and nonliving components of the ecosystem. Grundy (12) points out that nutrients without a prominent gaseous phase, such as phosphorus, calcium, silica, and potassium, are more likely to be limiting factors in biologic productivity since they have no atmospheric reservoir and less complete cycles. These nutrients are naturally circulated by processes of erosion, sedimentation, and biological activity. Historically, phosphorus has been considered the limiting factor in algal metabolism most consistent with Liebig's Law of the Minimum. Phosphorus has a sedimentary cycle and is relatively rare in natural waters because of the insolubility of its inorganic compounds. Provasoli (13) has noted the importance to algal productivity of sodium, potassium, trace metals, and vitamins, but Hutchinson (14) maintains that trace elements more likely affect the quality of algal populations rather than the total quantity. Weiss (15) has suggested nitrogen as the limiting factor while Kerr _et al._ (16) and Kuentzel (17) have maintained that carbon in the form of dissolved free CO_2 is the dominant nutrient in stimulation of algal growths. Hutchinson (14) minimizes the limiting role of dissolved CO_2. Additional CO_2 can always diffuse into water from the atmosphere, and various aquatic plants, including significant bloom-forming algae, can use HCO_3^- ion in place of CO_2 as a source of carbon in photosynthesis. Atmospheric nitrogen can be fixed by certain algae and bacteria in water, so Hutchinson also minimizes nitrogen's limiting role. He concludes that phosphorus is the nutrient likely to be limiting in most situations.

Strategies for control of manmade eutrophication center about nitrogen and phosphorus removal since both are constituents of treated sewage and runoff waters. In Wisconsin lakes Sawyer (18) found that concentrations of 0.01 mg/l of soluble phosphorus (0.0326 mg/l as $PO_4^{\equiv}$) and concentrations of 0.30 mg/l inorganic nitrogen (1.4 mg/l as NO_3^-) were sufficient to support algal blooms when other environmental growth conditions were optimum. Sylvester (19) reported limiting concentrations of 0.01 mg/l P and 0.2 mg/l N from his work on Green Lake near Seattle, Washington. For flowing streams Mackenthun (20) recommended that total phosphorus concentration should not exceed 0.1 mg/l P (0.326 mg/l $PO_4^{\equiv}$) at any point within the stream, nor should 0.05 mg/l P (0.163 mg/l $PO_4^{\equiv}$) be exceeded where 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/l P at 48 percent of the stations sampled (21). A Public Health Service study also monitored stations on river systems throughout the U.S. (9). An average of 77 percent of the stations reported water samples containing at least 0.1 mg/l $PO_4^{\equiv}$ and 60 percent reported nitrate concentrations greater than 1.4 mg/l NO_3^-.

In addition to stimulating algal growth, nitrates and phosphates have other detrimental effects on the quality of surface water. The AWWA Task Group (2) reported that combined triphosphate and pyrophosphate levels of 0.3 mg/l P interfere with the efficiency of coagulation-flocculation, sedimentation, and lime-softening processes in water treatment. High concentrations of nitrate can cause methemoglobinemia in infants and can also poison livestock. As a result, the U.S. Public Health Service drinking water standards limit the concentration of nitrates in potable water to 45 mg/l NO_3^-. Another compound of nitrogen, ammonia, also causes problems in surface waters. Ammonia significantly increases the chlorine demand of water if an uncombined chlorine residual is required, and ammonia concentrations exceeding 2 mg/l are toxic to fish (10).

Elemental nitrogen exists as a gas at standard temperature and pressure. According to the AWWA Task Group Report (2), the atmosphere contains about 4 million tons of nitrogen, which calculates out to 69 million pounds of atmospheric nitrogen over each acre of land surface. Hutchinson (14) points out, however, that only certain bacteria, fungi and algae can fix atmospheric nitrogen so much of this nitrogen is not available for plant growth. The AWWA report estimates that the total nitrogen content of most soils in the U.S. averages about 3000 pounds per acre of plow depth (6 inches), with the exception of prairie soils which contain even higher nitrogen levels. Webber and Elrick (22) point out that 98 percent of this soil nitrogen is in organic form which is also of limited availability to plants. The primary plant nutrients are the ionic forms of nitrogen, NH_4^+, NO_2^-, and NO_3^-. These ionic forms are water soluble and thus affect aquatic plants as well as land plants.

Nitrogen may reach the aquatic environment by leaching through the soil to the groundwater table. According to Witzel (23), nitrates appear in groundwater because they are anions which are only slightly adsorbed by soil. Nitrates are free to migrate downward unless absorbed by the roots of growing plants or unless water is logged. If water is logged, anaerobic conditions prevail and biological denitrification will take place. With denitrification, NO_3^- will be converted to volatile gases (N_2O or N_2) and lost to the atmosphere (24). Organic and ammonia nitrogen forms do not percolate through to groundwater. Organic nitrogen is not water soluble and the soluble ammonium ion is effectively retained in the soil by absorption or ion exchange (6). Under certain conditions, both forms will undergo nitrification in aerobic soils and be converted by bacteria to soluble nitrate which may reach groundwater. According to Reinhorn and Avnimelech (25), a rapid equilibration takes place between mineral and organic nitrogen in the soil. The steady state level of each depends on climate and soil structure. An increase in mineralized nitrogen by fertilizer applications may result in high nitrate levels in underlying aquifers during the equilibration period.

Nitrogen is also transported to streams and lakes through soil erosion and surface runoff. According to Holt _et_ _al_. (26), 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.

Phytoplankton and rooted aquatic plants use ammonia or nitrates to synthesize organic nitrogen compounds. Nitrates can be used by most land and water plants, but Brezonik (27) maintains that ammonia is the preferred form for planktonic assimilation since it is already reduced. Plants using nitrate as their nitrogen source must reduce it to ammonia before incorporating the nitrogen into organic compounds. Heterotrophic bacteria degrade dead plant tissue by returning organic nitrogen to ammonia. Brezonik (27) points out that ammonia tends to be lost from solution by sorption onto sediments and by volatilization at high pH. However, the ammonia which does remain in aqueous solution is available for reconversion into organic matter by phytoplankton. Through the same nitrification process that occurs in soil, ammonia can be oxidized in a stepwise process to nitrite and then nitrate for use by macrophytes. The step from nitrite to nitrate is usually faster than from ammonium to nitrite so practically no nitrite accumulates. McCoy (24) describes what happens to nitrates and nitrites entering the aquatic environment. In addition to being taken up by algae and rooted plants, nitrates may undergo bacterial reduction first to nitrite and then to ammonia. As in the soil, nitrite and nitrate under conditions of poor aeration may also be reduced to N_2 or N_2O by denitrification within the body of water. These gaseous nitrogen forms are lost to the atmosphere.

According to the AWWA Task Group report (2), phosphorus compounds are scarce in the atmosphere but quite abundant in the earth's solid sphere. Approximately 10^{19} tons of phosphorus-containing compounds exist within the earth, or about 160 billion pounds per acre of the earth's surface. Assuming a 0.10 to 0.12 percent phosphorus content in soils, the Task Group estimates an average of 2,000 pounds of phosphorus per acre of plow depth. The apatite minerals contain most of the earth's phosphorus. Many of these minerals are only slightly soluble in water, and this limits the phosphorus concentrations found in natural waters. According to Black (28), however, phosphorus does occur in all natural waters in dissolved, colloidal or particulate form as inorganic orthophosphate or polyphosphate or as organic phosphorus. Detergent polyphosphates are important because of their ability to produce orthophosphate by hydrolysis in natural waters. Soil supplies phosphorus to the aquatic environment both in solution and in suspended solids.

Phosphorus occurs in soil in both organic and inorganic forms. Biggar and Corey (29) 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. Inorganic forms of phosphorus are found mainly as iron and aluminum phosphates in acid soils and as calcium phosphates in alkaline soils. Ninety to 70 percent of the fertilizer phosphorus added to soils is also chemically fixed (22). Neither organic nor inorganic forms are very soluble, and phosphorus rarely occurs in water percolating through the soil. Black (28) cites values of 0.011 mg/l to 0.016 mg/l of phosphorus as being typical groundwater concentrations.

Black (28) 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. Black reports that suspended solids impart a phosphorus-buffering capacity to a stream. The phosphorus bonded to soil particles tends to equilibrate with the phosphorus in solution in the stream. If the particles come from a surface soil water high in phosphorus, they will support a relatively high concentration of phosphorus in solution. If, on the other hand, the particles come from a subsoil low in phosphorus, they will support a low concentration of phosphorus in solution. If subsoil particles were introduced into a stream containing a high concentration of soluble phosphorus, they would adsorb phosphorus and lower the concentration in solution. 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_. (30) 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 concentrations in surface waters exhibit both a dilution effect and a runoff effect as described by Cahill _et al_. (21). The dilution effect represents the lowering of phosphate concentration in a river receiving storm water runoff, while the runoff effect involves the opposite situation of increasing phosphate concentrations with increased flow. In their investigations of the Brandywine River, Cahill _et al_. (21) found that the dilution effect occurred during steady flow conditions due to the dilution of point source orthophosphate by less concentrated water from nonpoint source runoff. During unsteady stage flow the runoff effect was exhibited. The authors attributed the increase in phosphate concentrations to the scouring of bottom sediments containing adsorbed phosphate and to the contributions of runoff from land adjacent to the river. Keup (31) also supports bottom scour as the source of increased phosphate concentrations during high flows. According to Keup, substantial amounts of phosphorus accumulate in stream bottom deposits during low flows by adsorption on clays and assimilation by periphyton. During high flows, this phosphorus is resuspended and transported in bed load sediment.

Phosphorus is assimilated rapidly from flowing water masses. According to Keup (31), 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*. (30) 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 pollutes by transporting chemicals, radioactive materials, and pathogens. Sediment itself is a pollutant which has a number of detrimental effects on water quality. According to Johnson and Moldenhauer

(32), sediment pollutes by 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 (33) 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. According to Holt, Dowdy and Timmons (28), 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. Sediment transported by a stream may be divided between bed load and wash load. The coarser particles carried by surface runoff have a sufficiently high settling velocity to deposit on the streambed. These particles make up the "bed-material load" which moves on or very close to the bed. The fine particles transported in runoff make up the "wash load" and are suspended in the flow by turbulence. Einstein (34) lists two basic differences between bed load and wash load. There is a great difference in their travel speeds. The wash load travels at about the velocity of the water, while the bed load has a travel velocity several orders of magnitude smaller than that of the stream. The second difference between sediment loads lies in their mode of transport. The wash load moves continually from the point of original scour while the bed load travels in a series of moves and stops, each new move depending on the amount of flow at the time. According to Johnson and Moldenhauer (32), this difference in movement results from the interaction of sediment load and stream capacity. The supply of fine particles is usually much less than the stream can convey, and wash load is transported continuously. When the bed load is appreciable, the supply of particles is usually greater than the stream can carry. Consequently, the amount transported as bed load depends on the amount of flow.

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 (35). Johnson and Moldenhauer (32) quote studies which show that 95 to 85 percent of total sediment discharge is in suspension. During storm events, peak sediment concentrations occur near, and in most cases before, the peak discharge. Keup (31) explains that land runoff brings in additional quantities of wash load particles while the increased stream discharge scours the bed and resuspends bed load material. During such high flows, the detrimental effects of particles in suspension predominate. As runoff subsides, velocity and turbulence are reduced and the capacity of the stream to transport particles is decreased. The coarser particles begin to settle out, and benthic fauna experience the effects of siltation. Siltation is also a problem when a river enters a quiescent lake, reservoir, or estuary where a large portion of the transported sediment may be deposited.

All living organisms depend upon oxygen in one form or another to support growth and reproduction. In aquatic systems dissolved oxygen is the most important form of oxygen. The solubility of oxygen in fresh waters varies directly with atmospheric pressure and indirectly with water temperature. The low solubility of oxygen is the major factor that limits the purification capacity of natural waters and necessitates treatment of wastewater before discharge to receiving streams. According to Sawyer and McCarty (36), the oxygen demand of wastewater is created by three different types of compounds:

1. Organic compounds that act as sources of food for microorganisms.
2. Oxidizable nitrogen produced by nitrite, ammonia, and organic nitrogen compounds which also serve as food for bacteria.
3. Chemical reducing compounds such as ferrous iron, sulfite, and sulfide which combine with dissolved oxygen.

The amount of dissolved oxygen available determines whether the biological changes are brought about by aerobic or anaerobic organisms. Aerobic organisms use free oxygen for oxidation of organic and inorganic matter and produce innocuous end products. Anaerobic organisms reduce inorganic salts such as sulfates in order to carry on such oxidations and consequently produce obnoxious end products. Wadleigh (37) points out that depletion of dissolved oxygen in a stream is conditional upon the load of oxygen-demanding wastes added to a stream and the amount of streamflow available to waste assimilation. Low flows in late summer and fall in many rivers may be only one-fifth or one-tenth the average annual flow. Under such low flow conditions, the capacity of the stream to assimilate organic wastes is severely reduced.

Sawyer and McCarty (36) define biochemical oxygen demand (BOD) as the quantity of oxygen used by microorganisms in consuming biodegradable organic matter under aerobic conditions. Essentially complete biological oxidation of organic matter takes about 20 days. The standard BOD test is run for 5 days and measures about two-thirds of the total BOD. The BOD test is used in most countries of the world to measure the pollutional strength of waste water since its results are in terms of the dissolved oxygen that would be consumed if the waste water were discharged into a natural body of water. In using the test, everything that affects the rate at which organic matter is consumed must be closely controlled, including pH, nutrients, temperature, toxic materials, dilution water and nature of the microorganisms (36).

The chemical oxygen demand (COD) test is also used to measure the pollutional strength of waste waters. As defined by Sawyer and McCarty (36), COD is the amount of oxygen needed to oxidize both organic and oxidizable inorganic compounds. The COD test measures the total organic content that can be oxidized by potassium dichromate in a sulfuric acid solution. Most organic compounds can be oxidized to carbon dioxide and water under these conditions. The main limitation of the COD test is that it does not reveal whether the organic matter is biodegradable or nonbiodegradable. It also fails to give any idea of the rate at which giologically active material would be stabilized in a stream. Another disadvantage is that the COD test includes the effect of any chemical-reducing compounds that may be present. The main advantage of the test is that it can be run in only 3 hours while the BOD test requires 5 days.

NONPOINT SOURCES OF POLLUTION

A number of writers have called attention to the fact that a complete analysis of sources of pollutants entering the aquatic environment should include the following nonpoint sources of pollution (27, 38, 39, 40):

1. Atmosphere, including precipitation, aerosols, and dust
2. Groundwater
3. Agricultural land runoff
4. Forest land runoff
5. Urban runoff

ATMOSPHERE

As water vapor in the atmosphere condenses, nitrogen, oxygen, and carbon dioxide dissolve in the snow crystals or raindrops (41). Together with dissolved atmospheric salts, they are carried to the ground. According to the AWWA Task Group report (2), nitrogen exists in the atmosphere both in particulate and gaseous form, and phosphorus occurs as particulate matter. Goldberg (38) states that much atmospheric ammonia is attributed to industrial air pollution while the Task Group (2) identifies soil picked up by wind as the major source of ammonia in rainfall. Brezonik (27) supports the Task Group opinion in citing the correlation of high rainfall ammonia levels with alkaline soils and of low rainfall ammonia content with acid soils. He lists conflicting evidence regarding high rainfall nitrogen levels and industrial activity. Both Goldberg and the Task Group state that lightning plays only a minor role in fixing nitrogen in rainfall and that pollen, spores, and bacteria are a source of atmospheric organic nitrogen.

The Task Group (2) reviewed reports of nitrogen and phosphorus concentrations in precipitation from different areas of the U.S. Reported values for NH_3-N concentrations in rainfall ranged from 0.13 to 2.2 mg/l, with NO_3-N concentrations varying from 5 to 15 percent of the ammonia concentrations. Values of 0.15 mg/l and 0.8 mg/l were reported for NH_3-N concentrations in snowfall, with nitrite plus nitrate nitrogen concentrations averaging about 5 percent of the ammonia concentrations. Weibel _et al._ (42) reported inorganic nitrogen in Cincinnati rainfall as varying from 0.02 to 1.4 mg/l as N. Goldberg (38) and the Task Group (2) quoted varying nitrogen concentrations for dustfall and pollen.

Brezonik (27) found large local and temporal variations in the nitrogen and phosphorus concentrations of rainfall. Orthophosphate concentrations varied from 0.002 to 0.40 mg/l, NH_3-N varied from 0 mg/l to 1.26 mg/l, NO_3-N varied from 0.02 to 1.11 mg/l. Nutrient and particulate concentrations in precipitation were generally found to decrease during an extended rainfall, indicating a rapid cleansing from the atmosphere. According to Brezonik (27), the rapid decline of nutrient forms during rainfall suggests that the high initial concentrations may be low altitude aerosols originating from local, cultural activity such as auto exhaust and airborne fertilizer from plowed fields. The low concentrations which follow may reflect the natural levels of nutrients in the atmosphere.

GROUNDWATER

Groundwater may be polluted by fertilizers, manure, and pesticides depending on the permeability of the soil and the amount of infiltrating water. Fertilizers and pesticides are usually spread out over the land surface and are not applied continuously. LeGrand (43) points out that this pattern of application decreases the possibility that these pollutants will be carried with infiltrating water downward through the zone of aeration to the water table. LeGrand warns, however, that heavy concentrations of fertilizers and pesticides, especially near shallow wells or in areas where the soil is thin or highly permeable, may lead to considerable pollution of the groundwater. Animal and human wastes tend to leach into the water table. While this tendency is offset by the tendency of such wastes to decay and adsorb onto soil particles, groundwater is subject to infiltration by wastewater from several sources. Goldberg (38) lists such sources as septic tank effluents, waste stabilization ponds, waste treatment plant effluents, sludge lagoons, sanitary landfills, privies, barnyards, feedlots, leaking sewers, and irrigation systems.

As Viets (44) has explained, phosphorus is so tightly adsorbed by the subsoil through which it must percolate that groundwater concentrations are insignificant. Loss of nitrogen, practically all as nitrate, by percolation to water tables does pose a problem since the soil and subsoil have no retention capacity for nitrate. Goldberg (38) quotes values of 0.2 mg/l as the average concentration of ammonium nitrate in groundwater beneath irrigated fields and 4.5 mg/l as the average concentration beneath feedlots.

Minshall et al. (45) studied base flow from 36 agricultural watersheds in southwestern Wisconsin. Annual nitrogen loss per acre averaged 1.1 pounds, or about one-fourth of that lost in surface runoff. The average nitrogen content of base flow was only about 3 percent of that received in precipitation and applied fertilizers, the other 97 percent being lost through surface runoff, denitrification, and crop uptake. Annual phosphorus loss per acre averaged 0.10 pounds, or about 2 percent of the amount applied and one-tenth of that lost in surface runoff. Minshall et al. concluded that base flow in this region appeared to be a relatively insignificant carrier of plant nutrients and that storm runoff carried the major portion of the nutrients lost. LeGrand (43) also concluded from his review of the literature that the volume of groundwater polluted by plant nutrients, animal wastes, and pesticides appeared to be small. Both Minshall et al. and LeGrand warned, however, that concentrated application of these could pose a serious pollutional threat in areas with hydrogeologic conditions conducive to infiltration.

AGRICULTURAL RUNOFF

Animal wastes, sediment and fertilizers affect the composition of the surface water discharged from an agricultural watershed (46). Animal wastes are one of the largest sources of agricultural wastes. According to the U.S. Environmental Protection Agency, 2 billion tons of livestock wastes were produced in the U.S. during 1972 (1). The potential pollution of this waste in terms of human population equivalents is estimated to be 1.9 billion or 10 times that produced by the human population of the U.S. The EPA estimates that about one-half of this waste is produced by animals in confined feeding. Where animals graze a range or pasture, manure is uniformly distributed in light applications, liquids are absorbed by the soil, and the vegetative cover utilizes the added nutrients. Wadleigh (37) points out that the trend has been away from grazing and towards large feedlot operations. Holt (46) illustrates this trend with statistics on the Great Plains. In the period 1962 to 1968 the number of feedlots in this area carrying over 100 head of cattle increased by over 300 percent.

The major water pollutants arising from animal manures are infectious agents, oxygen-demanding matter, and plant nutrients. Color- and odor-contributing substances are pollutants of secondary importance. Wadleigh (37) summarizes the infectious agents carried by water polluted with animal wastes. Holt (46) explains the oxygen-demanding effects of animal wastes. According to his findings, fish kills attributed to feedlot runoff occur only when large quantities of organic matter are delivered to the stream at a rapid rate. Under most circumstances, however, feedlot runoff will cause a gradual lowering of dissolved oxygen, permitting fish to move out of the area. Even though dramatic fish kills do not result, feedlot runoff will affect the ecology of the stream by disturbing sessile or attached bottom-dwelling organisms which cannot avoid the low oxygen conditions. Miner and Willrich (47) point out that the ammonia nitrogen in feedlot runoff also exerts an oxygen demand in addition to that of the organic matter present. They estimate that the BOD of undiluted animal manures is about 100 times greater than BOD of municipal sewage. The concentration of soluble nutrients in animal waste is somewhat higher than that in the plant material from which it is derived. Consequently, runoff passing over accumulations of animal waste delivers appreciable amounts of dissolved nutrients to the water course. Nitrogen concentrations in particular are high in both ground and surface waters receiving feedlot runoff.

Miner and Willrich (47) reviewed data on the quality of runoff from feedlots and concluded that such runoff is of highly variable quality, depending on rainfall intensity, temperature, feedlot surface moisture content, and manure accumulation. Organic content as chemical oxygen demand (COD) in cattle feedlot runoff ranged from 3 to 11 times the COD in untreated domestic sewage. Groundwater contamination was found to be very low under lots continuously used to confine animals. Soil puddling and compaction by animal hooves reduced the infiltration rate in such lots. Groundwater beneath old feedlots had high nitrogen and organic carbon concentrations. Miner and Willrich (47) concluded that localized pollution of the water-table aquifer with nitrogen does take place near feeding areas but that widespread groundwater pollution is not likely due to the limited acreage used for feedlots.

Bernard (48) quoted average concentrations of pollutants in cattle feedlot runoff from a study by Owens, Wells, and Grub. Concentrations in runoff from a dirt feedlot averaged 4,000 mg/l BOD, 9,500 mg/l COD, 40 mg/l NO_3, 400 mg/l NH_3-N, 75 mg/l organic-N, 4,000 mg/l suspended solids. Concentrations in runoff from a concrete lot were even higher, yielding 7,500 mg/l BOD, 15,000 mg/l COD, 50 mg/l NO_3-N, 600 mg/l NH_3-N, 100 mg/l organic-N, and 6,000 mg/l suspended solids.

Miner <u>et al</u>. (49) also compared cattle feedlot runoff from a concrete lot with that from a dirt lot. Again pollutant concentrations from the concrete lot were higher. Concentrations in runoff from the dirt lot ranged from 1,900 to 8,900 mg/l COD, 50 to 540 mg/l TKN, 3 to 10 mg/l NO_3, and 1,100 to 7,000 mg/l suspended solids. Phosphate concentrations averaged 26 mg/l. Concentrations in runoff from the concrete lot ranged from 2,760 to 19,400 mg/l COD, 94 to 1,000 mg/l TKN, 3 to 10 mg/l NO_3, and 1,100 to 13,500 mg/l suspended solids. Phosphate concentrations averaged 50 mg/l. Miner *et al.* explained the low concentrations of nitrate as a result of the anaerobic conditions which generally exist in both feedlot runoff and litter. When feedlot conditions are sufficiently moist to allow bacteriological activity, ammonia is formed by the anaerobic breakdown of organic nitrogen and degradation of urea. Only when feedlots are dry during warm weather does nitrification take place and produce nitrate.

Robbins *et al.* (50) evaluated pollutant contributions from anaerobic swine waste lagoons, direct discharge operations, and land spread practices. Waste from 1,000 swine following treatment by anaerobic lagooning was still equivalent to raw wastewater from a community of 1,000 people. Robbins *et al.* concluded that the use of anaerobic lagoons as the sole means of treatment is an unsatisfactory practice in areas where rainfall exceeds evaporation. Direct dumping of wastes caused high concentrations of pollutants in the stream. Daily pollutant contributions per animal ranged from 0.08 to 1.67 pounds of BOD, 0.12 to 1.22 pounds of total organic carbon, 0.03 to 0.30 pounds of nitrogen, and 0.02 to 0.16 pounds of phosphate. Runoff from land spreading operations contributed the least amount of pollutants to the receiving stream. BOD contributions ranged from 0.020 to 0.218 pounds per day per animal, total organic carbon from 0.040 to 0.266 pounds, nitrogen from 0.012 to 0.05 pounds, and phosphate from 0.005 to 0.023 pounds.

According to the U.S. Environmental Protection Agency, 41 million tons of commercial fertilizer are consumed in the U.S. each year (1). Approximately 8 million tons of nitrogen and 2.1 million tons of phosphorus are contained in this fertilizer. The EPA estimates that 10 to 15 percent of the nitrogen in fertilizer reaches surface and ground water, more than half transported on sediment and the remainder by leaching. It is estimated that 25 percent of the phosphorus reaches surface waters, nearly all of it carried by sediment.

Following World War II, synthetic fertilizers became available at low cost and the cost of handling manure made it less competitive with such fertilizers. Holt (46) shows that total nitrogen applied as fertilizer quadrupled between 1950 and 1968 and that phosphorus use more than doubled over that time. Chemical fertilizers are applied primarily to surface soil where they are available for removal in runoff water either in the dissolved phase or adsorbed to sediment. According to Loehr (51), quantities of eroded solutes are highest in areas of abundant precipitation and runoff while concentrations of dissolved matter are highest in areas of low precipitation.

Concern over the nutrient content of drainage from fertilized fields has stimulated investigations into factors controlling the amounts of nitrogen and phosphorus reaching streams and lakes from agricultural watersheds. Several studies have concentrated on comparing nutrient losses from cropland under different types of soil management practices.

Romkens *et al.* (52) demonstrated the close relationship between soil loss and nutrient loss in their studies on cornfield runoff. They compared the effect of tillage methods on nutrient levels in both runoff water and runoff sediment. The five tillage methods varied in their effects on soil loss and on soluble nitrogen and phosphorus concentrations. However, all treatments contributed high percentages of total nutrients as components of the sediment.

Weidner _et al_. (53) also demonstrated the importance of controlling soil erosion in reducing nutrient losses in surface runoff. Nutrient losses were measured in runoff from a cornfield, a wheat field, and a meadow under both prevailing and improved practices. Improved practices included contour plowing, strip-cropping, adequate fertilization, and liming of the soil. Improved management reduced nitrogen in runoff by about 63 percent and phosphorus by 70 percent. Annual corn field losses decreased from 912 pounds of hydrolyzable phosphorus per acre and 237 pounds of total nitrogen per acre to 2.8 and 88 pounds, respectively. Annual wheat field losses decreased from 1.2 pounds of hydrolyzable phosphorus per acre and 31 pounds of total nitrogen per acre to 0.36 and 11 pounds, respectively. Only trace amounts of nutrients were lost from meadows under both prevailing and improved practices. The biochemical oxygen demand (BOD) and chemical oxygen demand (COD) of runoff also decreased with improved soil management. The annual BOD of corn field runoff decreased from 120 to 28 pounds per acre, and COD decreased from 1,300 to 480 pounds per acre. The annual BOD of wheat field runoff decreased from 16 to 4 pounds per acre, and COD decreased from 170 to 64 pounds per acre. This study showed that despite an increase in the amount of fertilizer and manure applied under improved practices, there was a marked decrease in the pollutional load in runoff due to a reduction in soil erosion.

Schuman et al. (54) further illustrated the effect of soil conservation practices on nutrient losses. They measured the nitrogen content of surface runoff from two level-terraced and two contour-planted corn watersheds. One field of each pair was fertilized at the recommended nitrogen rate of 150 pounds per acre, the other was fertilized at 2.5 times this rate. The conservation practice of level-terraced corn was effective in reducing water, sediment, and nitrogen yields when compared with contour-planted watersheds. The average annual total nitrogen (solution plus sediment) losses were 28.9 pounds per acre for the contour-planted watershed and only 9.4 pounds per acre for the level-terraced watershed. Sediment nitrogen losses comprised 92 percent of the total N loss from contour-planted watersheds and 86 percent of the total N lost from level-terraced fields. Differences in fertilizer application did not affect nitrogen concentrations of sediment but did affect water-soluble nitrogen losses. Excessive fertilization increased soluble nitrogen losses from both types of fields.

The studies reviewed above involved field experiments on small plots of land under highly controlled conditions. Investigations of runoff contributions have also been made on much larger watersheds under natural conditions. Engelbrecht and Morgan (55) estimated nutrient contributions of agricultural drainage in the Kaskaskia River Basin of Illinois. The only sources of phosphorus to the Kaskaskia River were agricultural drainage from highly cultivated land and sewage treatment plant effluents. In order to estimate the phosphorus carried in land runoff, domestic waste contributions were deducted from the river's phosphorus load. Approximately 35 percent of the total yield of ortho- and inorganic condensed phosphate, or 0.32 lb/acre/year was estimated to be of land drainage origin. Agricultural runoff concentrations of ortho plus hydrolyzable phosphorus were calculated to range from 0.01 to 0.4 mg/l, with an average of 0.07 mg/l. Concentrations at all times exceeded Sawyer's (18) and Mackenthun's (20) critical values for algal growth.

Sawyer (18) estimated nutrients contributed by agricultural runoff to three Wisconsin lakes by analysis of one tributary to each lake which did not receive municipal or industrial discharges. Estimates of pounds of nutrients lost per acre per year ranged from 4.4 to 6.9 for inorganic nitrogen, 1.6 to 1.8 for organic nitrogen, 0.06 to 0.10 for inorganic phosphorus, and 0.29 to 0.31 for organic phosphorus. The highest nutrient loads were contributed by marsh lands.

Dornbush _et al._ (56) monitored rainfall and snowmelt runoff from cultivated fields, permanent grass and alfalfa lands, and grazed pasture in South Dakota. Nitrate and phosphorus concentrations equaled or exceeded Sawyer's (18) critical values in snowmelt and rain runoff from all three types of land. Annual nutrient losses from cultivated land were calculated to be 0.27 lb P/acre, 0.33 lb NO_3-N/acre, and 1.00 lb TKN/acre. Annual nutrient losses from alfalfa and brome grassland were the smallest, contributing 0.09 lb P/acre, 0.21 lb NO_3-N/acre, and 0.65 lb TKN/acre. Snowmelt runoff comprised 67.8 percent of total runoff and contributed 44.9 percent of the annual phosphorus loss, 62.2 percent of the nitrate and 65.8 percent of the total Kjeldahl nitrogen.

It was concluded, therefore, that significant quantities of nutrients would still be lost annually even if all rainfall runoff were eliminated. Rainfall runoff contributed 93.7 percent of the suspended matter, but this suspended matter did not transport large quantities of nutrients. Contrary to findings by Weidner et al. (53) and Schuman et al. (54), a major portion of the nutrients in runoff was found to be in soluble form. All of the nitrate, 69 percent of the TKN, and 27.5 percent of the phosphorus were independent of any sediment. Annual contributions of suspended solids in pounds per acre were calculated as 255 for cultivated land, 10.5 for pasture, and 3.6 for alfalfa and brome grassland. Chemical oxygen demand (COD) was also measured, and yearly runoff contributions in pounds per acre were reported as 43 for cultivated land, 25 for pasture, and 12 for alfalfa and brome grassland.

Surface runoff from cultivated fields, hayland, and pasture was also monitored by Witzel et al. (57). Winter runoff during the study period was about twice the normal amount. Nutrient loads for this year were calculated as 3.6 lb N/acre, 1.1 lb P/acre, and 7.6 lb K/acre. The researchers estimated that in a year of average runoff, these losses would be reduced to 2 lb N/acre, 0.6 lb P/acre, and 4 lb K/acre.

FOREST RUNOFF

The principal pollutants from forests are sediment, organic matter, applied forest chemicals (pesticides, fertilizers, fire retardants), plant nutrients, and pathogens (1). Drainage from an established, undisturbed forest ordinarily carries a minimal concentration of pollutants. The tree canopy effectively breaks the impact of rainfall. Accumulated litter and vegetation protect the mineral soil by obstructing surface flow and by providing an adsorptive blanket to store much of the rainfall. Good permeability of the subsoil is maintained by decaying organic matter and root penetration of the covering vegetation. Rates of infiltration are often high enough that intense rainfall can be accommodated without surface runoff and soil erosion. Lumbering operations, disease, windstorms, droughts, and fires disturb forest cover, thereby increasing runoff and pollutant loads. Pollutant concentrations in forest drainage seldom have water quality significance in the absence of such disturbances.

Cooper (41) stated that rock weathering in undisturbed forests determines the relative concentrations of metallic ions in drainage waters but that soil processes govern the yield of anions. Chlorides, nitrates, and sulfates are received by the soil in precipitation. Ionic exchange and adsorption processes in the soil regulate losses of these anions to soil water. Cooper reported data on total quantities and concentrations of nutrients in drainage waters from forested areas in northern Minnesota. The basins were located in a glaciated area of low relief and poor drainage. Forests were mainly aspen-birch, with large areas of spruce-fir and pine vegetation. Nutrient outputs in pounds per acre per year ranged from 0.10 to 0.16 for NH_4-N, 0.23 to 2.38 for NO_3-N, 0.85 to 1.92 for Organic N, and 0.07 to 0.16 for phosphorus. Concentrations ranged from 0.03 to 0.08 mg/l NH_4-N, 0.34 to 0.91 mg/l NO_3-N, 0.18 to 0.69 mg/l organic N, and 0.023 to 0.060 mg/l P. Sawyer's (18) critical values for limiting algal growth were exceeded by both nitrogen and phosphorus concentrations.

Taylor _et_ _al_. (58) measured concentrations of nitrogen, phosphate, and potassium over a 4-year period in streams draining woodland and farmland near Coshocton, Ohio. The forest was predominantly deciduous hardwood and pine, and the farmland was half pasture and half rotation cropland. Fertilizer applications were confined to corn and wheat crops, and rates of application were low. The data revealed that significantly larger amounts of all nutrients were lost from farmland than were lost from woodland. Streams draining farmland from 1967 to 1969 carried nutrient loads each year averaging 9.1 lb/acre potassium, 1.2 lb/acre reduced N, 2.9 lb/acre nitrate N, 4.1 lb/acre total N, and 0.05 lb/acre phosphorus. Streams draining woodland carried annual loads of 6.2 lb/acre potassium, 1.2 lb/acre reduced N, 0.9 lb/acre nitrate N, 2.1 lb/acre total N, and 0.04 lb/acre phosphorus. The effect of fertilizer application on nutrient losses was most evident in the phosphorus data where total farmland loss over the 4-year period was about 50 percent greater than woodland loss. The average concentrations of phosphorus in runoff were 0.022 mg/l P for farmland and 0.015 mg/l for woodland. Excluding an unusually high nitrate loss from farmland in 1968, average concentrations of nitrate in runoff were 0.53 mg/l NO_3-N for farmland and 0.34 mg/l for woodland. Sawyer's (18) critical values for limiting algal growth were exceeded by phosphorus and nitrate concentrations in runoff from both woodland and farmland. However, Mackenthun's (20) critical phosphorus values for limiting algal growth in flowing streams were not exceeded in runoff from either watershed. Nutrient losses from woodland were largest in 1968, and the increases were attributed to the effects of thinning operations in 1967.

Thomas and Crutchfield (59) measured nitrate and phosphorus in streams draining woodland and farmland in Kentucky. Eight watersheds were monitored in which land use ranged from completely forested to mostly cultivated. Contrary to the findings of other studies (53, 56), a good relationship was not demonstrated between nitrate-N and land use. Nitrate-N concentrations varied from 6 mg/l to 0 mg/l, with the highest value found in a stream draining a watershed which received little nitrogen fertilizer and was essentially all in bluegrass pasture. One intensively cropped watershed showed rather high values for nitrate-N in stream water but another similarly cultivated and fertilized watershed did not. A good relationship was also not found between phosphorus and land use. Instead the phosphorus concentrations were directly related to the geological formations through which the streams ran. The two streams with intensively cultivated watersheds showed minimal phosphorus concentrations while the stream draining pasture and flowing through high phosphate limestone showed the highest phosphorus concentrations. Thomas and Crutchfield's findings did agree with those of Taylor et al. (58) in showing that larger amounts of nutrients were lost from farmland than from woodland. The predominantly forested watershed had the smallest losses of nitrogen and phosphorus. During the January through May sampling period, nitrate removal from the woodland watershed was calculated to be 1.9 lb/acre as compared to the high loss of 19.8 lb/acre from bluegrass pasture. Phosphorus removed from the woodland watershed during this 5-month period was calculated to be .009 lb/acre as compared to the high loss of 0.98 lb/acre from bluegrass pasture. Nutrient losses for the other watersheds were between these two extremes.

Jaworski and Hetling (39) also compared nutrient yields from forest and agricultural runoff. Annual yields from forested watersheds in the Potomac River Basin averaged 0.09 lb/acre total phosphorus, 1.15 lb/acre NO_3-N, and 0.23 lb/acre TKN. Nutrient quantities carried by farmland runoff were twice as large. Annual yields from cropland and pasture averaged 0.7 lb/acre total phosphorus, 3.0 lb/acre NO_3-N, and 0.4 lb/acre TKN. Jaworski and Hetling emphasized the minor contribution of forest land by pointing out that although 62 percent of the Potomac River Basin was covered by forest, 64 percent of the nutrients from land runoff came from agricultural areas.

Sylvester (19) investigated nutrient contributions from three forested watersheds in the State of Washington. Annual yields ranged from 0.3 to 0.8 lb/acre total phosphorus and 1.3 to 3.0 lb/acre NO_3-N. The total phosphorus concentration averaged 0.069 mg/l P with a soluble phosphorus concentration of 0.007 mg/l P. The mean NO_3-N and TKN concentrations were 0.130 mg/l and 0.074 mg/l, respectively.

URBAN RUNOFF

Sources of pollution in urban runoff include debris and contaminants from streets, contaminants from open land areas, publicly used chemicals, air-deposited substances, ice control chemicals, and dirt and contaminants washed from vehicles (60). Urban wastes may enter a stream via storm sewers, seepage, overland flow, gullies, conduits and outfalls (61).

Sartor et al. (60) analyzed street surface contaminants from 12 cities in the U.S. They found that runoff from street surfaces is generally very contaminated. Weighted means for all samples, reported in pounds per curb mile, were as follows: 1,400 total solids, 95 COD, 1.1 phosphate, 0.094 nitrates, 2.2 total Kjeldahl nitrogen, 0.65 zinc, 0.20 copper, 0.57 lead, 0.05 nickel, 0.073 mercury, and 0.11 chromium. Substantial quantities of organic pesticides and fecal coliforms were also found in street contaminants. The quantity of contaminant material existing on street surfaces was found to vary widely according to surrounding land use, elapsed time since streets were last cleaned, local traffic volume and character, street surface type and condition, public works practices, and season of the year. In general, industrial land-use areas tended to accumulate contaminants faster than commercial or residential areas. Industrial sites had an average loading intensity for solid material of 2,800 pounds per curb mile, twice the average for the entire city. Residential areas were found to have an average loading intensity of 1,200 pounds per curb mile which is comparable with the average for the entire city. Commercial areas had the lightest loading intensities, 290 pounds per curb mile, probably because of the frequent street sweeping in such areas.

Kluesener and Lee (62) measured the nutrient content of stormwater runoff from a residential section of Madison, Wisconsin. Madison's storm sewers discharged into Lake Wingra. Kluesener and Lee calculated annual nutrient contributions to the lake from urban runoff to be 0.45 lb/acre NH_3-N, 160 lb/acre NO_3-N, 0.57 lb/acre dissolved P, and 0.98 lb/acre total P. Other sources of nutrients to the lake were determined to be precipitation, atmospheric fallout, and spring flow. Nutrient loads from these sources were calculated and compared to urban runoff contents. Urban runoff contributed 35 percent of the total N, 80 percent of the total P, and 90 percent of the dissolved P. Possible sources of nutrients in urban runoff were identified as precipitation, dust fall, leachate from living vegetation, street litter, lawn and garden fertilizers, dead vegetation, and gasoline combustion products. Phosphorus generally resulted from accumulated vegetation litter and automotive exhaust discharged to the streets. Most of the ammonia-N and about one-third of the nitrate-N appeared to be contributed by rainfall. Kluesener and Lee found that nutrient concentrations rose sharply during the early stages of storm runoff and then decreased gradually with time. Three factors seemed to cause the initial rise in runoff concentrations. The concentration of nutrients in rain decreased with time during a storm. Thus, rain contributed more nutrient per unit of rainfall in the early stages of the storm. Rainfall intensity was usually greatest early in the storm, and the higher flow rates yielded greater loading per unit of time. Also the litter and pollutants accumulated on impervious surfaces during dry weather were flushed out early in the storm.

In a review of the literature on urban runoff, Whipple _et al_. (61) quote pollutant concentrations measured in urban stormwater from 10 different cities. Concentrations ranged from 1 to 285 mg/l BOD, 20 to 3,100 mg/l COD, 274 to 13,800 mg/l total solids, 5 to 14,541 mg/l suspended solids, and 0.02 to 7.3 mg/l total phosphate. Whipple _et al_. analyzed stormwater in Morristown, New Jersey, a predominantly residential urban area. Analyses were made during a wet period in March and a dry period in August. Urban runoff from the area contributed an average of 0.24 lb/acre/day BOD in March and 0.06 lb/acre/day in August. The phosphate contribution was 0.91 lb/acre/day in March and 0.11 lb/acre/day in August, with respective concentrations of 2.1

mg/l and 1.5 mg/l. Nitrate yields amounted to 0.53 lb/acre/day in March and 0.20 lb/acre/day in August, with respective concentrations of 2.9 mg/l and 1.2 mg/l. The authors pointed out that these heavy nutrient loads were particularly serious since a large, shallow water supply storage reservoir had been proposed for the river. As a result of their study Whipple et al. concluded that relatively clean residential and shopping areas contribute about 0.02 to 0.03 pounds of BOD per day per person in urban runoff and that larger pollutant loadings can be expected from areas with considerable commercial and industrial activities.

Weibel et al. (42) investigated runoff from a residential and light commercial area served by separate sewers in Cincinnati, Ohio. Runoff concentrations averaged 19 mg/l BOD, 99 mg/l COD, 210 mg/l suspended solids, 0.4 mg/l NO_3-N, 0.6 mg/l NH_3-N, 1.7 mg/l organic-N, and 0.8 mg/l total phosphate. Fecal streptococcus counts exceeded fecal coliform counts, indicating sources of nonhuman pollution. Total pollutant yields for a year were 8.9 lb/acre total N, 1.25 lb/acre nitrates, 2.5 lb/acre total phosphates, 730 lb/acre suspended solids, 240 lb/acre COD and 33 lb/acre BOD. These yields were compared to the raw sanitary sewage load estimated to be produced by the test area. Stormwater suspended solids averaged 140 percent of the projected raw sewage discharge, COD averaged 25 percent, BOD 6 percent, phosphate 9 percent, and nitrogen 11 percent.

Colston (63) also analyzed stormwater runoff from a residential and light commercial area, but his test site in Durham, North Carolina, had no storm sewer system. Instead he measured runoff in street gutters, pipes, and culverts. Runoff concentrations averaged 170 mg/l COD, 1223 mg/l suspended solids, 0.96 mg/l total Kjeldahl nitrogen, 0.82 mg/l total phosphorus, 16 mg/l aluminum, 0.23 mg/l chromium, 0.15 mg/l copper, 12 mg/l iron, 0.46 mg/l lead, 10 mg/l magnesium, 0.67 mg/l manganese, 0.15 mg/l nickel, and 0.36 mg/l zinc. Annual yields of pollutants from stormwater runoff were calculated to be 938 lb/acre COD, 470 lb/acre ultimate BOD, 6690 lb/acre suspended solids, 6.1 lb/acre TKN, 4.7 lb/acre total P, 1.6 lb/acre Cr, 1.6 lb/acre Cu, 2.9 lb/acre Pb, 1.2 lb/acre Ni, 2.0 lb/acre Zn. Wet periods producing stormwater runoff occurred only 20 percent of the year. Runoff pollutant yields were compared to the yields of raw municipal waste during 20 percent of the year. Colston found that downstream water quality during wet weather was primarily governed by urban land runoff. Urban runoff represented 82 percent of the total COD contributed by runoff and domestic waste during storm periods, 77 percent of the ultimate BOD, 99 percent of the suspended solids, and 27 percent of total phosphorus. Urban runoff contributions of heavy metals varied from 57 percent of the zinc to 94 percent of the chromium.

Soderlund and Lehtinen (64) compared the pollutant content of urban stormwater runoff in separate sewers with that of treated effluents and storm overflow water from combined systems. They made individual analyses of stormwater runoff from three sections of an urban drainage district in Stockholm. One section contained terrace housing, one a suburban shopping center, and one a heavily trafficked highway junction. Highway runoff proved to be much more contaminated than runoff from the other two sections. Runoff concentrations from the whole area averaged 129 mg/l suspended solids, 9 mg/l BOD, 0.08 mg/l total phosphorus, 1.2 mg/l total nitrogen, 41 mg/l oil, 0.004 mg/l lead, 0.278 mg/l zinc, and 0.086 mg/l copper. Stormwater runoff discharges took place 7 percent of the year or 600 hours. Total yield of stormwater runoff pollutants was calculated and compared to the 600-hour contribution of treated sewage and of storm overflow. Stormwater runoff contributed 196.3 lb/acre suspended solids, 11.6 lb/acre BOD, 0.09 lb/acre total phosphorus, and 1.6 lb/acre total nitrogen. Storm overflow, calculated to be 1 percent of a year's flow of sanitary wastewater, was estimated to contribute 12.5 lb/acre suspended solids, 12.5 lb/acre BOD, 0.7 lb/acre total phosphorus, and 2.1 lb/acre total nitrogen. Treated sanitary wastewater yielded in 600 hours 8.0 lb/acre suspended solids, 8.0 lb/acre BOD, 0.4 lb/acre total phosphorus, and 10.7 lb/acre total nitrogen. Soderlund and Lehtinen concluded that urban stormwater runoff in separate sewers was contaminated to the same extent as mixed storm overflow from combined sewers. The pollutant content of both runoff and overflow exceeded that of treated sanitary wastewater, with the exception of nitrogen contributions.

Sylvester (19) measured the nutrient content of street gutter drainage water in Seattle, Washington. Runoff samples were collected from major highways, arterial streets, and residential streets. The major highway contributed the greatest amount of nitrogen; the arterial streets contained the most soluble phosphorus; and the residential streets yielded the highest total phosphorus concentrations. Mean nutrient concentrations were reported as 2.01 mg/l TKN, 0.53 mg/l NO_3-N, 0.076 mg/l soluble P, and 0.208 mg/l total phosphorus.

COMPARISON OF SOURCES OF POLLUTION

Table I summarizes pollutant contributions reported in the literature for agricultural, forest, and urban runoff. In order to evaluate the relative significance of nonpoint sources of pollution, several investigators have compared the nutrient contributions of nonpoint sources to the contributions of point sources. Table II summarizes the data from these studies. In 1967 a Task Group of the American Water Works Association prepared a report on the sources of nitrogen and phosphorus in water supplies in the U.S. (2). Nutrient yield estimations were based on data obtained in small scale studies, and Armstrong and Rohlich (65) point out that such extrapolation of localized evaluations to large areas gives estimations of rather low reliability. Nonetheless, the estimations made by the Task Group are useful in evaluating the relative significance of various nutrient sources. The Task Group estimated that agricultural land contributed about 60 percent of the nitrogen and 42 percent of the phosphorus carried to water supplies in the U.S. each year. To arrive at these figures it was assumed that the 308 million acres of cultivated land in the U.S. contributed 5 to 50 lb/acre/year N and 0.4 to 4 lb/acre/year P. Estimates for point source contributions attributed 10 percent of the nitrogen and 22 percent of the phosphorus to domestic waste and 7 percent of the nitrogen to industrial waste. The remaining percentages of N and P transported to water supplies were allocated to nonagricultural rural runoff, farm animal waste, urban runoff, and rainfall.

Birch (66) found that agricultural drainage was the primary cause of eutrophication in Hoover Reservoir. Of the total 94,344 pounds of

Table I.--Nutrient Yields from Land Runoff

Land Runoff (lb/acre/year)	Investigator(s) and Study Area												
	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)
Agricultural Runoff													
Tot P	0.36-9.2	0.32	0.35-0.41	0.58	1.1			0.7	0.05				
NO_3-N				0.90				3.0					
TKN				2.46				0.4					
Tot N	11-237		6.6-1.7		3.6				4.1				
SS				3.6-255									
COD	64-1300			12-43									
Forest Runoff													
Tot 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					
Tot N							1.3-3.0		2.1				

Table I - Continued

Land Runoff (lb/acre/year)	Investigator(s) and Study Area												
	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)
Urban Runoff													
Tot P								0.6		.09	2.5	4.7	.98
NO_3-N								1.5					160
TKN								0.4				6.1	
Tot N										1.6	8.9	6690	
SS										196	730	938	
COD											240		

Table II.--Nutrient Yields from Nonpoint and Point Sources

Nutrient Yields	Researcher(s) and Study Area			
	Birch Hoover Reservoir Ohio	Sridharan and Lee Green Bay, Michigan	Jaworski and Hetling Potomac River Basin	Baumann and Kelman Des Moines R. Iowa
<u>Wastewater Effluents</u>				
lb/yr	3,027 N 35,555 P	1,515,000 P	23,725,000 N 9,003,333 P	2,320,000 N 572,000 P
% Total	1.8 N 38.0 P	62.0 P	53.0 N 86.5 P	8.0 N 32.0 P
<u>Agricultural Runoff</u>				
lb/yr	160,987 N 55,992 P	822,000 P	12,683,750 N 871,576 P	27,200,000 N 1,200,000 P
% Total	93.6 N 59.0 P	33.6 P	29.0 N 8.4 P	92.0 N 68.0 P
<u>Forest Runoff</u>				
lb/yr			7,183,200 N 447,955 P	
% Total			16.0 N 4.3 P	

Table II - Continued

Nutrient Yields	Researcher(s) and Study Area			
	Birch Hoover Reservoir Ohio	Sridharan and Lee Green Bay, Michigan	Jaworski and Hetling Potomac River Basin	Baumann and Kelman Des Moines R. Iowa
Urban Runoff				
lb/yr	647 N		897,900 N	
	1,842 P	95,800 P	88,485 P	
% Total	0.4 N		2.0 N	
	2.0 P	3.9 P	0.8 P	
Groundwater				
lb/yr	277 N			
	99 P			
% Total	0.2 N			
	0.1 P			
Precipitation				
lb/yr	6,915 N			
	856 P	12,700 P		
% Total	4.0 N			
	0.9 P	0.5 P		

phosphorus entering the reservoir annually, 59 percent was derived from agricultural runoff, 38 percent from wastewater effluents, 2 percent from urban runoff, 0.1 percent from groundwater, and 0.9 percent from precipitation. Of the total 171,853 pounds of nitrogen entering the reservoir annually, some 93.6 percent was derived from agricultural drainage, 1.8 percent from wastewater effluents, 0.47 percent from urban runoff, 0.2 percent from groundwater, and 4 percent from precipitation. Nitrate concentrations were sufficiently high at all times of the year to support nuisance blooms of algae. Soluble phosphate concentrations were limiting to algal growth only during a small part of the year when surface runoff was low.

In contrast to Birch's findings, Sridharan and Lee (67) found that municipal and industrial wastewater effluents were the primary cause of eutrophication in Green Bay, a shallow bay on the northwestern part of Lake Michigan. The Bay receives excessive amounts of aquatic plant nutrients from municipalities, industries, and agricultural activities in the Fox River Valley. About 62 percent of the total 2,445,500 pounds of phosphorus entering the Bay each year originated from municipal and industrial sources. Rural runoff was the next important source, contributing 33.6 percent of the total phosphorus. Urban runoff contributed only 3.9 percent of total phosphorus, followed by precipitation which contributed only 0.5 percent. Despite the fact that it contributed only one-half the phosphorus supplied by wastewater effluents, rural runoff was still a determining factor in the eutrophication of Green Bay. Sridharan and Lee pointed out that even if 80 percent of the phosphorus from wastewater sources was removed, as required by an EPA-State of Wisconsin agreement, the average concentrations of orthophosphate would only drop from 0.05 mg/l P to 0.02 - 0.03 mg/l P. These concentrations are two to three times above the critical concentrations Sawyer (18) found for the excessive growth of algae. Phosphorus input from agricultural runoff must be controlled in order to prevent further eutrophication of the Bay.

Extensive algal growths also occur throughout the Potomac River Basin, causing wide fluctuations in dissolved oxygen. Jaworski and Hetling (39) demonstrated that wastewater discharges were the major source of nutrients in this Basin. Of the 10,411,349 pounds of total phosphorus entering the Potomac River Basin in 1966, 86.5 percent originated from industrial and municipal effluents, 8.4 percent from agricultural runoff, 4.3 percent from forest runoff, and 0.8 percent from urban runoff. Of the 44,489,850 pounds of nitrogen entering the Basin, 53 percent came from wastewater sources, 29 percent from agricultural runoff, 16 percent from forest runoff, and 2 percent from urban runoff. Despite the secondary importance of land runoff in nutrient yields, concentrations of total phosphate and nitrate exceeded limiting values for algal blooms even in watersheds having no urban centers.

Baumann and Kelman (10) reported nutrient yields to the Des Moines River between Boone and Des Moines, Iowa. The study was initiated in response to the significant increases observed in the river's algal counts. Baumann and Kelman used values reported in the literature for various types of waste in order to estimate contributions from point and nonpoint sources of nutrients. Of the 14,760 tons of nitrogen contributed to the river each year, an estimated 6 percent was contributed by domestic wastewater, 2 percent by packinghouse wastes, 24 percent by animal wastes, and 68 percent by agricultural runoff. Of the 886 tons of phosphorus contributed each year, an estimated 30 percent was contributed by domestic wastewater, 2 percent by packinghouse wastes, 56 percent by animal wastes, and 12 percent by agricultural runoff. Baumann and Kelman concluded that during periods of dry weather when light and turbidity conditions were favorable for phytoplankton growth, the principal source of the nitrogen and phosphorus required to support such growth was derived from municipal and industrial wastewater discharges. Removal of these nutrients from wastewater discharges during low flow periods would help reduce phytoplankton growth. During wet periods of high stream flow, runoff from urban and rural lands and channel erosion contributed the greatest portion of nutrients to the river. Nitrogen and phosphorus removal from wastewaters would not reduce nutrient levels significantly during these periods. However, algal growth is not a problem during high flows since the increased turbidity and scouring action of the flow inhibit aquatic plant growths. Impounding this river would create a eutrophication problem since high flow nutrients would remain in the reservoir both in solution and in sediments.

SEASONAL VARIATION IN RUNOFF

MacCrimmon and Kelso (68) investigated seasonal variation in selected nutrients in the Grand River system of Ontario, Canada. The Grand River received agricultural runoff, domestic and industrial discharges. Dissolved oxygen levels varied inversely with water temperature because of temperature effects on gas solubility and biological activity. Dissolved oxygen levels were high at all stations from

December to March but dropped below 5 mg/l during the summer months. Total alkalinity and hardness were highest during late summer, fall and early winter and lowest during spring and early summer. This cyclic tendency was attributed to the utilization of carbonate forms during periods of greatest biological activity in spring and early summer, and the return of carbonate to solution during reduced activity in response to the lower temperatures of fall and winter. Highest levels of silica were observed during late fall and winter and lowest levels during spring and summer. This pattern was related to variations in plankton uptake of silica which increased when higher temperatures and greater sunlight increased plankton production. Levels of iron generally increased with increasing discharge and turbidity. Iron levels reflected the influx of suspended material to the stream since iron exists in association with soil or organic particles. Highest levels of ammonia (1.5 to 2.5 mg/l) occurred during January and February. Lowest levels of ammonia (0 to 0.22 mg/l) coincided with high discharges in December and March. Nitrate-N was extremely variable and showed no cyclic tendency during the year. High levels (1.24 to 1.90 mg/l) occurred irregularly during the winter, and levels usually decreased with increase in discharge. Phosphate levels in the Grand River system underwent large diurnal variations, but seasonal changes were irregular. No explanations were given for variations in forms of nitrogen or phosphorus.

In contrast to MacCrimmon and Kelso's findings, Owen and Johnson (69) observed that phosphorus loadings followed a seasonal pattern in their study of agricultural subwatersheds of Lake Ontario. From 73 to

80 percent of the annual yield of phosphorus from these areas was discharged during the high flow months of February, March, and April as compared with only 11 percent for the low flow period May to September. Headwater streams in particular exhibited higher concentrations during the spring high flows because of the phosphorus contributed by land drainage. During low flows, only trace amounts of phosphorus were present in headwater stations. Owen and Johnson attributed the progressive downstream increase in total phosphate concentrations during high flow periods to the increased proportion of surface runoff from cultivated land, a decreased proportion of discharged ground water, and increased sewage load. In addition, phosphorus added to the stream through the previous year and incorporated into the biomass and streambed deposits was resuspended by the scouring action of high flows. This resuspension effect was most dramatic where shallow stream gradients allowed greater sedimentation.

Gburek and Heald's (70) findings contradict those of Owen and Johnson. In their 3-year study of phosphorus output from an agricultural watershed in Pennsylvania, Gburek and Heald observed an inverse relationship between streamflow and phosphorus concentration. The highest concentrations of soluble phosphate (0.02 to 0.03 mg/l PO_4-P) occurred during summer low flow months, while the lowest concentrations (0.01 to 0.015 mg/l) occurred during early winter high flows. Highly variable streamflow during late winter and early spring resulted in highly variable soluble PO_4-P concentrations with no consistent relation to streamflow. Gburek and Heald did conclude, however, that there appeared to be a subtle seasonal variation in monthly phosphate levels that might be associated, not necessarily causally, with the variation of monthly streamflow. While they did not find higher concentrations with higher streamflow, phosphorus yields in pounds per month were higher during high flow periods. Integrating phosphate concentrations with streamflow showed that most of the soluble phosphorus output during the year was associated with the high flows and low concentrations found in early spring.

Jaworski and Hetling (39) also pointed out that phosphorus and nitrate loadings in pounds per day followed a seasonal pattern. Quantities of both nutrients increased significantly during high flow months. Consequently, they warned that sampling only under summer low flow conditions could lead to misleading conclusions as to the relative temporal and spatial distribution of nutrients.

Schuman _et al_. (54) found that variations in nitrogen levels were related to other factors than streamflow. They observed that both the water-soluble nitrogen and sediment nitrogen in runoff from agricultural watersheds were usually highest at the beginning of the cropping season and decreased progressively throughout the rest of the year. The crop seedbed and establishment period from May 1 to August 1 was the critical period for runoff and erosion. Because of the association of soluble nitrogen with high runoff and sediment nitrogen with soil erosion, this period was also critical for losses of both forms of nitrogen. Nitrogen losses were lowest during the crop reproduction and maturation period from August 1 to November 1. The period from November 1 to May 1, characterized by residue cover on the ground and precropping conditions, was critical for soluble nitrogen losses because surface runoff was substantial when the soil was frozen. Schuman _et al_. attributed the seasonal effect of progressive nitrogen removal to crop use, leaching, nitrogen tie-up in organic matter, and overland movement.

PREVIOUS STUDIES: SOUTH RIVER BASIN

In 1967 the Virginia Division of Water Resources (71) 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/l. At a point 20 miles below the city, concentrations at 6 A.M. had risen to 5 mg/l. During peak algal photosynthesis at 3 P.M., dissolved oxygen at the 10-mile point rose to about 3 mg/l. Concentrations below this point fluctuated between 0 and 5 mg/l and then rose sharply to 11 mg/l 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 (72) 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.

SIGNIFICANCE OF THIS STUDY

A number of field experiments have been conducted to investigate pollutant concentrations in runoff from small plots of land under highly controlled conditions (48, 49, 50, 52, 53, 54). While such small scale studies are useful in evaluating specific land use practices, their results cannot be extrapolated to large areas. This study of agricultural and forest land runoff in the Upper South River Basin will contribute to an understanding of how surface and subsurface drainage from a watershed under natural conditions affects stream water quality. A review of Tables I and II indicates that no generalization can be made about the relative magnitude of pollutant yields from nonpoint sources. Some researchers correlate the quality of surface runoff and groundwater with geologic formations, some with land use, and some with quantity of flow (59, 58, 39, 69, 70, 54). Any attempt to quantify pollutant contributions from the various sources in a drainage basin must involve field and laboratory analysis of that specific situation. Previous studies of other watersheds can only serve as guides in the conduct of a particular investigation.

As investigations by the Virginia Division of Water Resources (71) and Cairns and Dickson (72) have shown, high nutrient concentrations and extensive algal growth occur in the South River downstream of Waynesboro. This study of the South River upstream of Waynesboro will identify the sources of these nutrients and indicate if nutrient removal from municipal and industrial discharges will prevent stream enrichment and detrimental algal production. Observations of variations in streamflow and nutrient concentrations will also support or contradict past studies correlating high concentrations with high flows (68, 69, 70).

MATERIALS AND METHODS

This investigation of water quality in the Upper South River Basin was conducted from April 26, 1974 until July 30, 1974. A map of the Upper South River Basin is shown in Figure 1. Table III 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 nonpoint 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 IV. 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 pollutant concentrations of 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 at Stuarts Draft and Greenville. Domestic waste from the Stuarts Draft lagoon is the only significant point source discharge into this portion of the

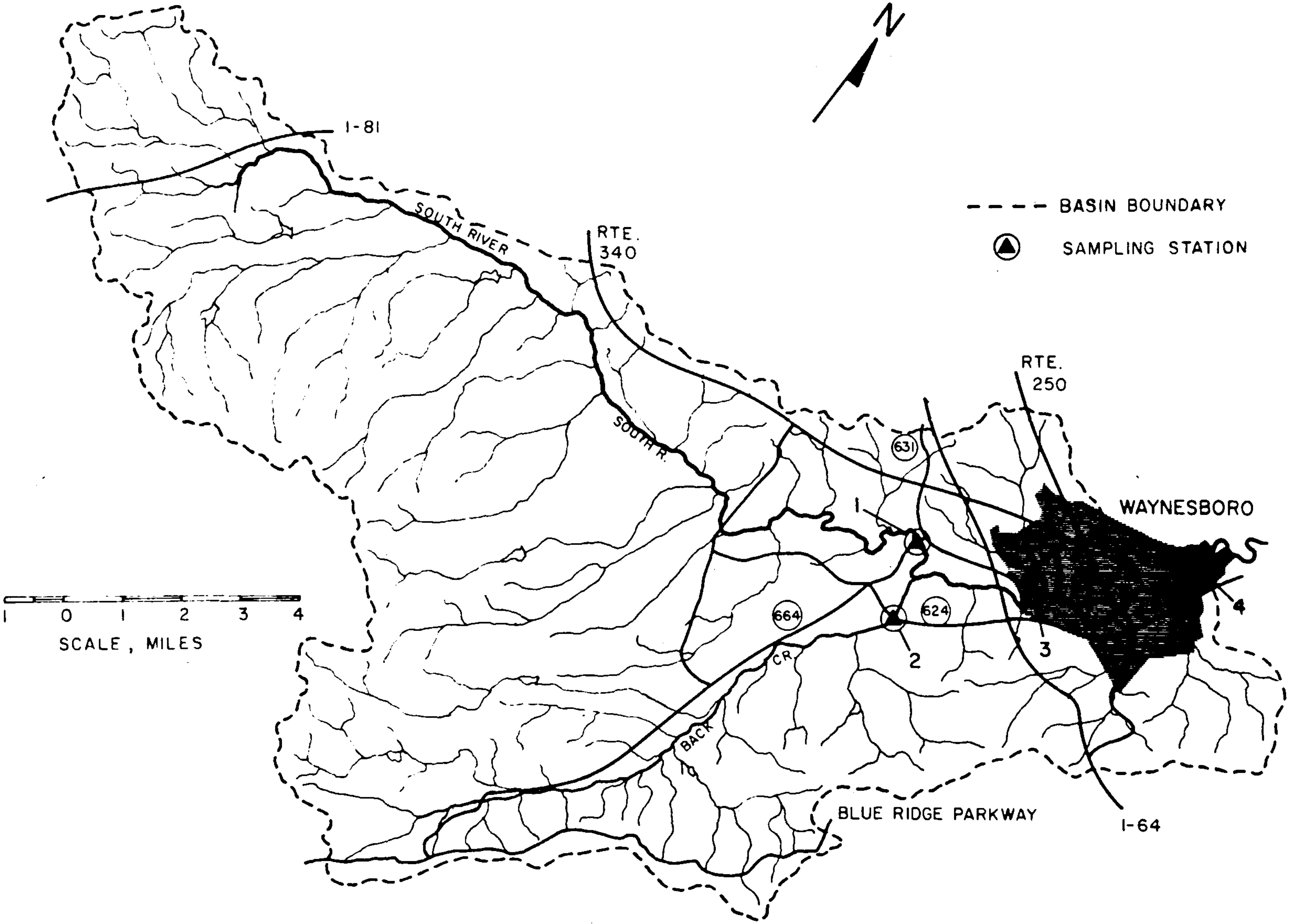

Figure 1. Upper South River Basin

Table III. Physical Characteristics of South River and Back Creek (73)

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 mouth (feet)	1,040	1,330

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

Description	Location	Drainage Area sq. miles	 % Total (74)
Site 1	Rte. 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
--forest/grassland		37	24
--cropland		14	9
--residential/industrial		10	6

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. Back Creek receives no domestic or industrial point source discharges. 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 drainage 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 was 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.

Chemical oxygen demand (COD) was determined according to the alternate procedure for dilute samples described in Standard Methods for the Examination of Water and Wastewater (75). 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 method in Standard Methods (75). 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 (75). 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 phenolphthalein 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 - 70CB was used for specific conductance measurements. Conductivity values were temperature-adjusted to 25°C using multiplication factors presented in Standard Methods (75).

Total suspended solids were measured by filtering samples through 5.5 centimeter glass fiber filters. In accordance with Standard Methods (75), 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.

RESULTS

CLIMATOLOGY 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 (76). 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.

Three kinds of storms bring heavy rainfall to the Basin--extratropical storms, tropical storms, and thunder storms. Extratropical storms generally originate in the northwestern U.S. or Gulf of Mexico area and move to the Appalachian mountains which tend to stall them. Atlantic lows usually react with these extratropical storms to produce long duration, heavy rainfalls of one to seven days. Tropical storms or hurricanes with fast moving low-pressure centers and heavy precipitation move across the Basin in summer or fall months. Exceptionally heavy rainfall occurs during these hurricanes over a 12 to 48 hour period. Thunderstorms and cloudbursts, occurring primarily in summer months, also produce heavy rainfalls in 1 to 6 hour periods over the Basin.

Table V 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_. (56) 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. Comparison of rainfall totals does reveal that the month of May during this study experienced average rainfall, June had 0.84 inches above the average rainfall, and July was very dry with 1.22 inches below the average.

HYDROLOGY SUMMARY

The average discharge of the Upper South River is 128 cfs based on 20 years of record from the U.S.G.S. gage at Site 3 (77). Extremes during the period of record range from a maximum discharge of 17,400 cfs

Table V.--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

*Averages based on 14 years of record (77).

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 detention 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 (5).

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 (76). Figure 2 presents the flow duration curve devised by the Virginia Division of Water Resources (76) 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.

PRESENTATION OF DATA

Streamflows and concentrations of parameters monitored during each day of sampling are shown in the Appendix. Tables VI-XII present average concentrations of each parameter according to weather conditions. As data on soil moisture, evaporation, and rainfall intensity are lacking, no comparison can be made among the wet weather samples. Consequently, each wet weather situation is presented separately with notations on total amount and time of rainfall. The May 12 storm event will be discussed in a separate section.

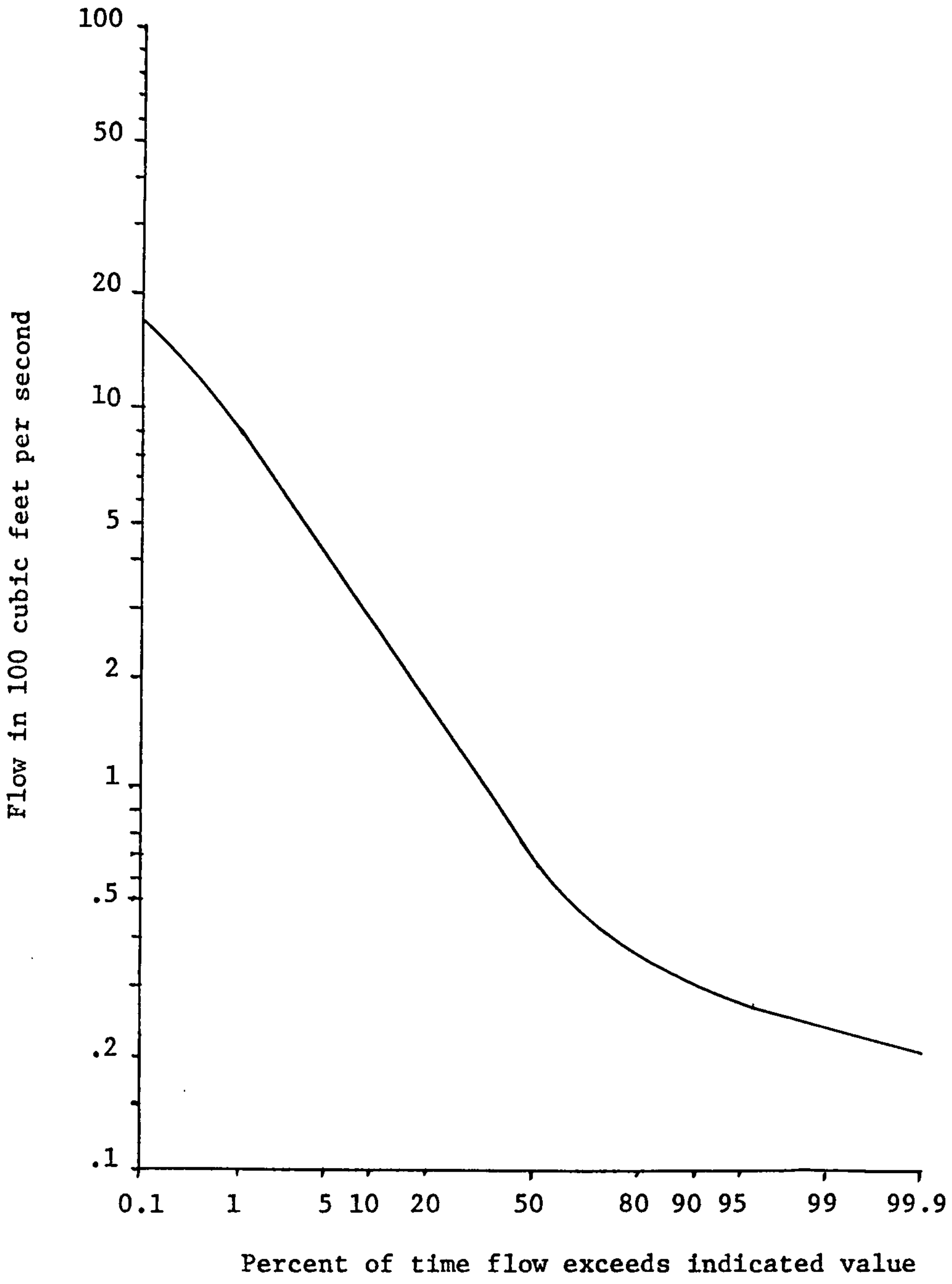

Figure 2. Flow duration curve for South River at Site 3. Source: Virginia Division of Water Resources.

Table VI.--Concentrations of Chemical Oxidation Demand*

Weather Conditions			Site No. 1	2	3	4
Dry		Average	4.3	4.0	5.0	20.5
		Range	1-8	1-8	2-12	15-35
Storm	(1.24") (6 hrs)	Range	28-36	24-52	4-76	68-100
Wet	(0.37") (19 hrs)		20	8	20	28
Wet	(0.87") (7.5 hrs)		14	6	8	14
Wet	(0.23") (7 hrs)		4	2	2.5	12
Wet	(0.11") (14.5 hrs)		4	3	3	17
Wet	(0.85") (14 hrs)		14	8	11	26
Wet	(0.70") (15 hrs)		2	2	5	19
Wet	(0.47") (9 hrs)		5	8	7	25

*COD, mg/l.

Table VII.--Concentrations of Total Suspended Solids*

Weather Conditions			Site No.			
			1	2	3	4
Dry		Average	11	1.4	9.0	7.4
		Range	4.4-15.0	0.4.2	4.8-14.0	2.4-17.2
Storm	(1.24") (6 hrs)	Range	38.5-56.5	15-311	30.5-476	45.5-771
Wet	(0.37" (19 hrs)		10.0	1.0	8.0	13.0
Wet	(0.87") (7.5 hrs)		46.8	5.0	40.0	29.4
Wet	(0.23") (7 hrs)		7.6	16.0	3.2	2.8
Wet	(0.11") (14.5 hrs)		18.0	4.0	7.6	3.2
Wet	(0.85") (14 hrs)		103.7	12.8	24.4	39.6
Wet	(0.70") (15 hrs)		13.0	10.0	10.0	4.8
Wet	(0.47") (9 hrs)		18.0	13.2	16.4	10.8

*TSS, mg/l

Table VIII.--Concentrations of Turbidity*

			Site No.			
Weather Conditions			1	2	3	4
Dry		Average Range	6 2.5-13.5	2 0.5-5.2	6 2.6-15.5	8.6 4.0-25.0
Storm	(1.24") (6 hrs)	Range	8-25	8-76	12-160	12-180
Wet	(0.37") (19 hrs)		16.0	4.3	15.0	18.0
Wet	(0.87") (7.5 hrs)		24.0	2.8	22.0	8.0
Wet	(0.23") (7 hrs)		5.8	1.2	3.5	4.3
Wet	(0.11") (14.5 hrs)		7.5	1.2	6.2	5.2
Wet	(0.85") (14 hrs)		27.0	3.5	8.0	9.0
Wet	(0.70") (15 hrs)		5.2	2.0	5.2	5.2
Wet	(0.47") (9 hrs)		6.1	1.6	8.0	8.0

*Turbidity, mg/l SiO_2

Table IX.--Values of Specific Conductance*

			Site No.			
Weather Conditions			1	2	3	4
Dry		Average	226	35.7	206	383
		Range	196-246	25.9-43.5	144-246	282-583
Storm	(1.24") (6 hrs)	Range	190-223	76.5-214	41.1-111	76.9-240
Wet	(0.37") (19 hrs)		205	29.7	156	295
Wet	(0.87") (7.5 hrs)		186	36.3	121	214
Wet	(0.23") (7 hrs)		224	33.1	181	301
Wet	(0.11") (14.5 hrs)		241	34.6	205	366
Wet	(0.85") (14 hrs)		272	36.8	207	284
Wet	(0.70") (15 hrs)		233	48.2	196	488
Wet	(0.47") (9 hrs)		223	37.1	230	451

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*Specific conductance, micromhos/cm @ 25°C

Table X.--Concentrations of Total Phosphorus as P*

Weather Conditions			Site No. 1	2	3	4
Dry		Average Range	0.12 .07-.2	0.04 .01-.08	0.10 .05-.16	0.48 .39-.62
Storm	(1.24") (6 hrs)	Range	.10-.27	0-.33	.06-.58	.15-.79
Wet	(0.37") (19 hrs)		0.07	0	0.11	0.39
Wet	(0.87") (7.5 hrs)		0.20	0.03	0.10	0.23
Wet	(0.23") (7 hrs)		0.10	0.07	0.12	0.45
Wet	(0.11") (14.5 hrs)		0.13	0	0.10	0.28
Wet	(0.85") (14 hrs)		0.34	0.08	0.18	0.46
Wet	(0.70") (15 hrs)		0.12	0.06	0.12	0.52
Wet	(0.47") (9 hrs)		0.15	0.06	0.14	0.40

*Phosphorus, mg/l P.

Table XI.--Concentrations of Total Kjeldahl Nitrogen*

Weather Conditions			Site No. 1	2	3	4
Dry		Average Range	0.95 0-2.9	1.04 0-2.15	0.98 0-1.26	3.47 1.68-5.42
Storm	(1.24") (6 hrs)	Range	1.05-1.47	1.05-1.68	1.05-1.68	1.26-2.52
Wet	(0.37") (19 hrs)		0.42	0.42	0.42	2.52
Wet	(0.87") (7.5 hrs)		1.05	0.84	0.74	1.89
Wet	(0.23") (7 hrs)		0.84	0.42	0.84	2.94
Wet	(0.11") (14.5 hrs)		1.26	<.42	0	2.10
Wet	(0.85") (14 hrs)		<.42	0	<.42	1.68
Wet	(0.70") (15 hrs)		1.26	1.26	1.26	5.00
Wet	(0.47") (9 hrs)		0.42	0.40	0.42	3.40

*TKN, mg/l N

Table XII.--Concentrations of Nitrate as N*

			Site No.			
Weather Conditions			1	2	3	4
Dry		Average	1.22	0.12	1.25	2.25
		Range	.54-2.38	0-.99	.45-3.19	1.16-3.48
Storm	(1.24") (6 hrs)	Range	.75-.99	0	0-.51	0-.57
Wet	(0.37") (19 hrs)		0.91	0.43	0.69	1.16
Wet	(0.87") (7.5 hrs)		2.10	0	0.91	1.68
Wet	(0.23") (7 hrs)		1.68	0	1.44	2.95
Wet	(0.11") (14.5 hrs)		1.60	0	1.52	2.74
Wet	(0.85") (14 hrs)		1.77	0	1.59	2.95
Wet	(0.70") (15 hrs)		1.32	0	0.82	1.77
Wet	(0.47") (9 hrs)		0.63	0	0.61	1.87

*Nitrate, mg/l N

Comparisons of concentrations reported in this study can be made with concentrations reported in the literature. Cahill _et al_. (21) and Keup (31) present convincing arguments that runoff during wet weather is primarily contributed by the land immediately adjacent to the stream. Consequently, runoff yields at Site 1 are considered to be agricultural contributions despite the fact that 53 percent of the drainage area is forested. The majority of land bordering the Upper South River is pasture, grassland, and cropland. By the same token, Back Creek runoff measured at Site 2 is derived primarily from forest land since 8.5 miles of the 12.5 river miles above the sampling station are bordered by woodland. Site 3 drainage is derived from a combination of agricultural and forest land, and Site 4 drainage includes urban runoff from the city of 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_. (58) and Thomas and Crutchfield (59) 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 much phosphorus is adsorbed on sediment (28). TKN and COD values at

Site 2 are generally lower but sometimes comparable to COD and TKN concentrations at Site 1. This effect can be attributed to the presence of algae in Back Creek which grow well in the quiescent waters. Nitrifying activity in Back Creek appears to be low since TKN concentrations are often high, but NO_3^- concentrations are negligible much of the time.

Phosphorus concentrations in forest runoff at Site 2 agree well with phosphorus concentrations reported by Cooper (41), Taylor _et al._ (58), and Sylvester (19). Nitrate concentrations at Site 2 are substantially lower than values reported in the literature on forest runoff. Phosphorus concentrations in agricultural runoff at Sites 1 and 3 agree well with concentrations reported by Engelbrecht and Morgan (55). In most cases nitrate and phosphorus concentrations at Sites 1 and 3 are higher than those reported by Taylor _et al._ (58) for farmland runoff. Concentrations at Sites 1 and 3 are comparable to grassland/ pasture values reported by Dornbush _et al._ (56) for nitrates, phosphorus, total suspended solids, and specific conductance. COD and TKN values for this study are significantly lower than those reported by Dornbush _et al._

Concentrations of all parameters except turbidity and total suspended solids are greater at Site 4 than at the other three sites. This is due to the contributions of urban runoff and wastewater discharges in the city of Waynesboro. As reported in the literature (62, 61, 42, 63, 64, 19), concentrations of urban runoff are very high in comparison with agricultural and forest land runoff. In addition, industrial and municipal effluents have high concentrations of organic matter and nutrients. Analyses made by the Virginia State Water Control Board report average concentrations for the two main industries and city sewage treatment plant as follows:

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

The pattern of total suspended solids concentrations can be explained by sedimentation and dilution processes. A bridge construction project at Site 1 inflates the concentration of suspended solids in that part of the stream. These solids settle out between Sites 1 and 3 when they exceed the carrying capacity of the river. Site 2 flow is very low in solids and its contribution to the combined flow at Site 3 dilutes the concentration. Concentrations at Site 4 are lower than at Site 3 because of dilution by about 20 cfs of ground water added to the river by the DuPont waste treatment system. Municipal and industrial effluents do not contribute enough suspended solids to raise the concentration in the increased flow.

In both June and July the low flows and low concentrations of Site 2 resulted in the lowest daily yield of pollutants while the high flows and high concentrations of Site 4 produced the largest loads. The calculated average daily load of each parameter monitored at the four stations is presented in Table XIII. Yields are not calculated for either April or May since so few samples were analyzed during those months. Daily yields in June are 2 to 5 times greater than those in

Table XIII.--Average Daily Yields from All Sources

Parameter (lb/day)	Site No.							
	1		2		3		4	
	June	July	June	July	June	July	June	July
COD	2,195	826	487	101	2,162	1,286	12,534	7,950
TSS	9,500	2,584	454	84	7,619	2,672	12,517	2,899
Total Phosphorus (as P)	56	27	5.5	1.4	53	26	284	194
TKN	276	253	99	37	281	306	1,889	1,579
NO_3-N	554	241	0	0	563	226	1,858	826

July. Monthly differences in yields are particularly great at Site 2 which experienced the greatest variation in flow. Higher June yields result from greater contributions by land runoff. Phosphorus yields in June are also higher because of the scouring action of high flows causing resuspension of bottom sediments and biomass. As shown in Table V, total rainfall in June exceeded July rainfall by 2.36 inches, thus causing higher flows and land drainage contributions.

The combined COD of the Upper South River, as measured at Site 1 and of Back Creek, as measured at Site 2 is calculated as 2682 lb/day. At Site 3, however, the combined flow of the Upper South River and Back Creek has an observed daily COD yield of only 2162 lb. The decrease in COD is attributed to the river's self-purification process of biodegradation along the 3.4 river miles between Sites 1 and 3. In July the observed COD at Site 3 is 359 lb/day greater than that contributed by the Upper South River at Site 1 and by Back Creek. This illustrates Wadleigh's (37) statement that under low flow conditions a stream's capacity to assimilate organic wastes is much reduced. The COD increases because of additional organic matter contributed by the extra drainage area. COD increases from Site 3 to Site 4 by a factor of 5.8 in June and 6.2 in July. This increase is due to the contributions from 24 additional square miles of drainage area and to point source discharges. The magnitude of this increase results from the dominance of point source discharges in determining yields of organic matter at Site 4. The June increase is smaller because of the greater assimilation of organic matter during wet weather flows.

The combined amount of total suspended solids contributed by the

Upper South River and Back Creek is calculated to be 9954 lb/day in June. The observed daily yield at Site 3 is 2335 lb less than expected. The decrease can be explained by the settling of particles along the 3.4 miles between Sites 1 and 3. As explained before, bridge construction at Site 1 contributes large amounts of suspended solids to the river during wet weather. Solids in excess of the carrying capacity of the flow settle out before reaching Site 3. In July the combined amount of suspended solids increased by 4 lb at Site 3. This slight increase can be attributed to the increase in wash load along the 3.4 stream miles between Sites 1 and 3. The dry weather in July prevented large contributions of sediment to the river from the construction at Site 1. Yields at Site 1 were, therefore, not inflated beyond the carrying capacity of the river. Daily yields of total suspended solids increase between Sites 3 and 4 by a factor of 1.6 in June and 1.1 in July. The increase is not nearly as great as in the case of COD yields since point source discharges have little effect on suspended solids loads. The increase is greater in June because of greater runoff contributions from the additional urban and agricultural land draining into Site 4.

The phosphorus load of the South River at Site 3 is 8.5 lb/day less in June and 2.4 lb/day less in July than that calculated for combined loads from Sites 1 and 2. The June decrease can be attributed to the uptake of phosphorus by organisms and the sedimentation of particulate matter. As Black (28) points out, the phosphorus transported in surface runoff is primarily in particulate form, either fixed in living cells or adsorbed on particulate matter. The sedimentation pattern shown in the June trend for total suspended solids decreases the phosphorus load. Decrease in July can be explained by organism uptake. Keup (31) states that phosphorus is assimilated rapidly from flowing water, particularly by periphyton. Between Sites 3 and 4 phosphorus increases by a factor of 5.4 in June and 7.5 in July. This increase is due to contributions from additional drainage area and to wastewater discharges. The magnitude of the increase stems from the dominance of point source contributions at Site 4. The July increase may be greater because of dilution by groundwater and less phosphorus uptake by organisms during critical low flow, low oxygen periods.

Daily yields of TKN follow the same pattern between Sites 1 and 3 as total suspended solids. As explained in the discussion of suspended solids, sedimentation occurs between these two sites during wet weather flows. According to Holt et al. (26), the organic nitrogen and ammonia nitrogen included in TKN values are carried on sediment transported in surface runoff. The organic nitrogen is not water soluble and the soluble ammonium ion is effectively retained in the sediment by absorption or ion exchange. Suspended solids which settle out carry organic nitrogen and ammonium nitrogen to stream bed deposits. In addition to losses by sedimentation, ammonia and organic nitrogen undergo nitrification to nitrate. Ammonia can also be taken up by aquatic plants. Consequently, the combined TKN yields of Sites 1 and 2 decrease from 375 lb/day to 281 lb/day at Site 3 in June. During July low flows, the observed yield at Site 3 is 16 lb/day greater than that calculated from the combined yields of Sites 1 and 2. This increase can be attributed to the increase in sediment between Sites 1 and 3 during the month of July. Between Sites 3 and 4 TKN increases by a factor of 6.7 in June and a factor of 5.2 in July. The increase reflects the contributions of land runoff from additional drainage area and of loadings from point source discharges. The magnitude of the increase reflects the dominating influence of wastewater contributions on TKN yields at Site 4. The increase is greater in June because of greater runoff contributions from the extra drainage area of Site 4.

In June nitrate loads increase between Sites 1 and 3 even though no additional nitrate is added by Back Creek. The increase can be attributed to the nitrification of organic and ammonia nitrogen to nitrate and to contributions of surface runoff. Unlike organic and ammonia nitrogen, the nitrate carried in runoff is soluble. It goes into solution and is not lost to stream bed deposits. The decrease in nitrate yield between Sites 1 and 3 in July can be explained by the uptake of nitrate by algae and rooted plants. McCoy (24) also states that nitrates may undergo bacterial reduction first to nitrite and then to ammonia. During this dry month there was not sufficient surface runoff with nitrate to replenish the losses. Between Sites 3 and 4, nitrate yields increased by a factor of 3.3 in June and 3.7 in July. The magnitude of this increase indicates an important contribution of nitrate by wastewater discharges. The increase is greater in July because ground water, which typically has relatively high nitrate concentrations, occupies a greater proportion of total flow at Site 4 during this month.

Table XIV presents the calculated wastewater loadings for the four most significant point source discharges in the Upper South River Basin.

Table XIV.--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

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

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. Though most of this waste is probably assimilated before reaching the sampling stations, it will be assumed that no such assimilation occurs in order to prevent overestimation of nonpoint source contributions. 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. It will also be assumed that no assimilation of these industrial and municipal wastes occur above Site 4. Industrial waste discharges account for 75 percent of the total COD yield from 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.

Table XV shows the calculated daily yields of parameters contributed by land runoff sources. TKN and nitrate yields are combined as total nitrogen since they undergo bacterial conversion from one form to the other and since both are available for algal use. Jaworski and Hetling (39) and others (68, 69, 54) have warned about the low reliability in extrapolating summer low flow yields to annual totals. The large differences seen in June and July yields support this conclusion. However, literature values for runoff yields have been reported in

Table XV.--Calculated Daily Yields from Land Runoff

	Site 1		Site 2		Site 3		Site 4	
	Agricultural Drainage		Forest Drainage		Agricultural & Forest Drainage		Agricultural, Forest & Urban Drainage	
Parameter	June	July	June	July	June	July	June	July
COD								
lb/day	2,088	719	487	101	2,055	1,179	4,999	415
lb/day/acre	0.038	0.013	0.018	0.004	0.024	0.014	0.050	0.004
TSS								
lb/day	9,476	2,560	454	84	7,595	2,648	11,972	2,354
lb/day/acre	0.174	0.047	0.016	0.003	0.089	0.031	0.119	0.023
Total Phosphorus (as P)								
lb/day	41	12	5.500	1.400	38	11	103	13
lb/day/acre	0.0008	0.0002	0.0002	0.00005	0.0004	0.0001	0.001	0.0001
Total Nitrogen								
lb/day	812	476	99	37	826	514	1,391	49
lb/day/acre	0.015	0.009	0.004	0.001	0.010	0.006	0.014	0.0005

terms of annual loads. For purposes of comparison only, daily loads calculated from this study can be extrapolated to annual yields. Based on June yields, the estimated annual agricultural runoff yields at Site 1 calculate out to 13.9 lb/acre COD, 63.5 lb/acre TSS, 0.29 lb/acre Total P, and 5.5 lb/acre Total N. As expected, these extrapolated low flow loads are lower in all cases than the annual agricultural yields presented in Table I. Estimated annual loads based on July yields are even farther below the range of literature values.

Based on June yields, the estimated annual forest yields at Site 2 calculate out to 6.6 lb/acre COD, 5.8 lb/acre TSS, 0.073 lb/acre Total P, and 1.5 lb/acre Total N. No COD or TSS yields were reported in the literature reviewed on forest runoff. Comparison of nutrient loads reveals that extrapolated low flow yields using June values are within the lower range of literature values. Extrapolation of July values falls below the total phosphorus and total nitrogen values reported in the literature. For all parameters monitored, agricultural runoff yields are greater than forest runoff yields in the Upper South River Basin. This trend is supported by the literature as shown in Table 1.

Except for COD values in July, unit area yields calculated from the combined agricultural and forest land flow at Site 3 are lower than Site 1 yields and higher than Site 2 yields. As shown in Table IV, yields at Site 3 are lower than those at Site 1 because of the greater proportion of forest land in the drainage area. Yields are higher than those at Site 2 because of the greater proportion of agricultural land. The exception of COD values in July stems from the fact that low flows during this dry month do not support the assimilation of organic wastes.

In June unit area yields at Site 4 are greater than those at Site 3. The increase is due to the contributions of urban runoff. In contrast to Site 3, the drainage area of Site 4 includes the city of Waynesboro with its 7 square miles of urban area. As shown in Table I, the literature reports very high yields of COD, TSS, Total P, and Total N in urban runoff. These high yields would be sufficient to raise the total load at Site 4 so that the calculated unit area yield would increase. In July unit area phosphorus yields at Site 4 are equivalent to those at Site 3 but COD, total suspended solids and total nitrogen are less. The reduction in these yields can be explained by the higher proportion of groundwater in Site 4 flow during the dry weather low flows of July. About 20 cfs of the flow at Site 4 consists of groundwater added to the river through the DuPont waste treatment system. During July daily discharges at Site 4 ranged from 64 cfs to 104 cfs, with an average of 80 cfs. Groundwater additions, therefore, made up an average of 25 percent of the total flow. As reported in the literature (43, 45), groundwater contains minimal concentrations of pollutants, thereby decreasing the total yield at Site 4.

Table XVI presents a comparison of the total and percentage yield of the parameters contributed at Site 4 by land drainage and wastewater effluents. During both June and July, land runoff is the major contributor of total suspended solids. Wastewater discharges are the primary contributors of COD, total phosphorus, and total nitrogen, but the proportions vary between the two months. In the wet month of June

Table XVI.--Comparison of Loadings from All Sources

Parameter	All Wastewater Discharges		Agricultural, Forest & Urban Drainage		Total	
	June	July	June	July	June	July
COD						
lb/day	7,535	7,535	4,999	415	12,534	7,950
% of Total	60	95	40	5	100	100
TSS						
lb/day	545	545	11,972	2,354	12,517	2,899
% of Total	4	19	96	81	100	100
Total Phosphorus (as P)						
lb/day	181	181	103	13	284	194
% of Total	64	93	36	7	100	100
Total Nitrogen						
lb/day	2,356	2,356	1,391	49	3,747	2,405
% of Total	63	98	37	2	100	100

Calculations Based on Data Obtained from Site 4.

the proportion of yields provided by wastewater discharges is much less than in July when little land runoff occurred. In June the proportions contributed by wastewater vary from 60 to 64 percent while in July they vary from 93 to 98 percent.

STORM EVENT ANALYSIS

On May 12, 1974, 1.24 inches of rain fell over the Upper South River during a 6-hour period. Figures 3 through 14 present variations in concentrations of parameters at the peak and declining phase of the storm hydrograph. Iron analysis was added to the chemical tests performed on the samples when neutralization of phosphorus samples resulted in noticeable iron precipitation.

Total suspended solids declined with flow at all sites except Site 1. Keup (31) explains how suspended solids follow the hydrologic pulse caused by a storm. On the rising side of the hydrograph, suspended solids rise and peak near, and in most cases before, the peak discharge. This is attributed to the addition of wash load particles in land runoff and resuspension of bed load material by the scouring of increased flows. On the declining side of the hydrograph, velocity and turbulence are reduced and the capacity of the stream to transport sediment is reduced. Consequently, concentrations of suspended solids decrease with decreasing flow. At Site 1, progressive decrease and then increase in suspended solids concentration with decreasing flow can be explained by construction activity at the site. The day the first two samples were taken was a Sunday and there was no work being done on the bridge. Suspended solids concentrations in these samples

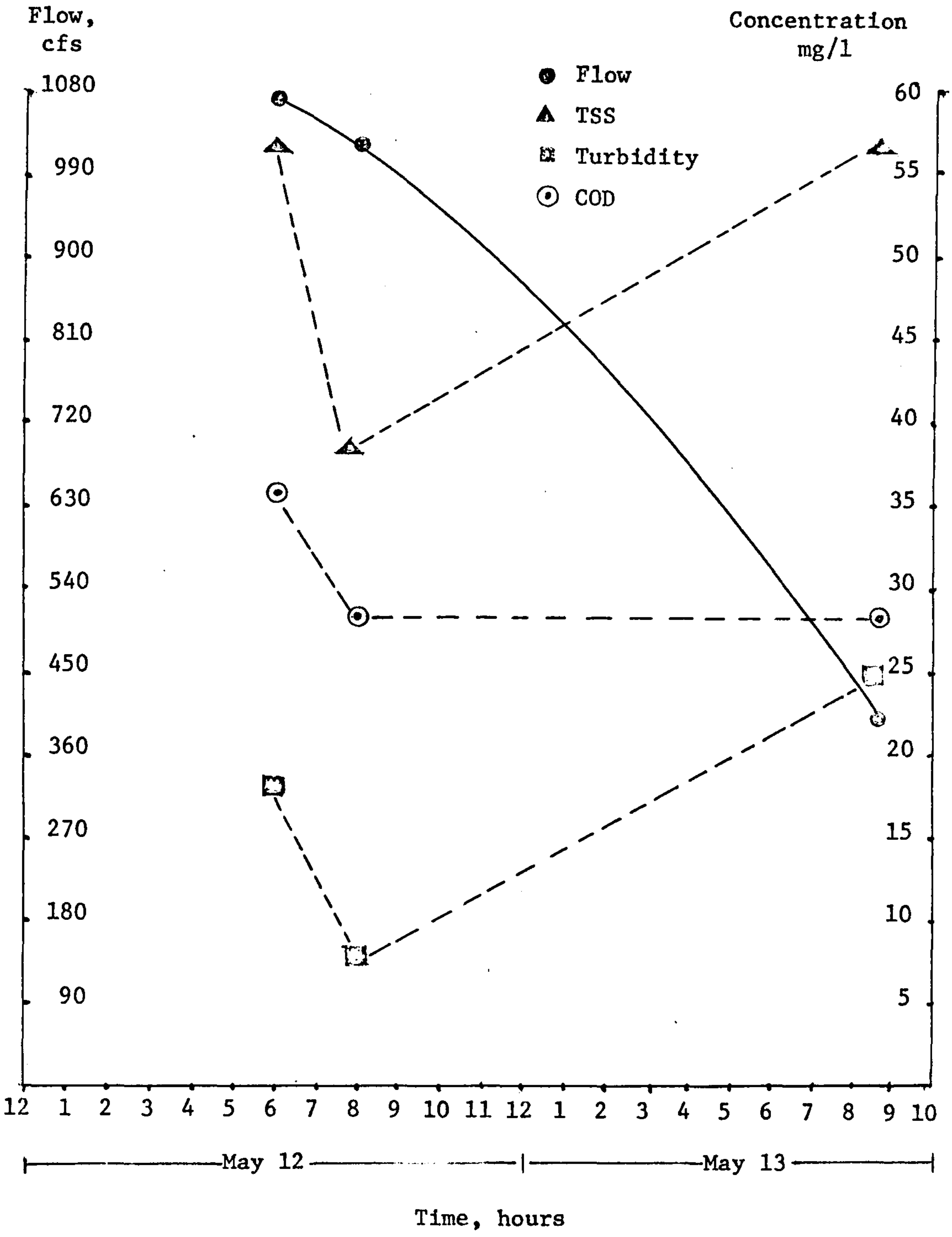

Figure 3. Variation in suspended solids and COD with flow at Site 1.

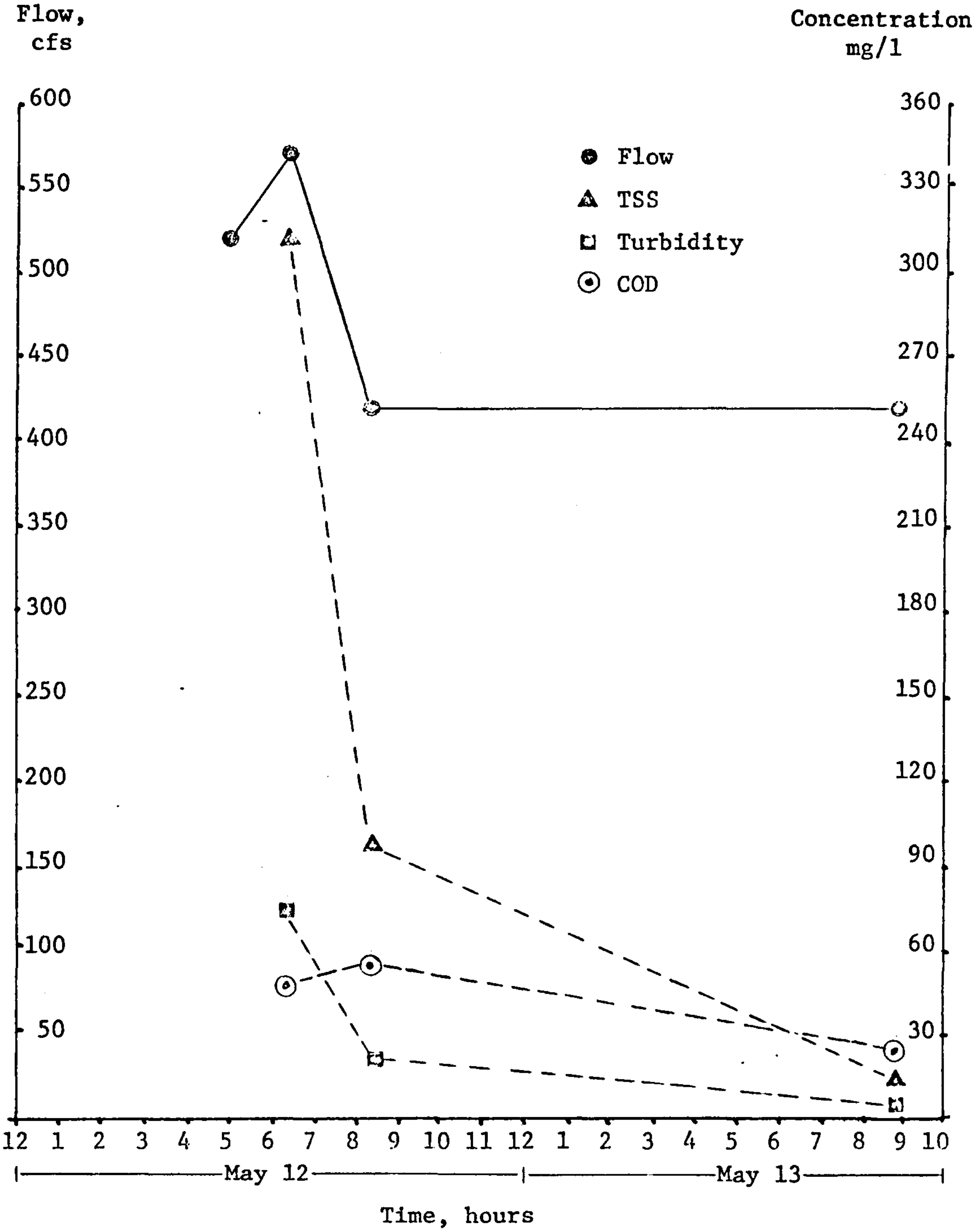

Figure 4. Variation in suspended solids and COD with flow at Site 2.

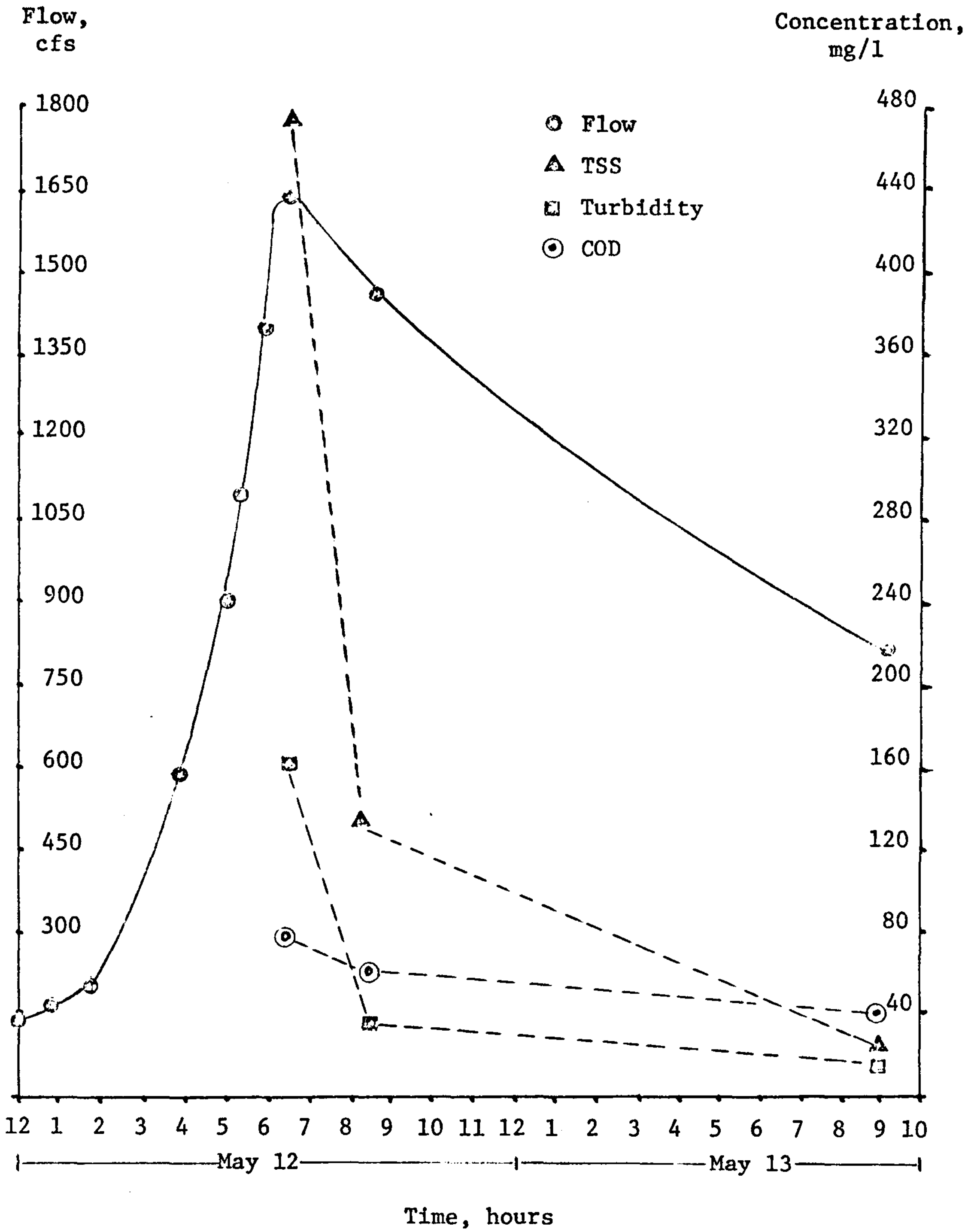

Figure 5. Variation in suspended solids and COD with flow at Site 3.

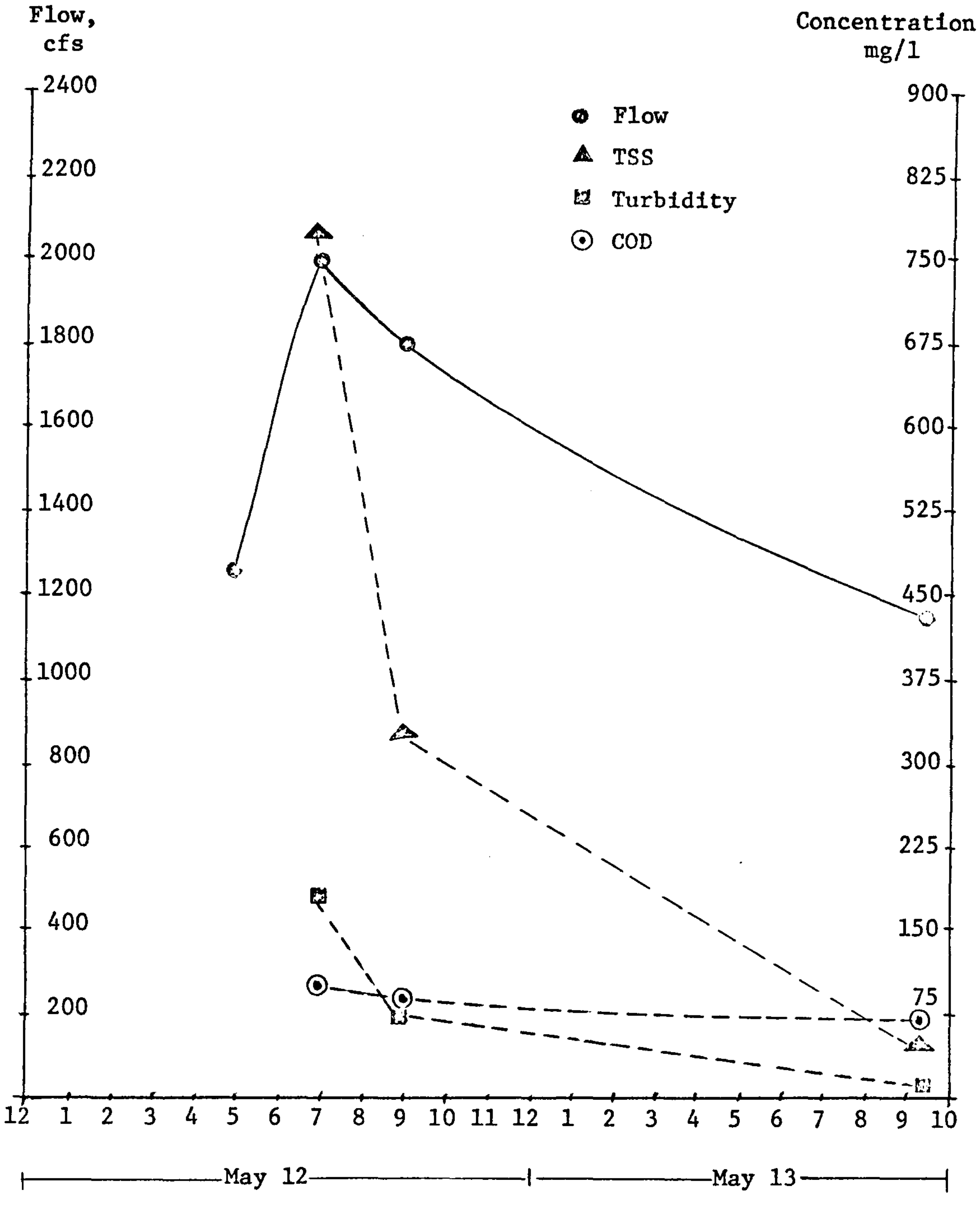

Figure 6. Variation in suspended solids and COD with flow at Site 4.

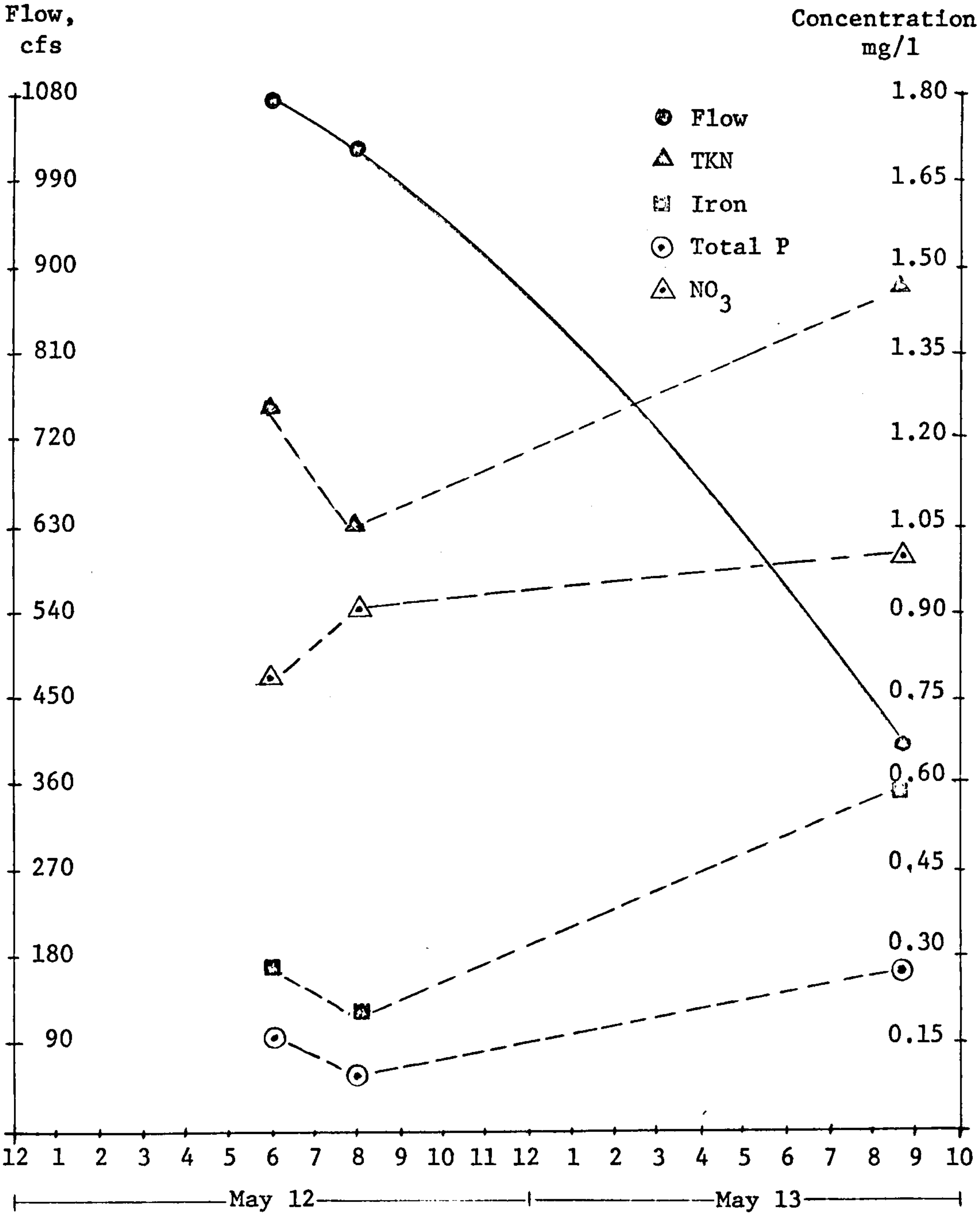

Figure 7. Variation in nutrients with flow at Site 1.

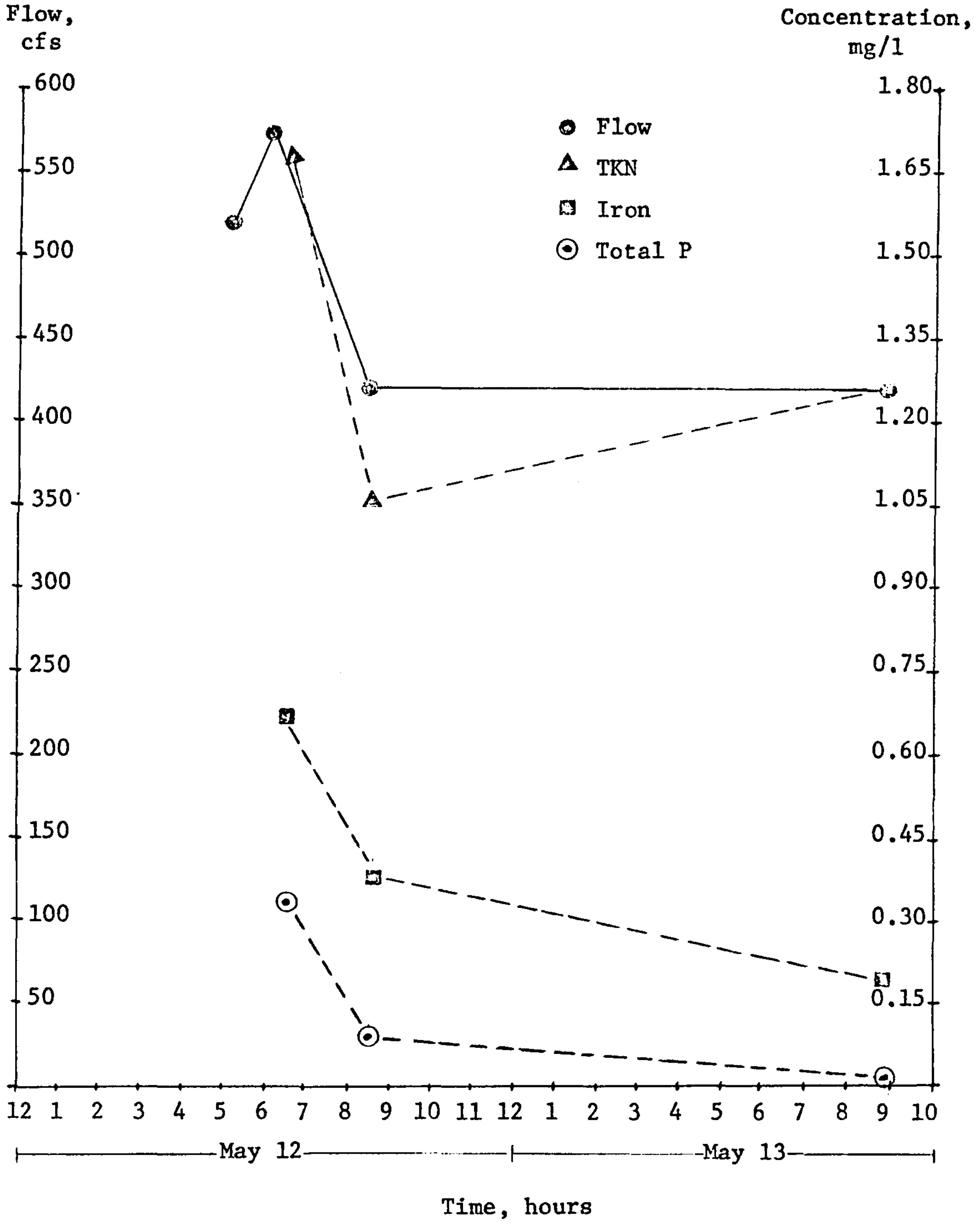

Figure 8. Variation in nutrients with flow at Site 2.

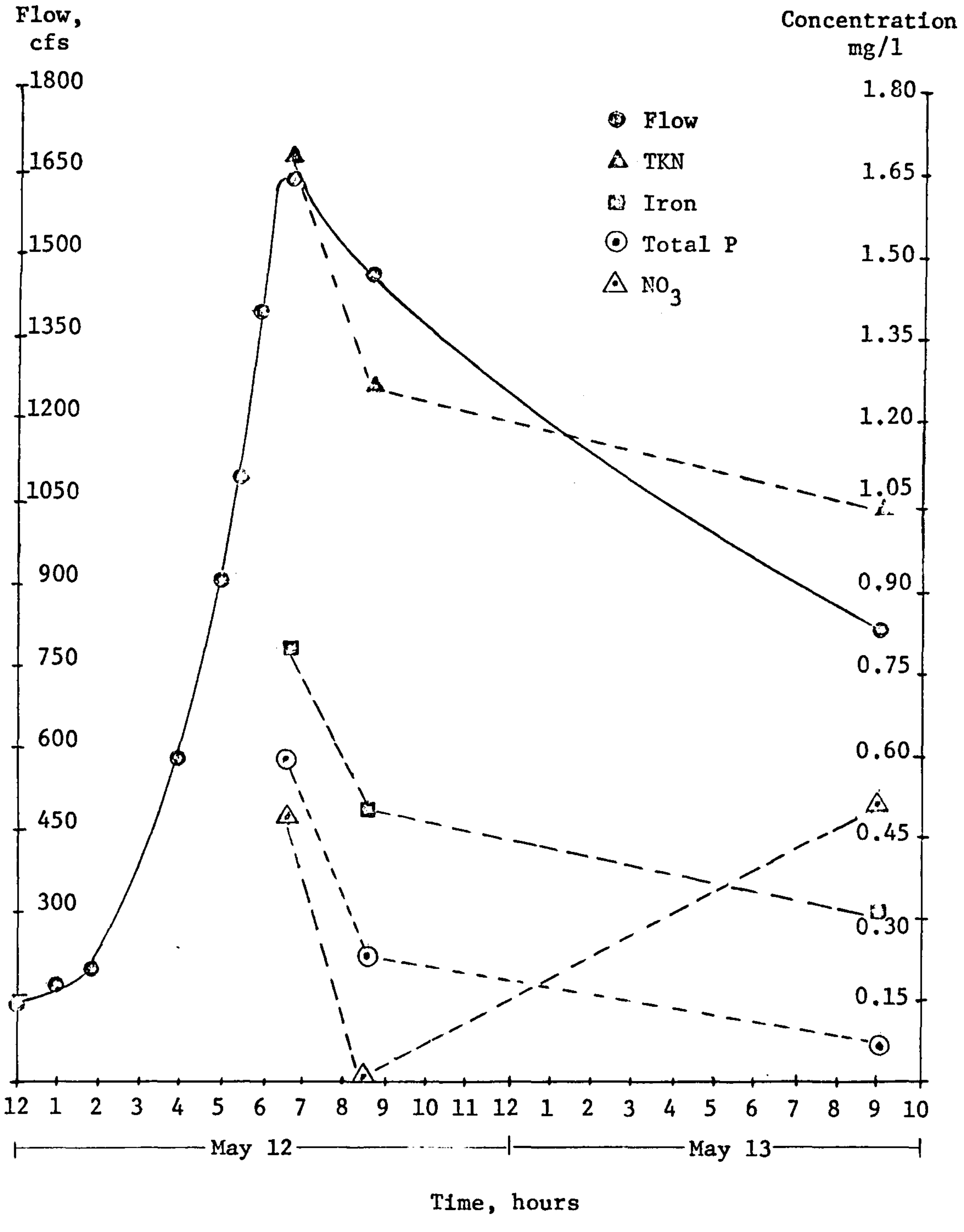

Figure 9. Variation in nutrients with flow at Site 3.

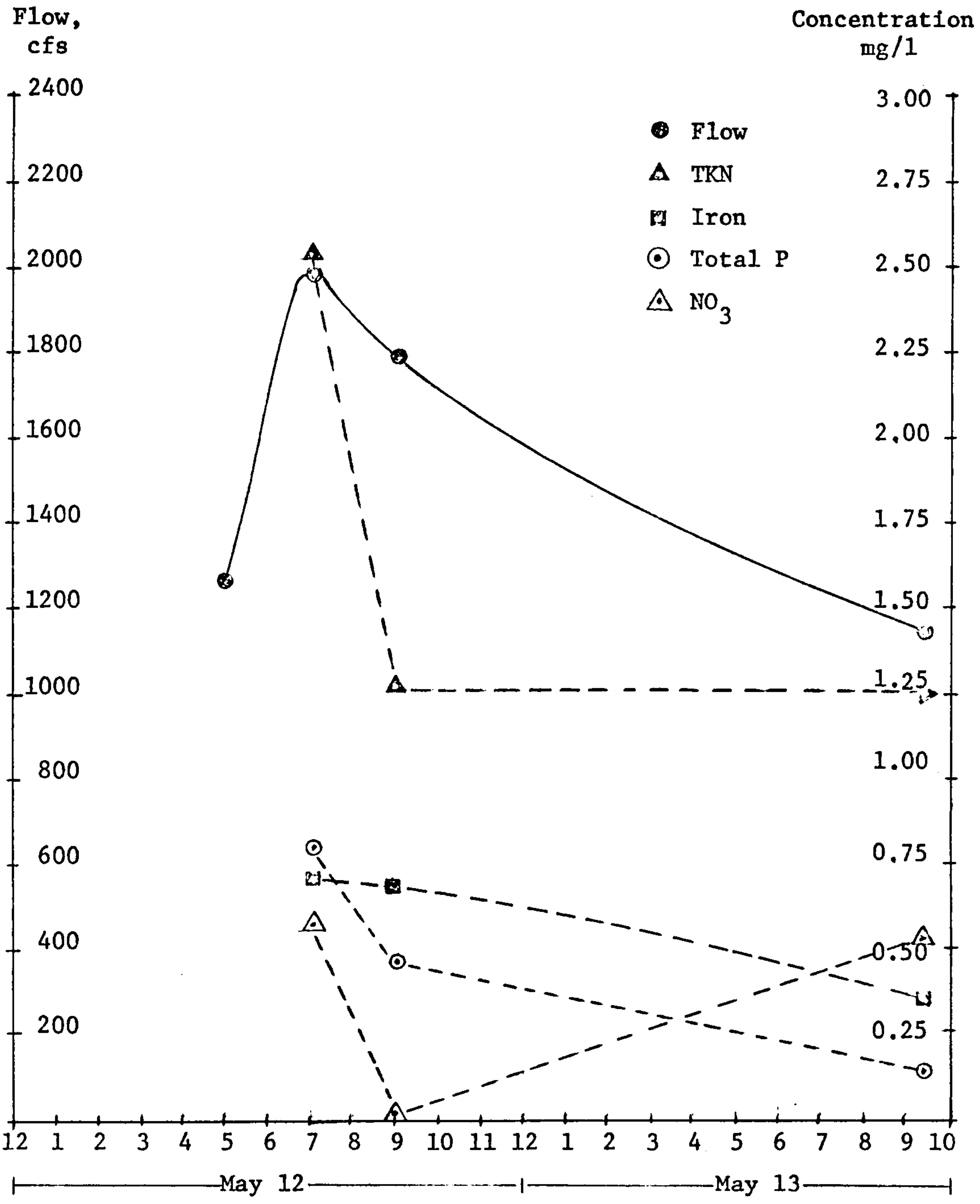

Figure 10. Variation in nutrients with flow at Site 4.

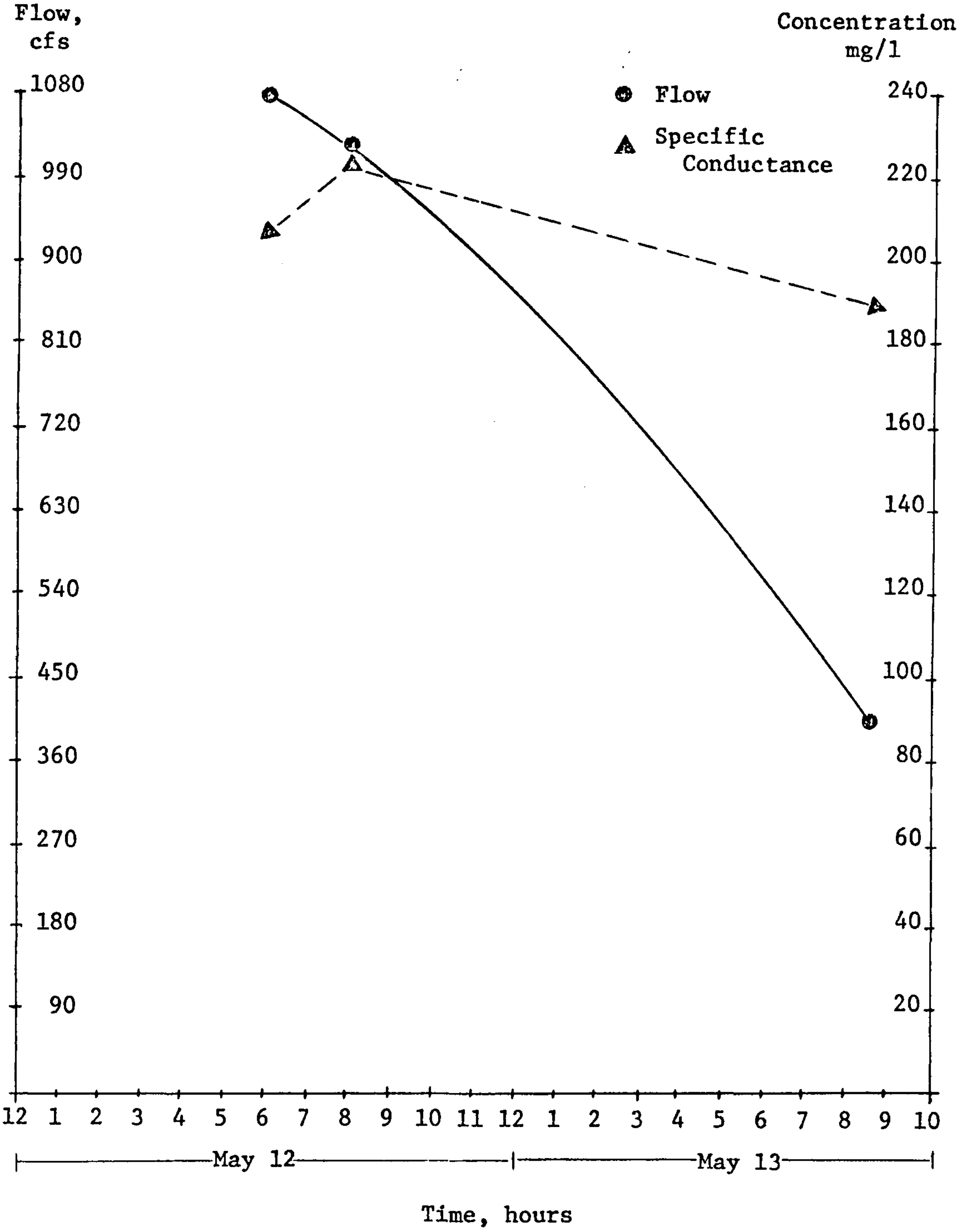

Figure 11. Variation in specific conductance with flow at Site 1.

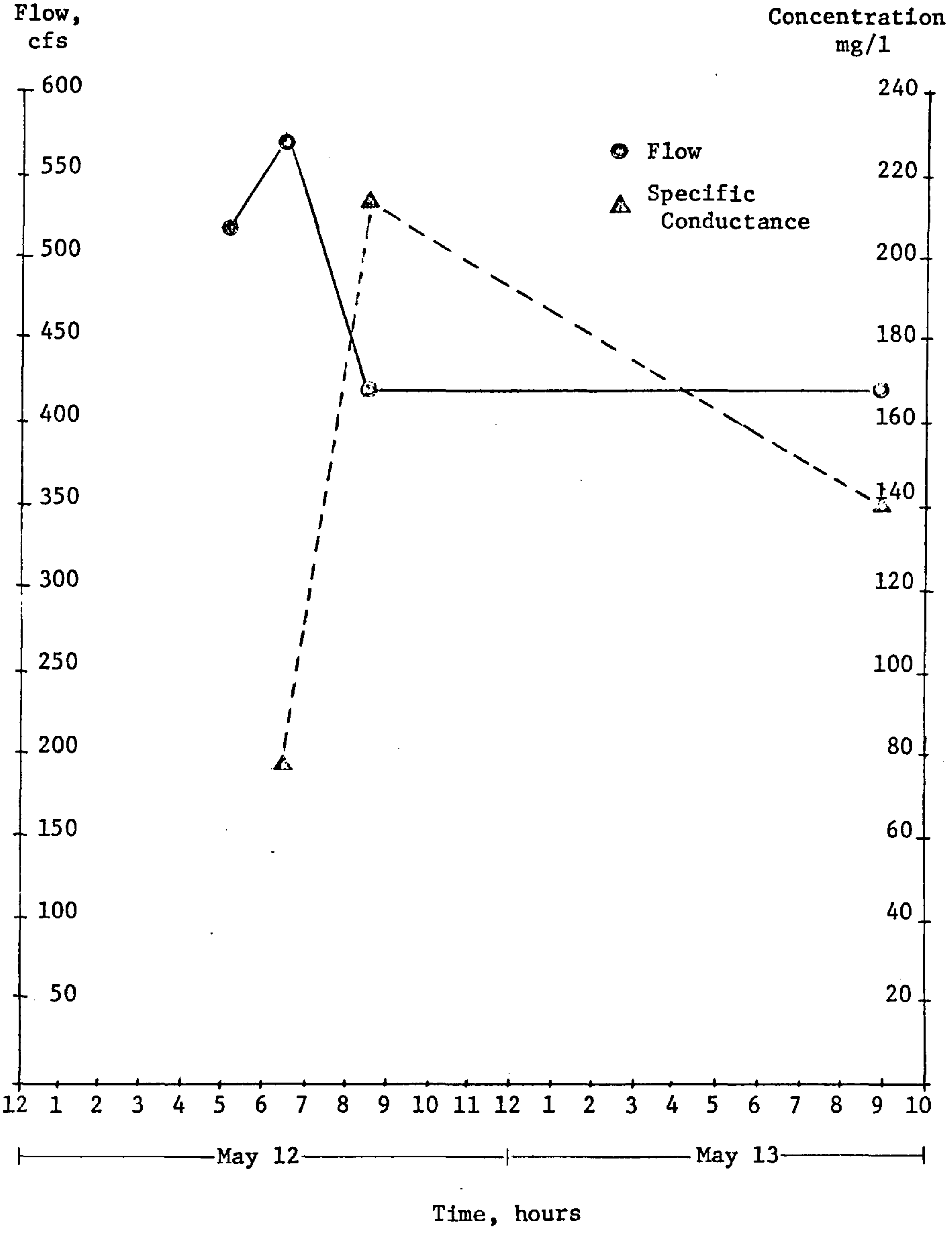

Figure 12. Variation in specific conductance with flow at Site 2.

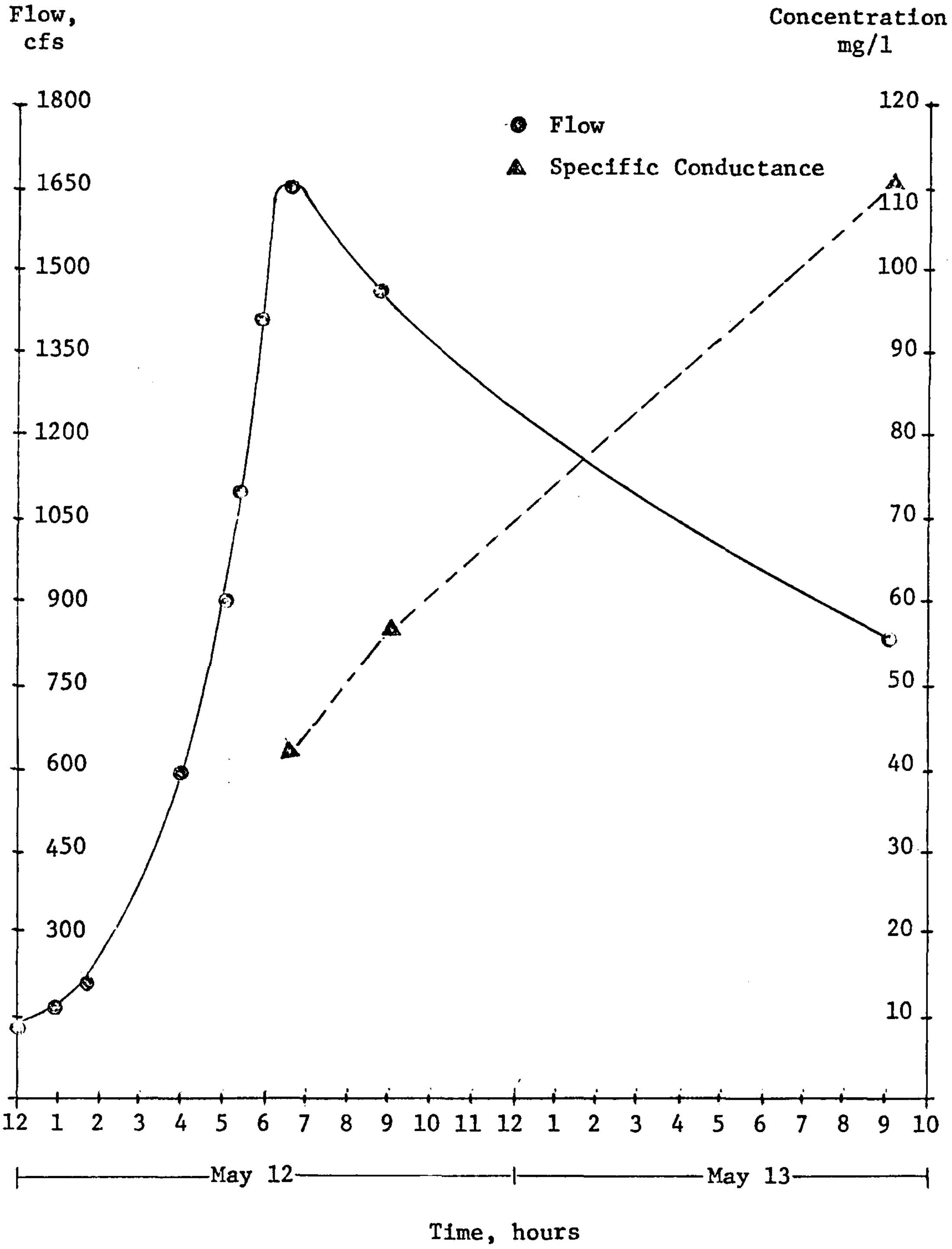

Figure 13. Variation in specific conductance with flow at Site 3.

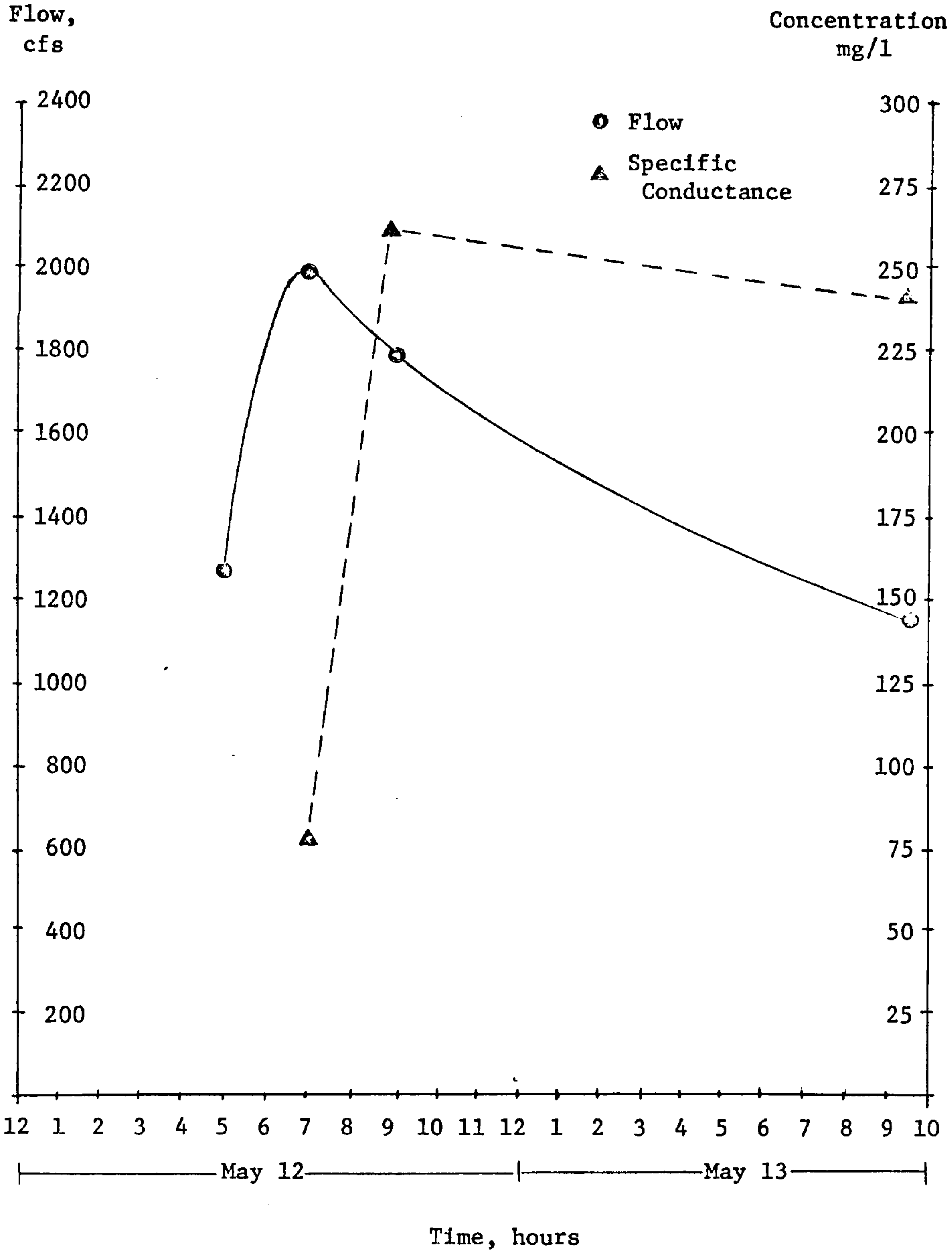

Figure 14. Variation in specific conductance with flow at Site 4.

follow the natural pattern described by Keup (31). The third sample was taken on Monday morning during considerable earth-moving activity at the construction site. This activity would account for the increase in concentration in that part of the stream.

As expected, turbidity at each site follows the variation in suspended solids concentration. Variations in iron and phosphorus concentrations also follow suspended solids concentrations. Iron and total phosphorus decrease and then increase with decreasing flow at Site 1, while both concentrations decrease constantly with flow at the other three sites. This similarity in pattern supports the view of Weidner _et al_. (53), Cahill _et al_. (21), Schuman _et al_. (54), and MacCrimmon and Kelso (68) that iron and phosphorus levels reflect the quantity of suspended material in the stream. MacCrimmon and Kelso explain the iron variations by showing that iron exists in association with soil and organic particles. Cahill _et al_. (21) explain the phosphorus variations. Phosphorus increases with increasing discharge because of the addition of phosphorus adsorbed on sediment in land runoff and because of the resuspension of stream bed deposits and biomass by the scouring action of high flows. Declining flows like those analyzed in this study are characterized by declining phosphorus concentrations as suspended matter settles onto the stream bed. This observed pattern refutes the findings of Gburek and Heald (70) that phosphorus concentrations decrease with increasing streamflow.

TKN concentrations follow variations in total suspended solids at Sites 1 and 3. This would be expected since sediment transported to surface waters carries organic nitrogen and ammonium nitrogen. The scouring of high flows also suspends stream bed sediment and biomass which would increase TKN concentrations with increasing flow. Settling of sediment and biomass during declining flows would decrease TKN levels. It is believed that the lack of correspondence between TKN concentrations and suspended solids at Site 4 results from the effects of point source discharges. As shown in Table XIV industrial and municipal effluents in Waynesboro contribute large amounts of TKN to the stream. TKN concentrations at Site 4 decrease with declining flow and then stay the same when flow has leveled out to about half the discharge at the peak of the hydrograph. Point source discharges occupy a greater proportion of the total TKN yield at this lower flow, and their influence is seen in the leveling of TKN concentration. It should be noted that TKN concentrations throughout the storm are below concentrations reported at Site 4 during June and July low flows. At Site 2 there is also a lack of correspondence between TKN and suspended solids. TKN concentrations at Site 2 decrease at first but then increase slightly. The increase is attributable to analytical error due to the insensitivity of the auto-analyzer to such dilute levels.

Except at Site 2, COD concentrations also follow TSS variations. The similarity of variation would be expected because of the organic content of suspended sediment and biomass. At Site 2, however, COD concentrations increase slightly from 48 mg/l to 54 mg/l and then decrease to 24 mg/l. It is believed that the anomalous increase is attributable to analytical error. The first two samples collected at Site 2 were very turbid. It is extremely difficult to get representative samples of such water for COD analysis. The high organic content of suspended matter can cause wide variations in the results.

Dornbush et al. (56) found that all of the nitrate in runoff was independent of any sediment. This study supports those findings since nitrate concentrations do not correspond with suspended solids levels. MacCrimmon and Kelso (68) found that nitrate levels were extremely variable with streamflows, but that nitrate concentrations usually decreased with an increase in discharge. The findings of this study support that observation. Nitrate concentrations at all sites during the storm are significantly less than concentrations observed during the low flows of June and July. Nitrate concentrations at Site 1 also increase with decreasing flow. Nitrate variations at Sites 3 and 4 are unexplainable. Unlike nitrate levels reported in forest runoff literature, runoff at Site 2 has negligible nitrate concentrations. The lack of data on the rising side of the hydrograph prevents the complete pattern of nitrate variation from being followed.

Since a water's ability to carry an electric current varies with both the number and type of ions the solution contains, specific conductance gives an idea of the amount of dissolved ionic matter in a sample. This amount may be approximated by multiplying the specific conductance by an empirical factor varying from 0.55 to 0.9. The proper factor depends on the ionic components in the solution. Specific conductance increases and then decreases at all sites except Site 3 where it increases continually as flow declines. Gburek and Heald (70) explain the observed patterns. Conductance values drop off after the hydrologic peak has passed because the effects of soil leaching diminish. During storm events salts which accumulate in the soil during dry periods are flushed into the stream, resulting in high conductance values. Salt concentrations diminish gradually as runoff subsides and base flow returns.

An attempt was made to estimate the total pollutant yields of the storm. Rainfall began at 9:00 AM on May 12 and continued until 3:00 PM. Discharge reports from gages at Sites 2, 3, and 4 show that high flows lasted through the morning of May 13 and then dropped to one-half as high by May 14. It was decided to estimate yields for COD, TSS, Total P, and Total N during the 24-hour period from 9:00 AM May 12 to 9:00 AM May 13. Iron yield was not estimated because of the lack of baseline data. The dry weather data of April 29 was used as a rough estimate of baseline data for the other parameters. Calculations of daily yields in lb/24 hrs were made using this baseline data and data from the peak and declining phase of the hydrograph. These points were then plotted against hour of occurrence. The area under the curve gave an estimate of total yield over the 24-hour period.

Table XVII shows total daily yields and unit area yields from each site. In contrast to literature reports and to the findings of this study in June and July, yields from the forested area of Site 2 exceed those from agricultural land at Site 1. This can be explained by the very high concentrations of total suspended solids at Site 2 as compared to Site 1. As outlined in Table III, Back Creek has a much steeper gradient than the South River. The velocity and scouring action of Back Creek are, therefore, much greater during stormwater flows, and this results in higher suspended solid loads. In June and July, flows in Back Creek were never high enough to cause such scouring. The large suspended solids load at Site 2 also raises COD, total phosphorus and

Table XVII.--Average Daily Yields from Land Runoff during Storm Event of May 12, 1974

Parameter	Site 1 Agricultural Runoff	Site 2 Forest Runoff	Site 3 Agricultural, Forest & Urban Runoff	Site 4 Agricultural, Forest & Urban Runoff
COD				
lb/day	111,493	82,837	345,227	606,620
lb/day/acre	2.05	3.0	4.06	6.04
TSS				
lb/day	181,985	293,333	1,374,970	2,959,781
lb/day/acre	3.35	10.66	16.15	29.5
Total Phosphorus (as P)				
lb/day	523	314	1,745	3,418
lb/day/acre	.01	0.01	0.02	0.03
Total Nitrogen				
lb/day	7,558	2,656	3,620	12,479
lb/day/acre	0.14	0.10	0.04	0.12

total nitrogen loads because of the association of these parameters with suspended sediment and biomass. The unit area yield of total nitrogen at Site 2 is less than that at Site 1 because of the absence of nitrate in Back Creek runoff.

In contrast to findings in June and July, Site 3 unit area yields are greater than those at Sites 1 and 2 except for total nitrogen yields. The increase results from the high yields of pollutants in runoff from the roads and residential area surrounding Site 3. During June and July, runoff from this residential area was not sufficient to increase unit area yields. During the intense storm in May, however, considerable runoff from the surrounding area occurred. Sarter et al. (60), Sylvester (19), and Colston (63) all emphasized the high pollutant loadings of stormwater runoff from such residential areas. It would appear that these loadings were great enough to increase the unit area yield for the entire watershed. Site 2 yields of total nitrogen dilute those from the agricultural land above Site 1. This would not account completely for the large decrease in nitrogen yields at Site 3. Runoff from the residential area must be very low in TKN and nitrate despite the significant yields reported in the literature on urban runoff.

As expected, Site 4 unit area yields are much greater than those at the other three sites. This is attributable to urban runoff contributions from the City of Waynesboro.

Land runoff yields during the 24-hour storm period can be compared with the daily yields calculated for June and July in Table XV. Storm yields during a day's time surpass COD and TSS yields during the entire month of June, even though June's total monthly rainfall is 4.58 inches. Total phosphorus and total nitrogen loads during the storm are also considerably larger than daily yields in June. Comparisons with July show even greater differences in pollutant yields. Table XVIII compares storm runoff loadings at Site 4 with wastewater discharges. Water quality during the storm is completely dominated by runoff contributions.

Table XVIII.--Comparison of Loadings from All Sources during Storm Event of May 12, 1974

Parameter	All Wastewater Discharges	Agricultural, Forest and Urban Drainage	Total
COD			
lb/day	7,535	606,620	614,155
% of Total	1	99	100
TSS			
lb/day	545	2,959,781	2,960,326
% of Total	0.01	99.99	100
Total Phosphorus (as P)			
lb/day	181	3,418	3,599
% of Total	5	95	100
Total Nitrogen			
lb/day	2,356	12,479	14,835
% of Total	16	84	100

Calculations Based on Data Obtained from Site 4.

DISCUSSION

Studies by the Virginia Division of Water Resources (71) and Cairns and Dickson (72) 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 (18) and Mackenthun (20). For flowing streams, Mackenthun recommended that 0.1 mg/l P should not be exceeded at any point within the stream, or that 0.05 mg/l P should not be exceeded where water enters a standing body of water. Sawyer found that in lakes concentrations of 0.01 mg/l of soluble phosphorus and 0.30 mg/l 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 June and July nitrate concentrations at Site 1 were 2 to 8 times the critical value Sawyer reported. The average phosphorus concentration)0.12 mg/l 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 in June and July. Phosphorus concentrations at Site 2 occasionally exceeded Mackenthun's 0.05 mg/l P limit but never exceeded the 0.1 mg/l critical value. At Site 3 concentrations of phosphorus and nitrate exceeded limiting values at all times.

Nitrate concentrations were 2 to 10 times as great as Sawyer's critical value, but phosphorus concentrations only slightly exceeded the 0.1 mg/l 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/l P limit.

Throughout the storm event, phosphorus concentrations at all sites exceeded the 0.1 mg/l P limit. Nitrates also exceeded the 0.30 mg/l N limit at all but Site 2. Baumann and Kelman (10) 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 June and July 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, Table XVI shows that 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 Mackenthun's 0.1 mg/l P limit.

This study was conducted during low flow conditions in the summer of 1974. Streamflow in the Upper South River was far below the annual average discharge of 128 cfs, except during the storm event of May 12. In June discharge was about one-half that of the annual average, and July flows were one-third as high. Jaworski and Hetling (39) pointed out the error in using summer low flow yields to estimate annual yields of nutrients from nonpoint sources of pollution. They estimated that daily phosphorus loads in the spring were 1000 times greater than summer loads and that daily nitrogen yields were 200 times greater. The results of this study show that differences in yields between June and July were large even when differences in flow were not that great. Figure 15 presents recorded flows at Site 3 for the water year October 1972 to September 1973. Judging from the correlation between river discharge and pollutant yields reported in the literature, land drainage yields to the South River should increase dramatically in winter and spring over those reported in this study.

Summer pollutant loads are lower because of low concentrations as well as low flows. Nutrient yields in the summer are expected to be lower than at other times of the year, especially when compared to the spring crop fertilization period. In summer plant uptake is at a maximum during the growing season and less material is lost by leaching. Streambank erosion and ground water yields are also at a minimum during summer low flows, thereby reducing TSS, COD, and dissolved ions as well as nutrients.

In summary it appears that land runoff in the Upper South River makes its greatest impact on water quality in the contribution of suspended solids and nutrients. Algal growths and dissolved oxygen fluctuations are most critical during the summer low flows. If phosphorus concentrations observed during this study are typical summer concentrations, it is believed that phosphorus reduction in effluent of the Waynesboro sewage treatment plant may significantly decrease algal

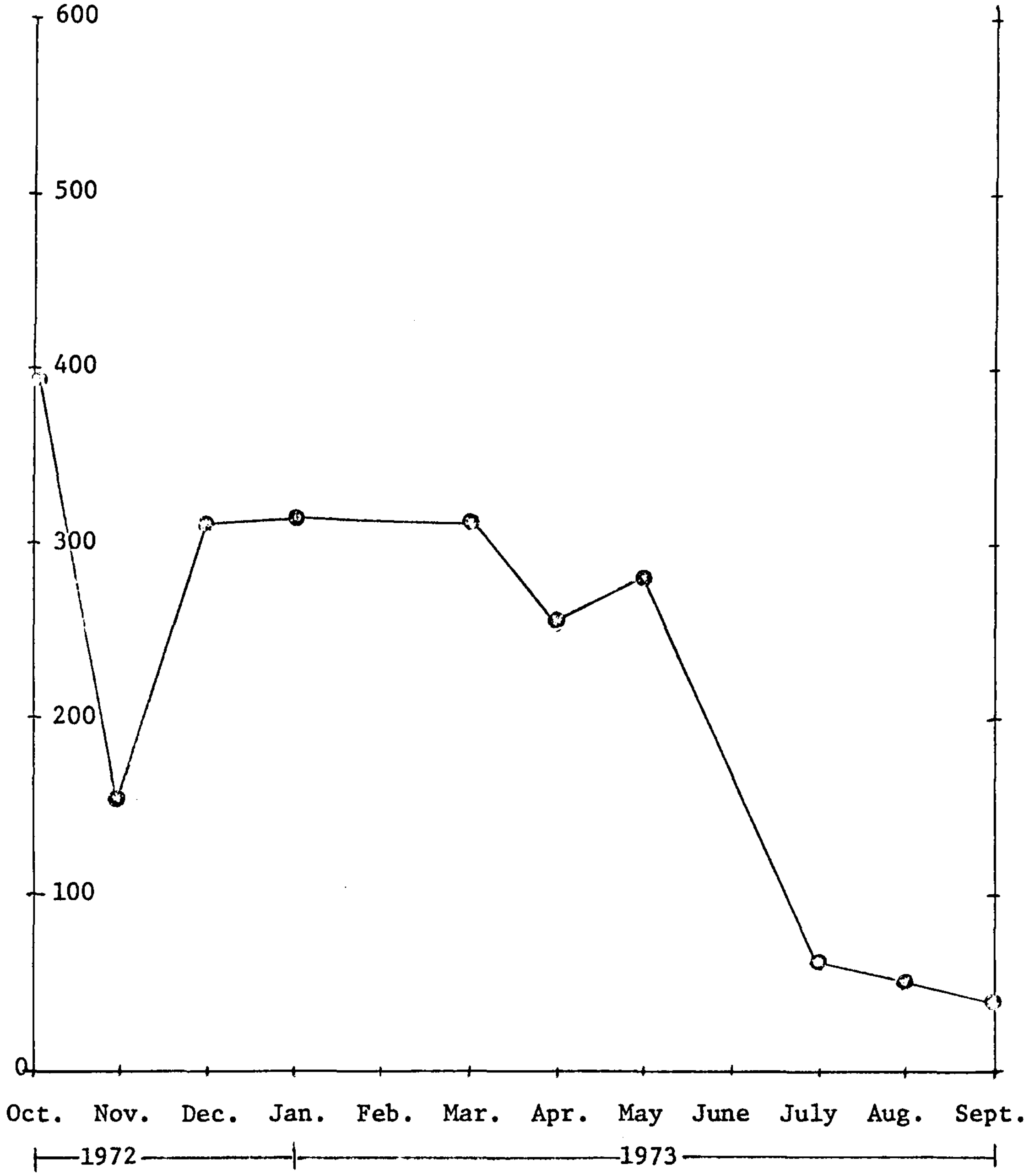

Figure 15. Monthly average discharges at Site 3 USGS gage on the Upper South River.

growth problems. If summer flows are typically higher than this summer, as precipitation records would indicate, upstream phosphorus concentrations may more consistently exceed the "limiting" value, thereby maintaining nuisance growths of algae. Additional study is needed to clarify this situation.

Land runoff contributions of suspended solids can be reduced by greater use of soil conservation methods in the Basin. At present, the Augusta County Soil Conservation Service estimates that about 70 percent of all the farms above the City of Waynesboro are operating under soil and water conservation farm plans. Approximately 50 percent of all planned conservation practices have been applied. The expansion of this program should result in reduced sediment loadings as well as decreased nutrient yields.

CONCLUSIONS

1. On occasion nutrient concentrations in the Upper South River exceed the levels generally promulgated as being adequate to support excessive productivity in lotic environments.
2. In June wastewater discharges contributed 60 percent of the chemical oxygen demand, 4 percent of total suspended solids, 64 percent of total phosphorus, and 63 percent of total nitrogen entering the South River below Waynesboro.
3. In June agricultural, forest and urban drainage contributed 40 percent of the chemical oxygen demand, 96 percent of total suspended solids, 36 percent of total phosphorus, and 37 percent of total nitrogen entering the South River below Waynesboro.
4. In July wastewater discharges contributed 95 percent of the chemical oxygen demand, 19 percent of total suspended solids, 93 percent of total phosphorus, and 98 percent of total nitrogen entering the South River below Waynesboro.
5. In July agricultural, forest and urban drainage contributed 5 percent of the chemical oxygen demand, 81 percent of total suspended solids, 7 percent of total phosphorus, and 2 percent of total nitrogen entering the South River below Waynesboro.
6. During the high flows of intense storms like that of May 12, 1974, land runoff contributions are the primary source of organic matter, suspended solids, and nutrients.

7. Reduction in phosphorus of the Waynesboro sewage treatment plant effluent may lower concentrations in the South River below the city to levels approaching limiting conditions during the critical summer period.

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APPENDIX

Table XIX.--Chemical and Physical Quality Characteristics of Upper South River and Back Creek

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/l SiO_2)	11.2	5.2	15.5	25
Specific conductance (micromhos/cm @ 25°C)	214	35.4	146	309
Total phosphorus as P	.065	.02	.065	.39
Total kjeldahl nitrogen	..42	0	1.26	1.68
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/l SiO_2)	13.5	4.3	12.3	22.4
Specific conductance (micromhos/cm @ 25°C)	196	25.9	144	282
Total phosphorus as P	.07	.01	.065	.39
Total kjeldahl nitrogen	.42	0	.42	2.52
Nitrate as N	.85	.43	1.87	1.16

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

Table XIX - Continued

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/l SiO_2)	16	4.3	15	18
Specific conductance (micromhos/cm @ 25°C)	205	29.7	156	295
Total phosphorus as P	.07	0	.11	.39
Total kjeldahl nitrogen	.42	.42	.42	2.52
Nitrate as N	.91	.43	.69	1.16

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	56.5	311	476	771
Turbidity (mg/l SiO_2)	18	76	160	180
Specific conductance (micromhos/cm @ 25°C)	206	76.5	42.1	76.9
Total phosphorus as P	0.16	0.33	0.58	0.79
Total kjeldahl nitrogen	1.26	1.68	1.68	2.52
Nitrate as N	0.79	0	0.48	0.57
Fe	0.28	0.67	0.79	0.71

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

Table XIX - Continued

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	38.5	99.5	135.5	328
Turbidity (mg/l SiO_2)	8	22	36	76
Specific conductance (micromhos/cm @ 25°C)	22.3	214	56.7	261
Total phosphorus as P	0.10	0.13	0.21	0.46
Total kjeldahl nitrogen	1.05	1.05	1.26	1.26
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	56.5	15	30.5	45.5
Turbidity (mg/l 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	1.47	1.26	1.05	1.26
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/l) except as noted.

Table XIX - 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	46.8	5.0	40.0	29.4
Turbidity (mg/l 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	1.05	0.84	0.74	1.89
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	14.2	0.4	4.8	11.8
Turbidity (mg/l SiO_2)	10	1	5	17.5
Specific conductance (micromhos/cm @ 25°C)	214	31.6	172	323
Total phosphorus as P	--	--	--	--
Total kjeldahl nitrogen	1.05	0.84	0.74	1.89
Nitrate as N	1.38	0	0.91	2.38

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

Table XIX - Continued

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	7.6	1.6	3.2	2.8
Turbidity (mg/l SiO_2)	5.8	1.2	3.5	4.3
Specific conductance (micromhos/cm @ 25°C)	224	33.1	181	301
Total phosphorus as P	0.1	0.07	0.12	0.45
Total kjeldahl nitrogen	0.84	0.42	0.84	2.94
Nitrate as N	1.68	0	1.44	2.95

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	11.2	1.2	6.6	5.6
Turbidity (mg/l SiO_2)	5.2	1.2	4.3	5.2
Specific conductance (micromhos/cm @ 25°C)	228	35.5	200	338
Total phosphorus as P	0.18	0.08	0.16	0.48
Total kjeldahl nitrogen	1.68	1.26	1.05	5.42
Nitrate as N	2.10	0	1.68	1.77

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

Table XIX - Continued

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	7.6	3.2
Turbidity (mg/l SiO_2)	7.5	1.2	6.2	5.2
Specific conductance (micromhos/cm @ 25°C)	241	34.6	205	366
Total phosphorus as P	0.13	0	0.1	0.28
Total kjeldahl nitrogen	1.26	.42	0	2.10
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	103.7	12.8	24.4	39.6
Turbidity (mg/l SiO_2)	27	3.5	8.0	9.0
Specific conductance (micromhos/cm @ 25°C)	272	36.8	207	284
Total phosphorus as P	0.34	0.08	0.18	0.46
Total kjeldahl nitrogen	.42	0	.42	1.68
Nitrate as N	1.77	0	1.59	2.95

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

Table XIX - 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	8.6
Turbidity (mg/l SiO_2)	5.2	1.2	5.2	4.3
Specific conductance (micromhos/cm @ 25°C)	230	34.1	203	368
Total phosphorus as P	0.11	0.01	0.11	0.4
Total kjeldahl nitrogen	.42	0	0.63	2.10
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	14.4	0.4	14.0	5.6
Turbidity (mg/l SiO_2)	3.7	1.2	4.3	4.3
Specific conductance (micromhos/cm @ 25°C)	231	36.4	213	373
Total phosphorus as P	0.2	0.06	0.13	0.57
Total kjeldahl nitrogen	0.84	3.15	0.84	3.8
Nitrate as N	1.77	0	1.45	3.19

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

Table XIX - Continued

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	13.6	1.0	11.6	5.6
Turbidity (mg/l SiO_2)	5.2	1.2	4.8	5.2
Specific conductance (micromhos/cm @ 25°C)	227	33.4	210	355
Total phosphorus as P	0.12	0.04	0.11	0.50
Total kjeldahl nitrogen	0.84	1.0	0.84	4.62
Nitrate as N	2.38	0	1.68	2.74

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	11.6	2.8	10.8	17.2
Turbidity (mg/l SiO_2)	5.2	2.0	5.2	6.1
Specific conductance (micromhos/cm @ 25°C)	225	35.2	221	394
Total phosphorus as P	0.10	0.02	0.07	0.48
Total kjeldahl nitrogen	0.84	0.63	0.84	2.94
Nitrate as N	0.85	0	0.82	1.68

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

Table XIX - Continued

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	11.2	0	12	6
Turbidity (mg/l SiO_2)	4.5	3.5	7.5	7.2
Specific conductance (micromhos/cm @ 25°C)	222	39.0	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	13.0	1.0	10.0	4.8
Turbidity (mg/l SiO_2)	5.2	2.0	5.2	5.2
Specific conductance (micromhos/cm @ 25°C)	233	48.2	196	488
Total phosphorus as P	0.12	0.06	0.12	0.52
Total kjeldahl nitrogen	1.26	1.26	1.26	5.0
Nitrate as N	1.32	0	0.82	1.77

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

Table XIX - 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	4.4	1.4	5.6	2.4
Turbidity (mg/l SiO_2)	3.8	0.5	4.3	4.8
Specific conductance (micromhos/cm @ 25°C)	233	36.8	224	393
Total phosphorus as P	0.07	0.02	0.07	0.44
Total kjeldahl nitrogen	1.2	1.05	1.26	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	9.0	4.2	7.4	5.2
Turbidity (mg/l SiO_2)	5.2	1.0	4.0	4.0
Specific conductance (micromhos/cm @ 25°C)	237	41.2	229	449
Total phosphorus as P	0.1	0.02	0.07	0.51
Total kjeldahl nitrogen	1.26	1.26	1.26	4.2
Nitrate as N	0.99	0	0.72	2.38

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

Table XIX - Continued

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	9.6	-	9.0	6.8
Turbidity (mg/l SiO_2)	2.5	-	3.5	4.5
Specific conductance (micromhos/cm @ 25°C)	228	-	236	413
Total phosphorus as P	0.15	-	0.05	0.62
Total kjeldahl nitrogen	1.26	-	1.26	3.78
Nitrate as N	0.74	-	0.74	2.38

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	8.6	-	8.2	6.2
Turbidity (mg/l SiO_2)	3.6	-	2.6	4.3
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

[*] All concentrations in milligrams per liter (mg/l) except as noted.

Table XIX - Continued

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	11.6	3.4	8.6	6.0
Turbidity (mg/l SiO_2)	5.2	1.5	4.7	5.6
Specific conductance (micromhos/cm @ 25°C)	237	43.5	233	428
Total phosphorus as P	0.15	0.14	0.15	0.47
Total kjeldahl nitrogen	0.42	0.40	0.42	3.36
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	18.0	13.2	16.4	10.8
Turbidity (mg/l SiO_2)	6.1	1.6	8.0	8.0
Specific conductance (micromhos/cm @ 25°C)	223	37.1	230	451
Total phosphorus as P	0.15	0.06	0.14	0.4
Total kjeldahl nitrogen	0.42	0.4	0.42	3.4
Nitrate as N	0.63	0	0.61	1.87

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

AGRICULTURAL AND FOREST LAND RUNOFF IN UPPER SOUTH RIVER NEAR WAYNESBORO, VIRGINIA

by

Elizabeth Vail Southerland

(ABSTRACT)

Sources and yields of organic matter, suspended solids and nutrients in the Upper South River Basin were investigated during the summer low flow period of 1974. Parameters monitored at sampling stations in the basin included chemical oxygen demand, total suspended solids, turbidity, specific conductance, total phosphorus, total Kjeldahl nitrogen, nitrate, and iron. These data were used with flow and drainage area data to determine the relative magnitude and daily yields of materials from various sources.

Sources of organic matter, suspended solids, and nutrients entering the South River included agricultural, forest and urban land drainage as well as domestic and industrial wastewater effluents. The yields of materials from the various sources were computed during an intense storm in May, wet weather flow in June, and dry weather flow in July.

During the short term period of high storm flows, land runoff was the primary source of all pollutants. On the long term basis, however, wastewater effluents were the major contributors of all parameters except total suspended solids. Industrial effluents contributed the

greatest proportion of chemical oxygen demand and total nitrogen. The Waynesboro sewage treatment plant supplied the greatest phosphorus loading.

In comparison with forest drainage, agricultural land drainage was found to be a greater source of all materials monitored. Urban runoff was not analyzed separately, but it appears to contribute significant pollutant loads.

It was found that reduction of phosphorus in the Waynesboro sewage treatment plant effluent may reduce excessive algal production in the South River below the city of Waynesboro.