STORMWATER QUALITY MANAGEMENT STRATEGY
PETERS CREEK WATERSHED

by

Maureen P. Castern

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APPROVED:

C. W. Randall, Chairman

R. C. Hoehn

T. J. Grizzard

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Committee Chairman: Clifford W. Randall
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ABSTRACT

The effect of stormwater runoff on the water quality of Peters Creek was investigated. Creek water was sampled at rural, suburban and urban sites. Background and runoff samples were analyzed for sediment, nutrient and heavy metal concentrations.

The area upstream of the suburban site was found to contribute the greatest contamination to the creek but the heavy metal contributions were accumulated throughout the watershed. The creek water contained sufficient nutrients to potentially contribute to the eutrophication of Smith Mountain Lake downstream. As the watershed has been developed, flooding has increased in frequency.

The detrimental effects of runoff can be reduced in the watershed by clearing the trash from the creek bed, enforcing construction erosion control and creek bed alteration ordinances and by building a series of detention basins in the creek upstream from common sites of flooding.

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I. INTRODUCTION

The national concern with improving the quality of water in our environment has coincided with the recent development of the Roanoke Valley. The Federal Water Pollution Control Amendments of 1972 began the most comprehensive program ever attempted to control water quality (1). Section 208 of the law required states to formulate water quality management plans and recognized the importance of both point and non-point pollution sources. The Roanoke area-wide plan was published in 1976 (2) and suggested best management practices that would reduce projected non-point source loads.

The Roanoke Valley lies between the Allegheny and Blue Ridge Mountains in Southwestern Virginia. As the South has grown in the past two decades, the Valley has grown from a population of 190,000 in 1970 to 213,300 in 1980 (3). Consolidation of municipal governments is periodically locally debated, but the Valley is now divided into the governments of the Cities of Roanoke, Salem, Vinton, and Roanoke County (Figure 1).

The Roanoke River is formed by several streams flowing down from the mountains and running through the City of Roanoke. This study investigated Peters Creek, which runs from Brushy Mountain in Northwest Roanoke County and flows southeast to meet the Roanoke River. The River is dammed about fifty miles downstream of Roanoke forming Smith

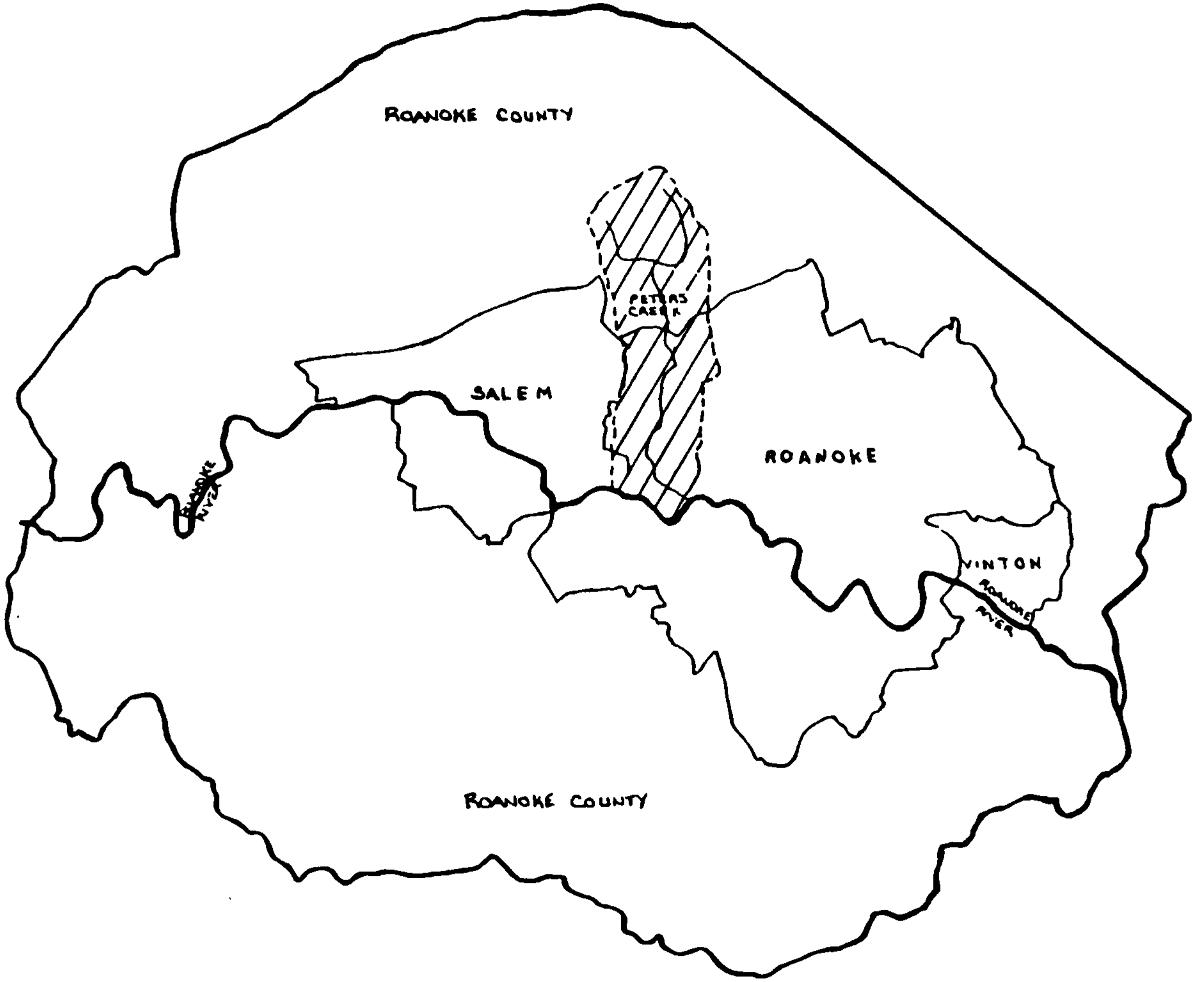

FIGURE 1. THE ROANOKE VALLEY

Mountain Lake. The commercial exploitation of the recreational possibilities of Smith Mountain Lake has created concerns about its eventual eutrophication and in 1980 the State Water Control Board published "The Impact of Non-point Sources on the Water Quality of Smith Mountain Lake" (4). In 1982 the West Regional Office received a grant from the Environmental Protection Agency (EPA) to determine a watershed management strategy (5). The study found that fourteen watersheds or stream segments out of forty four studied in the Roanoke Area are damaged by non-point source pollution such that beneficial uses of the streams are denied. Peters Creek was one of these impaired watersheds.

The Valley is hilly, so flooding has been an additional problem. In 1968 a study was performed to determine the flood plain of Peters Creek, as flooding occurred on an average of once every three years (6). Subsequent land development has increased the frequency of flooding to the extent that three property damaging floods occurred during the summer storms of 1984.

This report builds upon the information and concerns of past studies of flooding and non-point source pollution on Peters Creek. Specifically, the objectives of this report are:

1) to determine the effects of development in the Peters Creek watershed on the quantity and quality of storm runoff.

2) to determine the extent of impairment of the beneficial uses of Peters Creek due to pollution

from runoff.

3) to determine if runoff from Peters Creek could potentially accelerate the eutrophication of Smith Mountain Lake.

4) to make recommendations to responsible governments and civic organizations concerning methods of reducing the detrimental effects of the runoff.

This study was done under a grant to Roanoke County from the State Water Control Board. It was intended to be a pilot study of the Peters Creek watershed that can be applied to other watersheds in the Valley in the future. This report should be useful to all government officials and concerned citizens and therefore the use of technical terms has been limited. An extensive glossary and appendix section were written to supply additional information. The sampling methods and results sections were meant to be useful to those doing analogous future studies of other watersheds in the Valley.

Environmental problems have often been found to require the coordination of several levels of governments. As areas develop, problems too narrowly viewed by one municipality become the infuriating problems of a locality downstream. This report was written in the hope that careful planning among the cooperating local governments can minimize future problems of stream pollution and flooding in the Roanoke Valley.

II. LITERATURE REVIEW

CURRENT KNOWLEDGE ABOUT STORMWATER RUNOFF

This chapter will briefly summarize the research done on stormwater runoff and solutions to the problems it presents. The subject draws on information from many scientific fields: limnology, hydrology, agronomy, demography, and meterology, and a complete discussion of all of these subjects is beyond the scope of this report. Additional information can be found in the references listed in the bibliography and a brief summary of especially helpful references is given in the appendix.

THE PROBLEM OF POLLUTION IN RUNOFF

The cycle of evaporation and rainfall is as important as the sun to the life on Earth. The water is distilled into a cloud and drifts until falling to the Earth. On the ground it either is taken up by plants, percolates through the soil to the groundwater, is re-evaporated, or flows overland joining streams and rivers. Problems can occur in this cycle, however. While falling through the air, the rain can pick up air pollution causing acid rain. Volatile organics from industries are washed out by rain. Rainwater can also become polluted as it flows overland picking up particles of soil, organic material, spilled chemicals and trash, fertilizers, pesticides, and herbicides on fields and lawns, and chemicals leached from the soil and roadways such as limestone, iron, road salt, and lead. In an intense rain, debris such as tree limbs and construction trash can clog stream beds. If the rain falls faster than it can flow downhill and away, flooding will occur. The force of rushing water can cause erosion, damage to property, disruption of daily life and loss of animal and human life.

Pollution runoff can damage the ecosystem of rivers and lakes by killing the biota or by producing excessive water plants and algae blooms. Microbes that decay dead algae and other organic matter can utilize all of the dissolved oxygen in the water producing anaerobic conditions which can cause fish kills, black stinking mud and turbid, discolored water that smells of sulfur. Desirable fish such as trout are replaced by carp and bullhead. In time, the lake or river can be filled in as sludge from organic matter settles to the bottom, slowly creating a swamp.

POLLUTION DENIES THE BENEFICIAL USES OF WATER

A general definition of water pollution is that it refers to "any additional substance (or something) in the water which changes its natural quality downstream of the addition" (1). These changes can deny the beneficial uses for which the flowing, ground, or impounded water was meant. Sections of streams are classified as to the type of use desired and therefore the quality required. Water that will be used as a municipal drinking supply must have higher quality standards than those of water used for irrigation, recreation or simply for navigation (7). Some industries require water that is very pure to avoid damaging boilers or for processing foods, while others can use less pure water for floor cleaning or fire fighting.

The Virginia State Water Control Board and the EPA have determined standards for each classification of water use and have approved standardized testing procedures to analyze the acceptability of a water source. Where the term "standard" is too specific and research on harmful effects too sketchy, a criterion is listed instead.

STREAM SELF-PURIFICATION

Pollution in any water will not remain in the same form at the same concentration for an indefinite time. Every type of pollution has its own eventual "fate" which it will reach in varying periods of time. Discussions of the effects of pollution on water quality must include a description of the fate of each pollutant type and its ultimate effect on water uses. Dilution is not considered one of these self-purification reactions. The types of transformations and transport processes that the pollutants can undergo are given in Table I. The fate of some pollutants, especially complex hydrocarbons and aromatic compounds, must be determined by sophisticated laboratory techniques. It is important to note that the contaminant that is discharged

Table 1

Possible Fates of Contaminants in Water

Fate	Mechanism	Examples
Changes Chemical Form	Ionization	Dissociation of Salts
	Acid-Base Equilibria	Ammonia Converts to Ammonium Ion
	Oxidation-Reduction Reactions	Ferric Converts to Ferrous Ion
Becomes a More Simple Chemical	Biodegradation	Microbial Enzymes Convert Organic Molecule to Water and Carbon Dioxide
	Photolysis (Process May Produce More Complex Compounds, Too)	Sunlight Provides Energy for Esters Converted to Acid
	Hydrolysis	The Pesticide Carbaryl Plus Water Convert to Napthanol, Methylamine and Carbon Dioxide
Settles to Bottom of Creek	Sedimentation	Leaf Litter Settles Out
	Sorption onto Particles	Phosphates Onto Clay
	Precipitation-Solubility	Oil Spills in the Ocean
Escapes to Atmosphere	Volatilization	Hydrocarbons Such As Phenol
	Biodgradation	Nitrates to Nitrogen Gas
		Organic Carbons to Methane
Consumption by Biota	Metabolism	Water Plant Uptake of Phosphorous
		PCB Concentration in the Fat of Seabirds

into the stream may be absent or unrecognizable several days downstream.

THE ORIGIN AND ANALYSIS OF COMMON WATER POLLUTANTS

Many types of pollution are known to reduce water quality. The complete analysis of water for all of these parameters is very expensive and is beyond the scope of this study. The parameters that were considered will be discussed below along with their possible origins, fates and a brief discussion of the testing procedures. Other types of pollution and other tests that were not a part of this study, but are commonly associated with stream water quality are also discussed. Table II lists some quality parameters and suggested values for Peters Creek. The State Water Control Board has classified it as a Mountainous Zone, Class IV stream and has set many of these values for the creek knowing its geological characteristics and the desired beneficial uses.

Methods of Water Analysis

Since science first recognized the relationship between impure water and disease, tests have been developed to determine the safety of our water. Hundreds of tests exist to determine everything from the number of pathogenic microorganisms present to the concentration of each of the thousands of industrially produced chemicals. The EPA continually strives to improve the reproducibility, simpli-

Table II

Water Quality Criteria For Peters Creek

Quality Parameter	Value
Dissolved Oxygen (mg/L)	
Daily Average	5.0a
Minimum Permissable	4.0a
pH	6.0 - 9.5a
Maximum Temperature (°C)	31a
Total Kjeldahl Nitrogen (mg/L)	0.1b
Total Phosphorus (mg/L)	0.01b
Nitrates (mg/L as Nitrogen)	10
Chemical Oxygen Demand (mg/L)	As Low As Possible
Solids	As Low As Possible

a. Virginia State Water Control Board
b. To Avoid Eutrophication (See Body of Report)

city and cost effectiveness of water analysis tests. The approved test methods are distributed to water laboratories nationwide. The American Public Health Association has also met this need with their publication "Standard Methods for the Examination of Water and Wastewater" (8). This volume lists the rationale, potential problems and expected accuracy for all commonly tested water impurities. The Association has an ongoing program in which each test is critically studied and improved. The water analysis done in this study by the Roanoke Sewage Treatment Plant Laboratory was done using EPA approved tests. Anyone interpreting results of tests such as these must be familiar with the limitations of the procedure, any interferences that they may have, and their limits of precision and reproducibility. Such information can prevent the common mistake of drawing inappropriate conclusions from testing data.

Sediments and Suspended Particles

Technically, everything in water that is not H_2O can be classified as a solid (9). Solids can be trees uprooted during a flood or nitrous oxides from air pollution that have been picked up by rain and converted to nitric acid. Streams with a great flow carry surface and subsoils, stream bank and channel bed erosion, atmospheric deposition and detritus (10). In streams with low flow, sediments are mostly detritus. Sediments damage water in many ways:

1) Water with solids and sediments loses its clear, clean appealing appearance.

2) Many pollutants such as lead and phosphorus are adsorbed onto sediments. If the sediments can be removed, many pollutants will also be removed. Not all types of pollutants are uniformly adsorbed onto all sediment sizes, however, so the type of sediment removal is important.

3) Sediments settle and cover the stream bed smothering the benthos and covering fish nesting sites.

4) Organic solids are microbially degraded reducing the dissolved oxygen in the water.

5) Sediments cement large debris such as trees and shopping carts onto the creek bottom or against bridge abutments reducing the volume of the creek bed.

Solids

Water with greater than 500 milligrams per liter (mg/L) concentration of solids may taste bad, be aesthetcally unsatisfactory and cause physiological reactions, such as diarrhea (8).

Total Solids are most easily determined by simply placing a well-mixed, measured volume of water into a pre-weighed dish and heating the dish to 103 degrees Centigrade (°C) until the residue is dry and then re-weighing the dish. A temperature of 103°C is used to minimize the burning or vaporizing of the volatile solids.

Volatile and Fixed Solids are the approximate weight of organic and inorganic material in the dried total solids. The solids are heated to 550°C which is sufficient to burn off organics and yet not hot enough to combust inorganics. The solids left after this heating are the fixed, inorganic solids, such as metals and sand. The volatile solids will be dead organic material, such as leaves, paper and hydrocarbons.

Suspended Solids are those in the water that will not pass through a pre-weighed filter. The filter is dried at 103°C and re-weighed. These solids are the coarse sediments in the water, either organic or inorganic. The suspended volatile and fixed solids are a measure of the organic and inorganic constituents of the waters' sediments. Silt and sand are the major contaminants in runoff (11).

Dissolved Solids are the concentrations of total solids minus the suspended solids and consist of mostly inorganic salts, dissolved gases and organic matter.

Chlorides

Excessive chlorides (greater than 250 mg/L) can give water a brackish taste if the cation involved is sodium. Since sodium chloride passes through the body, high concentrations can indicate polluted water and testing for chlorides was done historically for this purpose (9). High concentrations of chlorides may be corrosive to pipes and harmful to aquatic life. They can have geological sources such as igneous rock, or be from the beds of long dried lakes. They can be from atmospheric hydrochloric acid, air pollution and even volcanos. Anthropogenic sources are sewage and road salt (8).

Chloride concentrations are determined using chemical indicators or by measuring the change in voltage across a potentiometer as silver nitrate is added slowly to the sample.

Nutrients

Nutrients are chemicals that are necessary for the growth of living cells. If a stream does not contain a a sufficient concentration of these, it will become lifeless. Conversely, an abundance of nutrients helps to make a stream productive. The nutrients most often discussed in water analysis are carbon, nitrogen and phosphorus (12). Other chemicals, such as sulfur, are also nutrients but are required in much smaller amounts.

Excess nutrients in reservoirs and lakes can lead to over productivity or eutrophication. Algal blooms during the summer months can cause nuisance conditions such as "pea soup" appearance, taste and odor problems, anaerobic conditions, fish kills, filter clogging and production of precursors to trihalomethane formation (13). Algae form mats and crowd out aquatic life that is the food of sporting fish (14). Algae grow until the supply of an essential nutrient, usually nitrogen or phosphorus, is exhausted, although some can utilize atmospheric nitrogen (15). Concentrations of nitrogen over 0.1 m/L (9) and 0.01 mg/L (14, 16) are considered by experts to be sufficient to lead to eutrophication.

Nitrogen

The study of the different forms of nitrogen in water is an important environmental consideration. Nitrogen can be present as organic nitrogen, ammonia (or the ammonium ion) nitrite, nitrate, or as dissolved nitrogen gas. There are different water analysis tests for the different forms. Industrial wastes can contain unusual forms of nitrogen, but these should not occur in Peters Creek. Sediments often contain organic nitrogen and ammonia adsorbs onto soils and clays, but when nitrogen is an anion it does not adsorb onto sediment. Nitrites and nitrates, therefore, remain dissolved in the runoff and are transported along with the flowing water (10). In urban areas air pollution from automobile emissions can produce 99% of the nitrogen found in runoff (18). Research in Northern Virginia showed that as land became developed and was covered with asphalt and concrete, the amount of soluble nitrogen in the runoff increased (13).

Organic Nitrogen is the nitrogen that has a -3 valence state as it is found in living cells in proteins, peptides, nucleic acids and urea. Animal or plant material in water will all contribute organic nitrogen.

The organic nitrogen concentration of water is found with the Kjeldahl method. The complex nitrogen compounds are broken down to ammonia by acid digestion. The ammonia is distilled and converted to ammonium borate which is titrated with an acid or measured with a colorimetric analysis (Nesslerization). The amount of nitrogen determined is called "TKN". The amount of ammonia must be found in the water by repeating the process without acid digestion. The concentration of organic nitrogen is then the TKN minus the ammonia concentration.

Ammonia is produced by the microbial decay of organic nitrogen compounds in nature which is similar to its degradation to ammonia in the Kjeldahl method. Fertilizers leached from soil can also be the source of ammonia in water (17). Excessive ammonia can harm aquatic life. The Kjeldahl and Nesslerization methods are used to determine ammonia concentrations in water analysis.

Nitrites and Nitrates are produced by the anoxic metabolism of ammonia by Nitrosomonas and Nitrobacter bacteria, respectively. They are, therefore, indicators of old or upstream pollution in creek water. The techniques for determining nitrate and nitrite concentrations are complex and imprecise. In the cadmium reduction method, nitrate is reduced to nitrite using cadmium and the nitrite is diazotized to produce an azo dye that is measured colorimetrically. The nitrite concentration can be found by following the same procedure without the cadmium reduction step.

Excessive nitrate ingestion causes methemoglobinemia in infants and is limited to 10 mg/L in drinking water standards (8). Since nitrate and nitrite are soluble, they will leach through soil into groundwater.

Phosphorus

Like nitrogen, phosphorus takes many forms in water. The forms can be grouped into three classifications: ortho-, condensed and organic phosphates. Phosphorus is found in fertilizers, and some detergents contain up to fifty percent phosphates (9). Like nitrogen, the phosphorus concentration in runoff increases as an area is developed. Phosphorus is adsorbed onto sediments under aerobic conditions. Studies have shown that under varying conditions four to forty four times as much phosphorus is adsorbed onto sediments as remains soluble in water (10). Before analysis, the adsorbed phosphorus must be extracted from the sediments. When used by algae and macrophytes, it is re-leased into water as extracellular excretions. Therefore, phosphorus may recycle through the waters of a lake or reservoir for years (19). The nitrate concentration in water can inhibit phosphorus release from sediments by maintaining a high oxidation-reduction potential (20). Conversely, iron and aluminum organic complexes can inhibit phosphorus adsorption onto soil (10).

Ortho-phosphates can be used directly by plants and microorganisms in building cells and represent the simplest form of phosphorus and the final form of degraded organic material.

There are several methods for determining the amount of ortho-phosphate in water. In this study, the ascorbic acid method was used in which ammonium molybdate and potassium antimonyl tartrate react with ortho-phosphates to form molybdenum blue which is then measured colorimetrically.

Condensed Phosphates are an intermediate step in the degradation of organic phosphorus. Condensed phosphates (also called acid-hydrolyzable and poly-phosphates) are converted to ortho-phosphates by mild boiling with acid which hydrolyzes their bonds.

Organic Phosphorus is phosphorus as it is found in cells or as it is excreted by them. Adenosine Triphosphate (ATP) is the energy carrier in cell metabolism. Organic phosphorus is converted to ortho-phosphates slowly by microbial action in the environment, or quickly in the laboratory by digesting the organic material with concentrated acids and heating. The digestion process differs from the hydrolysis by the strength of the acid used.

Dissolved Oxygen

The amount of dissolved oxygen (DO) in a stream will determine the types of aquatic life that can live there. Sudden changes in the level can stress and potentially eliminate the fish and benthos. Pollution discharged into a creek can oxidize and therefore exert an oxygen demand that reduces the DO. Organic material is metabolized by microorganisms either aerobically or anaerobically if there is no oxygen present in the water. Aerobic metabolism can lower the DO to levels that cannot be tolerated by the animals in the creek. If the low DO persists, desirable sporting fish are replaced by more tolerant fish such as carp. The products of anaerobic metabolism can produce odor and taste problems in water and cover the creek bed with black, sulfurous muck. Organic nitrogen and ammonia also exert an oxygen demand as microorganisms convert them to nitrites and nitrates.

The chemical oxygen demand (COD) test measures the oxygen needed in the acid oxidation of all organic material in a water sample. COD values can vary from as low as 10 mg/L in drinking water to 10,000 mg/L in industrial wastes. The COD test may hydrolyze organic compounds that would not normally be metabolized by microorganisms and would, therefore, measure an artificially high oxygen demand. Also, The test will not detect if a water contains compounds toxic to the microbes and aquatic life.

The biological oxygen demand (BOD) test addresses the deficiencies of the COD test. In the BOD test, the water sample is placed in a bottle of distilled water to which nutrients are added and the bottle is stoppered, usually for five days. The microorganisms use oxygen while metabolizing the contamination in the water sample. After five days the bottle is opened and the amount of oxygen that has been consumed is measured. This test presents a more natural oxygen up-take measure, but results can be skewed by the addition of inappropriate nutrients or by the mix of microbes present.

Carbon

All life forms require either organic or inorganic carbon for cell synthesis and energy. Microorganisms require carbon, nitrogen and phosphorus in a ratio of 13:5.5:0.8 (21). Carbon in streams is generally plentiful from detritus, carbon dioxide and carbonates. High levels of carbon indicate pollution and exert an excessive oxygen demand. In one study (22) for an urban area with little vegetation, the hydrocarbons in the runoff were found to be from crankcase oil. In more rural areas sources of carbon are plant material and bird and animal wastes.

Many dangerous toxic compounds such as herbicides and pesticides are organic in nature. The tests for these are very complex and expensive and require sophisticated instrumentation. These contaminants can enter streams through industrial discharges and spills or by washing off fields.

The total organic carbon in water can be determined experimentally by oxidizing the sample using chromic acid, potassium iodate phosphoric acid and sulfuric acid and collecting the resulting carbon dioxide. Infrared analysis can be used to measure the carbon dioxide. Carbonates and dissolved carbon dioxide in the sample water can be removed before analysis by acidifying and purging the sample with nitrogen gas.

Heavy Metals

Metals often occur naturally in waters in minute concentrations, but prove to be toxic to aquatic life if in too high a concentration. Research has shown that the high concentrations of metals that are often found in stormwater runoff are primarily from automobiles. Barkdoll (23) found that almost all of the lead in runoff was due to emissions from automobiles. Pitt (24) found that rainwater near San Jose, California contained 0.01 mg/L lead and gutter flow contained 1.0 mg/L lead. Hartigan and Douglas (13) found the concentrations of lead and zinc in stormwater to be proportional to the amount of pavement in an area. During an EPA nationwide urban runoff study (25), zinc, lead and copper were found in 95% of the samples analyzed. Other metals such as chromium, mercury, nickel, and cadmium were found in over 10% of the samples. Metals come from gasoline and fossil fuel combustion, metal alloy corrosion and the wearing away of tires.

Metals adsorb onto sediments in fresh water (26) and are often eaten by the stream benthos. Whipple and Hunter (27) found the concentration of lead in stormwater to be proportional to the total suspended sediments. Lead and zinc concentrations in the tissue of sampled benthic animals have been found to be 100 - 500 times higher than the concentration in the water (24).

Metals are detected in water by using an atomic adsorption spectrophotometer. A sample of water is atomized and burned before a light source emitting light at a particular wavelength for the metal under consideration. The metal particles will adsorb the light and a decrease in its intensity on a phototube is proportional to the metal concentration in the sample.

Table III lists the metals tested in this study and their standards set by the State Water Control Board (28). Aquatic life can tolerate high concentrations of metals for only a short time such as would be the case during a storm when the creek rises temporarily. During the longer dry periods, the metals must be more dilute to assure the health of the aquatic life in the stream. This is reflected in the different standards for "instantaneous acute" and "24-hour chronic" conditions chosen by the State Water Control Board. Metal toxicities are influenced by the hardness of the water. A hardness of 200 mg/L as calcium carbonate was found for Peters Creek during a previous study (5) and this value was used in the calculation of the standards.

Bioassays

Information concerning the health of a creek can be obtained by studying the types of its biota. The greater the species diversity, the greater the health of the water environment. Some species can tolerate stressful polluted conditions better than others. If a stream contains a

Table III

Water Quality Criteria For Heavy Metals For
For The Protection Of Aquatic Life

Metal	24-Hour Chronic Criteria (mg/L)	Instantaneous Criteria(mg/L)
Cadmium,[a] Active	0.01	0.01
Chromium Hexavalent	0.0072	0.011
Copper, Active	0.020	0.029
Lead, Active	0.0064	0.160
Mercury	0.0002	0.0011
Nickel, Total Recoverable	0.160	3.100[b]
Zinc, Total Recoverable	0.047	0.570[b]

Reference: Virginia State Water Control Board (28) unless otherwise noted.

a. All values computed using the value of Hardness of 200 mg/L as $CaCo_3$.
b. Virginia State Water Control Board (4).

large proportion of tolerant species and the less hardy species are few, or completely absent, then the water either is polluted, or recently has been.

Standardized procedures have been developed to perform bioassays that study the water's biota to determine its condition. These include benthic sampling techniques and classification of the specimens found. There are also standardized microcosms in which the suspected contaminated water is added and its effect on the species in the microcosms observed.

Other Water Quality Parameters Not Studied in This Report

Temperature

Temperature, like the other parameters considered, can be altered by man-made conditions. Changing the temperature of a stream can effect the health and types of aquatic life that the stream supports.

pH

pH is a measure of the inverse concentration of hydrogen ions in water. Briefly, the lower the pH, the more acidic the water. pH values over 7.0 indicate a basic water. The pH will effect life in the stream, and will influence the water's chemistry.

Pathogens

Pathogens, those bacteria and viruses that cause disease, can be carried in water and infect people who drink or swim in the water. Bacterial pathogens in water can cause typhoid fever, dysentary, diarrhea and cholera. One type of viral pathogen can cause hepatitis (21).

Rather than measuring for minute concentrations of pathogenic viruses and bacteria, tests have been developed that indirectly suggest their presence by directly measuring an associated group, the coliforms in a water sample. Coliforms are defined as "all of the aerobic and facultative anaerobic, gram-negative, nonspore-forming, rod-shaped bacteria that ferment lactose with gas formation within 48 hours at 35°C" (8). Coliforms are either Aerobacters or Escherichia. Some Escherichia and all Aerobacter coliforms can grow in soil in which the pathogens could not survive. The _Escherichia coli_ coliform, however, can only be present in the fecal matter of warm-blooded animals and is, therefore, an indication in water that pathogenic bacteria and viruses may also be present. Decades of testing for _E. coli_ as an indicator for pathogens have shown that it meets the requirements for a suitable indicator (29). The presence of coliforms is determined by using two tests together. The Membrane Filtration Method involves filtering a water sample and placing the filter on a growth medium specific for _E. coli_. The presence of bacterial colonies with a green sheen indicate that _E. coli_ are in the water and their concentration can be calculated. The Most Probable Number method determines the presence of lactose fermenting bacteria. Water samples are added to tubes of lactose broth in which inverted tiny glass vials are placed. If gas bubbles have formed in the vials at the end of 24 hours of incubation, the possible presence of pathogens is presumed.

THE NATURAL DRAINAGE SYSTEM

There is a natural system for dealing with the quality and quantity of runoff (30). Figure 2 depicts an undeveloped flood plain. The bed of the creek is sufficient to handle runoff from most storms. The water from more intense storms will come faster than the creek can accommodate and runoff will overflow the banks onto the flood plain. Here the rushing water will spread out and slow, and settle out its load of sediment and debris. Water infiltration into the soil and the natural vegetation on the plain prevent erosion. Slowly the water on the plain will subside and the creek bed will again contain the running water. Runoff percolating into the soil will move downward toward the ground water. Usually in a matter of days, the runoff reaches the aquifer. The aquifer flows underground and seeps into the bank of the creek replenishing it during rainless periods.

Soil surface and ground waters have natural processes to remove pollution from water. Microbes living in soil and water can metabolize organic materials. If given sufficient time and the proper mix of microbes, they will degrade the materials to nitrogen gas, carbon dioxide, and water. Soil

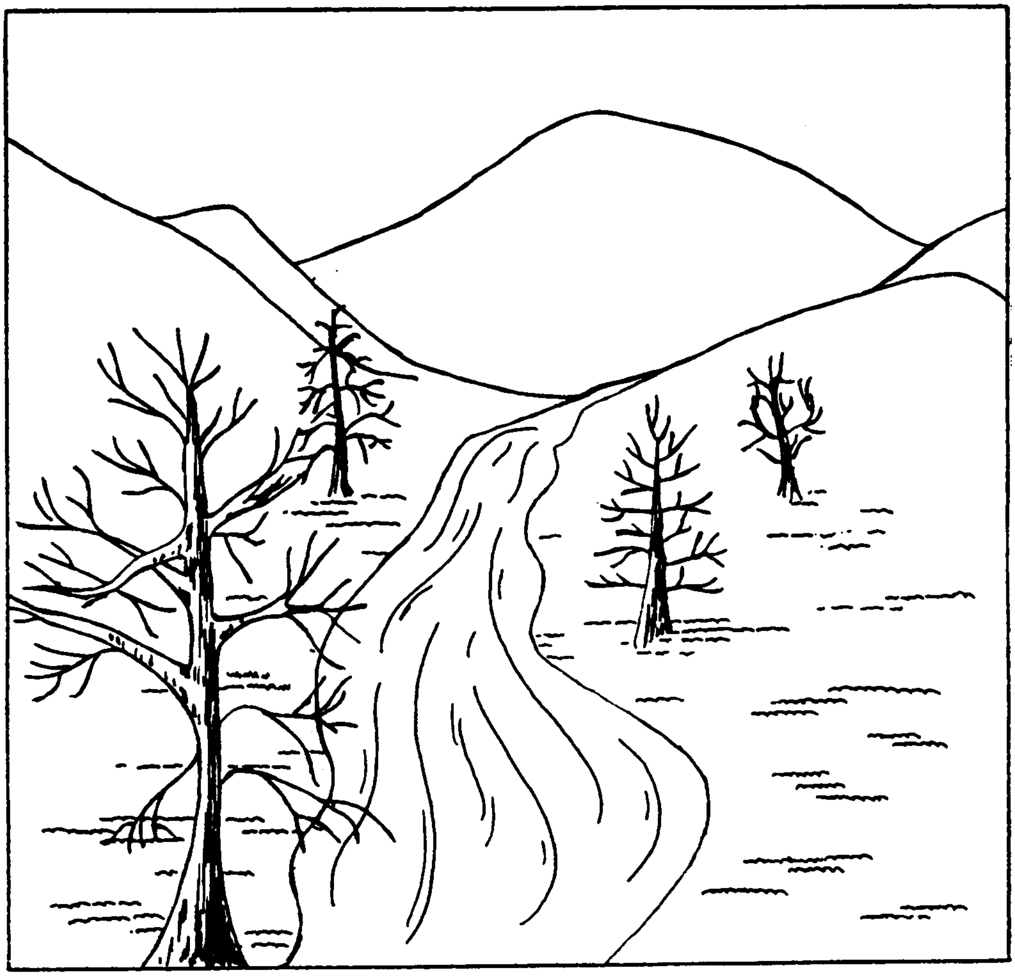

Figure 2--A Natural Flood Plain

particles act as filters adsorbing organic compounds and metals which can harm biota. Vegetation on the flood plain removes some of the excess water and nutrients such as ammonia and phosphates that can cause eutrophication. Roots and dead plant material help maintain a loose, aerated soil texture that allows for maximum microbial activity and open soil pores for adsorption (31).

Nature's system solves several runoff problems:

1. It limits physical and chemical damage to the environment by slowing raging water which carries surging debris and sedimentation.
2. It improves the quality of runoff by allowing time for physical, chemical, and biological processes in the water and soil to take place.
3. It ensures a sustained ground water and creek level during rainless periods.

Disruption of the Natural System

Disruption of the natural system takes place when the flood plain is developed. Figure 3 illustrates how the benefits of the natural system are reduced. When this happens, vegetation is stripped off the land during construction. The soil itself is covered by impervious roofs, asphalt, and concrete. Salt is dumped onto roads and bridges during icy weather and washes into creeks. Metals from fuels and worn auto parts are deposited on to roads. Trash litters the ground and fertilizers and pesticides wash off lawns and gardens. Chemicals are applied and spilled on the ground. More contaminants are carried into the air by cars and industries.

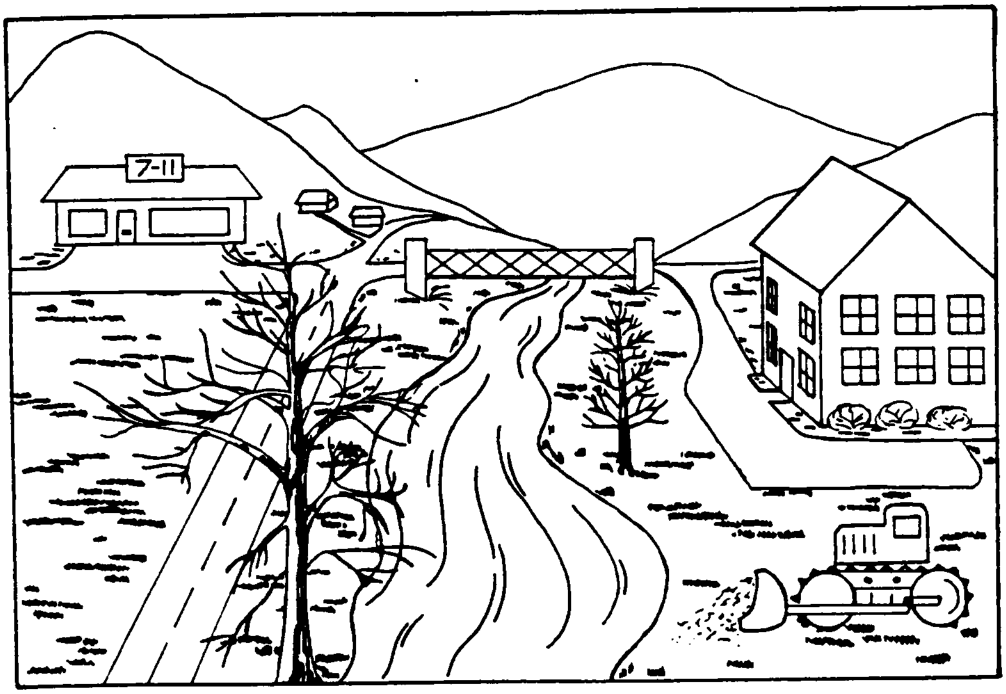

Figure 3. A Disrupted Flood Plain

During a storm the rain rolls quickly down paved hills and off of roof tops. It picks up the extra air pollution load. The exposed soil erodes away and nutrients are no longer utilized by plants and soil microbes, but rush downstream with the soil. The flood plain cannot percolate sufficient rain into the ground water since its surface is partially covered with concrete. The plain floods higher than ever, damaging additional developments. More runoff rushes through the plain, carrying its extra load of pollution and sediment along with large debris such as tree limbs. The sudden shock from the pollution kills a percentage of the life in the stream. Sediment smothers biota and fish nesting sites. When the runoff hits a bridge it dumps its load of debris against it, further blocking the stream bed. Sediment deposits cement the debris together. The flood rises higher and rushes downstream, scouring the stream bed and banks while adding more sediment to the load and destabilizing the banks.

Early Solutions to the Problem

Early solutions to the problem as towns grew in size, were to build systems to keep up with the transportation of runoff. Studies were done to determine how much runoff to expect from heavy storms and sewers were built to accommodate it. Curbs and gutters further helped rush the rain with its load of pollution away from the area.

Problems arose, however, if another town was built on the next hill upstream. Storm sewers and gutters were built in the new streets and more contaminated runoff flowed to the first community. Creeks over-flowed from this greater runoff volume. Their sewer system became flooded with infiltrated water or else with water that backed up from the flooded creek. Basements of houses in the plain became off-line storage facilities for the runoff. Worse, the sewers released domestic and industrial wastes onto the land and into homes.

In an effort to control and clean the contaminated runoff, many communities have expanded their sewage treatment plants and connected the storm sewers to those carrying domestic and industrial sewage. When these combined systems contain more water than the plant can handle, the system is "short-circuited" and the contaminated runoff with its companion load of raw sewage is dumped directly into the stream causing additional hazards for those living downstream.

With the advent of public concern about the environment and water quality coinciding with the development of many suburban areas which over-tax ageing sewer systems, the need for new solutions to the problem of storm water management has been recognized.

RESEARCH DONE ON THE CHARACTERISTICS OF STORMWATER RUNOFF

Methods of quantifying the problem of storm runoff have been developed along with models to quickly compare design options and efforts to find reliable, enforceable, cost effective solutions to this public problem.

Characteristics of Rain

Hydrology

Hydrology is the study that allows for accurate predictions of the amount of runoff that can be expected to need drainage in a watershed. The type of soil, vegetation, and slope of the land all must be taken into account, plus the intensity and duration of rainfall.

Rainfall patterns vary through the year and the importance of contamination in runoff also varies. The storms of summer in the Southeastern part of the United States tend to be sudden, short and intense compared with the rest of the year. Since much pollution is associated with automobiles, heavy metal and hydrocarbon deposition will be heavier in the summer. Air pollution from automobiles is also heavier in the summer months (32). Runoff pollution is high in the early spring in cold climates where snowmelt carries contamination laid down through cold periods before grass and other vegetation can contribute to nutrient up-take. In the autumn, leaf litter adds a heavy organic sediment load.

The runoff coefficient is the percent of rain in a storm that will become runoff. Factors that influence this value are the duration and intensity of the storm, period of time since the last rain, slope of the land, type of geology, and land use.

Most storms exhibit a peak flow of runoff in the first half of the storm. The first rain soaks into the ground and wets the pavement. After this initial wetting, runoff accelerates rapidly. The rate of runoff reaches a peak and then slacks off as the rain abates. The slope of the land, and soil types and percent of imperviousness all effect the magnitude of this peak. The direction and speed of the storm movement with respect to the alignment in the watershed will also greatly influence this peak flow (33, 34). If the rain begins at the downstream end of the basin, this peak will be minimal, but if it begins at the upstream end, and moves along the creek, the peak will grow in magnitude as it moves. Foround et al. (34) found that most storms move through the watershed faster than the runoff can accumulate.

The Transport of Pollutants by Rain

The transport of pollutants by rain occurs quickly once rain begins. At the beginning of a storm, studies have shown it picks up the pollution in the air. Griffin (35) found that in Northern Virginia the rain contained more pollution than the runoff. As puddles begin, dissolved pollutants and light sediment begin to wash away (36). If a storm has uniform intensity throughout its duration it would seem, intuitively, that contamination would be washed away quickly at first but with decreasing efficiency as the rain continues. This is the "first flush" effect and has been found to occur in many studies. Helsel et al. (26) illustrated first flush by plotting the cumulative percent of the total storm pollutant load versus time elapsed since the beginning of the storm. When comparing this to the graph of the cumulative percent of runoff versus time, he showed that the initial portion of the storm runoff carried a disproportionate amount of pollution. He found this to be true for ninety percent of storms sampled in an urban area, eighty percent of storms in a residential area, sixty four percent of those in farmland and that the effect did not occur at all in a forested area. Griffin (35) found that first flush was more important for pollutants that adsorb onto sediment than for soluble pollutants. Other studies, however, have not found first flushes to occur.

Hoffman et al. (37) found that hydrocarbons on a well-used parking lot followed the first flush effect of other pollutants by thirty minutes. Probably due to their hydrophobic chemistry, some hydrocarbons remained on the pavement after any storm that had less than a two inch rainfall. The extent of the first flush effect appears to depend on the type of pollutant under consideration and the sampling site.

It also seems intuitively true that the concentration of pollutants in runoff will be proportional to the number of previously rainless days, and in the early days of runoff studies this was assumed to be so. Recent research by Whipple (38) has shown that the daily rate of organic pollutant loadings on street surfaces accelerated as the number of dry days increased. This could be due to inefficient street cleanings. In the same study heavy metal concentrations and the weight of sediment in runoff were found to be proportional to the inches of rainfall and not to the antecedent dry days.

The Effect of Land Use

The results of land use and development studies have consistently shown that as areas become developed, the amount of pollution in stormwater runoff increases. Whipple et al. (39) found that urban and suburban areas had 0.02 to 0.03 pounds per day per capita of BOD from nonpoint sources. This extra load of contamination can over-tax a combined sewage treatment plant with unplanned pollution load. Whipple et al. also found (40) that nonpoint sources accounted for over fifty percent of the pollution in three streams studied in New Jersey. He noted that since the advent of improved sewage treatment plants, the relative importance of the contribution of nonpoint source pollution to source pollution has continued to grow.

Different land uses contribute different levels and types of pollution. Fertilized gardens and lawns contribute nutrients to the runoff. Weand et al. (41) found that a lightly grazed pasture contributed little pollution to runoff over a natural forested area, but that a heavily grazed pasture had substantial amount of contamination. Helsel et al. (26) found that agricultural areas contributed the highest concentration of suspended sediments from soil loosened by cultivation, but Griffin (35) found that more rain was needed to produce runoff on farmland due to the perviousness of the area compared to suburban and urban areas. Griffin also found that as the percent of imperviousness of an area rises, the pounds of pollution it yields per acre per inch of rain increases.

In a combined sewer system in Elizabeth, New Jersey, Kaufman (42) found that runoff contributed sixty five percent of the BOD in a stream, due to sewer overflow during times of heavy rain. Other factors that will influence the amount of pollution in runoff are the amount of traffic, construction, and the frequency and efficiency of the street cleaning, and population density. Table IV summarizes the effect of land use on runoff pollution load.

Models

Models have become useful tools in stormwater management since the advent of the computer. They are especially recommended where (39):

1. A direct measurement of stormwater quantity and quality data is impractical to obtain.
2. Alternative development options or BMP designs need to be quickly compared.

Table IV

The Effect of Land Use on Stormwater Quality

Land Use	Improvement Mechanisms	Pollution Contributions
Forest	Infiltration to Groundwater Plant Up-Take of Water and Nutrients Adsorption Unto Soil Microbial Decay in Soil	Plant and Animal Organic Material
Pasture	Same as Above	Plant and Animal Organic Material Fertilizers
Agriculture	Same as Above, But May Not Have Vegetation on Fields for Part of the Year	Plant Organic Material Erosion from Tilling, Fertilizers Herbicides, Pesticides
Single-Family Dwellings Neighborhoods	Same as Above, But Have Some Impervious Groundcover	Plant and Animal Organic Material Automobile:Emissions, Hydrocarbons, and Heavy Metals Trash and Litter Fertilizers,Pesticides Erosion From Construction

Table IV (Continued)

Land Use	Improvement Mechanisms	Pollution Contributions
Multi-Family Dwellings	More Impervious Groundcover	Some Plant and Animal Organic Material Hydrocarbons and Heavy Metals Very High, Trash and Litter High
Commercial and Public	Impervious Area Varies	Automobile Emissions High Hydrocarbons and Heavy Metals Very High Much Trash and Litter

3. Complex watersheds are being analyzed hydrological -ly.

Models are based on mathematic relationships between all significant parameters that may effect water quality and quantity. Implicit in these relations are built-in assumptions such as; first flush effects are insignificant, loads of all types of pollution in runoff are proportional to the antecedent number of dry days, or that all sizes of sediment particles settle in basins uniformly, with uniform pollution loads adsorbed onto the particles (43).

Models can be found to do better hydrolic analyses than stormwater quality analyzes because more data and certainty exist for hydrolic relationships today. The concern for, and study of, water quality is much more recent, and the research results more sketchy. Using models it is possible to predict rainfall and runoff coefficients and pollution loads and design an entire watershed stormwater management strategy without ever gathering an actual data point in the field.

The EPA has developed a Stormwater Management Model (SWMM) for highly urbanized areas which has been modified as research has shown the need. The Army Corps of Engineers has developed Storage, Treatment, Overflow, Runoff Model (STORM) which is well known and constantly improved (39). The Illinois State Water Survey often improves its Illinois Urban Drainage Simulator (ILLUDAS) (44). Others exist, each with special features and built-in assumptions. To ensure a proper result, models need to be "calibrated", that is, actual data are put into the program. After running, the result should be "verified" by checking calculated results with reality. This entails work in the field and laboratory and these steps are often eliminated to save time and money, often to the detriment of the final design.

In summary, choosing a proper model and using the results properly is a complex, confusing job. Careful attention must be paid to the appropriateness of a model to the watershed, the validity of its assumptions and the amount of actual reliable data that was used.

Field Studies

Field studies have been done in hundreds of locations to analyze the problem of stormwater runoff in the last twenty years, and no standardized procedure has developed. In 1978 the EPA attempted to establish a nationwide data base with their Nationwide Urban Runoff Program (NURP) using reproducible identical methods in over thirty locations across the country. Few studies can afford the complex duplication of numerous laboratory tests that the NURP entailed. It is therefore difficult and often invalid to compare data from different studies in different localities. This is especially true since further uncertainty is added by the random nature of the behavior of rain. The only way to gain confidence in conclusions made concerning runoff is to have a preponderance of data, and few studies can afford the time and the cost.

The years have given researchers some basic experience in technique in the field, however. A complete description of water sampling techniques is beyond the scope of this report, but a few of the common options will be outlined.

Sampling Equipment

Water sampling equipment in the field may be as simple as a bucket with samples taken from a stream at regular intervals during a storm. In the early years, this is exactly how studies were done. Since rainfall is unpredictable, automatic equipment has been found to be more convenient and accurate. This equipment is activated by a rise in the height or flow of the creek and takes regular, equal, discrete samples at either regular time intervals or at regular creek height intervals. After a storm, these samples can be analyzed separately. Plots of each sample pollutant concentration versus the time since the beginning of the storm show the extent of the first flush effect, especially when the height of the creek against time is compared on the same graph. An alternative procedure is to have the separate samples composited with volumes proportional to the height of the creek at the time each was taken and only one sample need be analyzed in the laboratory. This is a "flow-weighted composite" sample. This method assumes that the stream height is directly proportional to its flow rate. Much money and effort is saved in laboratory costs using this method, but characteristics of the storm event, such as first flush effect, are lost.

Stream Flow Measurements

Stream flow measurements are also important to measure during a studied storm. Meters are often in the form of weirs (39) that restrict creek flow and measure the head of pressure on the device. As the creek rises, the head is increased and recorded. By actually measuring the creek flow at different stages, the weir can be calibrated. Flumes operate by changing the channel area or slope and the resulting change in the creek height through the flume is measured. Flow rates can be determined by adding tracer chemicals in metered amounts upstream and determining their concentration downstream. The amount that the tracer is diluted during its trip is proportional to the flow of the stream.

Automatic devices can also be used. One simple device consists of a float that is attached by cable to a rotating drum covered with graph paper. A pen is moved along the chart by a simple clock and changes in the position of the float subscribe a curve proportional to the creek height change. These systems can be electronic or mechanical. Other devices measure the time it takes an ultrasonic wave to travel to the stream surface and back and others measure the pressure change in bubbles as they rise through the stream.

The volume of water flowing in the creek can be calculated by finding the cross-sectional area of the streambed at each creek height. The velocity of the water flowing can be found by simply timing an object or tracer as it floats a known distance or by counting the revolutions per minute of a metering device. The velocity multiplied by the cross-sectional area of the bed is the cubic feet per second of water at each flood stage. Multiplying this by the pollutant concentration gives the mass of pollution carried downstream each second. These values can be determined for each interval for the sequential water samples obtained, or an average flow volume rate can be calculated for each storm and multiplied by the pollutant concentrations of the flow-weighted composite for an average pollutant load per second for each storm.

Rain Gages

Rain gages can be simple as a graduated cylinder or as complex as a continuous measuring device that charts the rain with respect to time. Placement of the gages is important as storms can vary greatly, even within a small watershed just a few miles long such as Peters Creek.

CURRENT RESEARCH TOPICS

Hydrology is an older science in which much experience has resulted in numerous respected handbooks and techniques. The study of pollution in runoff is still at the stage where fundamental ideas, such as the first flush effect, are being investigated to determine their universality. The location, land uses, pollutant and type of rainfall all contribute to non-uniformities in expected pollution loadings and the effectiveness of the BMP's.

Numerous research projects are being done to determine the effect of land use on storm water runoff across the country (22,24,26,27,30,36,40,41). Studies look at the effect of such variables as percent of impervious ground-cover, population densities, fertilized lawn area, roof top area, pavement area, amount of traffic, off-street parking, curb lengths, soil type, slope of the land and the effects of natural and man-made drainage systems. The behavior of contaminants in water is also being studied in great detail. Pollutants carried by sediment are being investigated to determine which type of pollution adsorbs onto which size and type of particles and how these particles settle out of the water. Fesko (36) found that the amount of total phosphorus removal is proportional to the suspended solid removed in stormwater. Oliver and Grigoropoulos (45) found that the ammonia concentration in a lake increased as organic material was degraded and all other forms of pollution decreased.

Whipple and Hunter (27) concluded that the settleability of sediment will differ at each site at differing times since sediments interact and have varying specific gravities. In their study, hydrocarbons appeared to be adsorbed onto most sediments but the BOD and total phosphorus removals lagged behind suspended solid removal. Pitt and Bozeman (24) studied the different effects that short and long storms had on different types of pollution. They found that pollutants will be washed off of impervious areas during even a short rain, but in a hard rain, pollutants from agricultural areas provide the greatest source of pollutants since erosion occurs mostly during hard storms. Studies such as these are being done across the country to develop fundamental functions of pollutant transport by storm runoff, and to add to engineering knowledge and judgment.

BEST MANAGEMENT PRACTICES-NEW APPROACHES TO AN OLD PROBLEM

Experience with storm runoff has resulted in many improvements to the old engineering solutions to the problem. The use of sewers and gutters tends to reduce time lag between the start of the storm and the start of runoff and increases the runoff coefficient. The intensity of the peak flow increases and water quality is lowered.

The new systems slow the rush of water thereby providing opportunities for runoff to infiltrate into the soil. Designs for new developments can attempt to maintain pre-development runoff quality and quantity levels. The BMP's can take several forms: non-structural, low-structural, source controls, volume controls, and treatment controls. The choice of a design will depend upon present and planned land use, the availability of land, the type of existing natural and man-made drainage systems, the public needs and interests and the effect of the designed system downstream (46).

Non-structural Controls

Non-structural controls include planning and legislation to control land development. Maintenance of water quality has been the objective at Lake Tahoe since the 1950's (47). Pepper and Jorgensen expressed the concern that careful stormwater management unfortunately can encourage additional development on a flood plain or sensitive watershed. Here in Virginia, the Occoquan Watershed has provided experience in water quality preservation by cooperative planning by several communities (13,16). Planning and legislation can include such things as requiring erosion controls during construction, limiting the amount of impervious area in sensitive places in the watershed by zoning, or by integrating the decisions of several municipalities into one logical, whole plan.

Low-structural Controls

Low-structural controls are minor modifications to the natural drainage system by building small, simple structures. An example would be the lining of an unstable creek bank with riprap.

Source Controls

Source controls reduce either the amount of runoff or the amount of contaminants in the runoff in the first place. These can include street cleaning and erosion controls.

The National Urban Runoff Program had as one of its objectives the determination of the cost effectiveness of the BMP's. Several studies were done to investigate street sweeping effectiveness (48). Finnemore and Lynard (46) found that street cleaning was more effective for roads in poor condition and that the frequency of cleaning mattered more than the type of equipment used. They found it reduced the concentrations of heavy metals, grease, oil and salts on the roads but was ineffective for sediments and organic material, probably because these particles are too heavy to be efficiently removed. Bender and Rice (48) found that mechanical sweepers tend to break up litter and soil and make the particles more easily transported in rainwater and less likely to settle out.

Whipple and Hunter (38) felt that too much emphasis had been put on street sweepers for runoff water quality control since street deposition is only one source of contamination in urban runoff.

Erosion controls are especially important in agricultural and construction sites. Use of no-till techniques and placements of straw bales at outlets of disturbed soil can greatly reduce sediment loss. Enforcement and public education programs are necessary steps to implementation of these controls.

Volume Controls

Volume controls reduce the rush of runoff and delay the peak flow. These controls can be small scale on each site, or large scale to contain the runoff of many acres. For developments that are being planned, there are many choices of designs. Rainwater that hits buildings can be contained as it would be by pervious ground by using flat roofs as reservoirs (Figure 4) to hold a few inches of water and to slowly release it after the storm has passed. This technique is especially appropriate in areas where the soil does not percolate adequately.

Stormwater can be diverted to dry wells (Figure 5) which are ditches dug above the water table and left empty, or filled with some material with much void space such as gravel. These can be used to store water from small impervious areas such as parking lots and roofs (49,50). The water in the well will slowly percolate into the soil and eventually to the groundwater. Grass or gravel border strips (Figure 6) and grass swales (Figure 7) help to retain some of the runoff and reduce the pollutant loading by plant up-take and soil adsorption. Grass and gravel can be part of a concrete or asphalt modular pavement structure to reduce runoff and the load of hydrocarbons and heavy metals

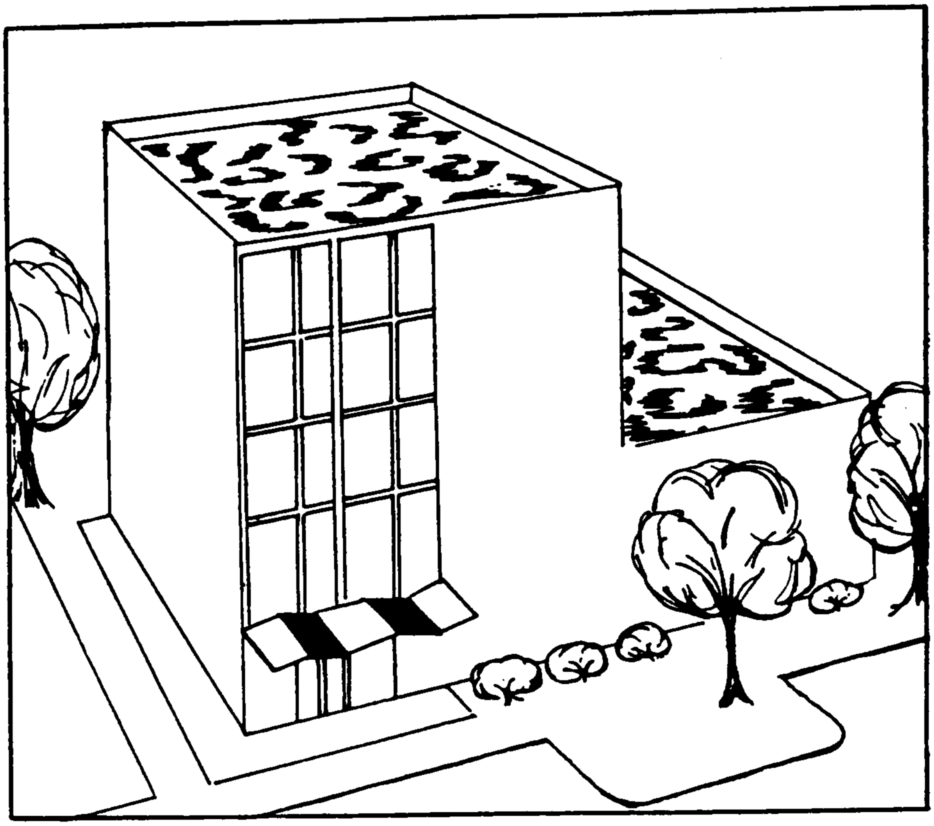

FIGURE 4. STORMWATER DETENTION ON A BUILDING

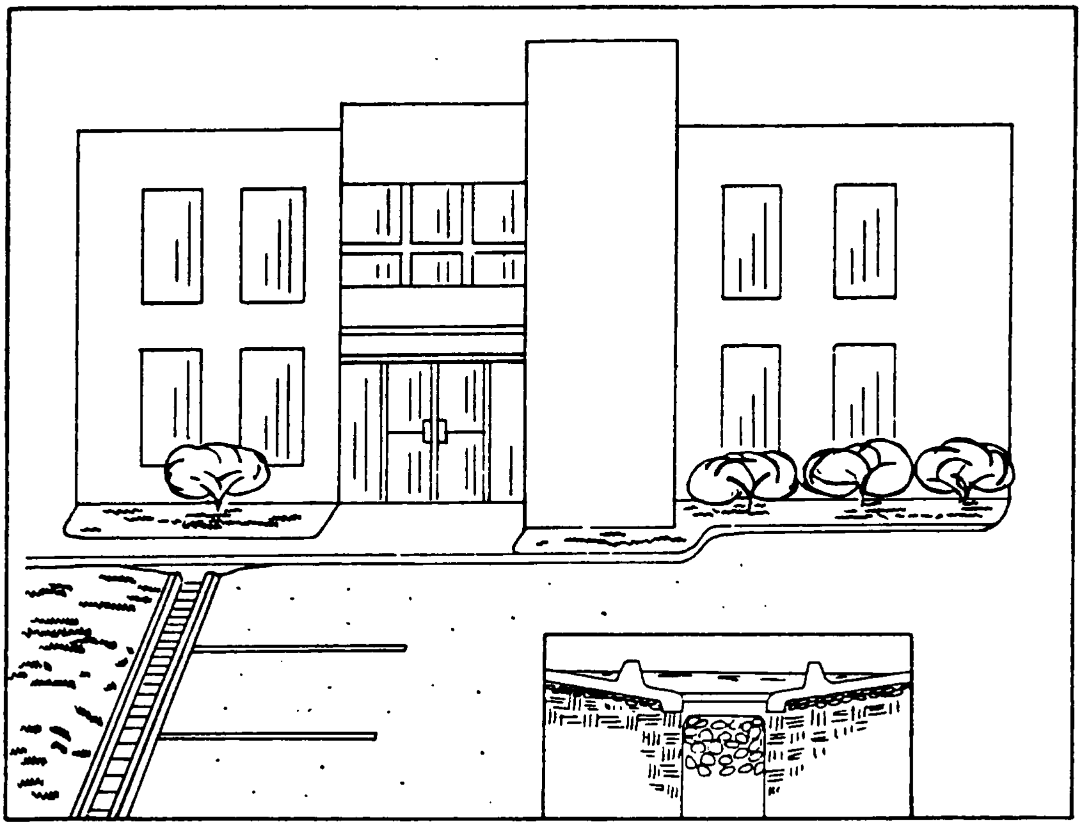

Figure 5. The Use of a Dry Well in a Parking Lot.

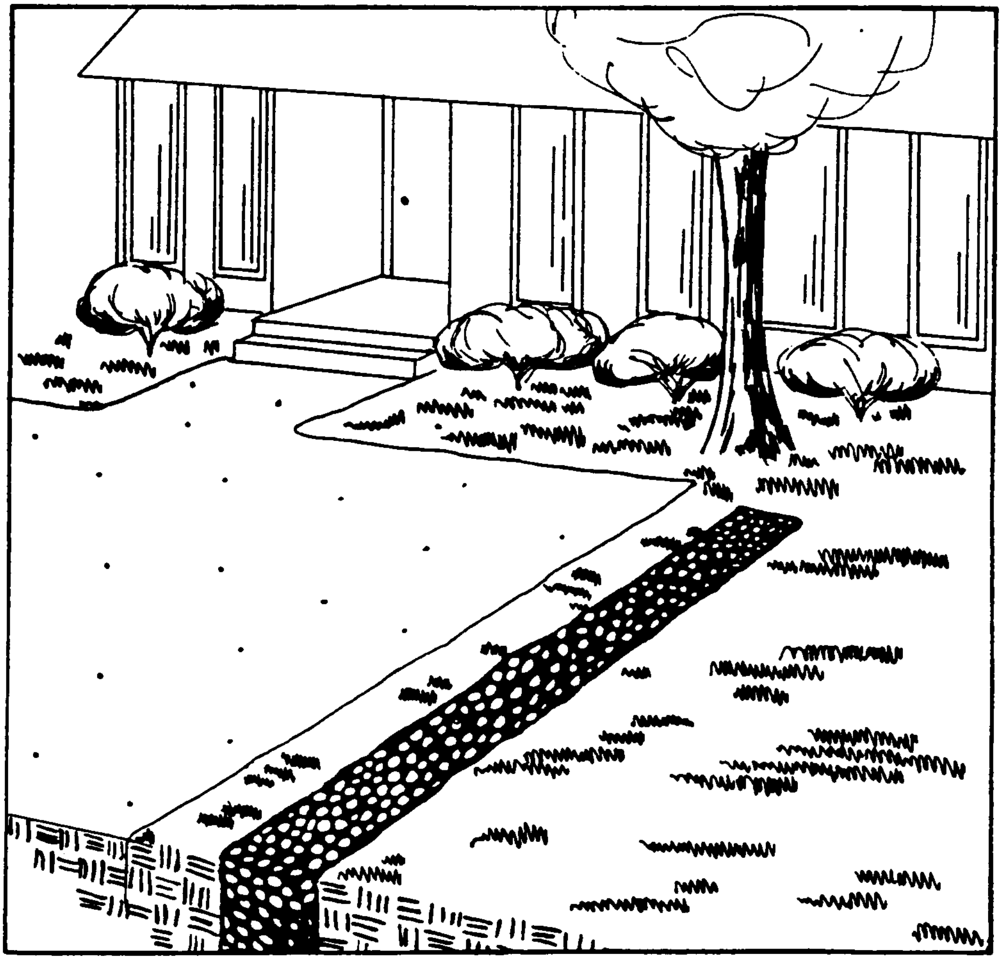

Figure 6. The Use of Grass and Gravel Border Strips in Runoff Control from a Parking Lot.

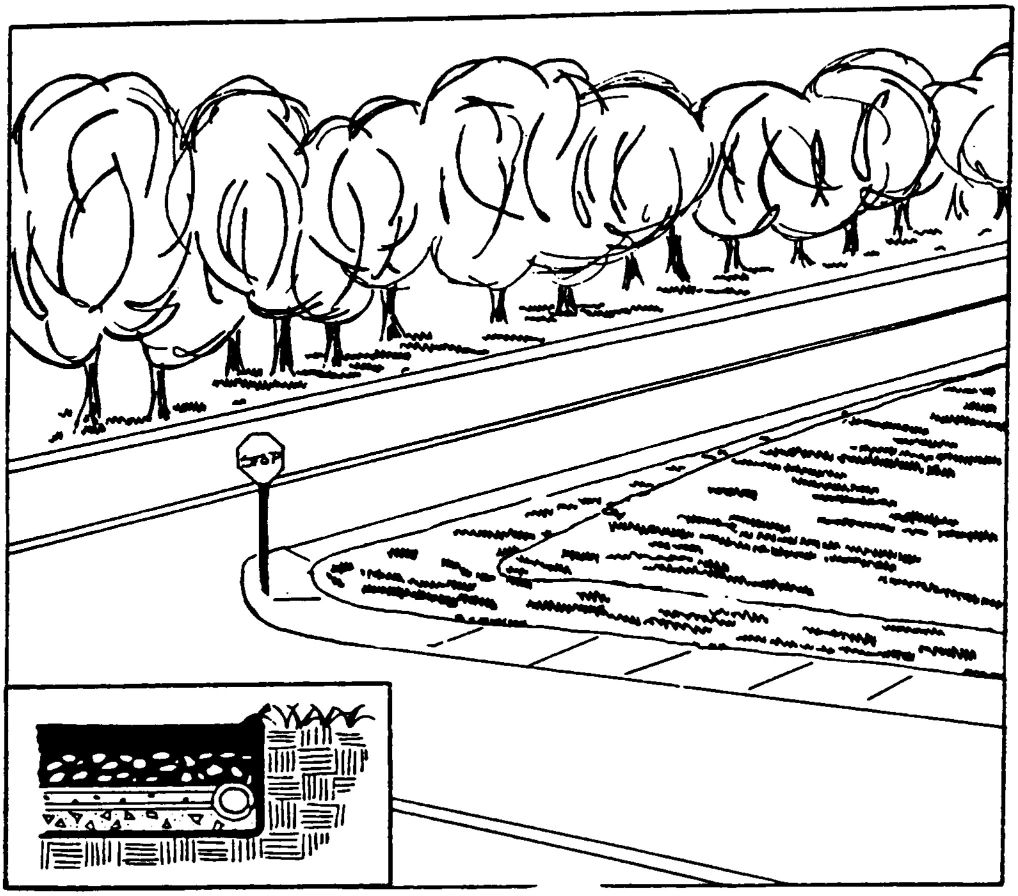

Figure 7. The Use of Grass Swales and Porous Pavement in Runoff Control from a Road.

often associated with parking lots (Figure 8).

Pavements can be made pervious by the use of porous pavement (Figure 7). Some experts do not have faith in the effectiveness and sturdiness of this new type of pavement (39), but Field et al. (51) found that the pavement costs less than conventional pavement in some instances and wears well, even in truck parking lots. Problems with heaving during winter did not develop even when it was used in Ontario, Canada. The pavement is not suited, however, to sloped roads and lots.

The use of basins has received much attention as a simple, inexpensive runoff solution. Temporary basins are required in many places to contain sediment in construction sites. Usually either retention or detention basins are built. A retention basin is an artificial pond built in a low lying area that is used to store runoff. The runoff either evaporates or percolates through the soil (Figure 9). Pollution is removed by microbial action or adsorption onto the soil. Correctly designed, a retention basin can add to the aesthetics of a site and can be used for lawn sprinkling or fire fighting and can even be used for recreation. Safety problems can be addressed by fencing the basin and designing a gently sloping bank. Goldfish can be used to minimize mosquito problems. Regular trash removal is necessary, and every several years it may be necessary to drain and scrape the bottom of the basin to remove accumu-

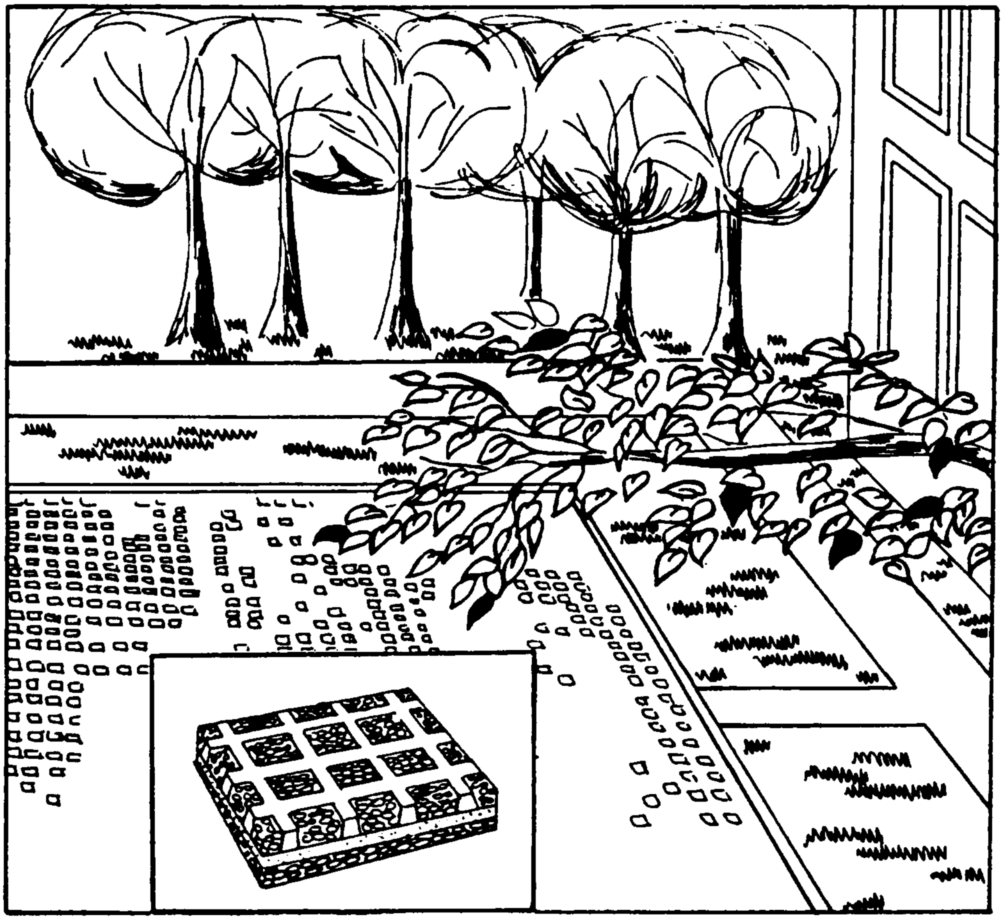

Figure 8. Modular Paving in a Parking Lot.

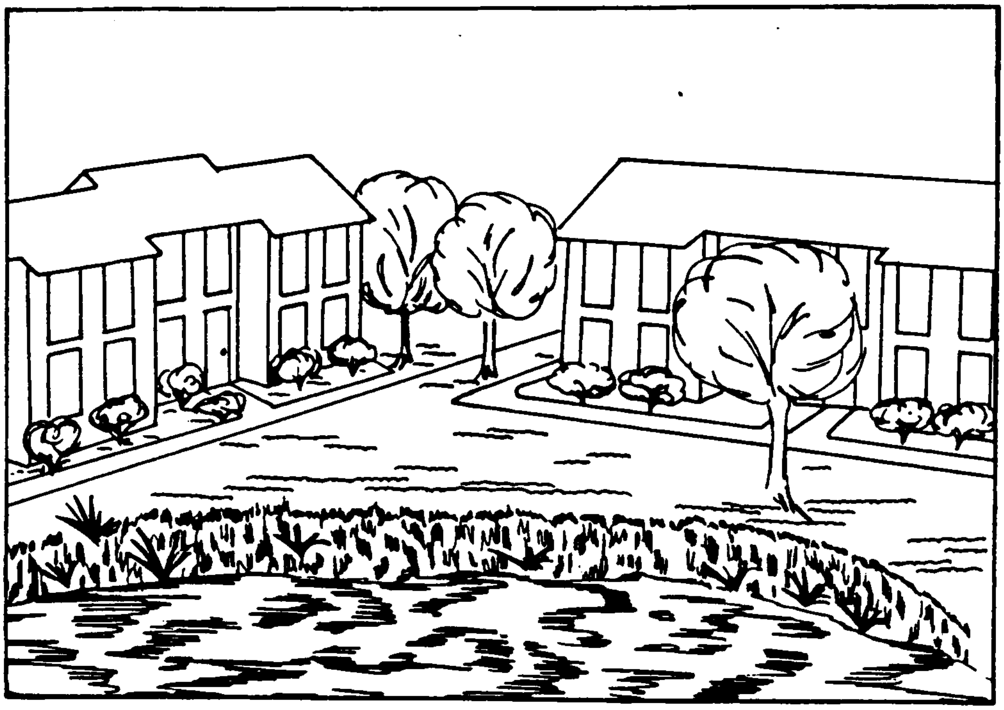

Figure 9. A Retention Basin.

lated sediment and re-open soil pores.

Detention basins are similar to retention basins except that these are designed to be empty during dry periods, and to slowly release the stormwater into the stream after a rain. They can be built to be connected with storm sewers and be opened and shut by electronic monitoring of the water levels in the sewers, or they can simply be a small dam across a stream with an outlet. The inlets and outlets must be carefully designed to eliminate scour from the force of the water. The basin should be shallow to allow for laminar flow and good settling throughout. Much study is being done to determine the optimum time of detention required for optimum pollutant removal (27,33,36,52). In general, detention basins have been found to remove large amounts of adsorbed pollutants and sediments, but do not give good removal of soluble pollutants such as nitrates.

Ferrara (53) found that the bulk of pollutants are adsorbed onto fine particles less than 1 micromillimeter in diameter, which do not settle well. He also found that the ammonia concentration increased through the basin as a result of microbial activity. Scherger and Davis (33) found that settling of sediments was not dependent upon the intensity of the storm since the most difficult sediments to settle are fine silt and even a small rain carries those into the basin. Building basins in series helps reduce even fine sediment concentrations. Detention basins have been built in several parks in Ontario, where water from snowmelts is a special problem (54).

Solutions for stormwater problems in urban areas are especially difficult since no land is available for basins and all buildings and parking lots have already been designed. Most solutions involve utilizing sewer capacity between storms. Municipalities in Michigan (46) use off-line storage basins and send the stormwater to sewage treatment plants during dry weather when the plant can handle the flow. This water is used to reduce normal diurnal swings in domestic sewage flow throughout the plant. Seattle, Washington, has computerized the gates and monitoring equipment in its sewers and gained much more efficient use of its system. Chicago has undertaken an enormous project to build an underground system of tunnels and reservoirs (55) to contain 136,000 acre-feet of runoff.

Treatment Controls

Treatment controls are the most expensive methods of reducing pollution loads in stormwater runoff. The water can be chemically treated in basins, but most often it is sent by sewers to treatment plants and additional capacity for the runoff must be built into the plant design. This method does not reduce the amount of runoff but does delay and reduce the peak flow into the natural drainage system.

SUMMARY

The problems of quantity and quality of stormwater runoff have become more important as rural areas across the country are developed, as pollution from point sources is reduced through improved sewage treatment plants, and as the public has requested an improved environment. Hundreds of individual and nationwide studies have been done to determine the relationships between runoff, land use, and geology. Best management practices have been developed and work is on-going to find optimum designs. Due to variabilities in location, research techniques, and the natural, unpredictable nature of rain, much more work remains before solutions to runoff problems can be addressed consistently in an efficient, reliable, cost effective manner.

III. METHODS AND MATERIALS

This chapter will describe the sites, procedures and equipment used to study the effect of stormwater runoff on Peters Creek. It is written to be useful for those doing further work on the watershed or doing similar studies on other watersheds. Inadequacies in the procedure and problems encountered are discussed. The sampling period of this study was June 1984, to October 1984.

DETERMINING THE DESIRED BENEFICIAL USES OF THE CREEK

The desired beneficial uses of the creek were determined by distributing a survey and by holding a public meeting. The survey and the meeting notices were mailed to all residents living close to the creek and the public meeting notices were distributed to students at local schools (Appendix A). The problems sited by those attending the meeting or returning the survey were recorded, along with suggestions from the citizens. At the meeting, the objectives of the study were outlined along with possible solutions to runoff problems.

DETERMINING LAND USES OF THE WATERSHED

Aerial photographs supplied by the Engineering Department of the City of Roanoke were used to determine the land uses for the watershed. The photographs were sectioned into the categories chosen and the area of each section was found using a numonics electronic grapics calculator, (Landsdale, Pennsylvania) supplied by Wingate Mapping Service in Roanoke. The use categories were: single-family dwellings, multi-family dwellings, commercial and public buildings (shopping centers, schools, parks, Veterans Administration Hospital), agricultural, and undeveloped land.

Entire lots were measured for the categories out to the middle of the street. For example; a single-family dwelling area would include all of the lawn, roof, sidewalks and a portion of the road in front of the house.

The watershed is not an urban area. There is no large area, such as a downtown area, that is totally impervious. Therefore, fertilized area was the sum of the areas of the single and multi-family dwellings, commercial and public and agricultural uses. Undeveloped land was considered to be all the area not fertilized. The different land uses were easily apparent on the maps from buildings, trees and subtle color changes marking the lot lines.

SELECTION AND DESCRIPTION OF SITES

Peters Creek watershed covers approximately 7,000 acres, and extends from forested mountains in the northwest portion of Roanoke County to the well developed Roanoke River plain to the south. Three sites were chosen to study the creek water (Figure 10). All were located next to

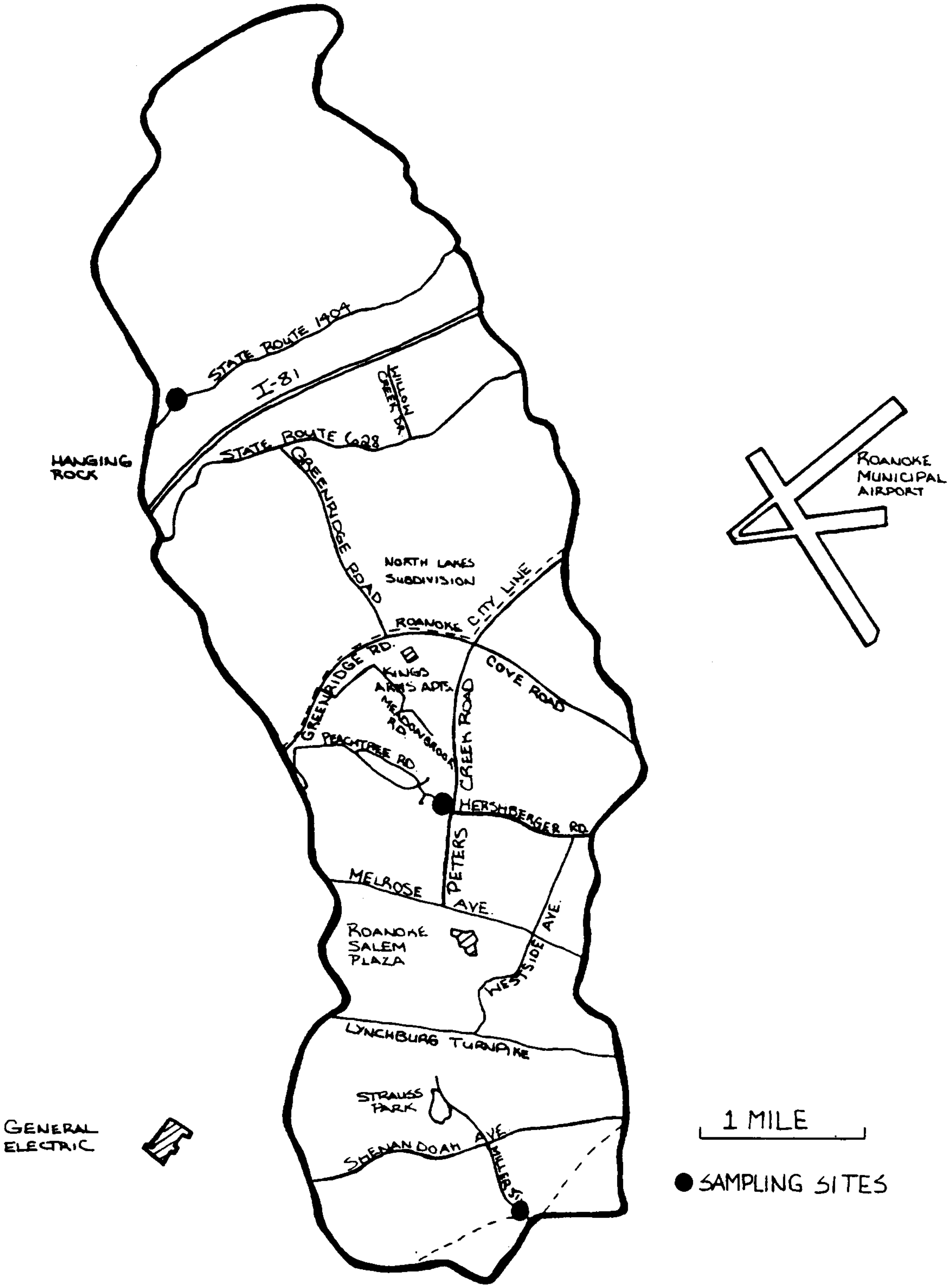

Figure 10. The Peters Creek Watershed

bridges crossing the creek. State Road 1404 crosses the creek at the northern site. Here the creek is barely a trickle, less than twelve inches across. Unpopulated, forested hills rise in the background and the creek flows onto a small plain on which stands one house with a vegetable and flower garden (Figure 11). The road crosses the creek at the south end of the plain and the creek flows south between a rocky cut in the hills. Vegetation grows on the bank and into the creek among the rocks. Several types of wild flowers grow along the banks. Birds live in sumac bushes nearby. Dragonflies, butterflies, crayfish and small snakes are among the inhabitants of the bank. Throughout the study period the stream never dried, but maintained its steady trickle. Portions did contain algae in the warmest weather and on one occasion the creek smelled of rotting material. The area was altered by the activities of people, and one week the water appeared to be sudsy with white foam covering about ten percent of its surface.

The watershed gradually changes from forests to suburban areas when travelling from State Road 1404 to the middle sampling site. Although houses and subdivisions line the roads continuously, there is much undeveloped land between roads. Roanoke County Planning Division has projected up to 35 percent increased development in this area.

The creek crosses a level, undeveloped plain just north

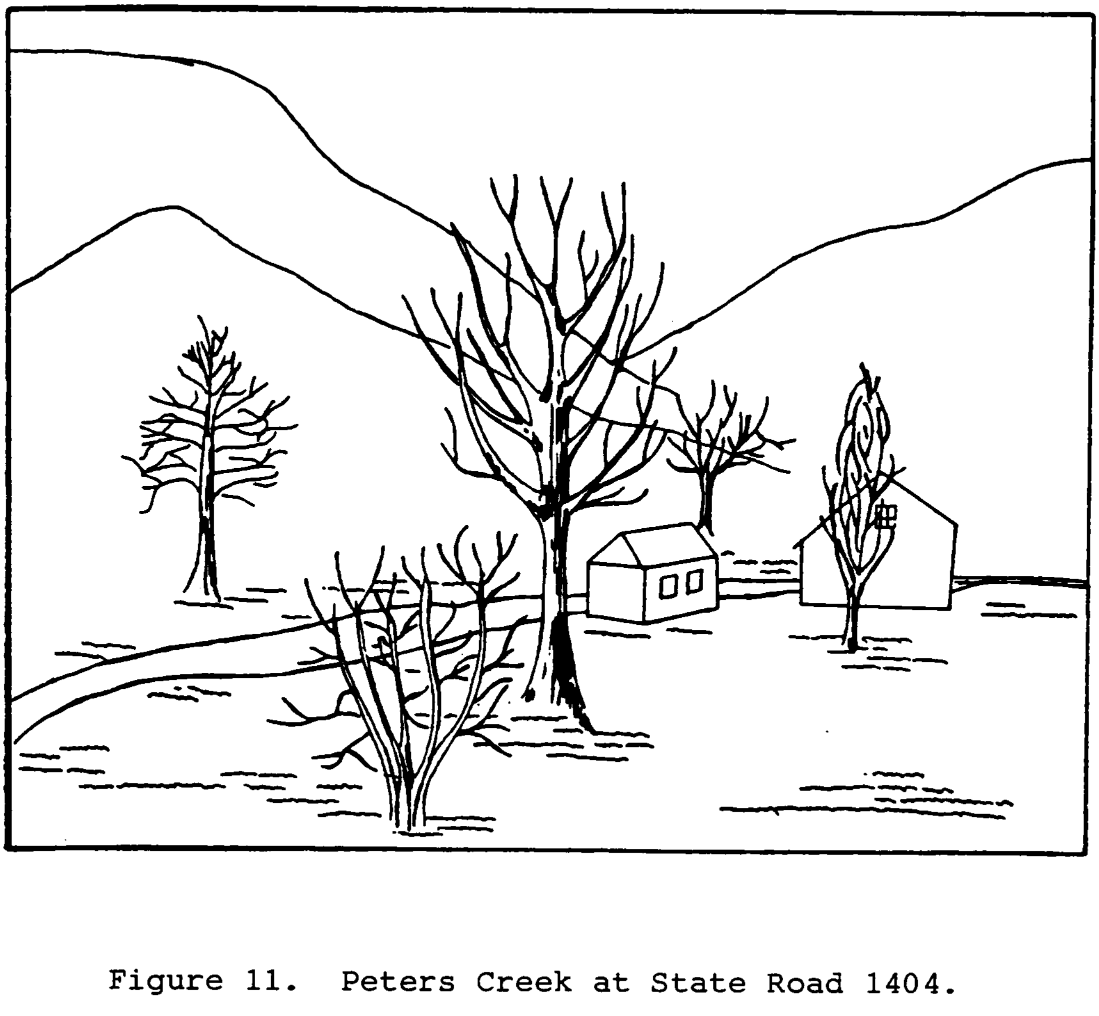

Figure 11. Peters Creek at State Road 1404.

of State Road 628. West from Greenridge Road only one housing development has been built on the plain in the watershed. Willow Creek contains over fifty houses built on a hill on lots of approximately one-quarter acre. A branch of the creek flows on the south side of State Road 628 with steep hills on one bank and the road on the other.

Peters Creek flows through a culvert under the driveway of the Unity Church and travels directly south along Greenridge Road to Cove Road. Few houses have been built along the flood plain here. A broken dam partially obstructs the creek as it approaches Cove Road. The occupants of a home in the plain said that the creek rises over its banks regularly, but has not damaged their house in many years.

The North Lake Subdivision of over two hundred houses rises on the hills east of Greenridge Road to Peters Creek Road and to State Road 628 to the north. This neighborhood has paved roads with curbs and gutters throughout. Storm sewers empty directly into Peters Creek by passing under Greenridge Road.

Just upstream of Cove Road, the creek is about three feet wide and one foot deep in dry weather. Below Cove Road the creek was artificially widened some years ago to accommodate runoff from a large apartment complex, the Kings Arms. The apartments are built onto a steep hill with the creek at its foot. The impervious area of the complex is over fifty percent. The other bank of the creek borders the backyards of homes on Meadowbrook Road, on a slightly lower hill than the one on which the apartments are built. In heavy storms the widened creekbed is insufficient to contain the runoff and flooding occurs on the homes on Meadowbrook Road that back up to the creek. Sewers overflow due to infiltration and sewage backs up into basements. Residents have lined the creek bank with lumber and cement in an attempt to reduce stream bank erosion.

The middle site was located next to a bridge which crosses the creek at Peachtree Road (Figure 12) just west of Peters Creek Road in Roanoke City. Peters Creek Road is a major throughfare on the west side of Roanoke and often floods during the summer months.

Peachtree Road winds upwards to a subdivision of a few hundred homes on lots of about one-half acre. Most of the streets have curbs and gutters. Meadowbrook Road is in this subdivision. Here the creek is about ten feet wide and two feet deep in dry weather. Trees and bushes solidly line the banks. Trash seen in the creek is covered with silt within a few weeks. Birds, tadpoles, water striders, rats, and water snakes inhabit the banks. Pieces of debris, such as leafy branches often lie against the bridge abutments. Home owners have lined the banks with lumber and trimmed tree branches in some locations.

South of this middle site the watershed has steeper

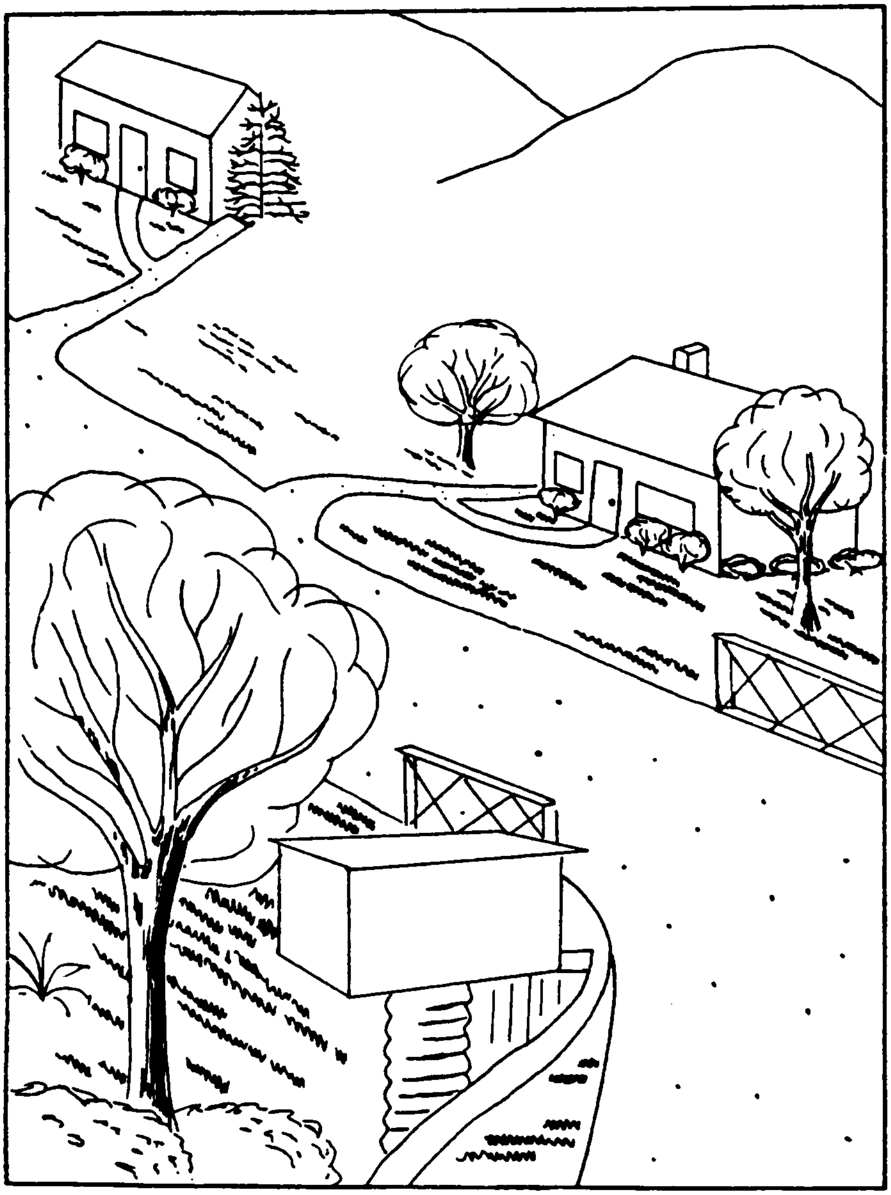

Figure 12. Peters Creek at Peachtree Road.

slopes and has more commercial building and multi-family dwellings. Stores and offices line Peters Creek Road down to Melrose Avenue. Behind the stores, the creek follows parallel to Peters Creek Road. The land along the banks here is undeveloped, probably due to frequent flooding. The Roanoke Salem Plaza Shopping Center is located on a hill on the southeast corner of Peters Creek Road and Melrose Avenue. The creek hugs the western side of the parking lot here with a steep hill on its other bank. Stormwater is sewered into the creek from the parking lot. During heavy summer rains the Plaza becomes an island with extensive flooding occurring along the streets of Melrose Avenue, Peters Creek Road and onto Lynchburg Turnpike to the south. South of the Lynchburg Turnpike, Shenandoah Avenue also often floods during storms.

The last sampling site (Figure 13) was located on Miller Street where the road crosses the creek at the entrance to Roanoke Electric Steel Company. Here several apartment buildings line the creek on the flood plain. The creek covers the road during heavy summer storms. The City of Roanoke raised a sewer next to the creek this past summer in order to alleviate sewage back up into basements during times of heavy rains. Debris in the creek is more man-made here: fast-food boxes, cans, shopping carts and bottles are covered with silt quickly and disappear. Children playing in the creek create dams of debris. This past summer a

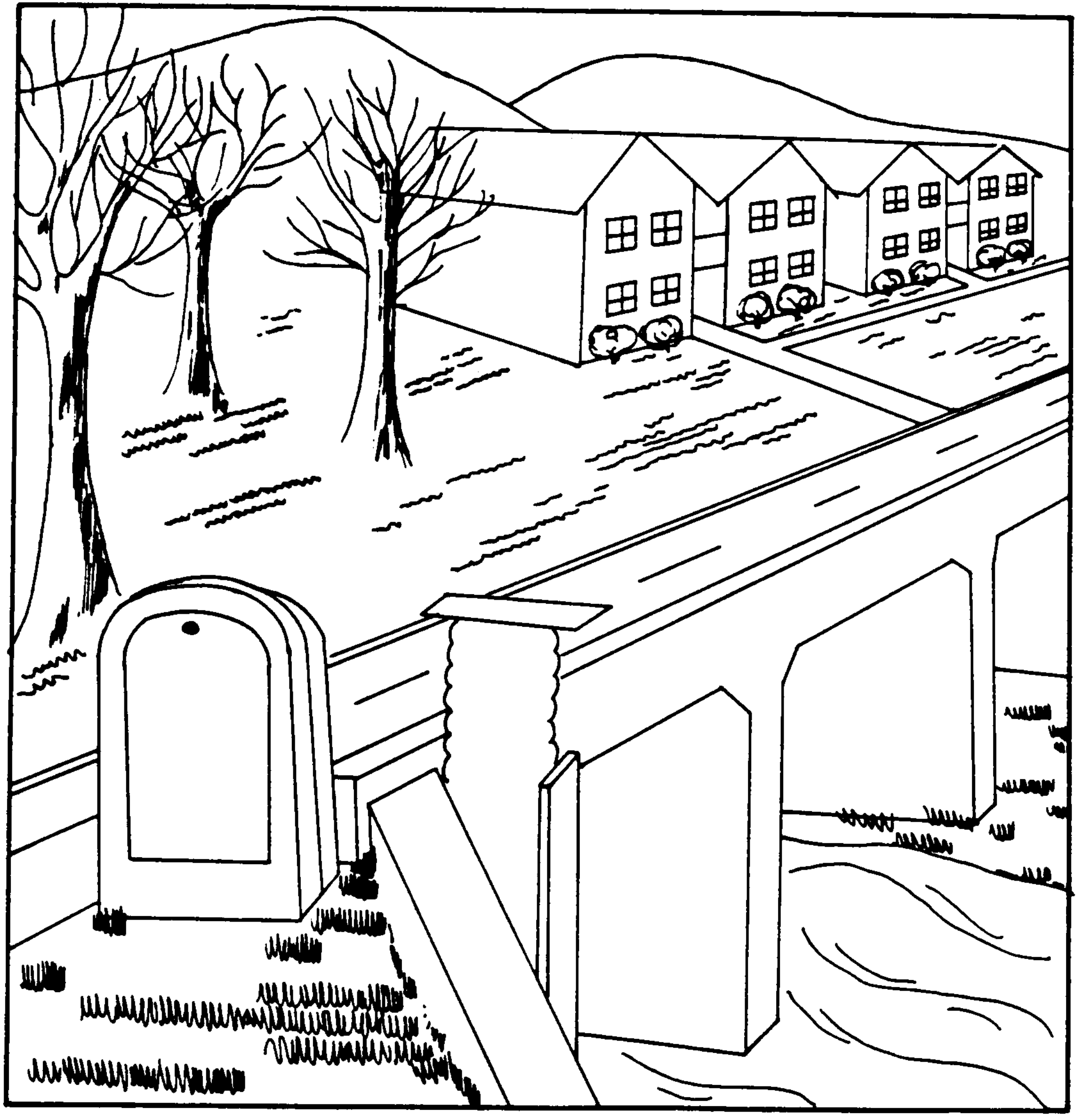

Figure 13. Peters Creek as it Flows under Miller Street.

neighborhood group of mostly women and children removed ten tons of trash from the creek behind the Miller Street Apartments in one afternoon. A group of workers from Total Action Against Poverty in Roanoke removed couches, refrigerators and other trash from the creek, but much work remains to be done. Several more trash dams remain to be removed. Small fish, frogs, and water striders live in the creek. Rats swim near the bridge. Grass and other vegetation solidly line its banks.

After passing the sampling site, the creek passes by Roanoke Electric Steel Company, through a tunnel under tracks of the Norfolk and Southern Railway and meets with the Roanoke River.

DETERMINATION OF THE RATING CURVES

The flow rate of the creek in cubic feet per second (CFS) was determined by State Water Control Board personnel for each site. The flow rate is the velocity of the flow (feet per second) multiplied by the cross-sectional area of the creek. The creek was divided from bank to bank into intervals and the depth at each interval was recorded. The stream velocity was determined by using a Pygmy Meter, Scientific Instruments of Wisconsin (Milwaukee, Wisconsin) when the creek could be waded safely. When it would be dangerous to wade the creek due to swift water, a Price AA Current Meter, Scientific Instruments of Wisconsin (Milwaukee, Wisconsin) was weighted and suspended from the bridge by a cable. The distance between each interval multiplied by the depth at that interval multiplied by the velocity at that interval is the flow rate through each interval of the creek. The summation of these flows is the flow rate for the entire creek. This procedure was done for each site several times at different creek heights. A graph was made for each site of height of the creek (gage height) versus flow rate and a curve drawn between the points. The flow rate of the creek at each site could then be simply read for any height by referring to these graphs (Appendix B).

SAMPLING EQUIPMENT

All of the equipment used was the property of the Virginia State Water Control Board and was installed and repaired by their personnel. The equipment was chosen so that samples of runoff from the creek could be obtained at regular time intervals once a storm started. The height of the creek during the storm was also recorded so that the regular samples could be made into flow-weighted composites with respect to the volume of runoff in the creek during each bottle's sampling interval. Rain gages at two sites also helped determine the intensity of the storm.

Each site was equipped with an Isco Sampler (Lincoln, Nebraska) set in a Fiberglass hut (Figure 14). During a storm, the creek water would rise, wet the actuator complet-

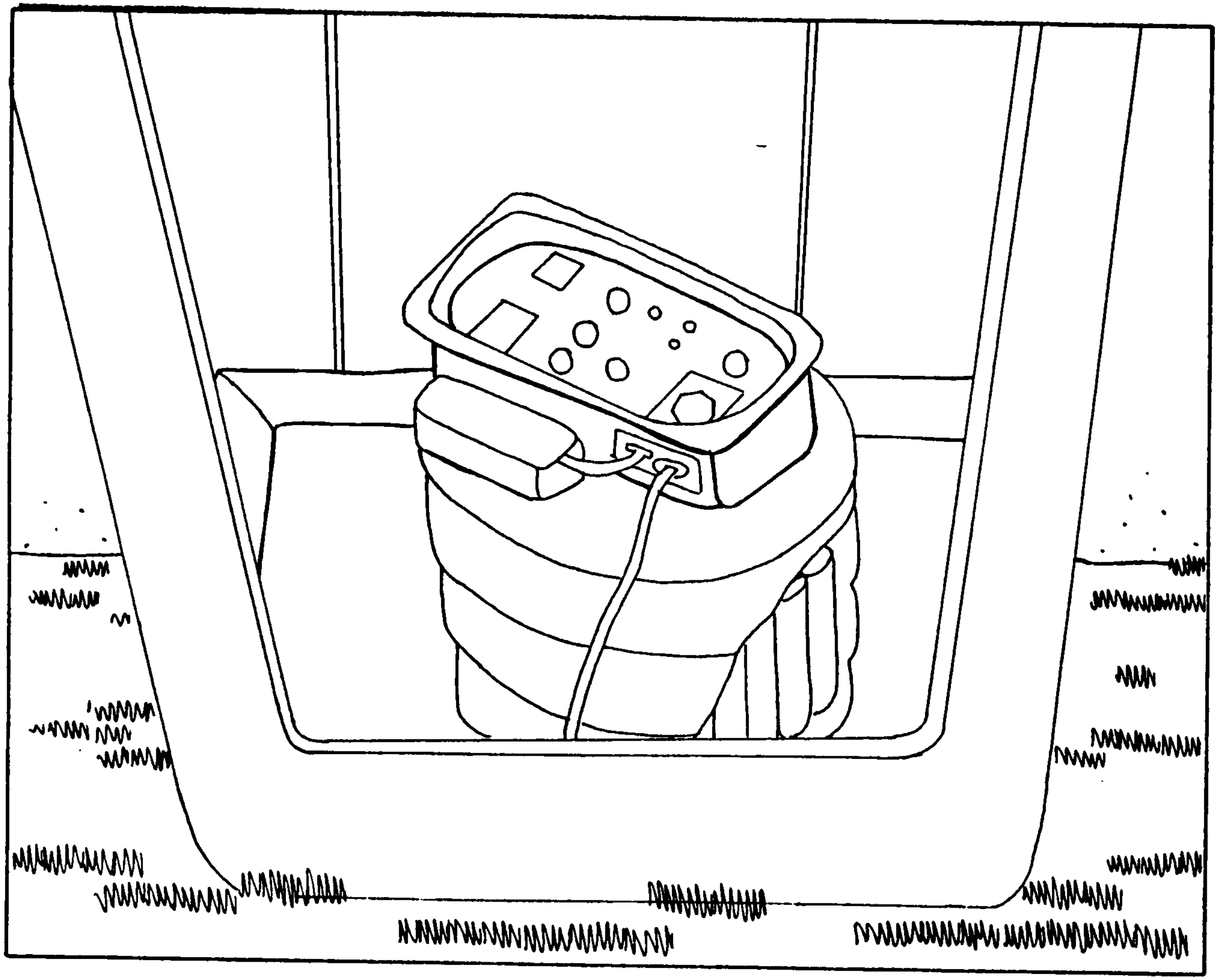

Figure 14. The Isco Sampler.

ing a circuit and begin the sampling cycle (Figure 15). A clock on the top of the sampler was set to activate the peristaltic pump every thirty minutes and the pump would draw creek water up a Tygon tube filling a 400 ml. glass bottle. After filling the bottle, the pump reversed, purging the tubing of creek water in preparation for the next bottle, and a plastic disk with a built-in funnel would rotate automatically to the next bottle. The tubing was secured to the bottom of the creek in an area where the water is well mixed. After fourteen hours, the twenty eight bottles were filled and the sampling cycle automatically ended.

The height of the creek was continuously recorded by a Stevens Recorder (Beaverton, Oregon). Graph paper was attached over a steel cylinder and a travelling pen was moved along the paper by a clock and cable mechanism. The pen would travel the width of the paper in twenty four hours. The clock needed rewinding every three days. In the event of a storm, the float in the stilling well would rise lifting a cable and rotating the drum. The pen would no longer draw a straight line, but would produce a graph (Figure 16) which showed the relative height of the creek with time. The actual height of the creek was determined by noting the creek height on the gage stick nearby each time the pen was re-set to the beginning of the graph. One inch of rise in the creek resulted in a one inch rise on the

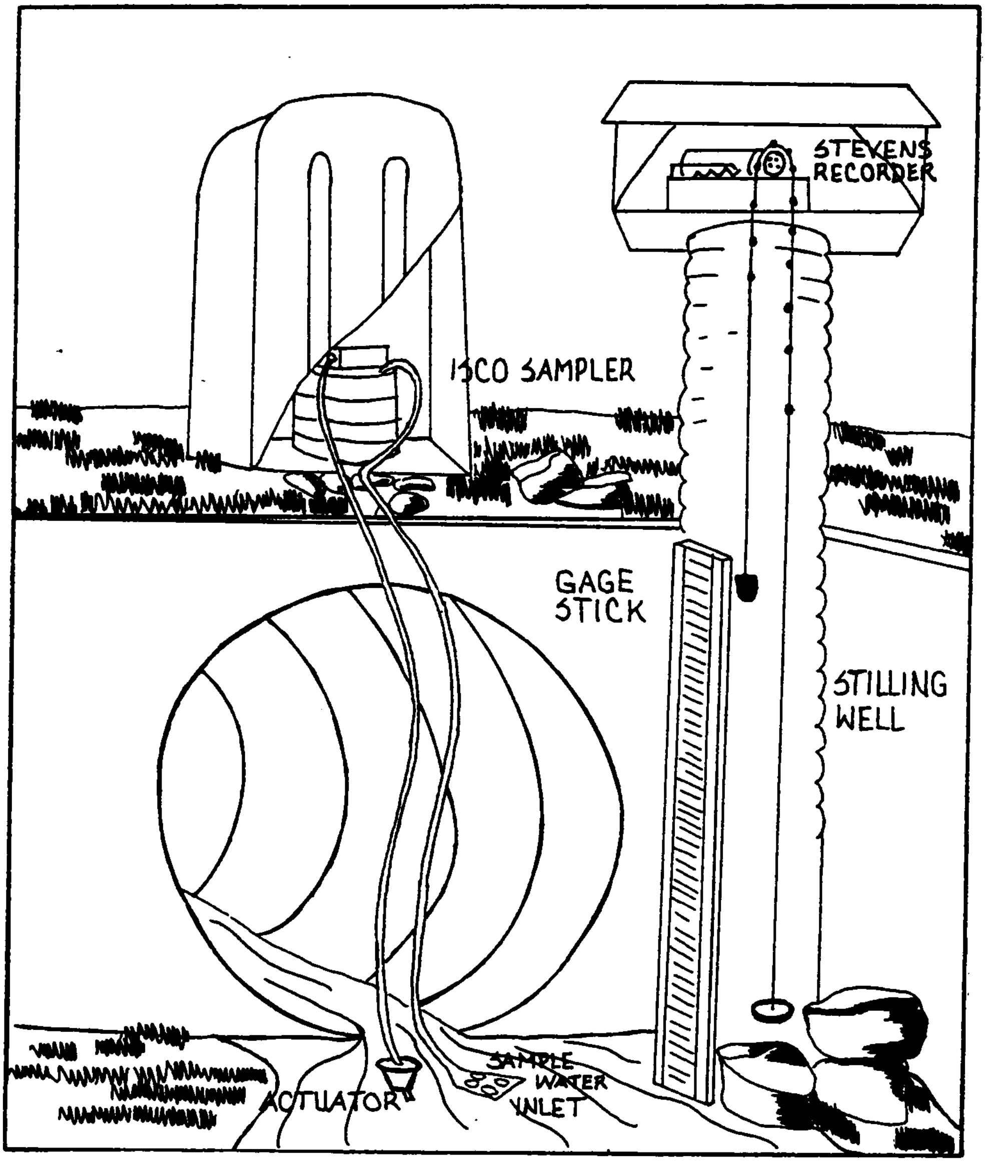

Figure 15. The Equipment at the State Road 1404 Sampling Site.

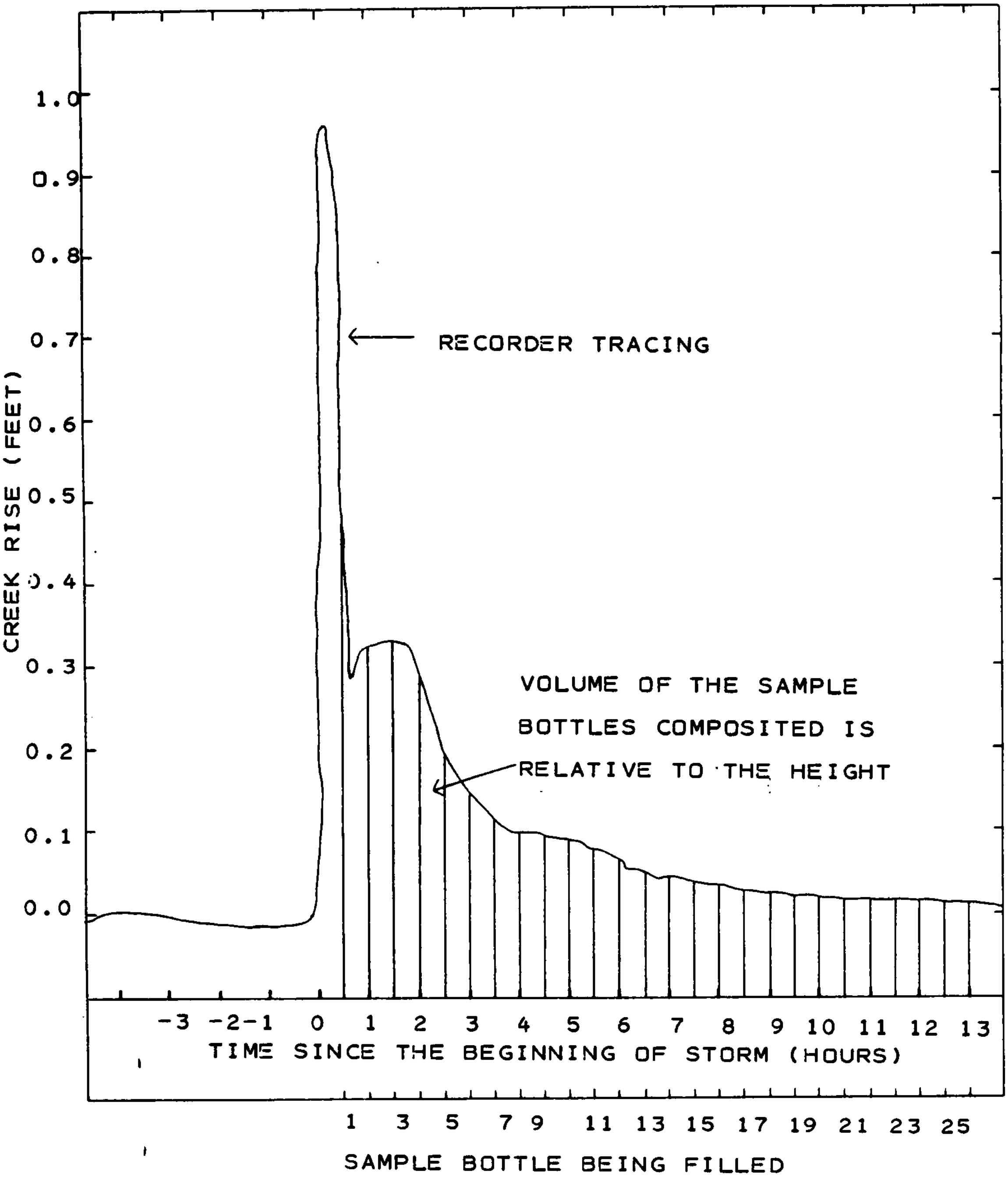

FIGURE 16. EXAMPLE OF STEVENS RECORDER TRACING OF THE CREEK RISE DUE TO A SHORT STORM

paper. The cylinder rotated freely and could make several complete rotations during a heavy storm.

The State Road 1404 and Miller Street sites were equipped with a plastic cylindrical gage which measured total rainfall. Detailed information on the equipment and its installation can be obtained from the State Water Control Board.

SAMPLING PROCEDURE

Ideally, when rain was forecast the machines at each site could be prepared, fresh batteries were installed and the machines would activate themselves when the storm raised the creek bed to complete the circuit in the actuator. Reality never proved to be the ideal. Weather forecasting was unreliable, especially in the summer months when thunder storms are localized and sudden. Machines left unattended for days could be vandalized. The actuators worked successfully throughout the study but the switches in the clock mechanism were very unreliable, and seemed sensitive to changes in humidity.

The best procedure that assured the best chance of sampling a storm was to keep the machines continually prepared. This ensured that sudden storms were sampled and that trouble-shooting the equipment was done on a continuous basis. For example, during a two week period two Isco machines would sample even when the actuator was out of water and set to "automatic" and had to be turned to "manual" in order to cycle automatically when it rained. One Isco would sample by itself under any conditions and had to be set to "off" and turned on by hand at the beginning of a storm. Only constant surveillance of machinery and frequent visits during a storm ensured proper sampling.

The pumps had difficulty lifting samples to the bottles in light storms that did not raise the creek level significantly. Often the pumps had to be turned on manually during the storm or a bottle would be incompletely filled. This occurred repeatedly at the Peachtree Road site.

Keeping the machines continually ready meant that they needed to be visited daily to check equipment and to set the pens on the recorders back to the edge of the graph paper.

<u>Daily Routine</u> (no rain for the previous 24 hours) at each site:

1. The Stevens Recorder was rewound and the pen set back to the start of the graph paper.
2. If the creek had not risen or lowered in the previous day, the pen should have made a straight line across the paper and the paper would not need changing.
3. The float cable position was checked.
4. The height of the creek on the gage stick was noted.
5. If a rain gage was present on the site, it was checked.
6. The Isco Sampler was checked to make sure that it had not begun to sample spontaneously.
7. All settings on the Isco were checked.

8. The creek and bank were observed to note anything unusual.

Storm Routine

1. As soon as the rain began, the first site to develop runoff, or which had the most temperamental equipment was visited.

2. If the Isco had not started sampling, the switch was set to the manual cycle and the clock was set ahead to the half-hour position to be sure the pump would start properly.

3. If the pen on the Stevens Recorder was nearing the end of its 24 hour journey, it was set back to the edge of the paper. Since the clock could run for about three days without rewinding, it generally did not need attention during a storm.

4. The equipment was rechecked at each site during each storm at least once more during the fourteen hour sampling cycle to make sure that the pumps and switches were functioning.

Compositing the Samples After the Storm

1. Samples were taken and analyzed only for rains which fell at all three sites.

2. The samples were taken as soon as possible to ensure their freshness.

3. The volume of each bottle that was put into the composite was determined as follows (refer to Figure 16):
   Half-hour intervals were marked off on the horizontal axis of the recorder paper starting with the beginning of the storm. The number of squares beneath the curve for each half-hour interval were counted. The entire 400 ml. in the sample bottle was used for the interval with the greatest area. A proportionate volume of each of the other bottles was added to the composite by comparing the number of squares under each interval to that of the interval with the greatest number of squares. This method assumed that creek height is directly proportional to the flow. A more accurate method would have been compositing based upon the flow rates, which were determined from the measured heights using a rating curve. All bottles were

shaken before pouring the proportional volume into the composite jug, so that all sediments were suspended.

4. The jugs were labeled carefully and delivered to the laboratory immediately or else put on ice. The laboratory developed a preservation scheme for samples that could not be immediately analyzed.

5. The wet bottles from the Isco Samplers were washed with a non-phosphate detergent and the batteries were recharged.

Grab Sample Technique

1. The creek was entered with a bucket that had been washed with non-phosphate detergent.

2. Care was taken to not kick up sediments.

3. The jug was filled with water taken from a well-mixed portion of the stream.

4. If more sample was needed, the bucket was again filled from a position upstream to avoid excessive sediment collection.

5. Fish, animals and leaves were removed from the jug.

6. Each jug was labeled carefully.

Compromises Made in the Sampling Techniques

Since the equipment malfunctioned often and four liters of samples were needed for testing, compromises had to be made in some of the sampling technique in order to finish the study within a reasonable period of time. Even with these compromises, it took seven months of effort to sample six storms such that samples were obtained from each site for each storm.

1. The rural site contained little pervious area, therefore most rain soaked into the ground and did not become runoff. The creek did not rise appreciably to raise the float in the stilling

well, although it wet the actuator in most instances setting off the Isco Sampler. The Stevens Recorder would, therefore, just produce a straight line. Four liters of sample were required to complete all of the testing, so in these instances the composites were prepared using 4000 ml/ 28 bottles = 143 ml from each 400 ml sample bottle. A few storms were heavy enough to raise the creek level at the State Road 1404 site, but these storms also caused flooding at the Miller Street site and could not be sampled.

2. The switches in the clocks on the Isco Samplers often malfunctioned and the pumps would not automatically start at the half-hour intervals. When this was found to have happened, the pumps were turned on manually, even if the half-hour point was well past. Fortunately, this occurred during gently sustained rains when the irregularity of the sampling times added little inaccuracy to the composited sample.

3. As the creek fell after a rain the head required by the pumps increased just as the batteries were wearing down. On occasion, the sampler would not fill 28 bottles or would not fill the bottles with 400 ml of water. In order to obtain enough water for the testing, water was pumped from the creek directly to the jug if the creek was still swollen with runoff or if it was still raining.

4. The compositing procedure would often produce samples of much less than four liters. Theoretically, in the event of a sudden, intense, short storm, samples of only 400 to 600 ml could be composited. In order to provide more water for testing, a greater proportion of the water in each bottle was used, attempting to keep the amounts still proportional to each other but just adding more of each one.

Table V lists the samples taken by date. Any problems encountered and the measures taken to save the sample are also listed. The grab samples presented no problems except that too little sample was collected for the first sample and all the metal analyses could not be completed.

The first storm was heavy and intense and the equipment

Table V

Summary of the Problems Encountered When Taking The Samples That Were Sent To The Laboratory For Testing

Date	Sample Type	Problem	Compensation
6/19	Grab	Insufficient Sample Taken	None; Laboratory Could Not Complete All Tests.
6/30	Storm	Peachtree Road Site Sampler Stopped At Bottle 19. State Rt. 1404 Site Malfunctioned	None Necessary; Short Storm
7/11	Grab	None	None
8/1	Storm	Peachtree Road Site Sampler Did Not Switch On At Beginning Of The Storm	Sampled Peachtree Road Site After The other Other Sites Had Begun. We Had A Gentle, Sustained Rain, However, So The Inaccuracy Was Acceptable.
8/16	Grab	None	None
8/18	Storm	Peachtree Road Site Sampler Stopped At Bottle 8.	Used Entire Sample From All 8 Bottles and Added Creek Water From The Site When The Creek Was Still Swollen To Make A 4 Liter Sample.
8/23	Grab	None	None

Continuation of Table V

Date	Sample Type	Problem	Compensation
8/29	Storm	Peachtree Road Site Sampler Stopped At Bottle 7.	Used Entire Sample From All 7 Bottles And Added Creek Water From The Site When The The Creek Was Still Swollen To Make A 4 Liter Sample.
9/23	Grab	None	None
9/28	Storm	Miller Street Sampler Jammed And Stopped At Bottle 13. Peachtree Road Sampler Stopped At Bottle 1, 5, And Finally at Bottle 8.	Composited with 13 Bottles For Miller Street Sample. Used All Water Sampled From Peachtree Road and Topped The Sample With Water From The Creek.
10/5	Grab	None	None
10/9	Storm	Sampler At State Road 1404 Was Turned On Manually. Peachtree Road Site Sampler Stopped At Bottle 8.	Sample From State Road 1404 Site Obtained After The Other Sites Had Begun Sampling. Used The Entire Sample From The PeachTree Road Site Sample and Topped the Sample With Water From The Creek.

worked well enough at all three sites to prepare very valid composites. The other storms were lighter and the equipment malfunctioned at least at one site each time. If the compromises necessary did not seem to add an unacceptable amount of composite error, the samples were saved. The most trouble-prone site was at Peachtree Road. Changing Isco's, batteries and even moving the equipment to a lower point on the bank did not improve performance. This was also the only site that was vandalized. Most storms that occurred from May to October were not sampled. Most were missed because of unacceptable equipment malfunction. In some cases rain did not fall at all sites. The equipment at the Miller Street site was submerged twice by flooding and had to be returned to the manufacturer for repair. Appendix C lists suggested changes in procedures that will minimize the troubles and compromises that had to be made in this study for those who may do similar studies in the future.

LABORATORY ANALYSIS

Table VI lists the tests performed to analyze the water samples. All testing was done by the laboratory at the Roanoke Sewage Treatment Plant under the supervision of Mr. John Wygal.

After delivery to the laboratory, the samples were shaken to re-suspend sediments and divided into the portions necessary for each test. Each portion was appropriately

Table VI

Methods Used In The Analysis Of Peters Creek Stormwater Runoff Samples

Pollutant	Method
Total Solids	Total Residue Dried At 103-105°C
Suspended Solids	Total Nonfiltrable Residue Dried At 103-105°C
Volatile And Fixed Solids	Total Volatile And Fixed Residue At 550°C
Chlorides	Argentometric Method
Total Kjeldahl Nitrogen	Nesslerization Direct Method
Ammonia	Nesslerization Direct Method
Phosphorus	Ascorbic Acid Method
Nitrite	Cadmium Reduction Method
Nitrate	Cadmium Reduction Method
Chemical Oxygen Demand	Dichromate Reflux Method
Cadmium Copper Lead Nickel Zinc	Chelation With Ammonium Pyrrolidine Lead Dithiocarbonate And Extraction Into Methyl Isobutylketone.
Mercury	Cold Vapor Technique
Metal Sample Preparation	Nitric Acid Digestion
Chromium	Atomic Absorption Chelation Extraction

preserved and stored until time could be found to complete the analysis.

All procedures used are EPA approved. A Perkin Elmer 306 Atomic Adsorption Spectrophotometer (Gaithersburg, Maryland) was used for heavy metals analysis. Samples were not filtered before analysis.

IV. RESULTS AND DISCUSSION

The results of the study of the stormwater runoff of Peters Creek will be presented and discussed in this chapter. All the data gathered are listed in Appendix D. Information was obtained on the desired beneficial uses of the creek, the land uses of the watershed, the pollutant concentrations carried by the creek during dry and rainy periods and the loadings (weight) of these pollutants that the creek carries passed each sampling site in dry weather and as a result of storms.

DETERMINING THE DESIRED BENEFICIAL USES OF THE CREEK

The public meeting was held November 27, 1984. Local citizens attended along with representatives of the State Water Control Board, and Roanoke City Office of Community Planing and Roanoke County Department of Development. The citizens were not concerned with runoff quality from Peters Creek, but were very concerned with flooding. They had seen an increase in flooding as the watershed developed upstream, until, now, some report flooding during every heavy summer shower. Creek water has caused sewer overflow into basements and yards causing destruction of property. Trees and trash were reported to be blocking culverts and bridges. Citizens were concerned for their health. Those attending approved of the study and the approach to finding a solution for their problems. They understood that very occasional flooding would be practically expected after any reasonable improvement, but felt that the present levels and frequency of flooding were definitely unacceptable. A follow-up meeting is planned after the publication of the report.

21 questionnaires were returned out of 114 mailed. Those responding agreed with those attending the meeting that the aesthetic and storm drainage uses of the creek are most important. Problems with tree debris and trash in the creek were reported. Some citizens reported property damage they could not afford to rectify. The creek bed is eroding along Meadowbrook Road and Rolling Hills Lane, which is a symptom of an unbalanced runoff system. Other problems listed were odors, oil slicks on the creek and mosquitos. Stream wildlife observed were fish, snakes, crayfish, turtles and frogs. The suggested solutions to solve the creek's problems were widening of the stream bed and a general plea to improve storm drainage.

DETERMINING THE LAND USES OF THE WATERSHED

Watershed sampling sections were those areas of land in which runoff would roll into the creek and pass the sampling site (see Figure 10). All runoff north of State Road 1404 passed the sampling site there. All of this runoff plus rain falling between State Road 1404 and Peachtree Road would pass the middle sampling site. All of the runoff in the watershed passed the Miller Street site before joining the Roanoke River.

Table VII lists the acres and land use percentages for each of the sampling sections of the watershed. The drainage area above the State Road 1404 site was 95 percent undeveloped with only three percent of the area in fields and gardens, less than one percent was homes or commercial area and no multi-family dwellings. The land can be assumed to be fertilized over five percent of the area.

The drainage area for the Peachtree site, excluding that area above the State Road 1404, was 66 percent undeveloped. The area was 34 percent fertilized with 19 percent in single-family homes, eight percent commercial and public and seven percent in fields. Less than one percent was in multi-family dwellings.

The Miller Street sampling site drainage area, excluding the Peachtree Road drainage area, was entirely within the limits of the City of Roanoke. It was considered to be the area south of Peachtree and Hershberger Roads. Its land uses were 40 percent single family dwellings, 25 percent undeveloped land, 13 percent public and commercial property and three percent multi-family dwellings. Although in a valley, Roanoke is hilly and often rocky, with limited useful land for agriculture. Therefore, the most level area south of Peachtree Road was only 19 percent fields and gardens. The amount of the area that was considered to be

Table VII

Peters Creek Land Uses Upstream Of Each Sampling Site

	Miller Street to Peachtree Road		Peachtree Road to Road 1404		Road 1404 to Origin of Watershed	
	(Acres)	(%)	(Acres)	(%)	(Acres)	(%)
Single Family Dwellings	720	40	700	19	7	<1
Multi-Family Dwellings	60	3	1	<1	0	0
Commercial, Governmental And Public	240	13	300	8	10	<1
Agricultural	350	19	270	7	40	3
Fertilized*	1350	75	1270	34	60	5
Undeveloped	460	25	2500	66	1280	95
Total	1830	100	3770	100	1340	100

*Fertilized = Single And Multi-Family Dwellings, Commercial And Agricultural.

fertilized was 75 percent.

As expected, the land gradually became more developed and less rural as it neared the center of Roanoke. The predominance of forests and mountains became a preponderance of single family homes with the number of service areas, such as public, commercial buildings and apartment buildings also increasing. The watershed is about 5 miles west of the downtown section of Roanoke, and the amount of undeveloped land throughout the studied area was appreciable. From the aerial maps, most of the unused land followed the creek bank closely, and the frequent flooding of Peters Creek may discourage full development of the watershed at this time.

RAINFALL DURING THE STUDY PERIOD

The amount of rain that fell during the period at each site is listed in Table VIII. Six storms were sampled out of 26. Six storms were missed because the equipment malfunctioned in such a way that the error in the composited sample would have been unacceptably high. Three were missed because they were soon after the preceeding sampled storm and the grab sample between storms had not been yet taken. Three rains were not sampled because the Miller Street equipment flooded. Seven storms were not sampled because the equipment was not ready due to being out for repairs, batteries needed recharging or the researcher was not

Table VIII

Rain Falling On The Peters Creek Watershed During The Sampling Period

Date (1984)	Miller Street Site (inches)	State Road 1404 Site (inches)	Reasons Not Sampled
6/25	0.65	0.39	Miller Street and State Road 1404 Equipment Malfunctioned
6/30	1.10	0.86	Sampled
7/5	0.56	0.09	Waiting To Do Grab Sample
7/6	0.16	0.60	Waiting To Do Grab Sample
7/9	0.31	0.02	Waiting To Do Grab Sample
7/12	0.43	0.03	Peachtree Road Isco Sampler Malfunctioned
7/15	0.15	0.20	Peachtree Road Isco Sampler Malfunctioned
7/17	0.13	0.20	Peachtree Road Isco Sampler Malfunctioned
7/18	0.73	0.45	Peachtree Road Isco Sampler Malfunctioned
7/22	0.26	0.69	Peachtree Road Isco Sampler Not Set Up

Table VIII (Continued)

Date	Miller Street Site (inches)	State Road 1404 Site (inches)	Reasons Not Sampled
7/23	0.17	0.28	Peachtree Road Isco Sampler Not Set Up
7/28	0.93	0.72	Equipment Flooded
8/1	0.04	0.03	Sampled
8/6	0.01	0.33	Out of Town
8/10	0.29	0.86	Out of Town
8/13	0.99	1.03	Equipment Flooded
8/15	0.05	0.08	Machine Not Set Up
8/19	0.06	0.10	Sampled
8/24	0.09	0.10	Machines Not Set Up
8/29	1.02	0.46	Sampled
8/31	1.01	1.02	Miller Street Site Equipment Flooded
9/3	0.86	0.56	Equipment Vandalized
9/15	0.15	0.14	Equipment At All Sites Malfunctioned

Table VIII (Continued)

Date	Miller Street Site (inches)	State Road 1404 Site (inches)	Reasons Not Sampled
9/28	0.18	0.16	Sampled
9/30	0.14	0.11	Equipment Not Set Up
10/9	0.14	0.21	Sampled

available at the beginning of the storm. The Peachtree Road equipment was vandalized and a storm was missed before the site could be repaired. Because storms were missed, the sampled storms were not necessarily those that immediately followed the background sampling. The number of antecedent dry days before the sampled storms varied from 4 to 13.

LABORATORY ANALYSIS OF THE SAMPLES

A total of six background samples and six storm samples were collected at each site. Background grab samples were taken on the same day at each of the three sites and storms sampled were only those that occurred at all of the sites. If rain at one or two sites set off the Isco samplers, the sample was discarded and the bottles rewashed.

In Terms of Concentration of Pollution

The analysis of the grab and flow-weighted composite samples were done to find the concentrations of different pollutants in the creek water. The water was tested for total solids, both volatile and fixed, suspended solids, both volatile and fixed, chlorides, Total Kjeldahl Nitrogen, ammonia, total and ortho-phosphates, nitrates, nitrites, and chemical oxygen demand. The concentrations of cadmium, chromium, copper, lead, mercury and zinc in the water and its sediments, were also determined. All of the data from the laboratory testing are listed in Appendix D.

Table IX lists the mean of the values of the concentra-

TABLE IX

STORM AND BACKGROUND SAMPLES AVERAGE POLLUTION CONCENTRATIONS FOR PETERS CREEK SAMPLING SITES

	STATE ROUTE 1404		PEACHTREE ROAD		MILLER STREET	
TEST	STORM MEAN	BACKGROUND MEAN	STORM MEAN	BACKGROUND MEAN	STORM MEAN	BACKGROUND MEAN
TOTAL SOLIDS (gm/L)	276	262	636	299	532	326
VOLATILE SOLIDS (mg/L)	163	207	343	165	291	207
FIXED SOLIDS (mg/L)	113	57	293	134	240	119
SUSPENDED SOLIDS (mg/L)	117	30	246	16	163	20
SUSPENDED VOLATILE SOLIDS (mg/L)	19	12	23	7	20	9
SUSPENDED FIXED SOLIDS (mg/L)	97	19	223	11	144	11
CHLORIDES (mg/L)	4.41	3.01	7.71	8.07	6.09	5.33
TOTAL KJELDAHL NITROGEN (mg/L as nitrogen)	0.6	0.5	0.05	0.4	0.8	0.4
AMMONIA (mg/L as nitrogen)	0.4	0.4	0.4	0.4	0.4	0.4
TOTAL PHOSPHORUS (mg/L as phosphorus)	0.18	0.05	0.42	0.05	0.29	0.05
ORTHO-PHOSPHATES (mg/L as phosphorus)	0.01	0.02	0.03	0.03	0.07	0.02
NITRATE (mg/L as nitrogen)	0.38	0.20	1.82	2.01	1.10	1.14
NITRITE (mg/L as nitrogen)	0.01	0.01	0.01	0.02	0.02	0.01

TABLE IX (CONTINUED)

STORM AND BACKGROUND SAMPLES AVERAGE POLLUTION
CONCENTRATIONS FOR PETERS CREEK SAMPLING SIT

	STATE ROAD 1404		PEACHTREE ROAD		MILLER STREET			
TEST	STORM MEAN	BACKGROUND MEAN	STORM MEAN	BACKGROUND MEAN	STORM MEAN	BACKGROUND MEAN	CHRONIC CRITERIA	ACUTE CRITERIA
CHEMICAL OXYGEN DEMAND (mg/L)	13	10	20	9	15	10	NA	NA
CADMIUM (ug/L)	5	5	5	5	5	5	10	10
CHROMIUM (ug/L)	8	9	8	5	6	4	7.2	11
COPPER (ug/L)	73	36	56	33	58	44	20	29
LEAD (ug/L)	104	102	119	113	120	107	6.4	160
MERCURY (ug/L)	2.5	0.9	1.8	0.6	1.9	0.5	0.2	1.1
ZINC (ug/L)	8	9	8	9	8	9	47	570
NICKEL (ug/L)	40	43	41	41	42	42	160	3100

tions of the pollutants tested for each site. The values for all six storms were averaged and the values for all six background samples were averaged. Graphs of the mean concentrations of the water quality parameters for each site are listed in Appendix E.

The total solids concentration for the storms was greatest at 636 mg/L at the Peachtree Road site with a background solids concentration of 299 mg/L. The Miller Road site had a total solids storm concentration of 532 mg/L with a background of 326 mg/L. The State Road 1404 site had little difference in total solids in the storm or background samples at 276 and 262 mg/L, respectively. Therefore, as the creek became more urban, the background total solids concentration increased, but during storms more solids were generated by the Peachtree Road area.

The analysis for the total volatile solids showed the same trend with the Peachtree Road and Miller Streets sites having storm concentrations of 343 and 291 mg/L and background concentrations of 165 and 207 mg/L, respectively. The background volatile solids at the State Road 1404 site were higher than those observed during storms. Volatile solids are organic in nature and the higher background value of 207 mg/L at the State Road 1404 site was probably due to algae growth in the stream during dry periods. Stormwater runoff would have diluted the algae causing the lower volatile solids concentration of 163 mg/L for that site.

The total solids water measured in this study showed the same trends as that of total solids. The storm value for the Peachtree Road site was the highest at 293 mg/L compared to 240 mg/L for the Miller Street site and 113 mg/L for the State Road 1404 site. Background concentrations also showed the same trend with 134 mg/L for the Peachtree Road site, 119 mg/L for the Miller Street site and only 57 mg/L for the State Road site. For all sites, for both storm and background samples, organic material comprized over 50 percent of the total solids.

The Miller Street area had a greater amount of agriculture which would encourage erosion and inorganic sediments. The Peachtree Road area, however, had more on-going construction since desirable land is still available. Probably more importantly, the Peachtree Road site is just downstream of Meadowbrook Road which exhibited the worst flooding and erosion of the creek bed in the watershed.

The suspended solids in all background samples were very low at less than 30 mg/L at each site. Again, the Peachtree Road site storm samples had the greatest concentration of sediments at 246 mg/L. Miller Street had lower storm solids concentration at 163 mg/L and the State Road 1404 site samples were even lower at 117 mg/L.

The volatile suspended solids were very low for the background samples at 9 mg/L for the Miller Street samples and 7 mg/L for the Peachtree Road samples. The State Road

1404 sample was higher at 12 mg/L, probably, again, due to algae. The storm samples had the same trends as before with the Peachtree Road site having the highest concentration at 23 mg/L compared with 20 mg/L for the Miller Street and 19 mg/L for the State Road 1404 site. These values are very small, however, and the difference between 19 and 20 mg/L may not be significant due to inaccuracies in weighing the filter and glassware during testing.

The fixed suspended solids were a much greater proportion of the total suspended solids indicating that most of the suspended solids were inorganic. Again, the Peachtree Road sample had the highest storm concentration of 223 mg/L compared with 144 mg/L for the Miller Street sample and 97 mg/L for the State Road 1404 sample. The background concentrations were low for all sites, with 19 mg/L for the State Road 1404 sample, and 11 mg/L for both of the other sites.

In summary, the total solids for all sites in both background and storm samples were more than fifty percent volatile or organic. The suspended solids, however, contained little volatile solids for the storm samples and were overwhelmingly fixed, or inorganic. Both fixed and volatile suspended solids were low for the background waters. This indicates that most organic material in the creek was in the form of very fine particles, or colloids that can pass through a fine filter. The coarse sediments were nearly all inorganic, such as sand and clay particles. The presence of algae at the State Road 1404 site probably was the cause of the high organic content of the background samples there, and was diluted by stormwater runoff. The Peachtree Road site consistently had the greatest difference in solids content between storm and background samples which was most likely due to stream bed disturbances.

There was not much difference between the storm and background sample chloride concentrations. The Miller Street site had a 6.1 mg/L average chloride concentration for the storm sample and 5.3 mg/L for the background samples. The background chloride concentration for the Peachtree Road site was higher at 8.1 mg/L than the average storm concentration of 7.7 mg/L. The State Road 1404 site samples had the lowest chloride concentration at 4.4 mg/L for storms and 3.0 mg/L for background samples. Since all sampling equipment was adjacent to bridges, the chlorides in the water were most likely from road salt deposited on the bridges through the winter. State Road 1404 is a smaller, less travelled road, and would, therefore, have less salt deposits.

The concentrations of the Total Kjeldahl Nitrogen (TKN) for all sites and samples were above the 0.1 mg/L criterion to avoid eutrophication downstream. However, the analytical precision of the laboratory was 0.4 mg/L for this analysis which is too high to adequately judge the eutrophipotential of the water. Water tested as having 0.4 mg/L TKN may actually have had anywhere from none to 0.4 mg/L TKN. Average values of 0.4 mg/L were found for the background water sample from the Peachtree Road and Miller Street sites. The State Road 1404 site had a more meaningful TKN level of 0.5 mg/L. Stormwater runoff contributed more nitrogen to the creek water at all sites with average values of 0.6 mg/L for the State Road 1404 site, 0.5 mg/L for the Peachtree Road site and 0.8 mg/L for the Miller Street site. These storm sample concentrations were high enough to conclude that Peters Creek stormwater runoff is potentially detrimental to the long-term water quality of Smith Mountain Lake. Refined testing methods must be used to justify more detailed conclusions.

All ammonia concentrations measured for storm and background samples at all three sites were below the 0.4 mg/L test detection limit. Therefore, no conclusion about the eutrophication implications of this nutrient into Smith Mountain Lake can be made. Neither can conclusions be made comparing the sites or background creek water to stormwater runoff. The results indicate that the TKN measured in the water was in the form of organic nitrogen rather than the degraded ammmonia form.

The values obtained by testing the samples for total phosphorus were all well above the 0.01 mg/L detection limit of the test method. All three sites had average background concentrations of 0.05 mg/L, which is well above the accepted criterion of 0.01 mg/L to avoid eutrophication downstream. The stormwater samples showed the same trend as the solids analysis in that the State Road 1404 site had the lowest total phosphorus concentration at 0.18 mg/L and the Peachtree Road site had the highest at 0.42 mg/L. The Miller Street site storm samples had 0.29 mg/L total phosphorus concentration. Since phosphorus adsorbs onto sediments in water, it is logical that the site with the most sediments would have the most phosphorus.

The background ortho-phosphate concentrations for the three sites were very similar at 0.02 mg/L for the State Road 1404 and Miller Street sites and 0.03 mg/L for the Peachtree Road site. The average storm runoff sample for the rural location was lower than the background at 0.01 mg/L, therefore the stormwater diluted the ortho-phosphates in the creek. The Peachtree Road site runoff averaged the same concentration as the background samples at 0.03 mg/L. The Miller Street site alone showed a definite deterioration of the creek water quality due to the runoff with the average storm sample having an ortho-phosphate concentration of 0.07 mg/L. Here, again, all the sites, with the posible exception of the site at State Road 1404, had concentrations that were above the 0.01 mg/L criterion and would contribute to eutrophication downstream.

Nitrates in water indicate converted organic pollution. The Miller Street site had no significant background and storm pollutant concentration difference with a nitrate background concentration of 1.14 mg/L as nitrogen and a storm concentration of 1.10 mg/L as nitrogen. The Peachtree Road Site had the highest pollutant concentration, again, with 2.01 mg/L as nitrogen in the background level and a lower storm concentration of 1.10 mg/L as nitrogen. Nitrate is soluble in water and is not a function of the sediment concentration. Only the State Road 1404 samples had higher storm than background nitrate concentrations at 0.38 mg/L as nitrogen and 0.20 mg/L as nitrogen, respectively. These results indicate that during both dry and rainy periods the watershed contained significant levels of nitrogen pollution that was discharged into the stream as it traveled downstream. The greatest pollution addition was between the rural and suburban sites with less nitrogen addition downstream.

Nitrosomonas bacteria slowly convert ammonia to nitrite and Nitrobacters quickly oxidize it to nitrate under most conditions. Waters, therefore, do not normally contain much nitrite. At all sites, the samples of Peters Creek contained very small nitrite levels of 0.02 mg/L as nitrogen or less.

The organic material in the creek, measured by the COD test, had levels of 20 mg/L or less, indicating an acceptable creek water quality for most beneficial uses. The stormwater samples averaged a higher COD level at all sites than the background levels, but the differences for the State Road 1404 and Miller Street sites at 3 and 5 mg/L, respectively, were so slight as to be of questionable value and could be due to analytical inaccuracies. The Peachtree Road site samples had greater differences with average storm level of 20 mg/L (also the highest COD value of any site) and a background average level of 9 mg/L (the lowest COD value). This indicates, again, that the watershed upstream of the Peachtree Road site contributed the greatest pollution load to the creek during storms. The additional volume of less contaminated water downstream of Peachtree Road diluted this organic matter.

In Table IX the concentrations of the heavy metals in the creek water for both background and stormwater samples were compared with the criteria set by the Virginia State Water Control Board. Background sample levels are expected to be of long duration and were therefore, compared with the 24-hour chronic criteria. Runoff is of an intermittent nature, and was compared with the instantaneous acute criteria for the safety of aquatic life.

The cadmium concentrations in all samples and from all sites were below the detection limit of the test method of 5 micrograms per liter (ug/L). Comparisons between the water quality of samples could not be made with respect to cadmium. Neither the acute nor chronic criteria of 10 ug/L were violated by the samples.

The average background chromium level at the State Road 1404 site at 9 ug/L was above the chronic criterion of 7.2 ug/L. The concentrations at other sites met the chronic criterion at 5 and 4 ug/L and at all sites met the acoute criterion of 11 mg/L. The individual background samples at the Miller Street site were often below the 1 ug/L test detection limit. The runoff slightly diluted the background water at the State Road 1404 site bringing the average storm water chromium concentration to 8 ug/L. The Peachtree Road site again showed the greatest increase in pollution levels between background and stormwater samples at 5 and 8 ug/L, respectively. The Miller Street site concentrations indicate that the chromium load was diluted downstream to 6 ug/L. Also, some of the chromium carried into Peters Creek by runoff lies on the creek bottom with the deposited sediments. Chromium in flowing water is associated with the use of automobiles in areas where industrial discharges cannot be suspected as contributing the pollution. A creek in the City of Salem, also in the Roanoke Valley, was recently found to have unusually high chromium concentrations. Investigations have not yet found the cause for these levels.

The criteria for copper concentrations in water are 20 ug/L for chronic and 29 ug/L for acute exposure of aquatic life. The average background levels varied as the creek flowed south with 36 ug/L at the State Road site, and 33 ug/L at the Peachtree Road site and 44 ug/L at the Miller Street site. Several individual samples were below the test detection limit of 20 ug/L, so these averages may have been calculated with numbers that are higher than the actual values.

The stormwater samples reversed this trend, with the average sample from the State Road 1404 site having a copper concentration of 73 ug/L, compared with the acute exposure criterion of 29 ug/L. The Peachtree Road and Miller Street sites had levels of 56 and 58 ug/L, respectively. The reason for these high levels is not known. Copper is usually associated with automobiles and copper pipes in homes. The copper concentrations of the creek water at all sites was at a level considered dangerous to aquatic life.

The detection limit of the test to determine the lead concentrations was not low enough to really be of use in studying Peters Creek water. Eleven out of seventeen individual background samples and 10 out of 18 runoff samples were below the detection limit of 100 ug/L. There was much variation in the other individual values, reaching as high as 182 mg/L, however, which brought the average background and runoff values for the sites above the detection limits. The lack of significant accurate data makes these average values meaningless in making comparisons between sites. Most likely, the chronic exposure level of 6.4 ug/L is exceeded at all sites by the creek water and all sites do meet the acute criterion of 160 ug/L.

Both the acute and chronic criteria for mercury levels (1.1 ug/L and 0.2 ug/L respectively) were exceeded for all sites. Again the State Road 1404 samples had the highest levels with 0.9 ug/L for the average background sample and 2.5 ug/L for the average storm sample. The level seemed to drop as the creek flowed south with background levels of 0.6 and 0.5 ug/L and stormwater levels of 1.8 and 1.9 ug/L for the Peachtree Road and Miller Street sites, respectively. Background samples were often below the test detection limit of 0.2 ug/L, but even if the water had no mercury in these samples, the average background levels would still violate the criterion. Mercury often originates with leaks from batteries and is therefore associated with automobiles. All levels of mercury found in the creek could be dangerous to aquatic life.

All average background samples for all sites contained 9 ug/L of zinc which is far below the chronic criterion of 47 ug/L. The average stormwater samples were even lower at 8 ug/L for all sites, far below the acute criterion of 570 ug/L. Zinc concentrations increased sharply in October for all sites for background and storm samples. Zinc is often associated with the wearing down of automobile tires.

Nickel is often associated with the use of automobiles.

Again the individual sample concentrations were below the test detection limit of 40 ug/L in 23 out of 35 samples and meaningful comparisons between the sites cannot be made. The concentrations, however, were well below the criteria of both chronic (160 ug/L) and acute (3100 ug/L) exposure levels for the safety of aquatic life.

In summary,

1. The area of the watershed between State Road 1404 and Peachtree Road contributed the greatest amount of pollutants both in sediment (organic and inorganic) and in chemical pollutants such as phosphorus, that bind to sediments.
2. The levels of phosphorus and nitrogen in the creek were sufficiently high to contribute to eutrophication problems in Smith Mountain Lake.
3. Since many heavy metals in water have their origins in the use of automobiles, the high metal concentrations found at State Road 1404 site, which has much less traffic than the other sites, were surprising. In general, the levels of cadmium, chromium (with the exception of the State Road 1404 site), nickel and zinc in the creek are safe for aquatic life. The background levels of lead, copper and mercury were above the chronic exposure levels and mercury and copper concentrations were above the acute exposure criteria.
4. The Roanoke Sewage Treatment Plant laboratory was

designed to detect relatively high levels of pollutants found in domestic and industrial treated and untreated wastewaters. The equipment and procedures of the laboratory are not sensitive enough to provide results that allow for the meaningful comparison of contamination levels in creek water. This was especially true for the metals analyses which were, by far, the most expensive and time-consuming to perform.

Pollution Loading

The quality of the creek can also be analyzed with respect to the mass of pollutants that it discharges downstream in a regular period of time. These pollutant loads will reflect the concentrations of the contaminants (mass per volume) and the increasing volume of water carried per minute as the creek flows south towards the Roanoke River. To determine these loads the pollutant concentrations have been multiplied by the creek flow rates at the time that the grab samples were taken. For the runoff samples, the plot from the Steven's recorder was analyzed to determine the average height of the creek during the storm. Rating charts are plots of creek height versus the discharge rate in cubic feet per second made at a particular point on the bank of the creek. The State Water Control Board personnel developed charts for Peters Creek at each of the sampling sites (Appendix C). The average creek height of each storm was found on the chart and the corresponding discharge rate was read. As in compositing the storm samples, the assumption was made that the flow rate was directly proportional to the creek height. Since the rating chart is a curve, rather than a line, this assumption is not correct, but will serve as an approximation. Tables X and XI list the average flow rates for each sample. A few of the average storm heights were off the top of the rating charts, and in these instances, the straight part of the curve was extended using the best fitting line and the corresponding discharges read. This too was adequate as a first approximation as the heights of the creek were well within the bed where the bank slopes are regular. The pollutant concentrations from the composited samples were multiplied by the corresponding discharge rate to give a measure of the loading rate in mass per unit time.

Table XII shows the average loading rate of each pollutant comparing background to storm samples and site to site. Notice that the loading rate units are in gram per minute (gm/min) and in milligrams per minute (mg/min). The tables from which these averages were calculated are listed in Appendix D. Care must be taken to not place more importance than is appropriate in these rates. The flows measured for the creek may or may not be representative of a future time or point along the creek. This is especially true of the average storm flows since no two storms will be

Table X

Stream Flowrates Of Peters Creek While Taking Grab Samples (CFS)

Date (1984)	State Road 1404	Peachtree Road	Miller Street
6/19	0.1	2.0	2.4
7/11	0.1	2.4	2.4
8/16	0.2	2.4	3.2
8/22	0.1	1.8	3.2
9/3	0.1	1.7	3.6
10/5	0.1	2.4	3.6

Table XI

Average Stream Flowrates Of Peters Creek During Each Storm Sampled (CFS)

Date (1984)	State Road 1404	Peachtree Road	Miller Street
6/30	Unknown	42	61
8/1	0.1	2.6	3.4
8/19	0.2	2.4	3.6
8/29	0.1	11.3	30
9/28	0.1	2.6	4.4
10/9	0.1	3.0	5.0

Table XII

Peter Creek Pollutant Loads For Average Background And Storm Flows

	State Road 1404 Site		Peachtree Road Site		Miller Street Site	
	Background Loads	Storm Loads	Background Loads	Storm Loads	Background Loads	Storm Loads
Total Solids (gm/min)	47	51	1,100	22,000	1,700	21,000
Volatile Solids (gm/min)	37	31	600	9,200	1,100	7,600
Fixed Solids (gm/min)	10	20	500	13,000	600	14,000
Suspended Solids (gm/Min)	5.5	18	60	16,000	97	13,000
Volatile Suspended Solids (gm/min)	2.1	3	30	870	43	1,200
Fixed Suspended Solids (gm/min)	3.4	17	40	15,000	55	11,000
Chlorides (gm/min)	0.51	0.8	29	120	28	180
Total Kjeldahl Nitrogen(gm/min)	0.11	0.09	1.5	37	2.1	42

Table XII (Continued)

	State Road 1404 Site		Peachtree Road Site		Miller Street Site	
	Background Loads	Storm Loads	Background Loads	Storm Loads	Background Loads	Storm Loads
Ammonia(gm/min)	0.08	0.08	1.5	7.3	2.1	12
Total Phosphorus (gm/min)	0.01	0.03	0.18	26	0.24	23
Ortho-Phosphates (gm as p/min)	0.005	0.002	0.10	0.19	0.11	3
Nitrates (gm as n/min)	0.035	0.02	7.3	18	6.3	25
Nitrites (gm as n/min)	0.003	0.002	0.05	0.33	0.06	0.8
Chemical Oxygen Demand(gm/min)	2.0	2.2	33	980	50	970
Cadmium(mg/min)	0.9	1.1	19	91	26	150
Chromium(mg/min)	1.9	1.5	19	60	22	150
Copper(mg/min)	8.4	13.2	140	1,200	220	2,200

Table XII (Continued)

	State Road 1404 Site		Peachtree Road Site		Miller Street Site	
	Background Loads	Storm Loads	Background Loads	Storm Loads	Background Loads	Storm Loads
Lead(mg/min)	21	21	400	2,800	550	4,300
Mercury(mg/min)	0.17	0.44	2.1	46	2.5	85
Zinc(gm/min)	1.7	1.5	27	210	50	270
Nickel(mg/min)	8.7	8.0	150	830	220	1,500

exactly alike. The loads do not represent the total mass of pollutants that the creek carried during the period of the study, either, since not every storm was sampled. The three storms that were missed due to flooding most probably had greater pollutant loads than any storm sampled due to the volume and power of the water. Lastly, it must be remembered that many of the concentrations used in the calculations were below the detection sensitivity of the test, and the pollutant loads calculated for those water quality parameters may be higher than the actual loads.

The background and runoff loads for the State Road 1404 site were not very different for most of the pollutants tested. In some cases, storm loads were lower than ambient loads. Inorganic sediment loads increased since the greater flows were better able to carry the weight. This was especially true for the larger suspended, fixed solids, which increased by a factor of 3 in the runoff loads. The organic sediment loads did not vary much between types of sample, however, because of the algae in the background samples. The heavy metal forms were also similar for both types of samples. These results are as expected since the natural drainage system that exists at the site does not often produce significant runoff, (Tables X and XI) and the runoff was well filtered by vegetation before running into the creek.

The Peachtree Road samples had a tremendous increase in dry weather pollutant loads over the State Road 1404 site. The total solids were nearly 30 times higher, with the fixed solid component 50 times higher. Chloride loads increased over 50 times, and the phosphorus forms were about 20 times higher. The nitrogen forms increased 10-fold, and the nitrates concentration, which is an indications of old pollution, was 200 times higher at the Peachtree Road site than at the more rural site. All heavy metal background loads also increased as the creek traveled downstream from between 10-fold times for chromium to over 20-fold times for cadmium.

The average storm loads at the Peachtree Road site were much higher than the background loads. The increased urbanization of the area increased the amount of runoff tremendously, disturbed the stream bed, and added an increase in the pollution washed off from the land. The total solid load increased 20-fold with the fixed suspended solids increasing nearly 400 times. Chlorides increased 4 times. The nitrogen load was raised from 6 to over 20 times, depending on the form. The nitrate loads only increased 2-fold, however, probably since the rushing water allowed no time for the oxidation of ammonia to occur. Similarly, total phosphorus increased over 100-fold but the ortho-phosphates less than doubled. COD loads rose over 30 times.

The heavy metal loads were less influenced by runoff at the Peachtree Road site, going from a 4-fold increase for chromium to a 21-fold increase for mercury.

The watershed downstream from the Peachtree Road site was more stable, and while background and storm flow rates increased, pollutant loads remained similar to the Peachtree Road area loads. The background loads for the Miller Street site were lower for chlorides and nitrates than those of the Peachtree Road site. All other values were higher at the Miller Street site, but were not doubled.

The Miller Street storm samples showed the same trend when compared with the Peachtree Road storm loadings. Some of the sediment settled out before reaching the Roanoke River and the heavy inorganic sediment went from a storm loading rate of 15,000 gm/min at the Peachtree Road site, to 11,000 gm/min at the Miller Street site. The other water quality parameters increased for the city site with the ortho-phosphate loads increasing 15 times and the COD remaining the same.

The heavy metal loading rates roughly doubled from the Peachtree Road to Miller Street sites, indicating that additional heavy metals did enter the creek south of the Peachtree Road due to stormwater runoff.

In summary, storms had little effect on the small amount of pollution that was carried by Peters Creek passed the State Road 1404 site. While the creek travelled south, much pollution, especially sediment, was added before it reached the Peachtree Road site. This was caused by the urbanization of the watershed in this area. The bed restabilized as the creek flowed to the Roanoke River allowing the deposition of some of the heavy sediment. The load of heavy metals, however, continued to increase as the river flowed south passed heavily travelled roads. This data should be interpreted as showing broad trends only, as the accuracy and reproducibility of the values used in the calculations are suspect.

Appendix G lists the mass of the pollutants that passed each site for each storm during which sampling took place. This table was generated by multiplying the pollutant loading rate by the duration of the sampling period.

SAFETY FROM WATER-BORNE DISEASE

The sudden washing of roof tops and backyards by rain can bring animal and bird wastes into creek water. Real health dangers are present, however, when stormwater causes sewers to overflow and allows domestic sewage to be deposited in basements or backyards. Such storms can overwhelm sewage treatment plant capacity causing the short-circuiting of raw sewage into the receiving river. Tests to detect *E. coli* are very time consuming and many have to be done to give statistically meaningful results. The Virginia State Board of Health is not equipped to provide these tests for all creeks and flooded basements in the Roanoke area. The

Board will provide advice and information when requested, however, and helps in assuring a safe clean-up, when asked, after flooding occurs. Special problems and health concerns should be addressed to their office in Vinton.

BIOASSAY RESULTS

A bioassay has been done by personnel of the Virginia State Water Control Board where Peters Creek runs parallel to Greenridge Road (56). This assay was to determine the diversity and health of the benthic animals. The testing dates were in April and October, 1984, which coincided with this stormwater runoff study. The conclusions of the assay were that the water quality of the creek at that location was good. The dissolved oxygen concentrations found at the times of the samples were also high at 9 and 13 mg/L.

The Roanoke Electric Steel Corporation also prepares frequent bioassays upstream and below the plant on Peters Creek just downstream of the Miller Street site, to assure that industrial dischargers will not impair aquatic life. Results of the recent testing indicate that the discharges will not cause environmental injury. More information may be obtained from the State Water Control Board.

V. CONCLUSIONS

This chapter will briefly outline conclusions derived from the analysis of the Peters Creek watershed. The results of the studies of citizens' opinions, the analysis of the data gathered and general observations made from travelling throughout the drainage area were all considered in these conclusions.

BENEFICIAL USES

The citizens living in the Peters Creek watershed are very concerned with the present erosion of the bank and the increased frequency of flooding. The resulting property damage and the possibility of dangers to health are especially worrisome to those living along the creek. They did not seem to expect to use the creek for recreational purposes, but they want it to be aesthetically pleasing, safe and contained within its banks during most summer storms.

LAND USES

The watershed is heavily forested to the north, but becomes gradually developed as the creek approaches the Roanoke River. Single-family homes predominate in the southern portion of the watershed with apartment buildings and public and commercial areas increasing. Agriculture is of minor importance. The land along the banks of the creek is mostly undeveloped.

THE NEED FOR PLANNING

Stormwater management planning is more effective, and in the long run, less expensive, if done before an area is developed. The watershed is expected to be one of the fastest growing areas of the Roanoke Valley in the next twenty years, therefore, now is the time for planning.

FLOODING

Flooding occurs with increasing frequency in several areas of the watershed; on Meadowbrook Road, at the corner of Peters Creek Road and Melrose Avenue, behind the Roanoke Salem Plaza Shopping Center, on the Lynchburg Turnpike and Shenandoah Avenue, and across Miller Street at the entrance to Roanoke Electric Steel. If more of the watershed is developed without proper planning, the flooding will be more frequent and severe.

This flooding is worsened by disruption of the natural drainage basin system by:

1. Man-made trash obstructing the creek.
2. Tree and limb litter reducing the creek bed volume.
3. Bridges and roads obstructing the creek bed.
4. The hilly geography of the region.
5. Increased impervious area in the floodplain by buildings and roads.

WATER QUALITY

In terms of pollutant concentrations, the suburban, middle sample area contributed the greatest amount of pollution from runoff in the form of sediment. This is probably due to flooding and stream bed erosion in the Meadowbrook Road area. Nutrient concentrations are high enough compared to criteria from experts to contribute to water quality problems in the form of eutrophication at Smith Mountain Lake. The background and runoff concentrations of copper and mercury were above the criteria for the safety of aquatic life at all sites. The concentrations found at the State Road 1404 site were especially surprising since heavy metals are often associated with the use of automobiles, and the road is a lightly travelled country lane. The background concentration of cadmium at that site was also above the chronic exposure criterion set by the State Water Control Board. The Roanoke Sewage Treatment Plant did not have the equipment or established procedures to do an analysis of adequate sensitivity for creek water. Chemicals and much time were spent doing analyses that were not useful for the purposes of the study.

In terms of pollutant loading, the State Road 1404 site contributed little to the pollutants carried downstream by the creek, during both dry and rainy periods. The pollutant loads increased greatly in the area just upstream for the Peachtree Road site, especially for sediment-adsorbed pollutants. Some of these sediments settled to the creek bottom before reaching the Miller Street site. The load of heavy metals increased throughout the watershed as the creek travelled towards the Roanoke River.

Generally speaking, the quality of Peters Creek is good for most beneficial uses, and the problem of flooding is of more immediate importance than that of pollution.

VI. RECOMMENDATIONS

Problems with stormwater management, like other human problems, are more easily prevented than rectified. Flooding is already a problem to the neighborhoods lining Peters Creek and will become worse as that portion of the watershed just south of I-81 is developed. Measures must be taken to contain and slow the rushing of stormwater runoff in the drainage basin and further developments must include provisions for additional runoff from the increased impervious area. Slowing and containing stormwater will also reduce the contaminants that the creek carries with the stormwater. Pollutants, such as phosphorus and heavy metals, that adsorb onto sediments will have a chance to settle out if the runoff is slowed. Allowing time for infiltration of water into the soil can also be expected to reduce colloidal and dissolved nutrients, such as nitrate. Recommendations for the improvement of the quantity and quality problems poised by runoff in Peters Creek will have as their objective:

1. Stabilizing and maximizing the existing creek bed.
2. Providing additional storage volume, where necessary, for heavy summer storms.

It is not practical, nor should it be expected, that additional runoff storage volume should be provided that is sufficient to contain runoff from any future possible storm. An engineering judgment must be made to decide how often flooding would be acceptable, and the probable frequency, damage, and inconvenience of such flooding must be weighed against the cost of its prevention.

1. Clearing Trash

The creek must first be cleared of existing trash and tree debris. Currently neither local government has the authority nor the man-power to do the job. Citizen groups such as the Clean Valley Council or neighborhood groups might be interested in taking on the project if dump-trucks for the disposal of the trash can be provided.

2. Creek Bed Alterations

Ordinances against the dumping of trash or alterations in the creek bed must be publicized and enforced.

3. The Use of Basins

Detention and retention basins could be built along the creek in areas that are currently undeveloped due to periodic flooding. The exact location, sizing and design of these basins is beyond the scope of this study and needs to be done by professional engineers. These basins can be easily made by damming the creek at strategic points and limiting the outflow. During excessive storms these basins may overflow, but, hopefully not until after the peak of the storm has passed and the first flush of the pollutants has been captured. Table XIII lists suggested locations for

Table XIII

Suggested Placements For Detention Basins In Peters Creek Watershed

Flood-Prone Area	Proposed Basin Location	Comments
Shenandoah Avenue Just North of Miller Street	Strauss Park	Easy Maintenance Since Publicly Owned
Lynchburg Turnpike By Old Stevens Road	North of the Lynchburg Turnpike Along Westside Avenue	Very Low Land Below Several Apartment Buildings
	Just South of the Roanoke Salem Plaza Shopping Center at the Southwest Edge of the Parking Lot.	Capture Runoff and Pollutants from the Steep Parking Lot. South Edge of Lot Currently Seldom Used.
Melrose Avenue at Peters Creek Road	Parallel to Peters Creek Road Behind St. Paul‘s Evangelical Church and Parker's Seafood	Limited Area, Road and Bridges Obstruct Creek Flow
Meadowbrook Road	Cove Road at Greenridge Road	Severely Limit Storm Creek Flow Upstream from the Kings Arms Apartments
Greenridge Road Area	Parallel to Greenridge Road	Will Be Especially Important If the Watershed is Further Developed

such basins, just upstream of current flood-prone areas.

4. Kings Arms Apartments

The runoff from the Kings Arms Apartments must be contained to alleviate flooding on Meadowbrook Road. Dry wells could be built under the few grass border strips along the edge of the asphalt, or runoff can be stored in low areas of the parking lot by building short levees along the bank of the creek. The runoff could also be diverted from the parking lot and sent to a basin located on an undeveloped lot belonging to the complex, at the low edge of the property. Under no condition should the County or City permit further development at the intersection of Cove Road and Greenridge Road unless a very careful runoff containment design is presented for approval. A little more development in this area will add much misery to neighborhoods downstream.

5. Construction Practices

Several building projects are currently underway in the Peachtree area without sufficient attention to hay bale placement and runoff control. Sediment carried into the creek upstream from Peachtree Road can be minimized by enforcing erosion control on construction sites. Possibly better compliance can be obtained by presenting better sediment control as a public relations project to the local construction firms.

6. Heavy Metals

The high heavy metal concentration found in both the background and runoff samples from the State Road 1404 site should be investigated. The sediments at the creek bottom and the dust along the banks could be analyzed. Someone has possibly dumped metal waste into the creek at some point or some automobile parts are rusting away in the creek somewhere.

The implementation of these recommendations will require the cooperation of several branches of local and state governments along with business and citizens' groups in the Valley. Hopefully, this study can serve as a pilot project for other watersheds and further improvement of the Peters Creek drainage basin. By working together and considering each others' problems, we can improve our environment and quality of life in a coordinated, cost effective way.

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GLOSSARY

AEROBIC: containing oxygen that can be utilized for metabolism.

AGRONOMY: the study of the relationship of plants to soil.

ANAEROBIC: does not contain oxygen, therefore, microorganisms must utilize other electron donors during metabolism.

AS CALCIUM CARBONATE: a convention whereby the different forms of hardiness in a water can be quantitatively compared. The actual weight of the hardiness is expressed as a weight of calcium carbonate by using a ratio of their mole weights.

AS NITROGEN: a convention whereby the different forms of nitrogen in a water can be quantitatively compared. The actual weight of the nitrogen form is expressed as a weight of nitrogen by using a ratio of their mole weights.

AS PHOSPHORUS: a convention whereby the different forms of phosphorus in a water can be quantitatively compared. The actual weight of the phosphorus form is expressed as a weight of phosphorus by using a ratio of their mole weights.

BENEFICIAL USES: the uses that can be expected to apply to a particular body of water, such as recreational, or wildlife drinking supply. Lakes and rivers can be classified by these uses.

BENTHOS: forms of aquatic life that stay primarily on the creek bottom.

BEST MANAGEMENT PRACTICES: techniques in planning design and construction that are accepted by the pollution control industry as practical and beneficial in reducing pollution discharges.

BIOTA: the fish, animals, plants and insects living within an environment.

CRITERIA: are recommended maximum stream contamination limits derived from the best available technical information that should protect the environment for aquatic life and the beneficial uses of the stream.

DEMOGRAPHY: the study of population density trends for a geographical area.

DETRITUS: dead and decaying organic material.

EUTROPHICATION: a natural process in which lakes and reservoirs gradually fill due to over-production of organic material. The addition of cellular nutrients by man greatly accelerates this process.

HYDRAULOGY: the study of the flow of water through pipes and basins.

HYDROLOGY: the study of rainfall and water flow in a geographical area.

HYDROLYZE: a chemical reaction, common in biochemistry, in which a complex compound is broken by the addition of water molecules to its bonds.

MICROCOSMS: small, artificial environments, stocked with biota and nutrients, that are often used to study pollution effects.

NONPOINT SOURCE DISCHARGES: are pollution discharges that originate from a large area or a moving source that are difficult to control, such as fertilizer on a golf course or automobile emissions.

POINT SOURCE DISCHARGES: are pollution discharges that originate from small, specific, controllable sources, such as factories or sewage treatment plants.

STANDARDS: are mandatory maximum stream contamination limits derived from the best available technical information that should protect aquatic life and the beneficial uses of the stream.

TRIHALOMETHANES: chemicals common in water that are suspected of causing cancer in humans. They are formed by adding disinfectants, such as chlorine and iodine, to water containing organic compounds.

APPENDIX A

PETERS CREEK WATERSHED QUESTIONAIRE

(Area around Peters Creek which ultimately drains into Peters Creek)

1. Name, address, and phone number. (Optional)

____

____

____

2. What do you use Peters Creek for? (Check appropriate responses.)

___ 1. Recreation
___ 2. Aesthetic Value
___ 3. Agricultural Water Supply
___ 4. Sewage drainage
___ 5. Public Water Supply
___ 6. Storm drainage from residential/commercial property
___ 7. Other -(please list)

____

____

3. What potential uses can you envision for Peters Creek?

___ 1. Recreation
___ 2. Aesthetic Value
___ 3. Agricultural Water Supply
___ 4. Sewage drainage
___ 5. Public Water Supply
___ 6. Storm drainage from residential/commercial property
___ 7. Other -(please list)

____

____

4. Has your property ever been flooded by Peters Creek? If yes, please list number of times and/or dates if possible.

____

____

____

5. What is the basic topography of your land?

____

____

____

-over-

APPENDIX A (CONTINUED)

6. Are there any dammed up areas caused by trash, tree limbs, etc. on your property? Where is it in relationship to your property?

____

____

7. Have you noticed any nuisances associated with Peters Creek? (Smell, Oil Slicks, etc.)

____

____

8. Is there any aquatic life in your area of Peters Creek?

___ insects

___ fish

___ snakes

___ crayfish

___ frogs

___ water plants

___ other (please specify)

____

____

9. Have you noticed any increase or decrease in runoff associated with a specific land use development in your area?

____

____

10. If there were any drainage improvements made to your area, have they increased or decreased the flooding of the creek?

____

____

11. Has there been any noticeable erosion to your creek bed?

12. What methods do you favor for reducing or delaying storm runoff? (List in order of most preferred to least preferred - <u>A</u> being most to <u>E</u> being least)

___ 1. Retention Ponds (Slows water down)

___ 2. Detention Ponds (Holds water permanently)

___ 3. Channelization (Widening of water course)

___ 4. Increase vegetation

___ 5. Other (please list)

APPENDIX B

Suggestions For Procedures For Future Similar Studies

1. After installing the equipment, by-pass the actuator and run a cycle of 28 bottles during dry,low creek conditions. If this sample is successful, the pump has adequate head for the chosen site.

2. Have twice as many batteries as sites. This will prevent missing storms due to uncharged batteries on the Isco samples.

3. Have access to extra equipment so machines can be readily replaced due to vandalism, submersion and general malfunctions.

4. The Isco samplers tend to operate better in heavy rather than light rains. Be prepared to check on machines several times throughout a storm. If sites are widely separated, or neighborhoods are dangerous at night, extra personnel may be required.

5. The switches on the Isco samplers are temperamental and malfunction in many unexpected ways. Daily surveillance is the best way to assure properly working equipment during storm sampling. Even then, be prepared for surprises.

6. In order to prepare composite samples at the laboratory, all bottles must be capped, labeled and carefully transported. It is easier to be prepared to composite the samples at the site.

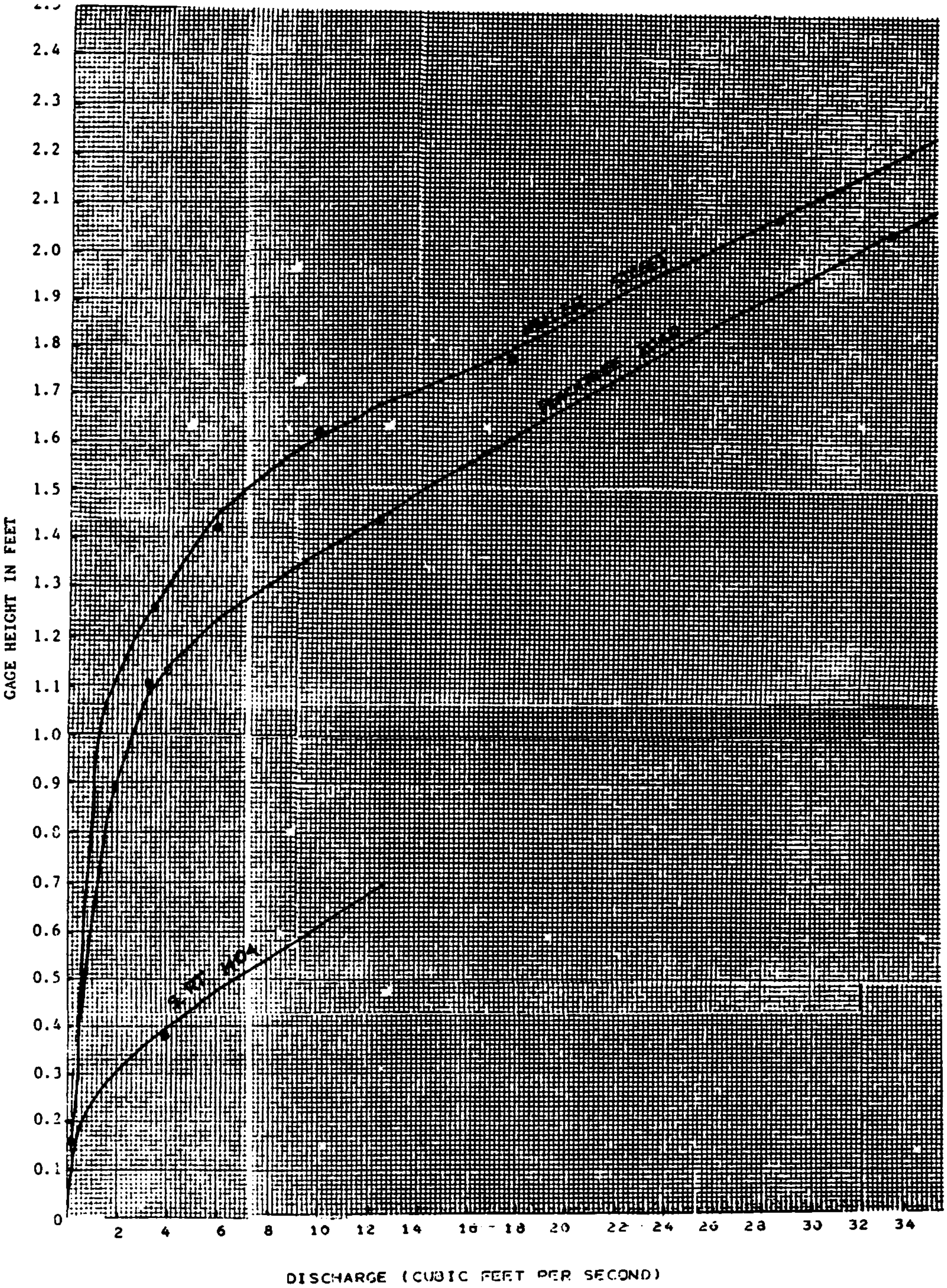
7. Carefully decide the amount of water that is needed in order to complete all testing. Be certain that the compositing scheme will provide a large enough sample, even for a short, intense storm.

8. Discuss with the laboratory:

    1. The best testing procedures that are appropriate for the concentrations of pollutants that are expected. Detection limits and reproducibilities can be different for different tests. Appropriate procedures for extracting pollutants from sediments must also be agreed upon.

    2. The amount of sample that the laboratory actually needs to complete all of the requested analyses.

3. A convenient time for sample delivery. The field personnel need to be aware of the laboratory schedule and the lab staff need to be aware of the possibility of sampling equipment malfunctions and subsequent delays and the vagaries of rain!



Appendix C-1. Rating Curves for Peters Creek at the Sampling Sites

Appendix C-2

The Height Of Peters Creek At Each Site During Grab Sampling (Feet)

Date	State Road 1404	Peachtree Road	Miller Street
6/19	-0.04	0.90	1.16
7/11	-0.04	0.96	1.16
8/16	-0.04	0.96	1.24
8/22	-0.04	0.88	1.24
9/3	-0.04	0.86	1.26
10/5	-0.04	0.96	1.26

Appendix C-3

The Average Height Of Peters Creek At Each Site During The Sampling Period Of Storms (Feet)

Date	State Road 1404	Peachtree Road	Miller Street
6/30	Unknown	2.31	2.84
8/1	0.00	1.00	1.26
8/19	0.02	0.97	1.27
8/29	0.00	1.35	2.11
9/28	0.00	1.00	1.33
10/9	-0.04	1.03	1.35

APPENDIX D-1

LABORATORY ANALYSIS OF SAMPLES
STATE ROUTE 1404 SAMPLING SITE

SAMPLE -	BACKGROUND 1	STORM 1	BACKGROUND 2	STORM 2	BACKGROUND 3	STORM 3	BACKGROUND 4	STORM 4	BACKGROUND 5	STORM 5	BACKGROUND 6	STORM 6
TEST												
TOTAL SOLIDS (mg/L)	364	618	650	164	100	156	140	174	128	200	180	264
VOLATILE SOLIDS (mg/L)	236	358	564	92	62	122	142	88	92	144	146	174
FIXED SOLIDS (mg/L)	128	260	86	72	38	34	6	86	36	136	34	90
SUSPENDED SOLIDS (mg/L)	100	354	12	13	13	3	4	38	7	67	46	216
SUSPENDED VOLATILE SOLIDS (mg/L)	32	36	10	10	7	2	3	8	3	13	16	42
SUSPENDED FIXED SOLIDS (mg/L)	68	318	2	3	6	1	1	30	4	54	30	174
CHLORIDES (mg/L)	0.2	2.6	7.9	6.1	0.2	3.0	1.6	4.8	3.7	7.4	4.5	2.6
TOTAL KJELDAHL NITROGEN (mg/L as n)	0.8	1.2	0.4^A	0.4^A	0.4^A	0.4^A	0.4^A	0.4^A	0.6	0.4^A	0.4^A	0.7
AMMONIA (mg/L as n)	0.4^A	0.4^A	0.4^A	0.4^A	0.4^A	0.4^A	0.4^A	0.4^A	0.4^A	0.4^A	0.4^A	0.4^A
TOTAL PHOSPHORUS (mg/L as p)	0.09	0.72	0.03	0.03	0.03	0.01^A	0.01^A	0.08	0.04	0.12	0.07	0.12
ORTHO-PHOSPHATES (mg/L as p)	B	B	B	0.01^A	0.03	0.01^A	0.01^A	0.01^A	0.02	0.02	0.03	0.01^A
NITRATES (mg/L as n)	0.16	0.29	0.85	1.08	0.01^A	0.06	0.09	0.13	0.07	0.08	0.04	0.11
NITRITES (mg/L as n)	0.01^A	0.01^A	0.01^A	0.01^A	0.02	0.01^A	0.01^A	0.01^A	0.01^A	0.01^A	0.01^A	0.01^A
CHEMICAL OXYGEN DEMAND (mg/L)	5	32	8	5	17	6	5	8	14	9	3	12
CADIUM (ug/l)	B	5^A	5^A	5^A	5^A	5^A	5^A	5^A	5^A	8	5^A	5^A

A. LOWEST DETECTION LIMIT. ACTUAL VALUE MAY BE LOWER
B. INSUFFICIENT SAMPLE TO COMPLETE TEST

APPENDIX D-1 (CONTINUED)

STATE ROUTE 1404

SAMPLE - TEST	BACKGROUND 1	STORM 1	BACKGROUND 2	STORM 2	BACKGROUND 3	STORM 3	BACKGROUND 4	STORM 4	BACKGROUND 5	STORM 5	BACKGROUND 6	STORM 6
CHROMIUM (ug/L)	B	12	1^A	1^A	8	3	6	11	10	12	22	10
COPPER (ug/L)	B	148	20^A	59	68	30	20^A	54	20^A	81	50	63
LEAD (ug/L)	B	100^A	100^A	111	111	100^A	100^A	100^A	100^A	111	100^A	100^A
MERCURY (ug/L)	0.2^A	3.5	1.2	1.2	1.6	0.8	1.9	1.1	0.2^A	1.4	0.2^A	6.7
ZINC (ug/L)	B	9	5^A	5^A	5^A	5^A	5^A	5^A	5^A	5^A	25	18
NICKEL (ug/L)	B	40^A	40^A	40^A	40^A	40^A	42	42	48	42	48	40^A

A. LOWEST DETECTION LIMIT. ACTUAL VALUE MAY BE LOWER
B. INSUFFICIENT SAMPLE TO COMPLETE TEST

APPENDIX D-2

LABORATORY ANALYSIS OF SAMPLES
PEACHTREE ROAD SAMPLING SITE

SAMPLE - TEST	BACKGROUND 1	STORM 1	BACKGROUND 2	STORM 2	BACKGROUND 3	STORM 3	BACKGROUND 4	STORM 4	BACKGROUND 5	STORM 5	BACKGROUND 6	STORM 6
TOTAL SOLIDS (mg/L)	304	1660	416	324	296	796	98	362	330	380	350	296
VOLATILE SOLIDS (mg/L)	126	650	222	164	128	690	74	124	188	218	250	212
FIXED SOLIDS (mg/L)	178	1010	194	160	168	106	24	238	142	162	100	84
SUSPENDED SOLIDS (mg/L)	14	1264	44	13	23	5	2	140	9	12	6	44
SUSPENDED VOLATILE SOLIDS (mg/L)	12	61	10	7	8	3	1	30	3	5	5	34
SUSPENDED FIXED SOLIDS (mg/L)	2	1203	34	6	15	2	1	110	6	7	1	10
CHLORIDES (mg/L)	6.3	6.3	8.8	8.8	7.7	8.5	7.9	6.9	10.0	7.9	8.0	7.9
TOTAL KJELDAHL NITROGEN (mg/L as n)	0.4^A	2.8	0.4^A	0.6	0.4^A	0.4^A	0.4^A	0.6	0.5	0.4^A	0.4^A	0.4^A
AMMONIA (mg/L as n)	0.4^A	0.4^A	0.4^A	0.4^A	0.4^A	0.4^A	0.4^A	0.4^A	0.4^A	0.4^A	0.4^A	0.4^A
TOTAL PHOSPHORUS (mg/L as p)	0.06	2.10	0.07	0.05	0.04	0.03	0.01^A	0.23	0.07	0.04	0.04	0.09
ORTHO-PHOSPHATES (mg/L as p)	B	B	B	0.03	0.02	0.01^A	0.01^A	0.02	0.05	0.02	0.03	0.06
NITRATES (mg/L as n)	2.73	0.48	1.89	2.13	1.86	2.30	1.60	1.87	1.82	2.28	2.18	1.86
NITRITES (mg/L as n)	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01
CHEMICAL OXYGEN DEMAND (mg/L)	5	74	5	5	17	5	5	24	15	7	8	7
CADIUM (ug/l)	5^A	5^A	5^A	5^A	5^A	5^A	5^A	5^A	5^A	5^A	7	5^A

A. LOWEST DETECTION LIMIT. ACTUAL VALUE MAY BE LOWER
B. INSUFFICIENT SAMPLE TO COMPLETE TEST

APPENDIX D-2 (CONTINUED)

PEACHTREE ROAD

SAMPLE - / TEST	BACKGROUND 1	STORM 1	BACKGROUND 2	STORM 2	BACKGROUND 3	STORM 3	BACKGROUND 4	STORM 4	BACKGROUND 5	STORM 5	BACKGROUND 6	STORM 6
CHROMIUM (ug/L)	1[A]	1[A]	1[A]	1[A]	8	9	2	8	4	10	14	10
COPPER (ug/L)	86	75	32	41	20[A]	28	20[A]	54	20[A]	72	50	20[A]
LEAD (ug/L)	168	182	100[A]	100[A]	100[A]	100[A]	100[A]	100[A]	111	129	101	100[A]
MERCURY (ug/L)	0.2[A]	3.1	1.0	0.9	0.6	1.0	1.6	1.3	0.2[A]	0.4	0.2[A]	3.8
ZINC (ug/L)	10	14	5[A]	5[A]	6	5[A]	5[A]	5[A]	5[A]	5[A]	20	15
NICKEL (ug/L)	42	49	40[A]	40[A]	40[A]	40[A]	40[A]	40[A]	48	40[A]	40[A]	40[A]

A. LOWEST DETECTION LIMIT. ACTUAL VALUE MAY BE LOWER

B. INSUFFICIENT SAMPLE TO COMPLETE TEST

APPENDIX D-3

LABORATORY ANALYSIS OF SAMPLES
MILLER ROAD SAMPLING SITE

SAMPLE - TEST	BACKGROUND 1	STORM 1	BACKGROUND 2	STORM 2	BACKGROUND 3	STORM 3	BACKGROUND 4	STORM 4	BACKGROUND 5	STORM 5	BACKGROUND 6	STORM 6
TOTAL SOLIDS (mg/L)	468	742	344	270	88	782	340	810	458	336	258	250
VOLATILE SOLIDS (mg/L)	278	196	190	138	64	702	224	330	308	176	176	206
FIXED SOLIDS (mg/L)	190	546	154	132	24	80	116	480	150	160	82	44
SUSPENDED SOLIDS (mg/L)	28	544	33	10	29	7	5	378	10	28	15	12
SUSPENDED VOLATILE SOLIDS (mg/L)	18	48	10	7	9	3	3	48	3	6	10	6
SUSPENDED FIXED SOLIDS (mg/L)	10	496	23	3	20	4	2	330	7	22	5	6
CHLORIDES (mg/L)	4.8	7.1	5.8	7.1	6.1	7.5	6.9	2.6	0.4	5.3	8.0	6.9
TOTAL KJELDAHL NITROGEN (mg/L as n)	0.4[A]	1.80	0.4[A]	0.4[A]	0.4[A]	0.4[A]	0.4[A]	1.10	0.4[A]	0.4[A]	0.4[A]	0.4[A]
AMMONIA (mg/L as n)	0.4[A]	0.4[A]	0.4[A]	0.4[A]	0.4[A]	0.4[A]	0.4[A]	0.4[A]	0.4[A]	0.4[A]	0.4[A]	0.4[A]
TOTAL PHOSPHORUS (mg/L as p)	0.08	1.02	0.10	0.03	0.06	0.02	0.01[A]	0.58	0.04	0.05	0.01[A]	0.05
ORTHO-PHOSPHATES (mg/L as p)	B	B	B	0.02	0.04	0.01[A]	0.01[A]	0.27	0.02	0.02	0.01[A]	0.03
NITRATES (mg/L as n)	1.11	0.69	0.08	0.20	1.35	1.65	1.44	0.90	1.56	1.46	1.32	1.68
NITRITES (mg/L as n)	0.02	0.04	0.01[A]	0.01[A]	0.01[A]	0.01[A]	0.01[A]	0.02	0.01[A]	0.01[A]	0.01[A]	0.01[A]
CHEMICAL OXYGEN DEMAND (mg/L)	5	38	8	5	24	5	5	35	11	5	4	3
CADMIUM (ug/l)	5[A]	5[A]	5[A]	5[A]	5[A]	5[A]	5[A]	5[A]	5[A]	5[A]	5[A]	5[A]

A. LOWEST DETECTION LIMIT. ACTUAL VALUE MAY BE LOWER
B. INSUFFICIENT SAMPLE TO COMPLETE TEST

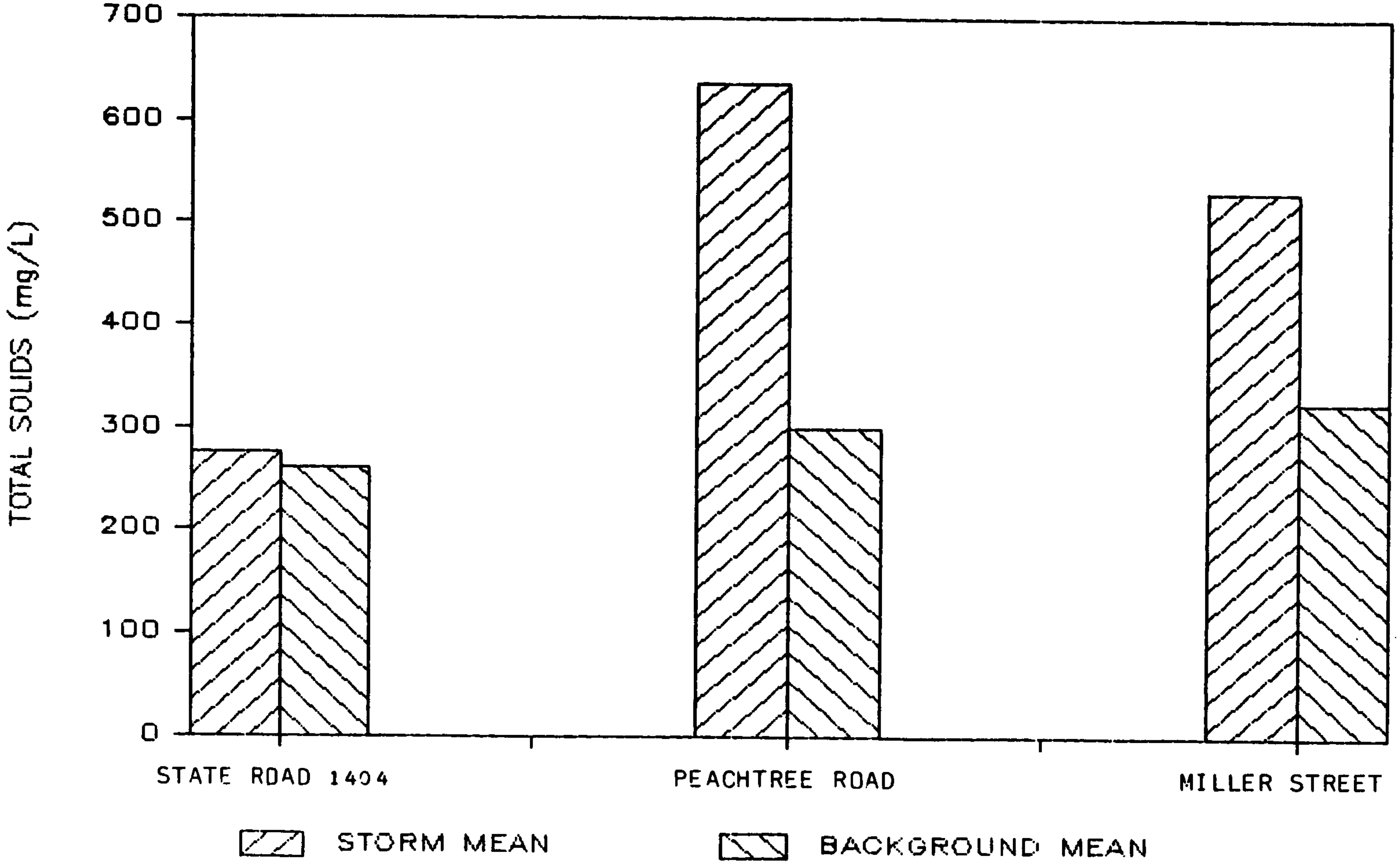
APPENDIX D-3 (CONTINUED)

MILLER ROAD

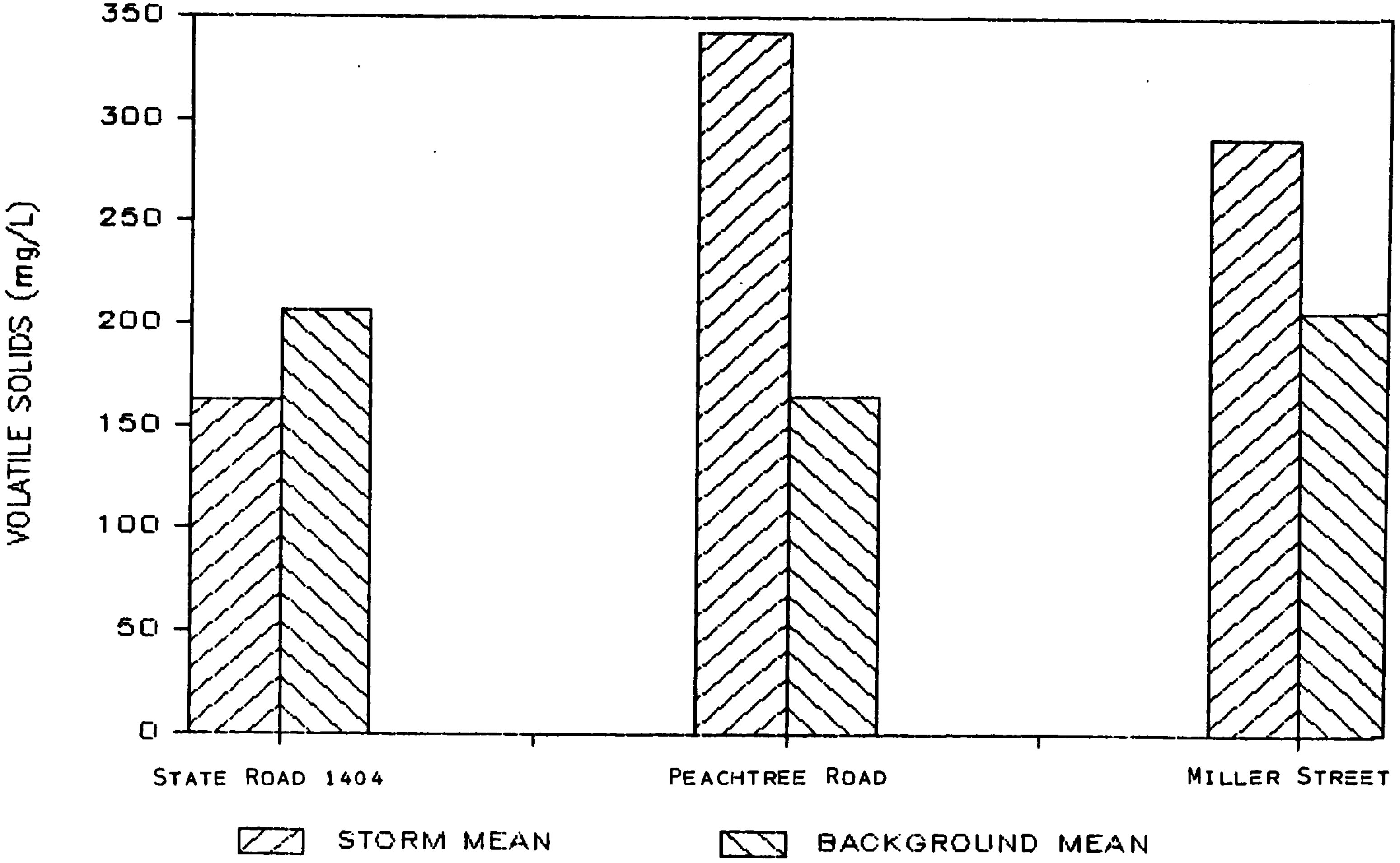
SAMPLE - TEST	BACKGROUND 1	STORM 1	BACKGROUND 2	STORM 2	BACKGROUND 3	STORM 3	BACKGROUND 4	STORM 4	BACKGROUND 5	STORM 5	BACKGROUND 6	STORM 6
CHROMIUM (ug/L)	1[A]	2	1[A]	1[A]	1[A]	1[A]	3	10	8	15	9	8
COPPER (ug/L)	75	90	59	41	41	28	20[A]	54	20[A]	81	50	54
LEAD (ug/L)	140	168	100[A]	100[A]	100[A]	100[A]	100[A]	111	100[A]	140	101	100[A]
MERCURY (ug/L)	0.4	3.7	1.2	1.1	0.2[A]	0.2[A]	0.8	1.6	0.3	1.8	0.2[A]	3.2
ZINC (ug/L)	12	11	5[A]	6	5[A]	5[A]	5[A]	5[A]	5[A]	5[A]	24	16
NICKEL (ug/L)	40[A]	54	42	40[A]	43	40[A]	40[A]	40[A]	40[A]	40[A]	48	40[A]

A. LOWEST DETECTION LIMIT. ACTUAL VALUE MAY BE LOWER

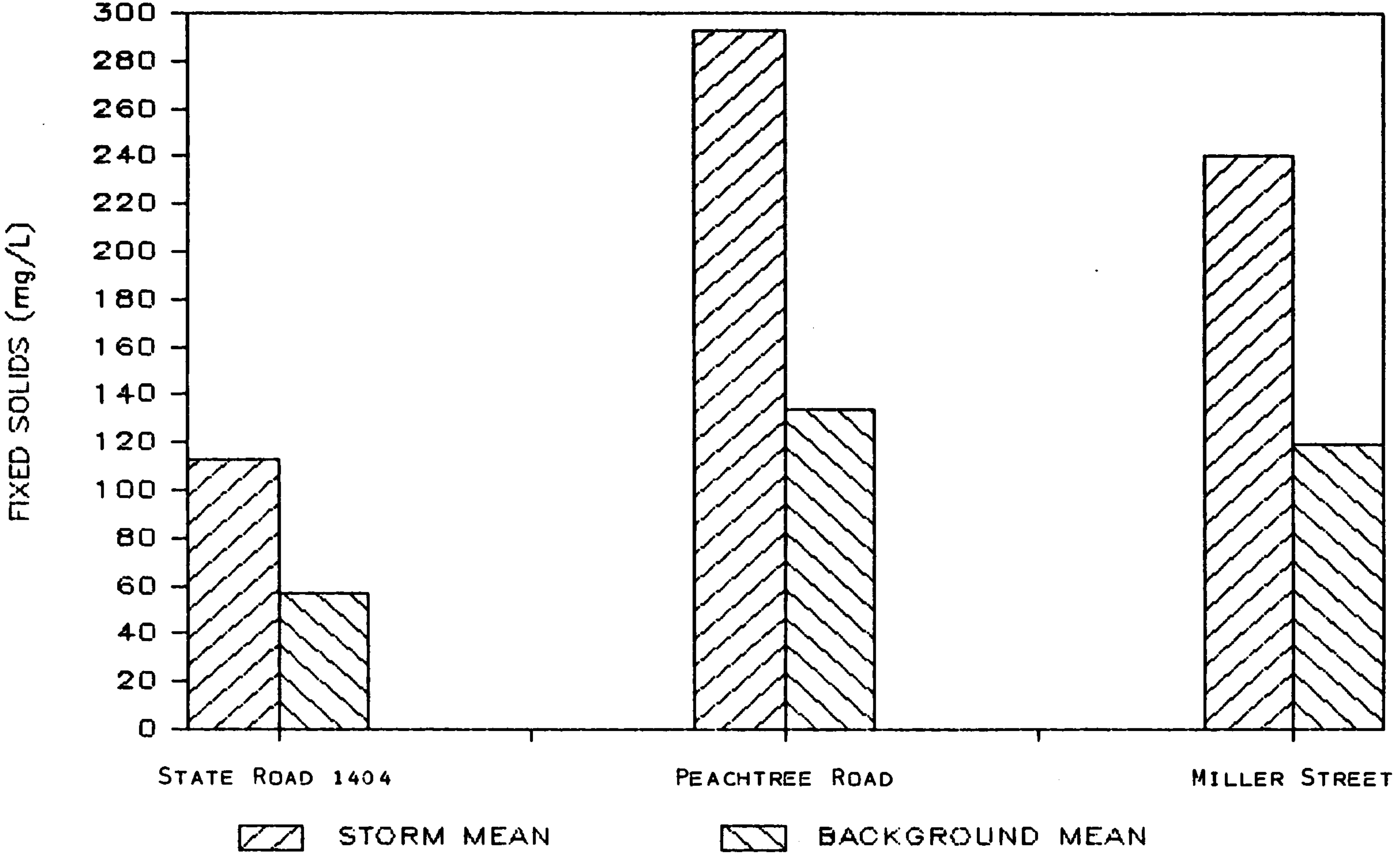
B. INSUFFICIENT SAMPLE TO COMPLETE TEST



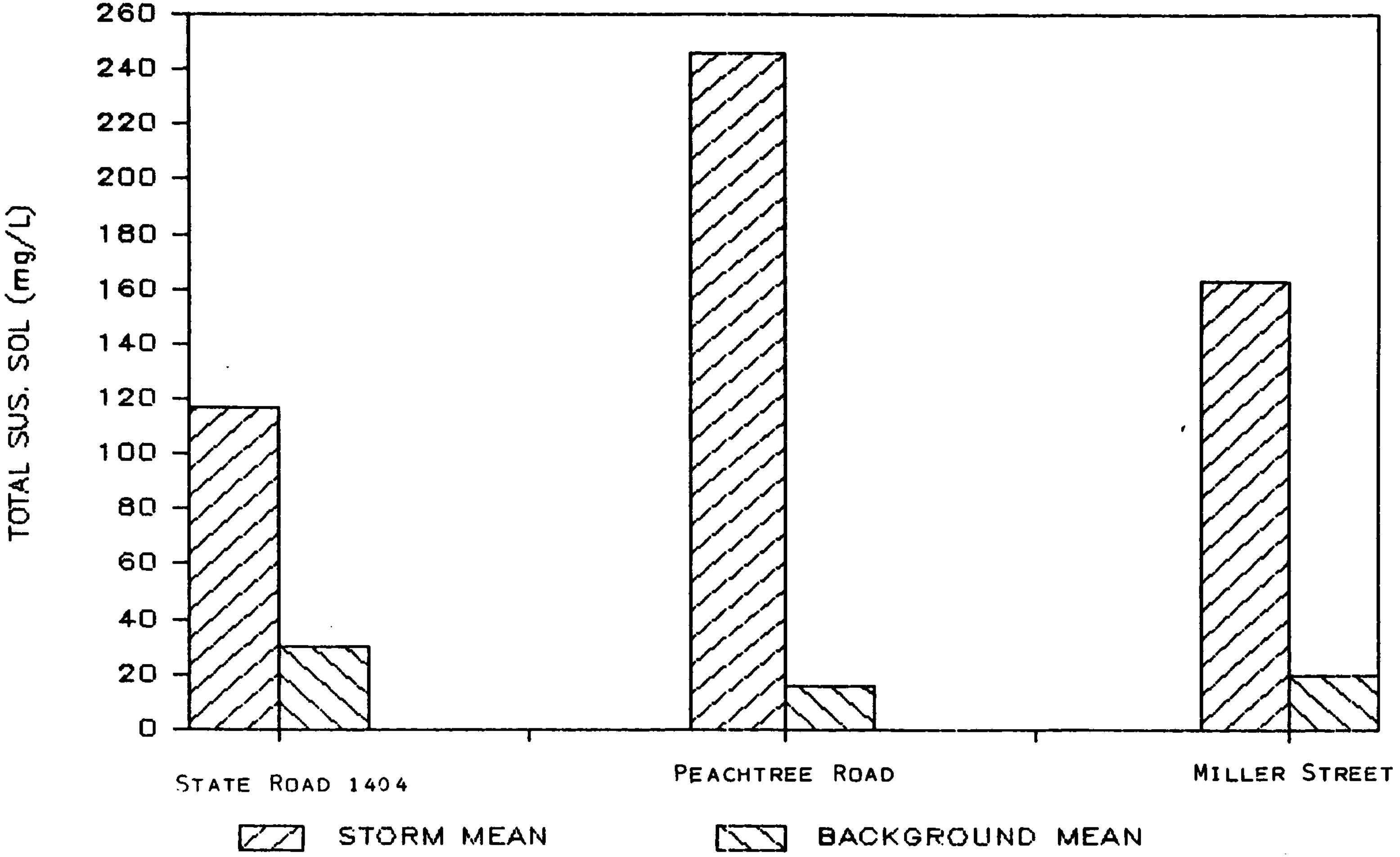
APPENDIX E-1. THE AVERAGE TOTAL SOLIDS CONCENTRATION OF THE BACKGROUND AND STORMWATER SAMPLES FROM PETERS CREEK



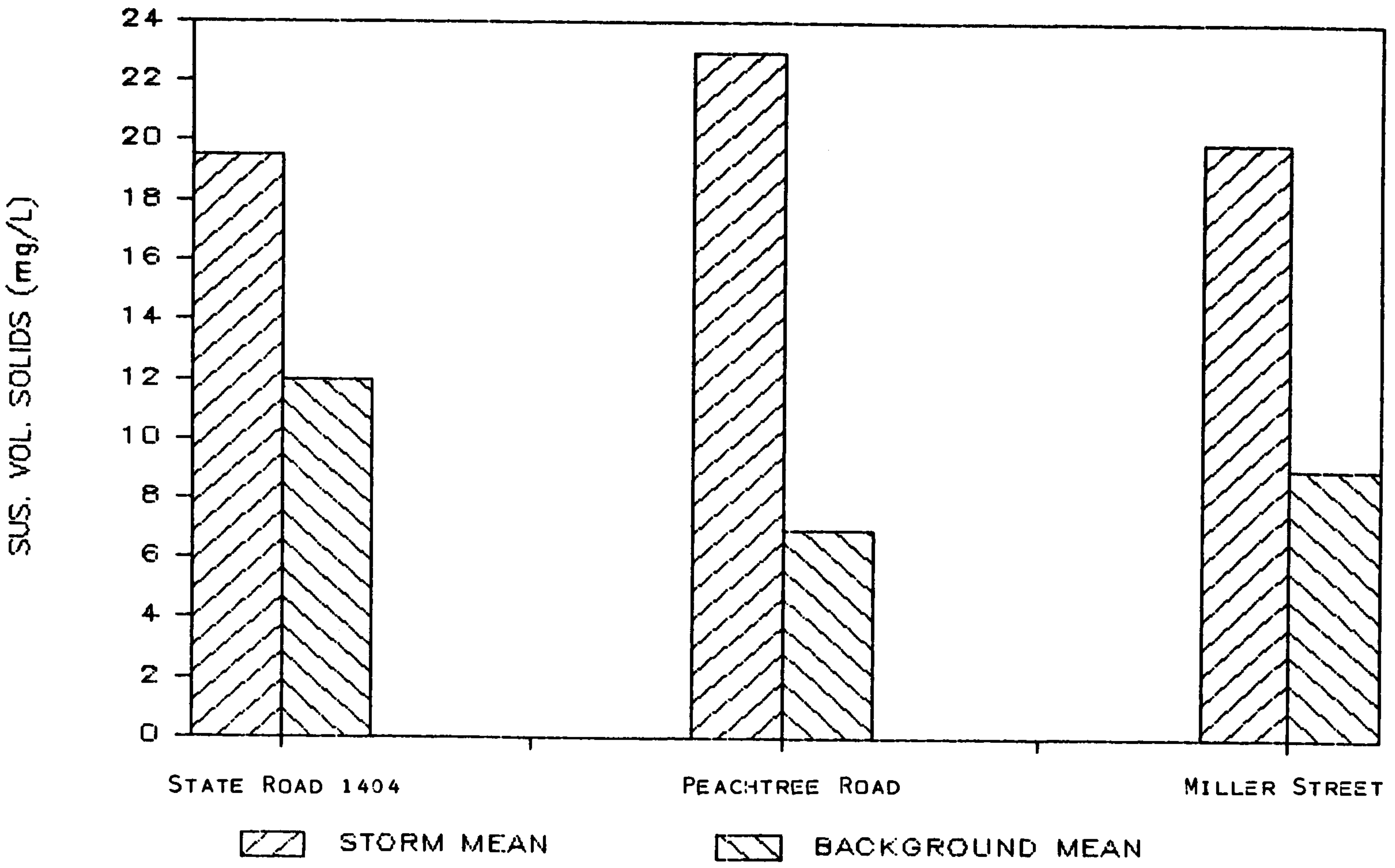
APPENDIX E-2. THE AVERAGE VOLATILE SOLIDS CONCENTRATION OF THE BACKGROUND AND STORMWATER SAMPLES FROM PETERS CREEK



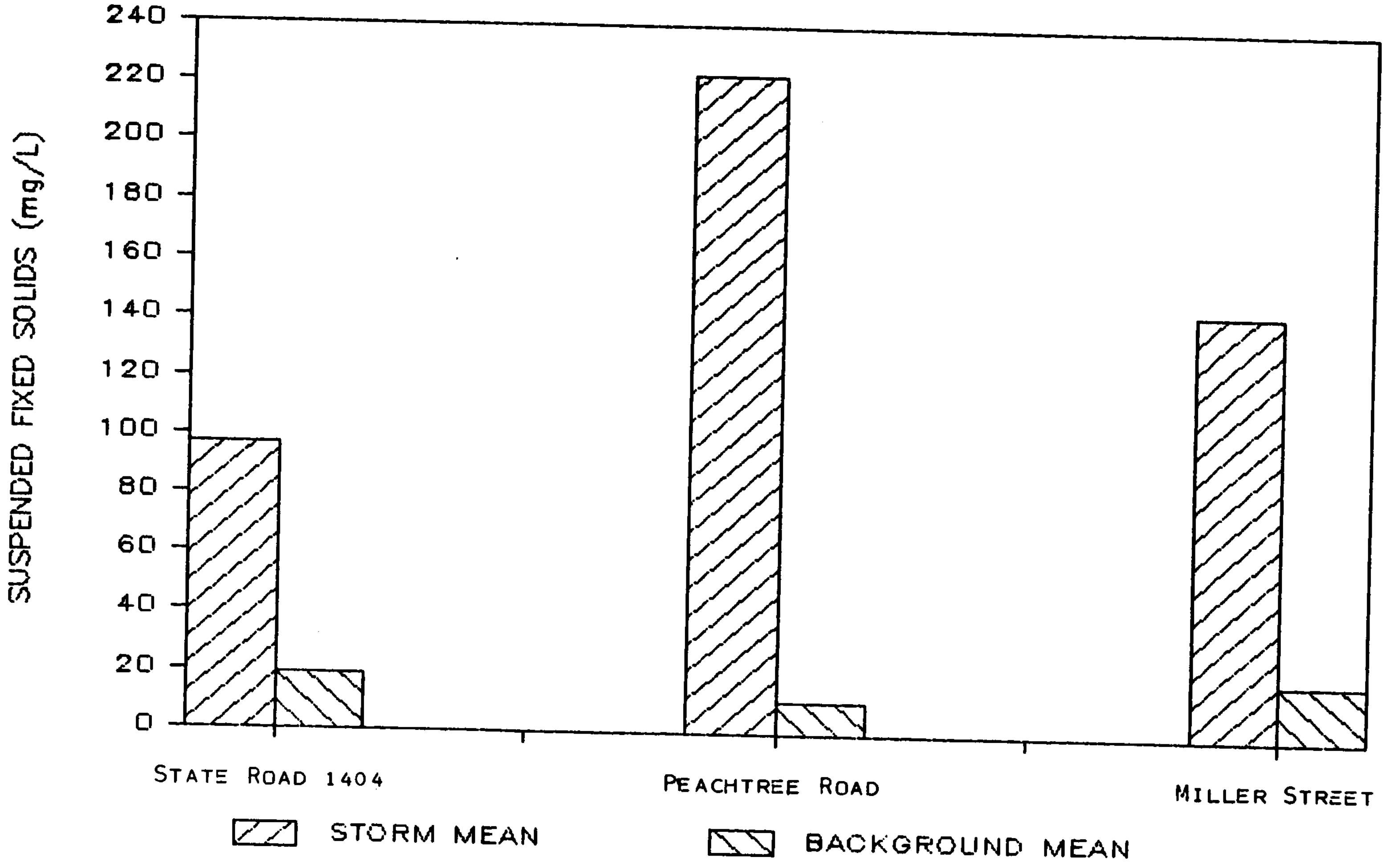
APPENDIX E-3. THE AVERAGE FIXED SOLIDS CONCENTRATION OF THE BACKGROUND AND STORMWATER SAMPLES FROM PETERS CREEK



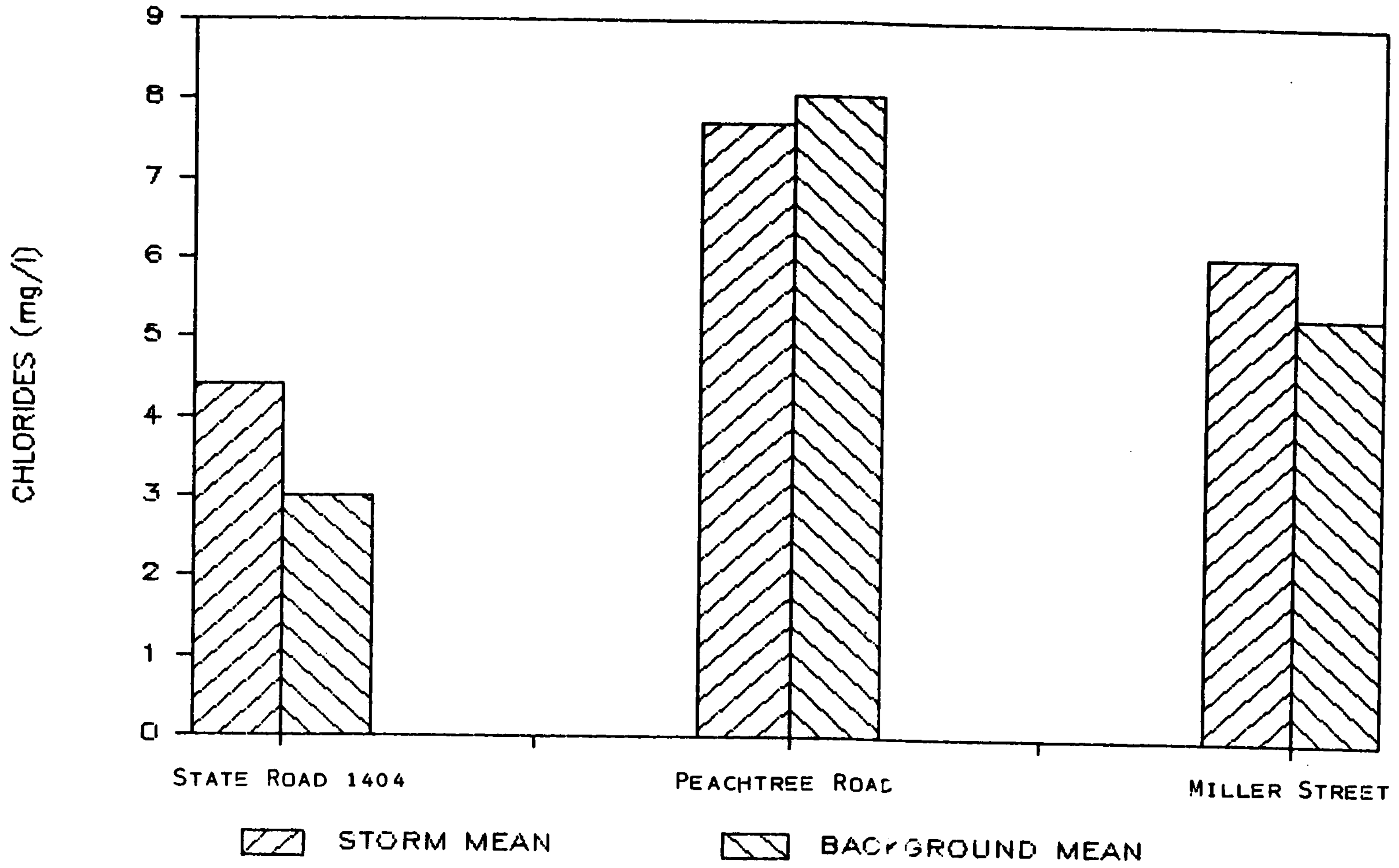
APPENDIX E-4. THE AVERAGE TOTAL SUSPENDED SOLIDS CONCENTRATION OF THE BACKGROUND AND STORMWATER SAMPLES FROM PETERS CREEK



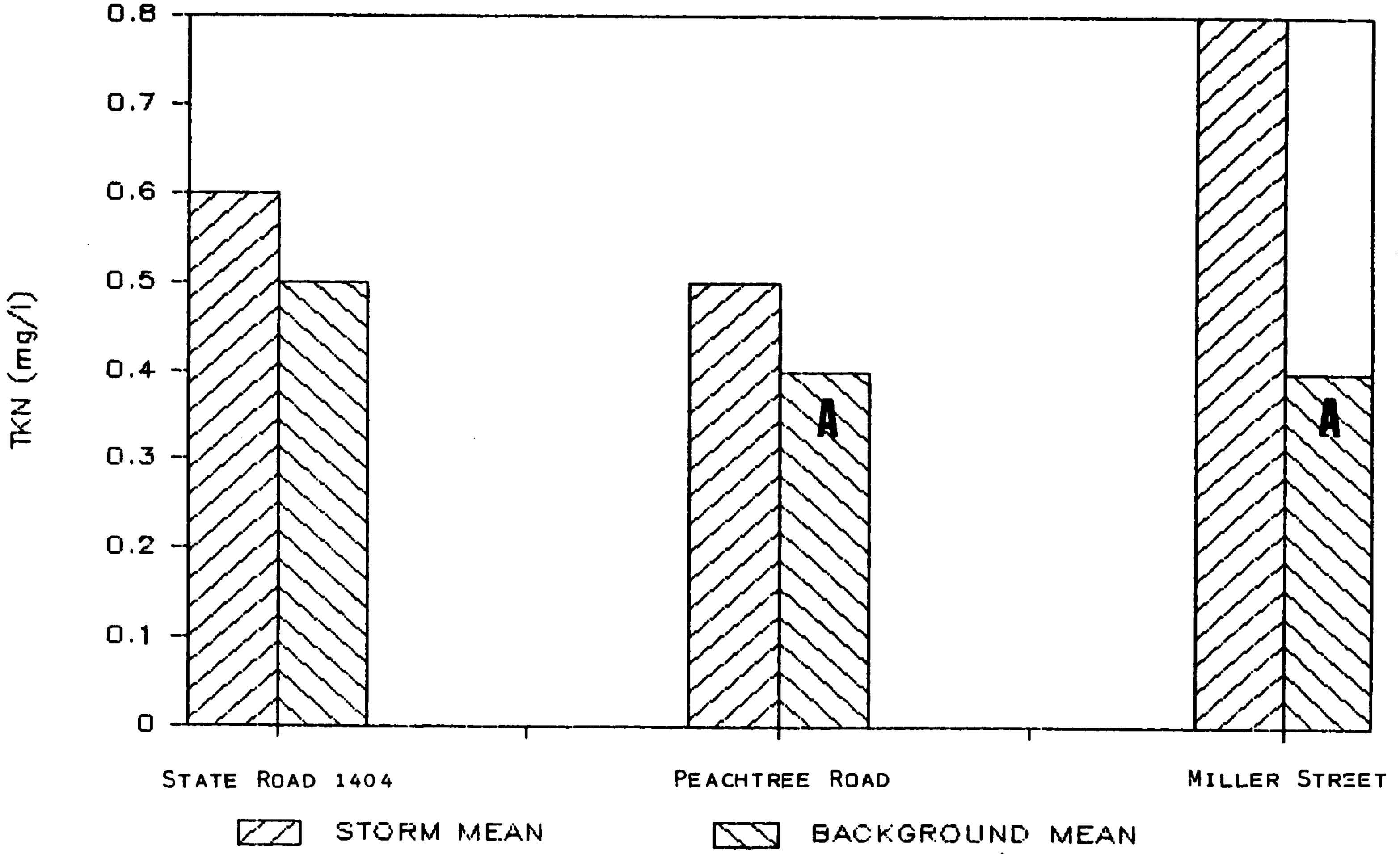
APPENDIX E-5. THE AVERAGE SUSPENDED VOLATILE SOLIDS CONCENTRATION OF THE BACKGROUND AND STORMWATER SAMPLES FROM PETERS CREEK



APPENDIX E-6. THE AVERAGE SUSPENDED FIXED SOLIDS CONCENTRATION OF THE BACKGROUND AND STORMWATER SAMPLES FROM PETERS CREEK

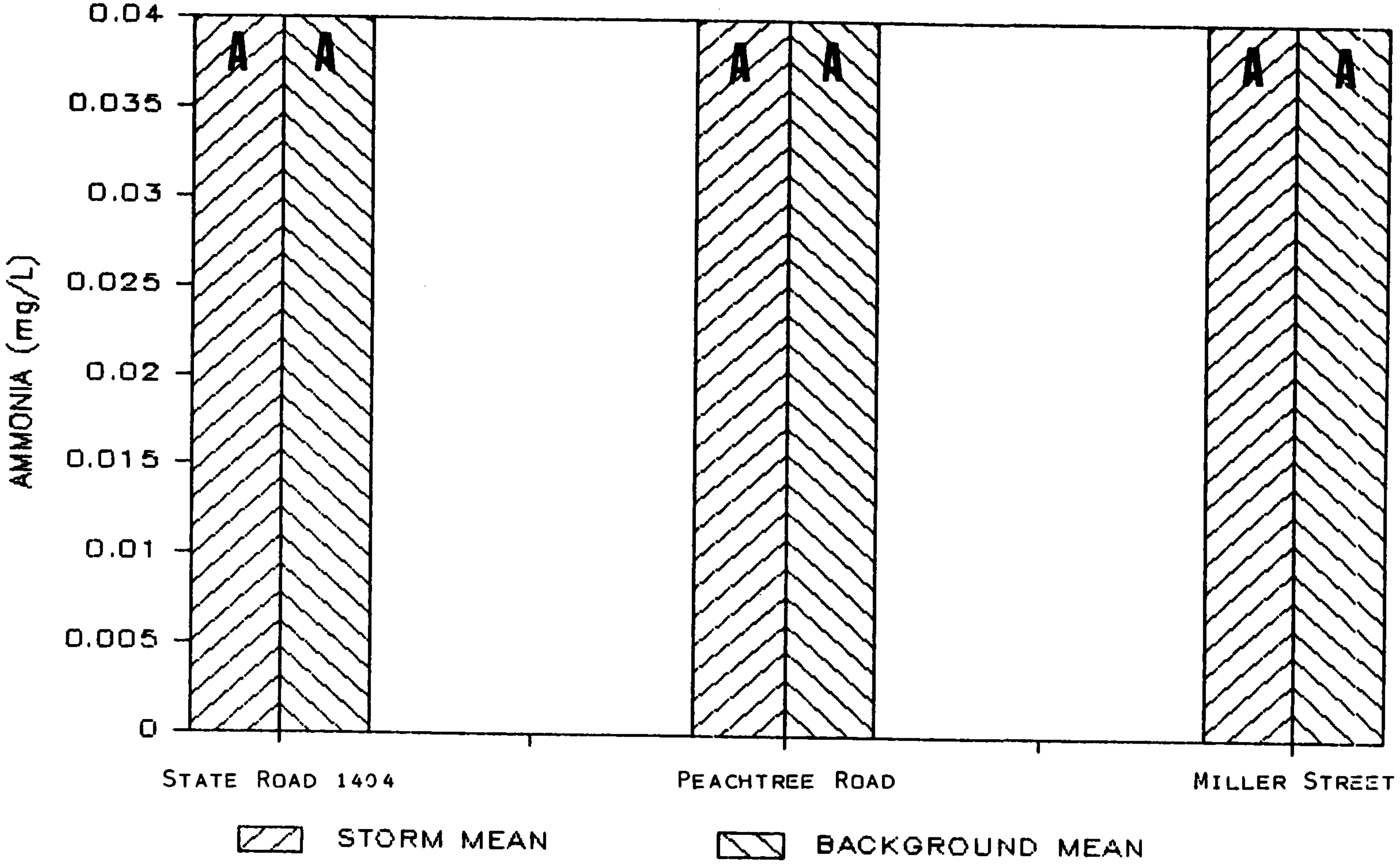


APPENDIX E-7. THE AVERAGE CHLORIDE CONCENTRATION OF THE BACKGROUND AND STORMWATER SAMPLES FROM PETERS CREEK



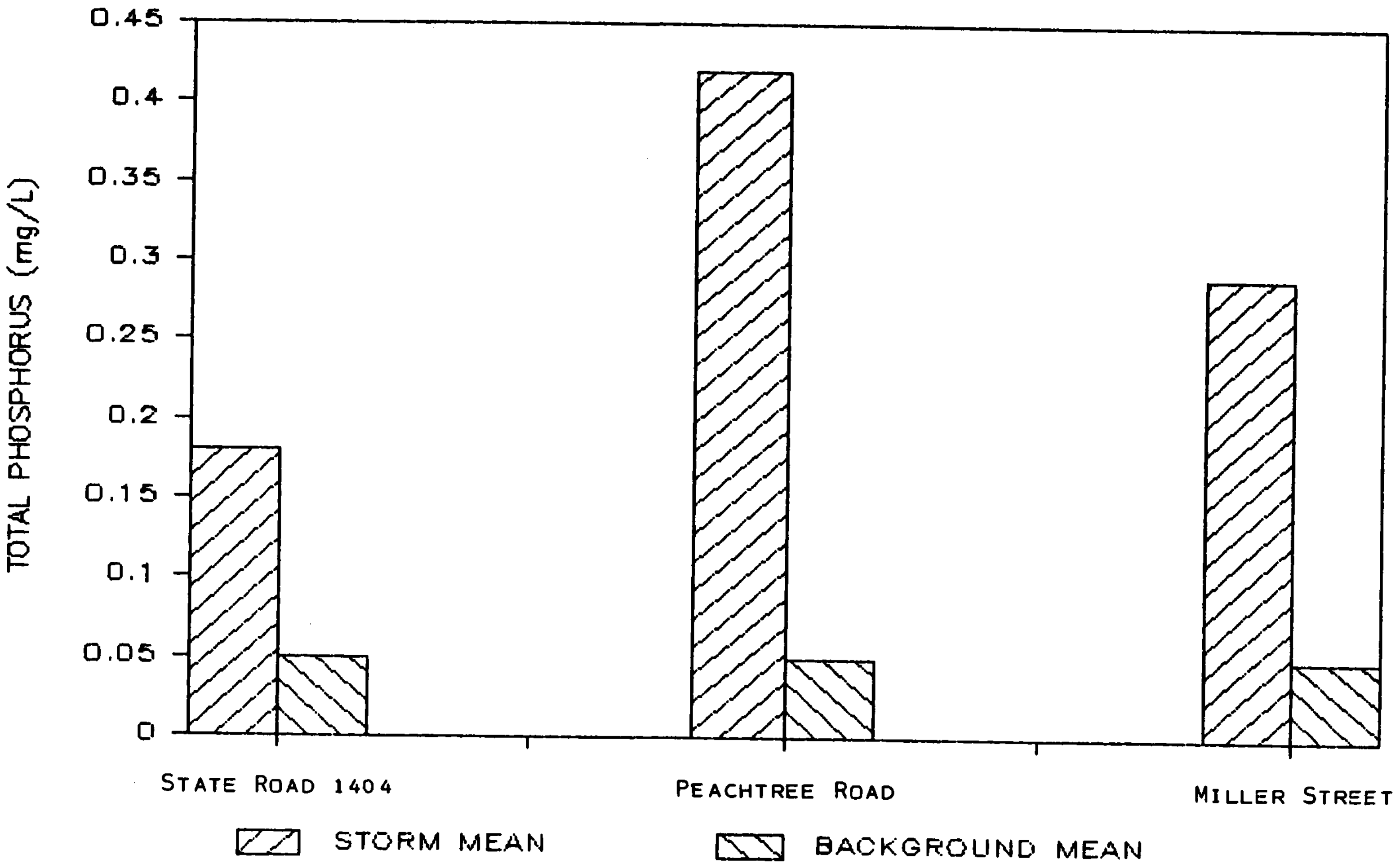
APPENDIX E-8. THE AVERAGE TOTAL KJELDAHL NITROGEN CONCENTRATIONS OF THE BACKGROUND AND STORMWATER SAMPLES FROM PETERS CREEK

A. THE LOWEST TESTING DETECTION LIMIT

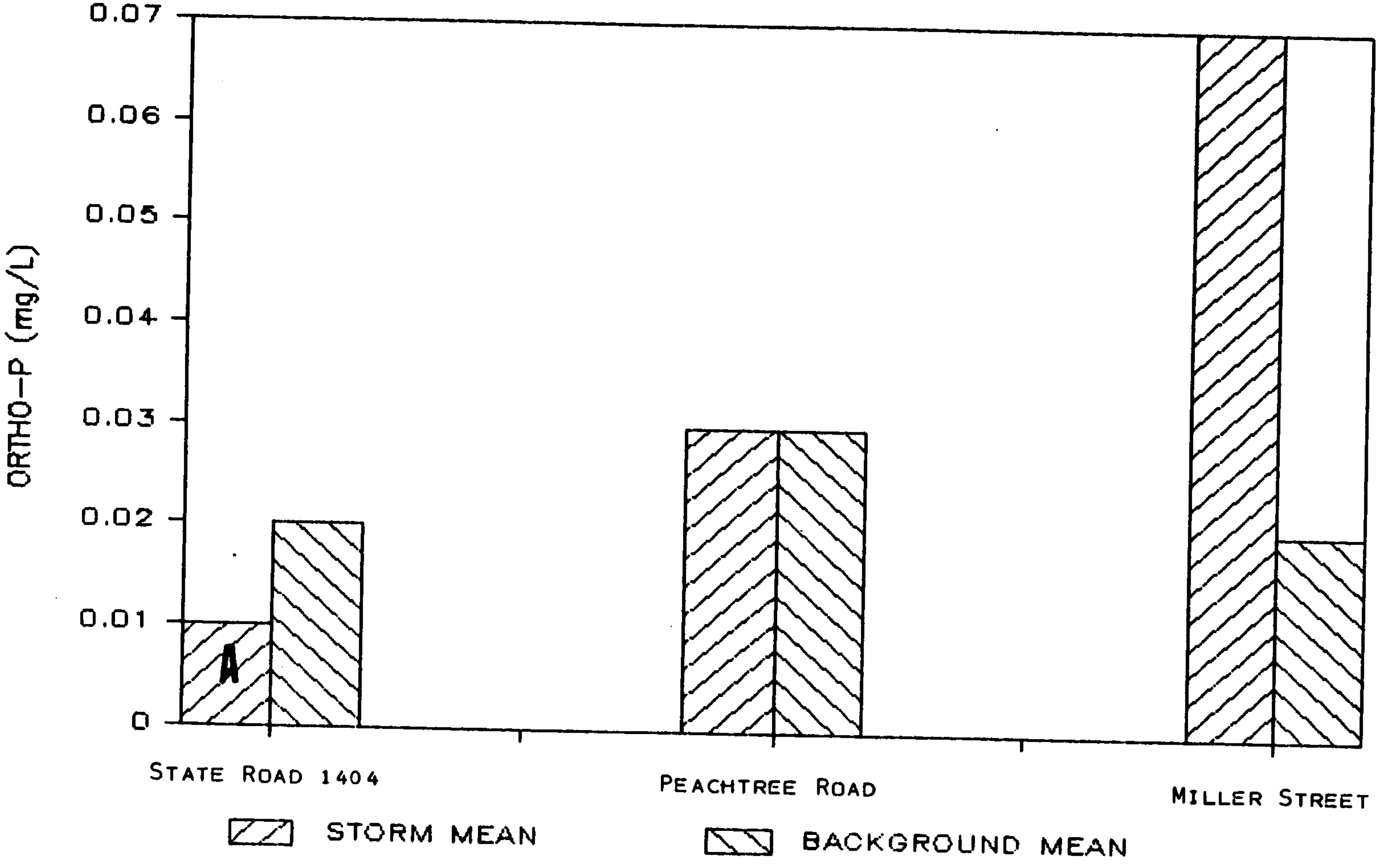


APPENDIX E-9. THE AVERAGE AMMONIA CONCENTRATION OF THE BACKGROUND AND STORMWATER SAMPLES OF PETERS CREEK

A. THE LOWEST TESTING DETECTION LIMIT

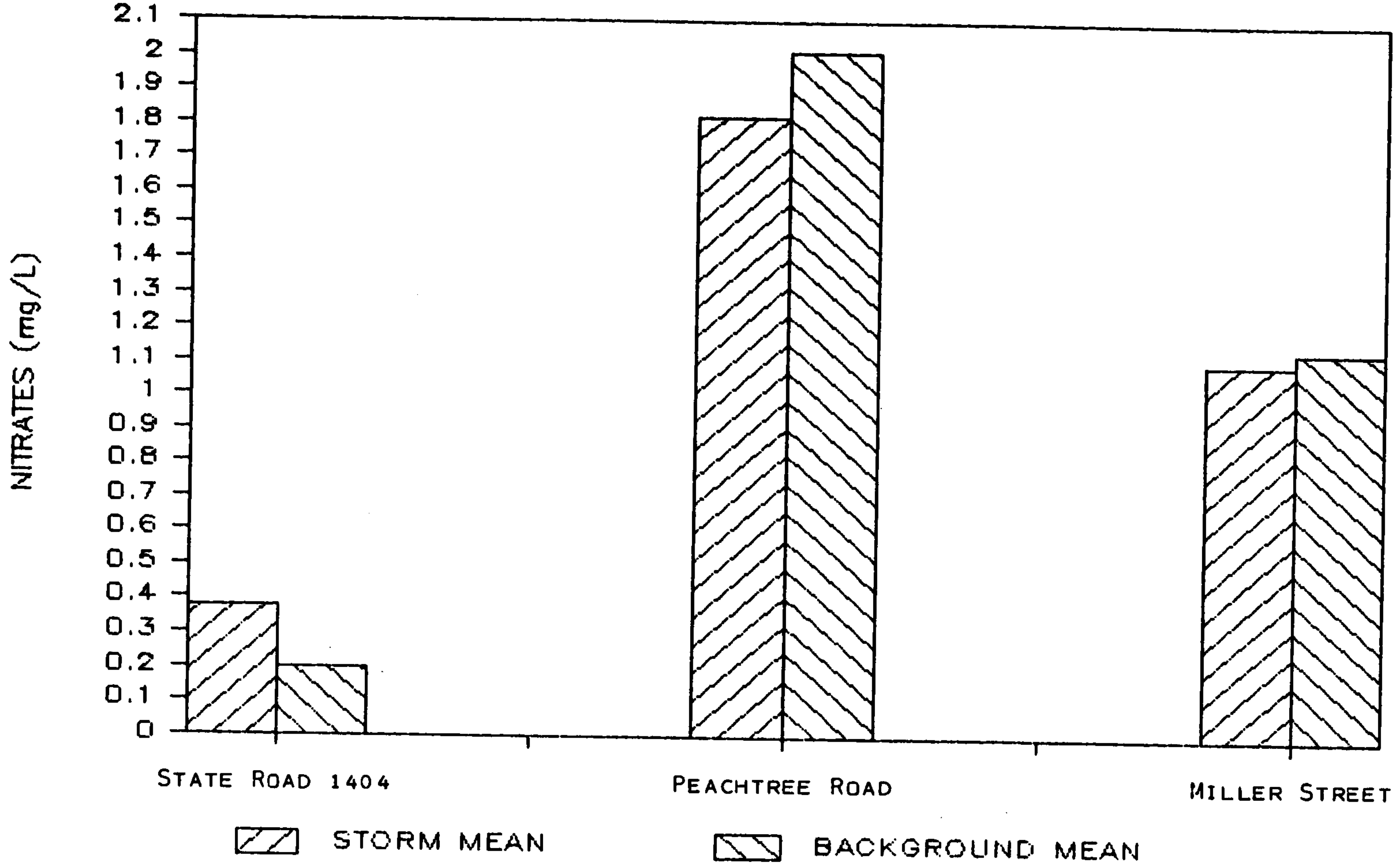


APPENDIX E-10. THE AVERAGE TOTAL PHOSPHORUS CONCENTRATION OF THE BACKGROUND AND STORMWATER SAMPLES FROM PETERS CREEK

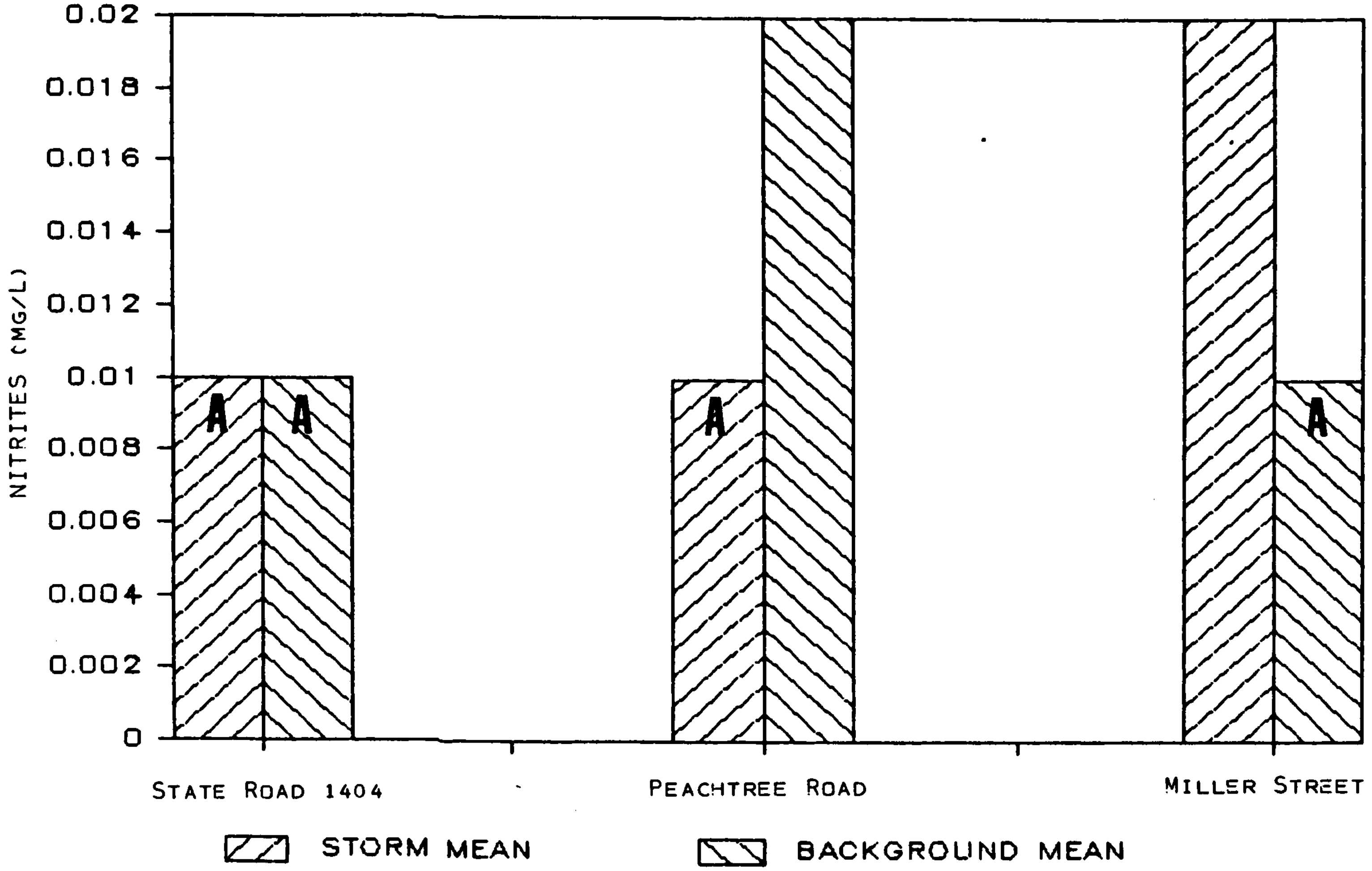


APPENDIX E-11. THE AVERAGE ORTHO-PHOSPHORUS CONCENTRATION OF THE BACKGROUND AND STORMWATER SAMPLE FROM PETERS CREEK

A. THE LOWEST TESTING DETECTION LIMIT

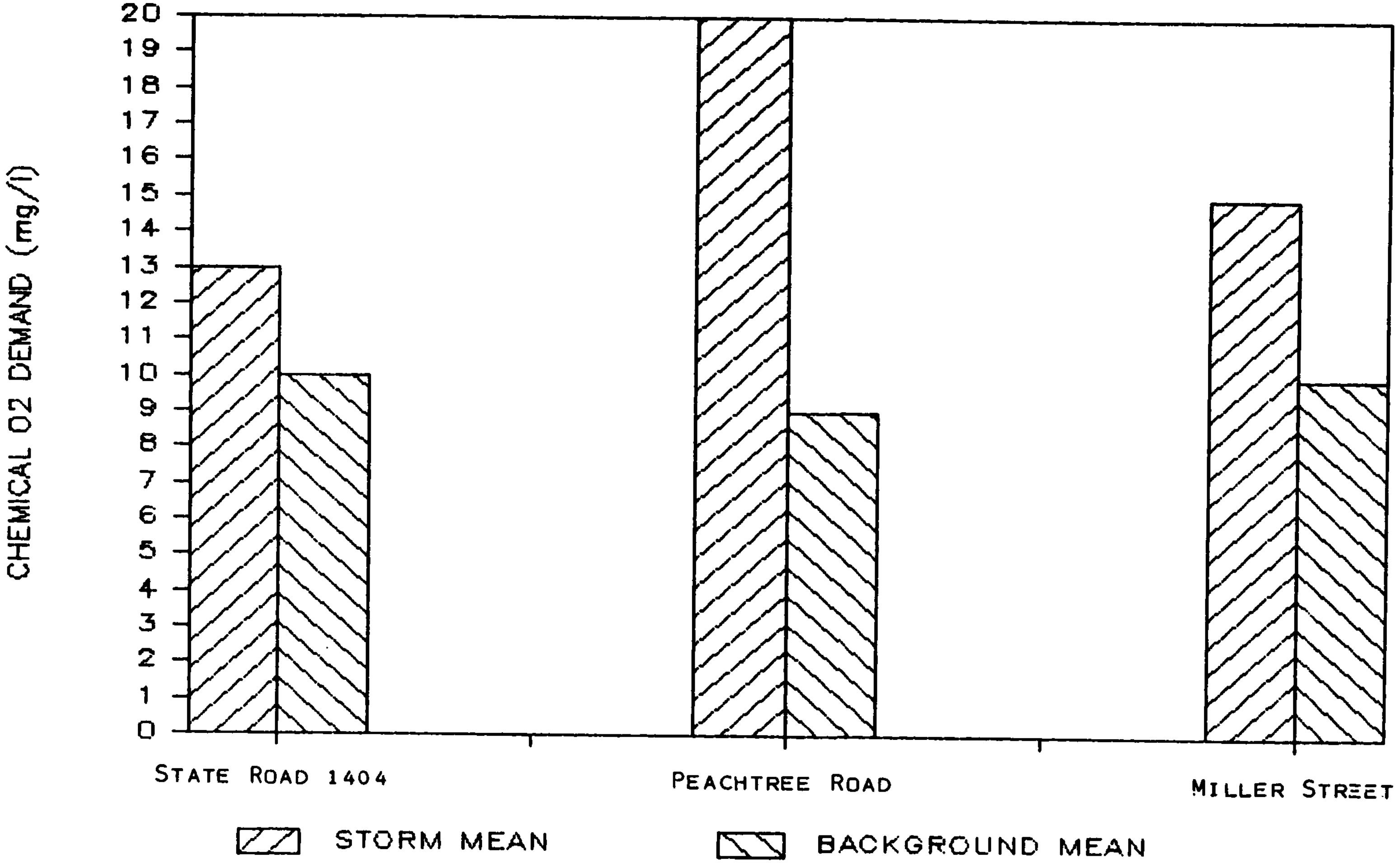


APPENDIX E-12. THE AVERAGE NITRATE CONCENTRATION OF THE BACKGROUND AND STORMWATER SAMPLES FROM PETERS CREEK

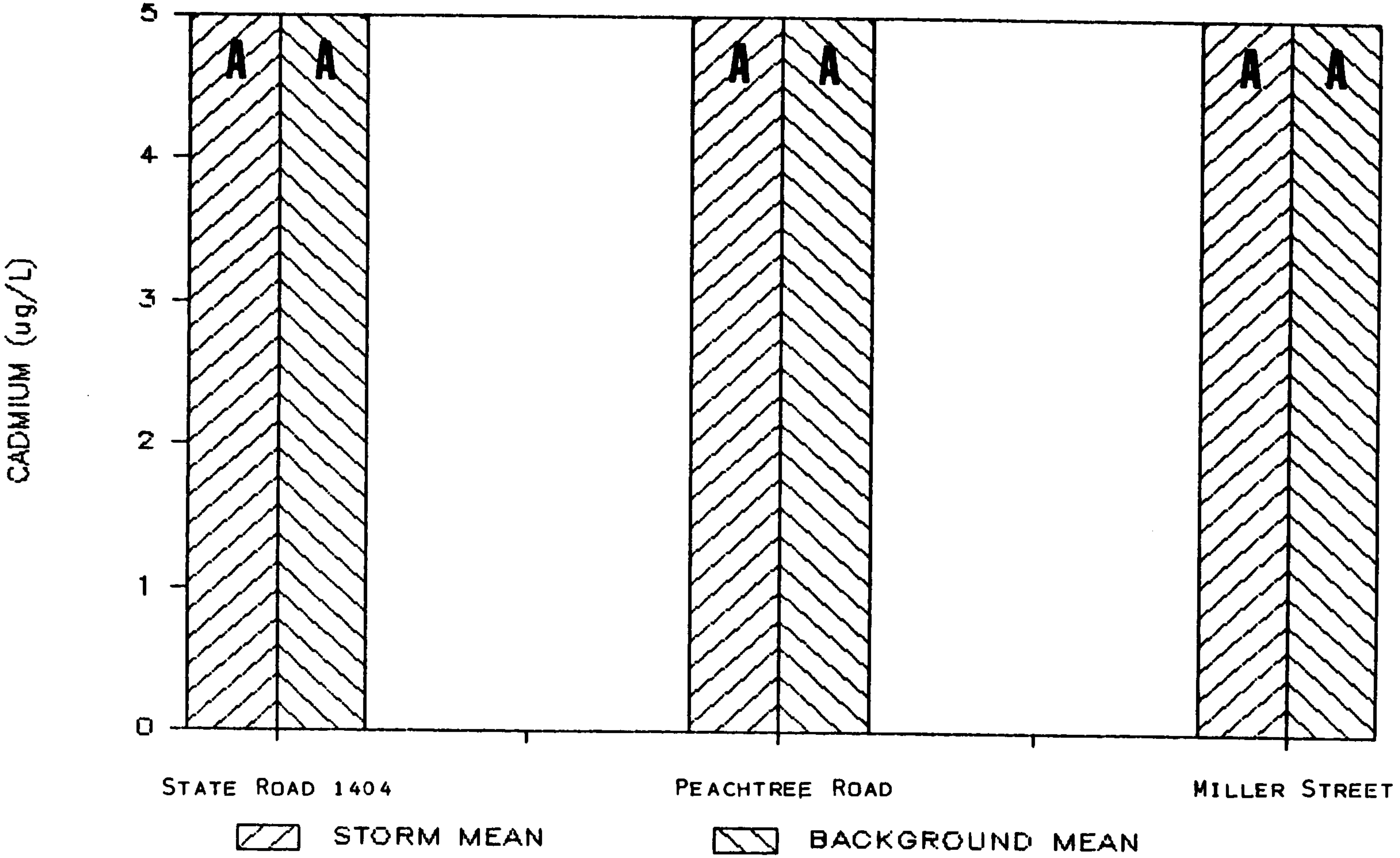


APPENDIX E-13. THE AVERAGE NITRITE CONCENTRATION OF THE BACKGROUND AND STORMWATER SAMPLES FROM PETERS CREEK

A. THE LOWEST TESTING DETECTION LIMIT

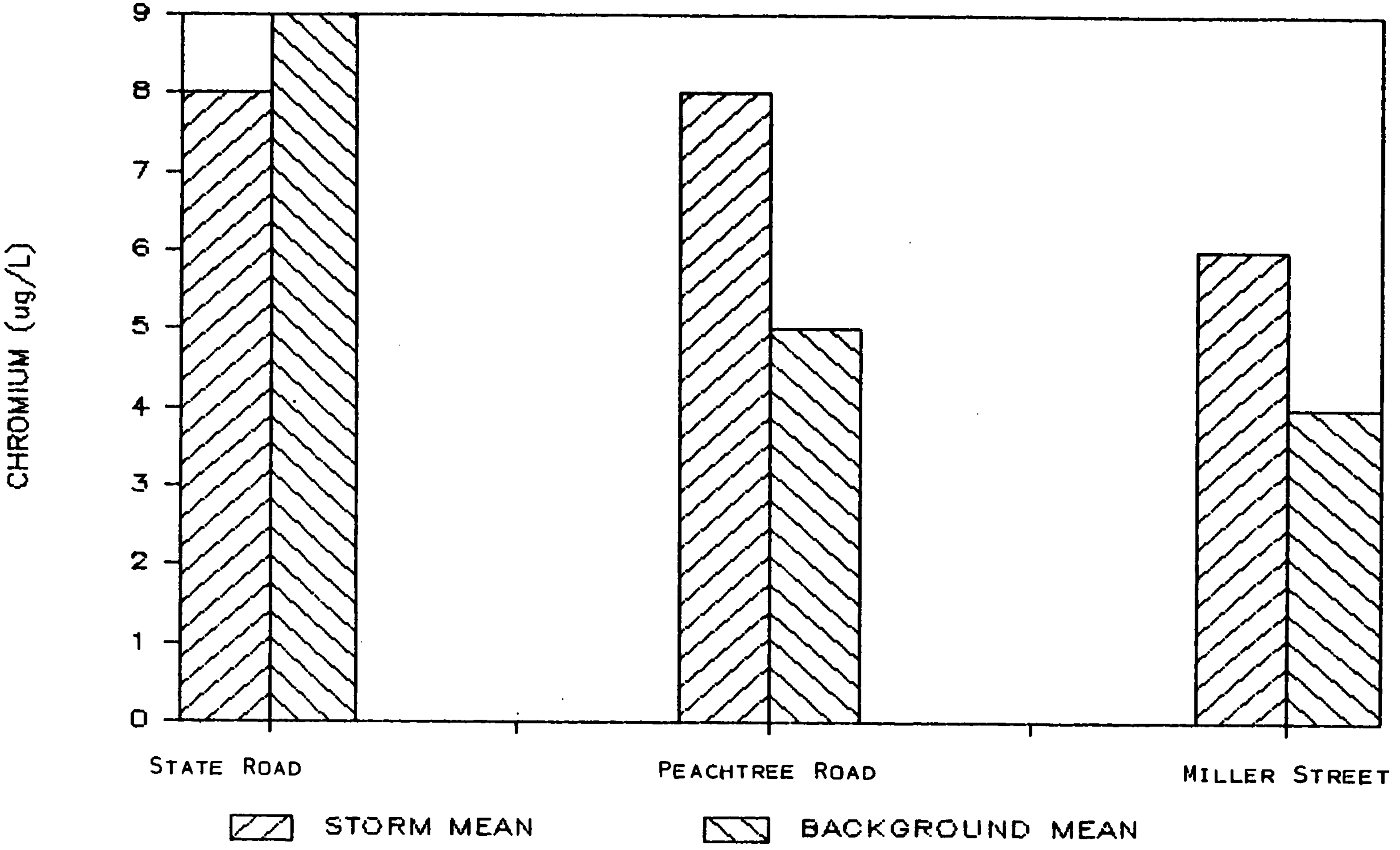


APPENDIX E-14. THE AVERAGE CHEMICAL OXYGEN DEMAND OF THE BACKGROUND AND STORMWATER SAMPLES OF PETERS CREEK

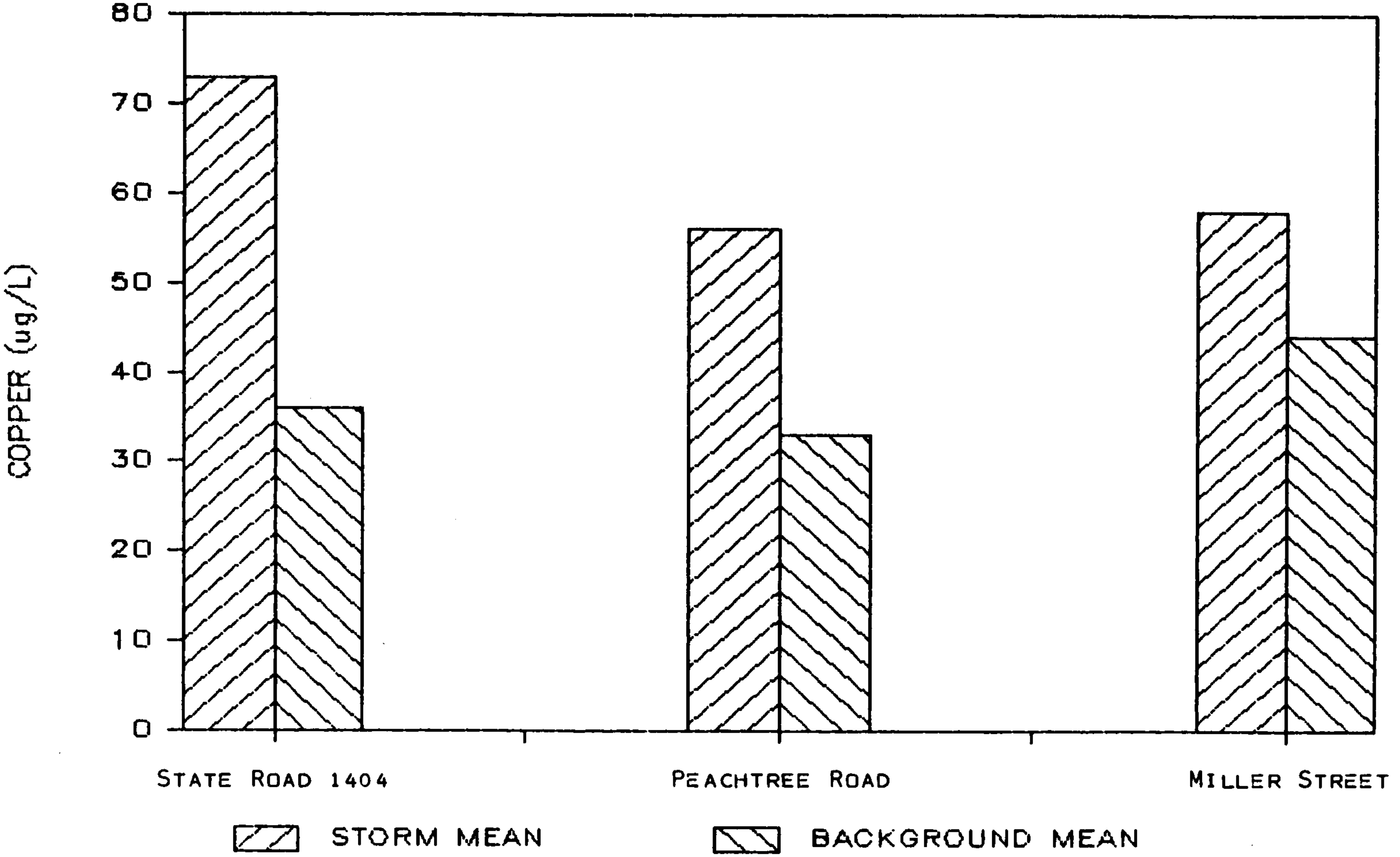


APPENDIX E.15. THE AVERAGE CADMIUM CONENTRATIONS OF THE BACKGROUND AND STORMWATER SAMPLES FROM PETERS CREEK

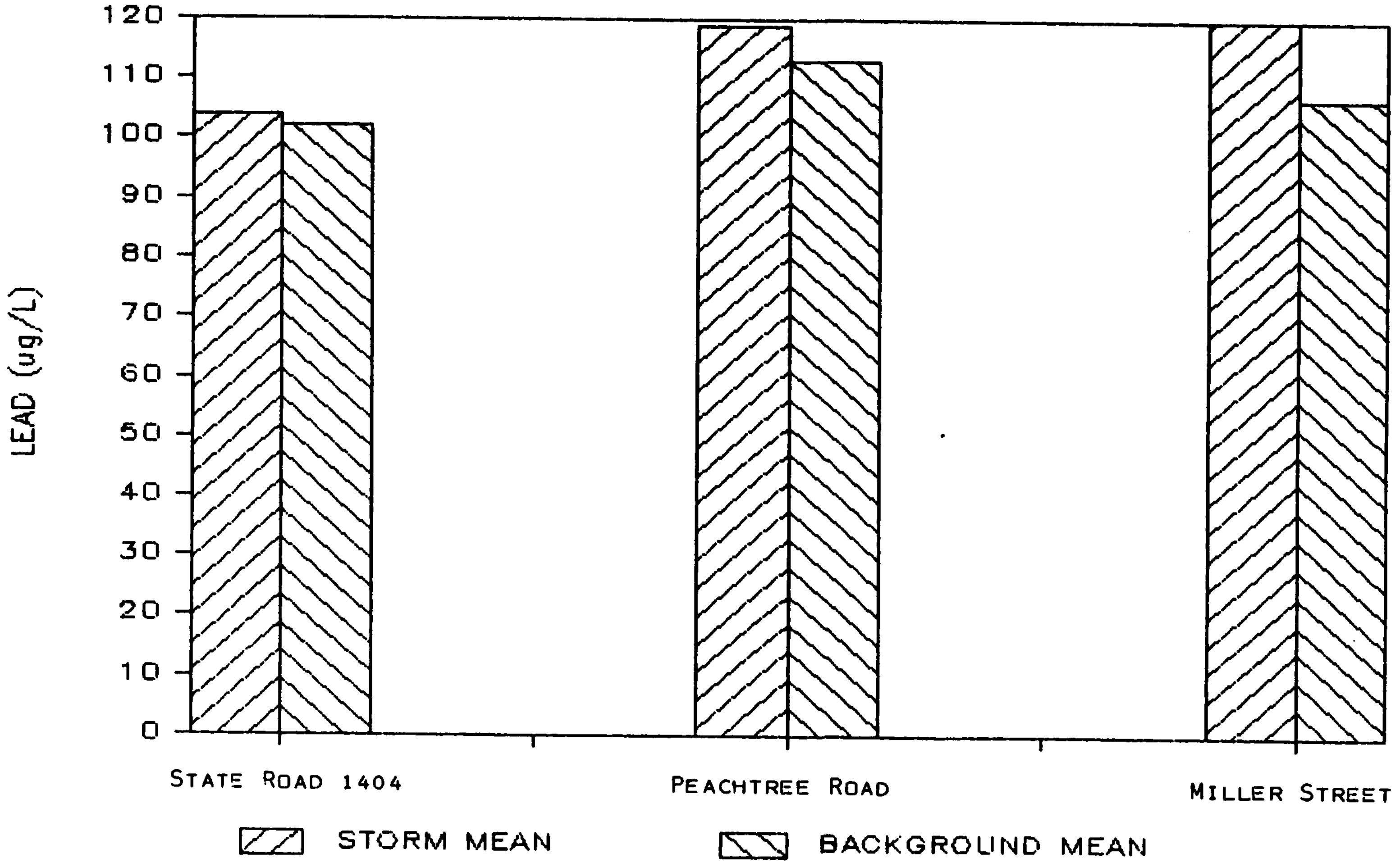
A. THE LOWEST TESTING DETECTION LIMIT



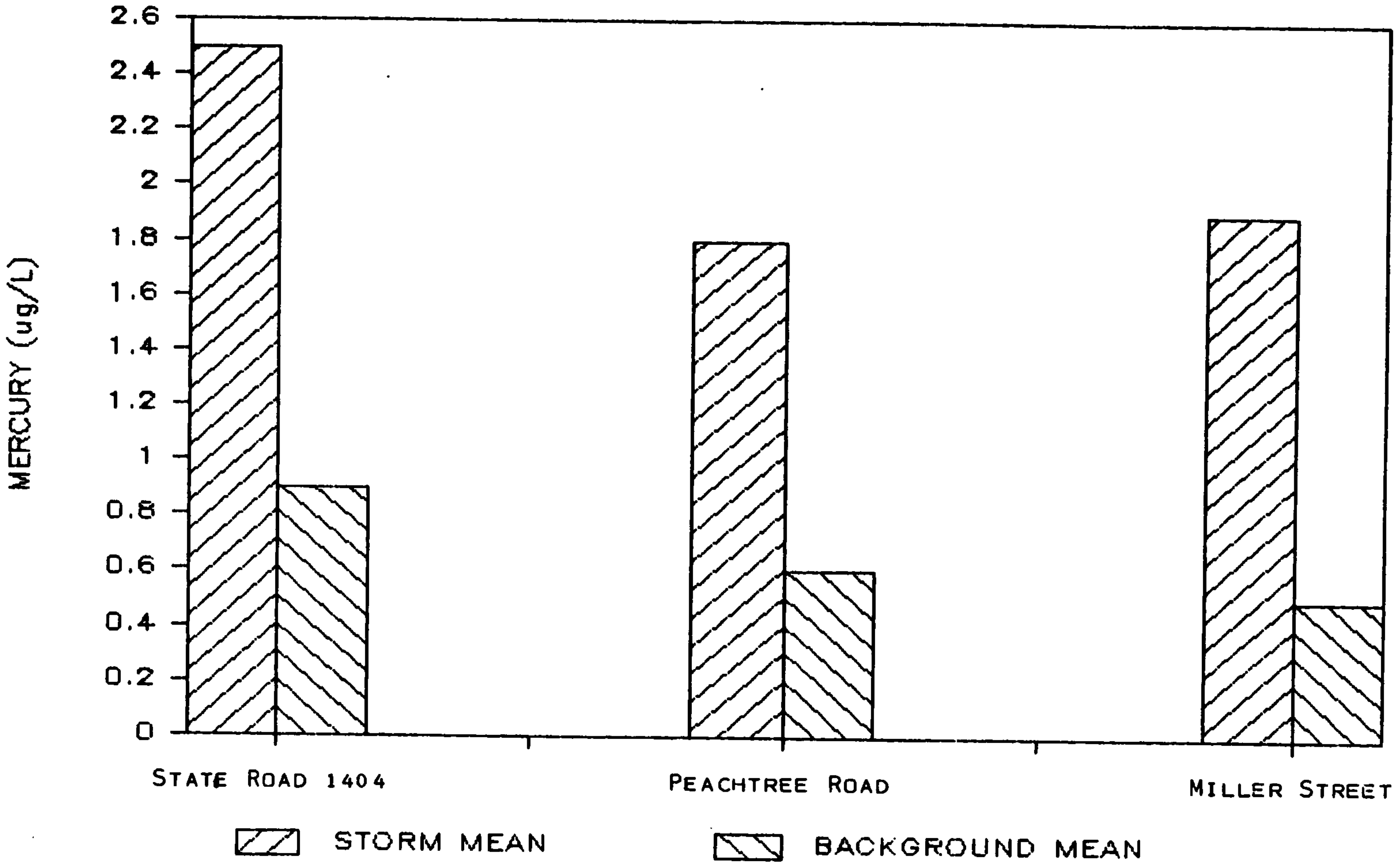
APPENDIX E-16. THE AVERAGE CHROMIUM CONCENTRATION OF THE BACKGROUND AND STORMWATER SAMPLES FROM PETERS CREEK



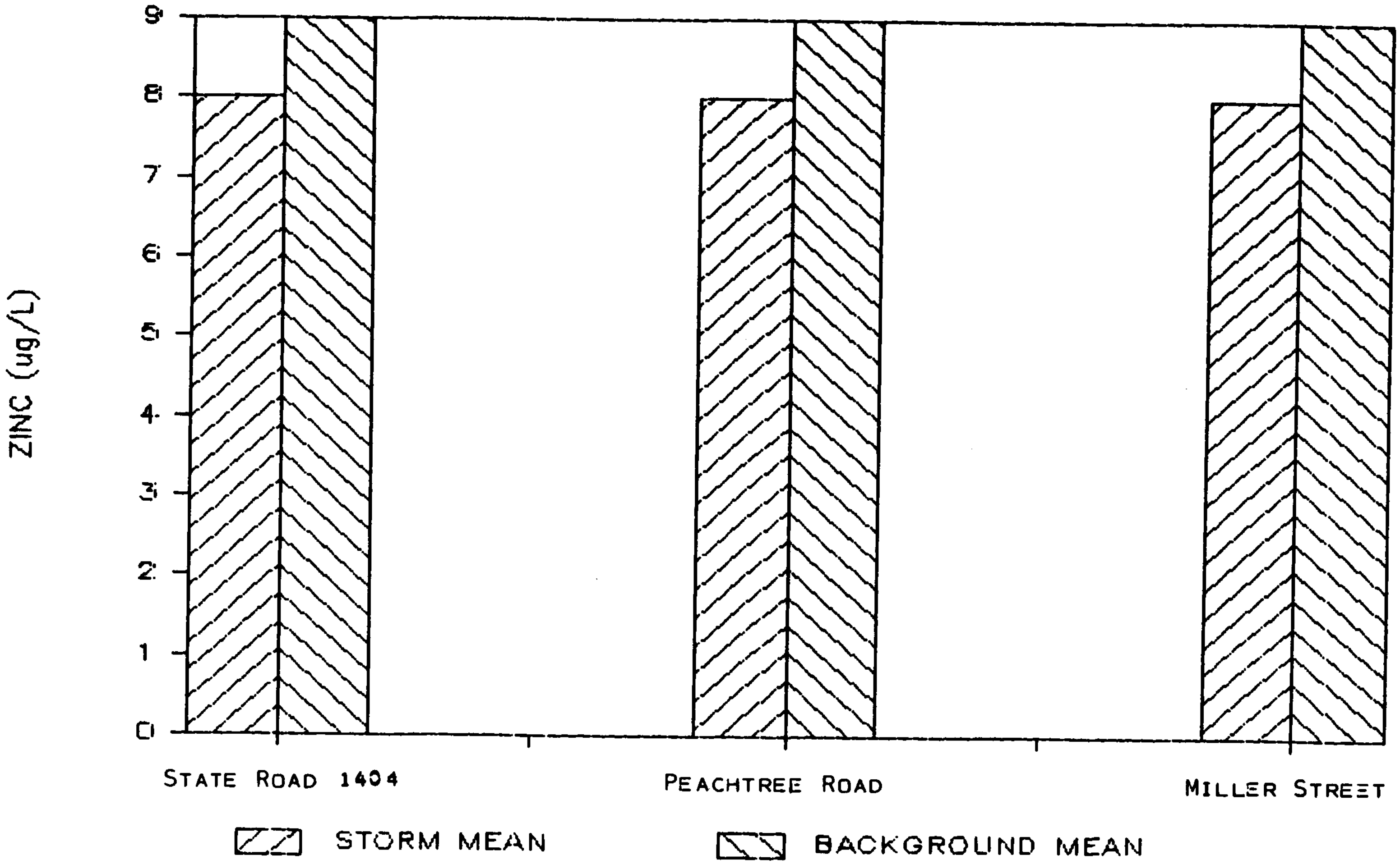
APPENDIX E-17. THE AVERAGE COPPER CONCENTRATIONS OF THE BACKGROUND AND STORMWATER SAMPLES FROM PETERS CREEK



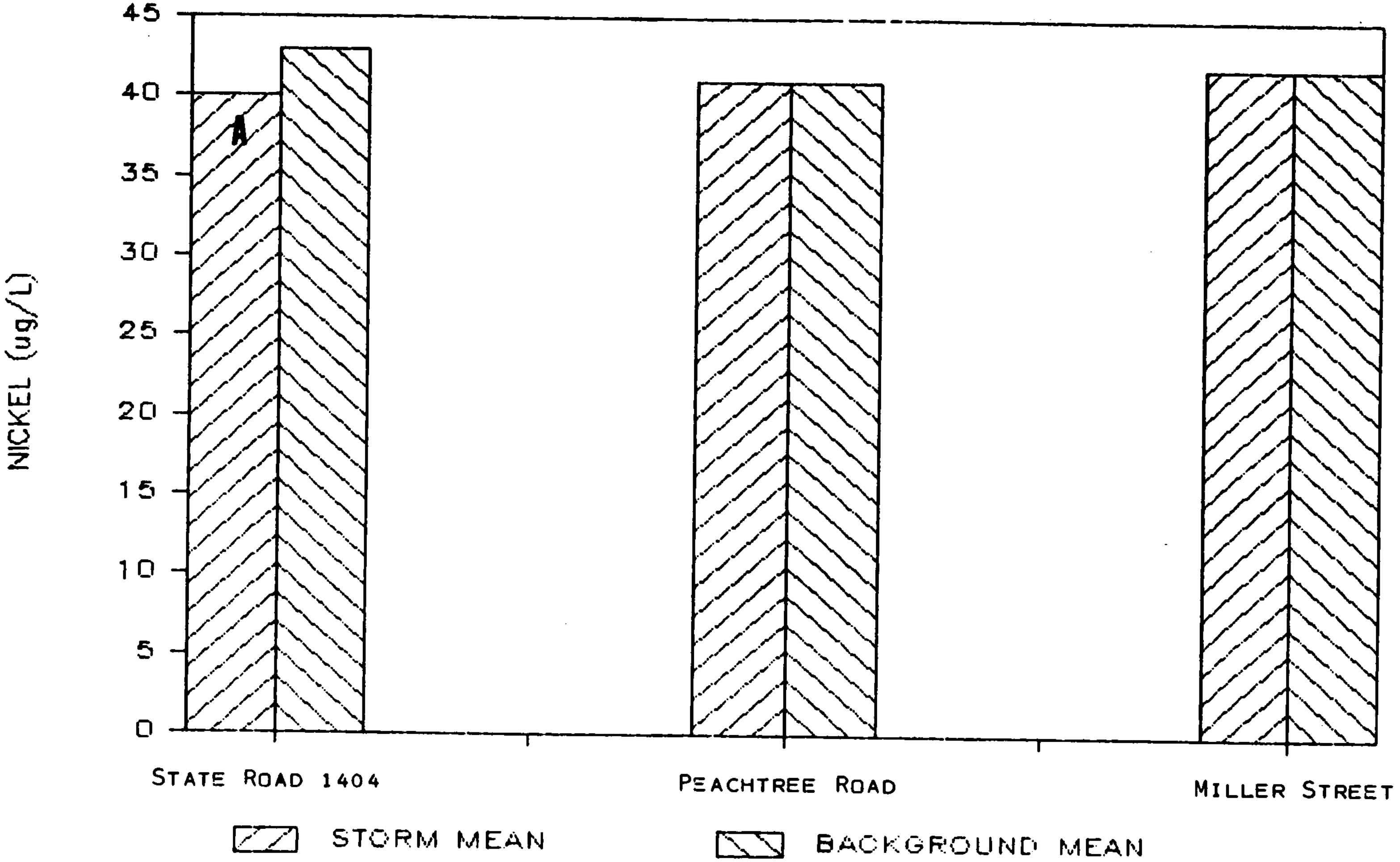
APPENDIX E-18. THE AVERAGE LEAD CONCENTRATIONS OF THE BACKGROUND AND STORMWATER SAMPLES FROM PETERS CREEK



APPENDIX E-19. THE AVERAGE MERCURY CONCENTRATION OF THE BACKGROUND AND STORMWATER SAMPLES FROM PETERS CREEK



APPENDIX E-20. THE AVERAGE ZINC CONCENTRATION OF THE BACKGROUND AND STORMWATER SAMPLES FROM PETERS CREEK



APPENDIX E-20. THE AVERAGE NICKEL CONCENTRATIONS OF THE BACKGROUND AND STORMWATER SAMPLES FROM PETERS CREEK

A. THE LOWEST TESTING DETECTION LIMIT

APPENDIX F-1

STATE ROUTE 1404 BACKGROUND SAMPLE POLLUTANT LOADS

TEST	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	SAMPLE 6	AVERAGE
TOTAL SOLIDS (gm/min)	62	110	34	25	22	31	47
VOLATILE SOLIDS (gm/min)	40	96	21	24	16	25	37
FIXED SOLIDS (gm/min)	22	15	13	1	6	5.8	10
SUSPENDED SOLIDS (gm/min)	17	2.0	4.4	0.7	1.2	7.8	5.5
SUSPENDED VOLATILE SOLIDS (gm/min)	5	1.7	2.4	0.5	0.5	2.7	2.1
SUSPENDED FIXED SOLIDS (gm/min)	12	0.3	2.0	0.2	0.7	5.1	3.4
CHLORIDES (gm/min)	0.03	1.3	0.07	0.27	0.63	0.76	0.51
TOTAL KJELDAHL NITROGEN (gm as nitrogen/min)	.14	0.07	0.14	0.07	0.10	0.07	0.11
AMMONIA (gm as nitrogen/min)	0.07	0.07	0.14	0.07	0.07	0.07	0.08
TOTAL PHOSPHORUS (gm as phosphorus/min)	0.02	0.005	0.01	.002	0.007	0.012	0.01
ORTHO-PHOSPHATES (gm as phosphorus/min)	B	B	0.01	0.002	0.003	0.005	0.005
NITRATES (gm as nitrogen/min)	0.03	0.14	0.003	0.02	0.01	0.007	0.035
NITRITES (gm as nitrogen/min)	0.002	0.002	0.007	0.002	0.002	0.002	0.003
CHEMICAL OXYGEN DEMAND (gm/min)	0.8	1.4	5.8	0.8	2.4	0.5	2.0
CADMIUM (mg/min)	B	0.8	1.7	0.8	0.8	0.8	0.9

B: INSUFFICIENT SAMPLE TO COMPLETE TEST

APPENDIX F-2 (CONTINUED)

STATE ROUTE 1404 BACKGROUND SAMPLE POLLUTANT LOAD

TEST	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	SAMPLE 6	AVERAGE
CHROMIUM (mg/min)	B	0.17	2.7	1.0	1.7	3.7	1.9
COPPER (mg/min)	B	3.4	23	3.4	3.4	8.5	8.4
LEAD (mg/min)	B	17	38	17	17	17	21
MERCURY (mg/min)	0.03	0.02	0.41	0.32	0.03	0.03	0.17
ZINC (mg/min)	B	0.8	1.7	0.8	0.8	4.2	1.7
NICKEL (mg/min)	B	6.8	14	6.8	8.2	8.2	8.7

B: INSUFFICIENT SAMPLE TO COMPLETE TEST

APPENDIX F-2

STATE ROUTE 1404 STORM POLLUTANT LOAD

TEST	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	SAMPLE 6	AVERAGE
TOTAL SOLIDS (gm/min)	U	28	53	30	48	45	41
VOLATILE SOLIDS (gm/min)	U	16	41	15	24	30	25
FIXED SOLIDS (gm/min)	U	12	12	15	23	15	15
SUSPENDED SOLIDS (gm/min)	U	2.2	1.02	6.5	11	36.7	11
SUSPENDED VOLATILE SOLIDS (gm/min)	U	1.7	0.68	1.36	2.2	7.1	2.6
SUSPENDED FIXED SOLIDS (gm/min)	U	0.51	0.34	5.1	9.2	29.5	8.9
CHLORIDES (gm/min)	U	1.0	1.02	0.82	1.3	0.44	0.92
TOTAL KJELDAHL NITROGEN (gm as nitrogen/min)	U	0.07	0.14	0.07	0.07	0.12	0.09
AMMONIA (gm as nitrogen/min)	U	0.07	0.14	0.07	0.07	0.07	0.09
TOTAL PHOSPHORUS (gm as phosphorus/min)	U	0.005	0.003	0.014	0.020	0.020	0.012
ORTHO-PHOSPHATES (gm as phosphorus/min)	U	0.002	0.003	0.002	0.003	0.002	0.002
NITRATES (gm as nitrogen/mi	U	0.18	0.02	0.02	0.014	0.019	0.051
NITRITES (gm as nitrogen/min)	U	0.002	0.003	0.002	0.002	0.002	0.002
CHEMICAL OXYGEN DEMAND (gm/min)	U	0.85	2.04	1.36	1.53	2.04	1.56
CADMIUM (mg/min)	U	0.85	1.70	0.85	1.36	0.85	1.12

B: INSUFFICIENT SAMPLE TO COMPLETE TEST
U: FLOW RATE UNKNOWN

APPENDIX F-2 (CONTINUED)

STATE ROAD 1404 STORM POLLUTANT LOADS

TEST	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	SAMPLE 6	AVERAGE
CHROMIUM (mg/min)	U	0.17	1.02	1.9	2.0	1.7	1.4
COPPER (mg/min)	U	10	10.2	9.2	13.8	10.7	10.8
LEAD (mg/min)	U	19	34	17	19	17	21
MERCURY (mg/min)	U	0.20	0.27	0.19	0.24	1.14	0.41
ZINC (mg/min)	U	0.85	1.70	0.85	0.85	3.1	1.5
NICKEL (mg/min)	U	6.8	13.6	7.1	7.1	6.8	8.3

S: INSUFFICIENT SAMPLE TO COMPLETE TEST
U: FLOW RATE UNKNOWN

APPENDIX F-3

PEACHTREE ROAD BACKGROUND SAMPLE POLLUTANT LOAD

TEST	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	SAMPLE 6	AVERAGE
TOTAL SOLIDS (gm/min)	1030	1700	1200	300	950	1400	1100
VOLATILE SOLIDS (gm/min)	430	910	520	230	540	1000	600
FIXED SOLIDS (gm/min)	600	790	680	73	410	410	500
SUSPENDED SOLIDS (gm/min)	48	180	94	6	26	24	60
SUSPENDED VOLATILE SOLIDS (gm/min)	41	41	33	3	9	20	30
SUSPENDED FIXED SOLIDS (gm/min)	7	140	61	3	17	4.1	40
CHLORIDES (gm/min)	21	36	31	24	29	33	29
TOTAL KJELDAHL NITROGEN (gm as nitrogen/min)	1.4	1.6	1.6	1.2	1.4	1.6	1.5
AMMONIA (gm as nitrogen/min)	1.4	1.6	1.6	1.2	1.6	1.6	1.5
TOTAL PHOSPHORUS (gm as phosphorus/min)	0.20	0.29	0.18	0.03	0.20	0.16	0.18
ORTHO-PHOSPHATES (gm as phosphorus/min)	B	B	0.09	0.03	0.14	0.12	0.10
NITRATES (gm as nitrogen/min)	9.3	7.7	7.6	4.9	5.3	8.9	7.3
NITRITES (gm as nitrogen/min)	0.10	0.04	0.04	0.03	0.03	0.04	0.05
CHEMICAL OXYGEN DEMAND (gm/min)	17	20	69	15	43	33	33

B: INSUFFICIENT SAMPLE TO COMPLETE TEST

APPENDIX F-3 (CONTINUED)

PEACHTREE ROAD BACKGROUND SAMPLE POLLUTANT LOAD

TEST	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	SAMPLE 6	AVERAGE
CADMIUM (mg/min)	17	20	20	15	14	29	19
CHROMIUM (mg/min)	3.4	4.1	33	6.1	12	57	19
COPPER (mg/min)	290	130	82	61	58	200	140
LEAD (mg/min)	570	410	410	310	320	410	400
MERCURY (mg/min)	0.68	4.1	2.4	4.9	0.58	0.08	2.1
ZINC (mg/min)	3.4	20	25	15	14	82	27
NICKEL (mg/min)	140	160	160	120	140	160	150

B: INSUFFICIENT SAMPLE TO COMPLETE TEST

APPENDIX F-4

PEACHTREE ROAD STORM SAMPLE POLLUTANT LOAD

TEST	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	SAMPLE 6	AVERAGE
TOTAL SOLIDS (gm/min)	120000	1400	3200	6900	1700	1500	22000
VOLATILE SOLIDS (gm/min)	47000	720	2800	2400	1000	1100	9200
FIXED SOLIDS (gm/min)	73000	700	430	4600	710	430	13000
SUSPENDED SOLIDS (gm/min)	91000	57	20	2700	53	220	16000
SUSPENDED VOLATILE SOLIDS (gm/min)	4400	31	12	580	22	170	870
SUSPENDED FIXED SOLIDS (gm/min)	87000	26	8.2	2100	31	51	15000
CHLORIDES (gm/min)	450	39	35	130	35	40	120
TOTAL KJELDAHL NITROGEN (gm as nitrogen/min)	200	2.6	1.6	11.5	1.8	2.0	37
AMMONIA (gm as nitrogen/min)	29	1.8	1.6	7.7	1.8	2.0	7.3
TOTAL PHOSPHORUS (gm as phosphorus/min)	150	0.22	0.12	4.4	0.18	0.46	26
ORTHO-PHOSPHATES (gm as phosphorus/min)	B	0.13	0.04	0.38	0.09	0.31	0.19
NITRATES (gm as nitrogen/min)	35	9.4	9.4	36	10.0	9.5	18
NITRITES (gm as nitrogen/min)	1.4	0.04	0.04	0.38	0.04	0.05	0.33
CHEMICAL OXYGEN DEMAND (gm/min)	5300	22	20	460	31	36	980
CADMIUM (mg/min)	360	22	20	96	22	26	91

APPENDIX F-4 (CONTINUED)

PEACHTREE ROAD STORM SAMPLE POLLUTANT LOADS

TEST	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	SAMPLE 6	AVERAGE
CHROMIUM (mg/min)	72	4.4	37	153	42	51	60
COPPER (mg/min)	5400	180	110	1000	320	100	1200
LEAD (mg/min)	13000	400	410	1900	570	510	2800
MERCURY (mg/min)	220	4.0	4.1	25	1.7	19	46
ZINC (mg/min)	1000	22	20	96	22	77	210
NICKEL (mg/min)	3500	180	160	770	180	200	830

APPENDIX F-5

MILLER STREET BACKGROUND SAMPLE POLLUTANT LOAD

TEST	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	SAMPLE 6	AVERAGE
TOTAL SOLIDS (gm/min)	1900	1400	480	1900	2800	1600	1700
VOLATILE SOLIDS (gm/min)	1100	770	350	1200	1900	1100	1100
FIXED SOLIDS (gm/min)	770	630	130	630	920	500	600
SUSPENDED SOLIDS (gm/min)	110	130	160	27	61	92	97
SUSPENDED VOLATILE SOLIDS (gm/min)	73	41	49	16	18	61	43
SUSPENDED FIXED SOLIDS (gm/min)	41	94	110	11	43	31	55
CHLORIDES (gm/min)	20	24	33	28	2.4	49	28
TOTAL KJELDAHL NITROGEN (gm as nitrogen/min)	1.6	1.6	2.2	2.2	2.4	2.4	2.1
AMMONIA (gm as nitrogen/min)	1.6	1.6	2.2	2.2	2.4	2.4	2.1
TOTAL PHOSPHORUS (gm as phosphorus/min)	0.33	0.41	0.33	0.05	0.24	0.06	.24
ORTHO-PHOSPHATES (gm as phosphorus/min)	B	B	0.22	0.05	0.12	0.06	.11
NITRATES (gm as nitrogen/min)	4.5	0.3	7.3	7.8	9.5	8.1	6.3
NITRITES (gm as nitrogen/min)	0.08	0.04	0.05	0.05	0.06	0.06	.06
CHEMICAL OXYGEN DEMAND (gm/min)	20	33	130	27	67	24	50
CADMIUM (mg/min)	20	20	27	27	31	31	26

APPENDIX F-5 (CONTINUED)

MILLER STREET BACKGROUND SAMPLE POLLUTTANT LOAD

TEST	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	SAMPLE 6	AVERAGE
CHROMIUM (mg/min)	4.1	4.1	5.4	16	49	55	22
COPPER (mg/min)	300	240	220	110	120	310	220
LEAD (mg/min)	570	410	540	540	610	620	550
MERCURY (mg/min)	1.6	4.9	1.1	4.3	1.8	1.2	2.5
ZINC (mg/min)	49	20	27	27	31	147	50
NICKEL (mg/min)	160	170	230	220	250	290	220

APPENDIX F-6

ILLER STREET STORM SAMPLE POLLUTANT LOAD

TEST	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	SAMPLE 6	AVERAGE
TOTAL SOLIDS (gm/min)	76000	1600	4800	41000	2500	2100	21000
VOLATILE SOLIDS (gm/min)	20000	800	4300	17000	1300	1800	7600
FIXED SOLIDS (gm/min)	56000	800	490	25000	1100	370	14000
SUSPENDED SOLIDS (gm/min)	56000	58	43	19000	210	100	13000
SUSPENDED VOLATILE SOLIDS (gm/min)	4900	41	18	2400	45	51	1200
SUSPENDED FIXED SOLIDS (gm/min)	51000	17	24	17000	170	51	11000
CHLORIDES (gm/min)	730	41	46	130	40	59	180
TOTAL KJELDAHL NITROGEN (gm as nitrogen/min)	190	2.3	2.4	56	3	3.4	42
AMMONIA (gm as nitrogen/min)	41	2.3	2.4	20	3	3.4	12
TOTAL PHOSPHORUS (gm as phosphorus/min)	110	0.17	0.12	30	0.38	0.43	23
ORTHO-PHOSPHATES (gm as phosphorus/min)	B	0.12	0.06	14	0.15	0.26	3
NITRATES (gm as nitrogen/min)	71	1.2	10	46	11	14	25
NITRITES (gm as nitrogen/min)	4.1	0.06	0.06	1.0	0.08	0.09	0.8
CHEMICAL OXYGEN DEMAND (gm/min)	3900	29	31	1800	38	26	970
CADMIUM (mg/min)	520	29	31	260	38	43	150

APPENDIX F-6 (CONTINUED)

MILLER STREET STORM SAMPLE POLLUTANT LOADS

TEST	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	SAMPLE 6	AVERAGE
CHROMIUM (mg/min)	210	5.8	6.1	510	110	68	150
COPPER (mg/min)	9300	240	170	2600	610	460	2200
LEAD (mg/min)	17300	580	610	5700	1100	850	4300
MERCURY (mg/min)	380	6.4	1.2	82	14	22	85
ZINC (mg/min)	1130	35	31	260	38	140	270
NICKEL (mg/min)	5600	230	240	2000	300	340	1500

APPENDIX G-1

STATE ROAD 1404 POLLUTANT MASS FOR EACH SAMPLED STORM (POUNDS)

TEST	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	SAMPLE 6
TOTAL SOLIDS	U	52	98	56	89	83
VOLATILE SOLIDS	U	30	76	28	44	56
FIXED SOLIDS	U	22	22	28	43	28
SUSPENDED SOLIDS	U	4.1	1.9	12	20	68
SUSPENDED VOLATILE SOLIDS	U	3.1	1.3	2.5	4.1	13
SUSPENDED FIXED SOLIDS	U	0.94	0.63	9.4	17	55
CHLORIDES	U	1.9	1.9	0.15	2.4	0.81
TOTAL KJELDAHL NITROGEN	U	0.13	0.26	0.13	0.13	0.22
AMMONIA (AS NITROGEN)	U	0.13	0.26	0.13	0.13	0.13
TOTAL PHOSPHORUS (AS PHOSPHORUS)	U	0.0093	0.0056	0.026	0.037	0.037
ORTHO-PHOSPHATES (AS PHOSPHORUS)	U	0.0037	0.0056	0.0037	0.0056	0.0037

U: UNAVAILABLE

APPENDIX G-1 (CONTINUED)

STATE ROAD 1404 POLLUTANT MASS FOR EACH SAMPLED STORM (POUNDS)

TEST	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	SAMPLE 6
NITRATES (AS NITROGEN)	U	0.33	0.037	0.037	0.026	0.035
NITRITES (AS NITROGEN)	U	0.0037	0.0056	0.0037	0.0037	0.0037
CHEMICAL OXYGEN DEMAND	U	1.6	3.8	2.5	2.8	3.8
CADMIUM	U	0.0016	0.0031	0.0016	0.0025	0.0016
CHROMIUM	U	0.00031	0.0019	0.0035	0.0037	0.0031
COPPER	U	0.019	0.019	0.017	0.026	0.020
LEAD	U	0.035	0.063	0.031	0.035	0.031
MERCURY	U	0.00037	0.00050	0.00035	0.00044	0.0021
ZINC	U	0.0016	0.0031	0.0016	0.0016	0.0057
NICKEL	U	0.013	0.025	0.013	0.013	0.013

U: UNAVAILABLE

APPENDIX G-2

PEACHTREE ROAD POLLUTANT MASS FOR EACH SAMPLED STORM (POUNDS)

TEST	SAMPLE 1	SAMPLE 2	APPENDIX 3	SAMPLE 4	SAMPLE 5	SAMPLE 6
TOTAL SOLIDS	100,000	2,600	5,900	4,600	1,300	2000
VOLATILE SOLIDS	40,000	1,300	5,200	1,600	750	1,400
FIXED SOLIDS	63,000	1,300	800	3,000	530	560
SUSPENDED SOLIDS	78,000	110	37	1700	40	290
SUSPENDED VOLATILE SOLIDS	3800	57	22	380	17	220
SUSPENDED FIXED SOLIDS	75,000	48	15	1400	23	66
CHLORIDES	390	72	65	87	26	52
TOTAL KJELDAHL NITROGEN	170	4.8	3	7.6	1.4	2.6
AMMONIA (AS NITROGEN)	25	3.3	3.0	5.1	1.4	2.6
TOTAL PHOSPHORUS (AS PHOSPHORUS)	130	0.41	0.22	2.9	0.14	0.60
ORTHO-PHOSPHATES (AS PHOSPHORUS)	U	0.24	0.074	0.25	0.068	0.40

U: UNAVAILABLE

APPENDIX G-2 (CONTINUED)

PEACHTREE ROAD POLLUTANT MASS FOR EACH SAMPLED STORM (POUNDS)

TEST	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	SAMPLE 6
NITRATES	30	17	17	24	7.5	12
NITRITES (AS NITROGEN)	1.2	0.074	0.074	0.25	0.03	0.065
CHEMICAL OXYGEN DEMAND	4,600	41	37	300	23	47
CADMIUM	0.31	0.041	0.037	0.063	0.017	0.034
CHROMIUM	0.062	0.0081	0.068	0.10	0.032	0.066
COPPER	4.6	0.33	0.20	0.68	0.24	0.13
LEAD	11	0.74	0.76	1.3	0.43	0.66
MERCURY	0.19	0.0074	0.0076	0.017	0.0013	0.025
ZINC	0.86	0.041	0.037	0.063	0.017	0.10
NICKEL	3.0	0.33	0.30	0.43	0.14	0.26

U: UNAVAILABLE

APPENDIX G-3

MILLER STREET POLLUTANT MASS FOR EACH SAMPLED STORM (POUNDS)

TEST	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	SAMPLE 6
TOTAL SOLIDS	65,000	3,000	8,900	32,000	2,200	2,900
VOLATILE SOLIDS	1,700	1,500	8,000	13,000	1,100	2,500
FIXED SOLIDS	48,000	1,500	910	20,000	950	520
SUSPENDED SOLIDS	48,000	110	80	15,000	180	140
SUSPENDED VOLATILE SOLIDS	4,200	76	33	1,900	39	77
SUSPENDED FIXED SOLIDS	44,000	31	44	13,000	150	71
CHLORIDES	630	76	85	100	34	83
TOTAL KJELDAHL NITROGEN	160	4.3	4.4	44	2.6	4.8
AMMONIA (AS NITROGEN)	35	4.3	4.4	16	2.6	4.8
TOTAL PHOSPHORUS (AS PHOSPHORUS)	95	0.31	0.22	24	0.33	0.60
ORTHO-PHOSPHATES (AS PHOSPHORUS)	U	0.22	0.11	11	0.13	0.36

U: UNAVAILABLE

APPENDIX G-3 (CONTINUED)

MILLER STREET POLLUTANT MASS FOR EACH SAMPLED STORM (POUNDS)

TEST	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	SAMPLE 6
NITRATES (AS NITROGEN)	61	2.2	19	36	9.5	20
NITRITES (AS NITROGEN)	3.5	0.11	0.11	0.79	0.069	0.13
CHEMICAL OXYGEN DEMAND	3,400	54	57	1,400	33	36
CADMIUM	0.45	0.054	0.057	0.210	0.033	0.060
CHROMIUM	0.18	0.011	0.011	0.40	0.095	0.095
COPPER	8.0	0.44	0.31	2.0	0.52	0.64
LEAD	15	1.1	1.1	4.5	0.95	1.2
MERCURY	0.33	0.012	0.0022	0.065	0.012	0.031
ZINC	0.97	0.065	0.057	0.21	0.033	0.20
NICKEL	4.8	0.43	0.44	1.6	0.26	0.48

U: UNAVAILABLE