AN ABSTRACT OF THE THESIS OF

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Title: Analysis and Estimation of Urban Runoff Constituent Concentrations as Functions of Land Use Characteristics of Watersheds at Emporia, Kansas

Abstract approved: [signature]

Eleven watersheds that drain the city of Emporia were investigated to determine relationships between land use and urban runoff water quality. Discharge, conductivity, and pH of dry-weather flow were monitored in each watershed from February through July of 1997. Samples from June and July were analyzed for major nutrients and composited for analysis of major ions and selected metals. The eleven watersheds were mapped and divided into inner, middle, and outer zones based upon distance from the main drainage channels. Land uses and soils in each watershed were mapped. Five data sets for land use and soil coverage were generated by applying five sets of distance-weighting factors to the watershed zones. Each set of land use and soil data was correlated with water quality variables and the five resulting sets of correlation coefficients were compared. The strongest correlations were generally obtained with either the land use data set that gave equal weight to all areas of each watershed or the land use data set that gave weight to the inner zones only. Correlations with concentrations were generally stronger than correlations with rates of loading, and correlations with soil classes were generally weaker than correlations with land use variables. Major ion concentrations had few strong correlations with land use variables but were found to be higher in urbanized areas. pH was lower in urbanized areas, and nitrate concentrations were clearly higher in urbanized areas. Phosphate, potassium, and iron concentrations were linked to vegetated and industrial land uses, and zinc concentrations correlated strongly with railroad land uses. Models of water quality in dry-weather runoff were formulated by regression analysis of constituent concentrations as functions of eight selected watershed variables. Models from the U.S. Geological Survey were used to estimate mean

concentrations and total loads of several pollutants in storm runoff for watersheds which drain into the Neosho River and the Cottonwood River, and the estimates were used to model pollutant concentrations in the receiving rivers. Concentrations of nitrate, phosphate, ammonia, copper, and zinc exceeded statutory or suggested water-quality standards in some samples or estimates. A water quality problem at one sampling site was recognized by the consistent absence of macroscopic life.

ANALYSIS AND ESTIMATION OF URBAN RUNOFF CONSTITUENT CONCENTRATIONS AS FUNCTIONS OF LAND USE CHARACTERISTICS OF WATERSHEDS AT EMPORIA, KANSAS

A Thesis

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My wife, Dilsa, and our first daughter, Kristina Alejandra, have patiently endured the stress and demands of my work on this thesis. We can be glad, together, that it was successfully completed. Finally, I dedicate this thesis to our second daughter, Angelica Michelle, who was born during the course of its completion.

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Chapter 1: Introduction

Research projects during the past two decades have firmly concluded that urban stormwater runoff is a major source of surface water quality problems in the United States. Non-point source pollution in urban runoff contributes over 100 different contaminants to receiving waters at sites in the U.S. (EPA, 1983). In the 1994 Report to Congress, the United States Environmental Protection Agency identified urban runoff as the fourth most important of eight principal causes of water quality problems in streams and the third most important cause of problems in lakes (EPA, 1994). The study of the relationships between water quality in urban runoff and the characteristics of urban watersheds will help to establish a basis for prediction of water quality and management of urban watersheds.

The quality of stormwater runoff from the city of Emporia has not been studied previously. Emporia hosts industrial and commercial enterprises and extensive residential areas that may contribute to water quality problems in runoff. Watersheds which drain the city of Emporia also include large tracts of agricultural land, vegetated land, and other land uses. The stormwater sewer system is separate from the sanitary sewer system and delivers runoff into small lakes and two rivers that support wildlife, recreation, wildlife harvesting, and other uses downstream.

The primary objectives of this study were to monitor runoff from the principal watersheds of Emporia over an extended period of time, to determine the concentrations of major ions in runoff from the principal watersheds during average or repetitive conditions, to analyze the principal land uses for the watersheds, and to describe major ion concentrations and water quality as functions of land use in each watershed. As secondary objectives, this study was designed to detect the occurrence of water quality problems in runoff from Emporia, to estimate chemical loading on receiving waters, and to assess possible negative effects upon receiving waters.

This study focused on eleven watersheds which drain most of the city of Emporia. An accessible sampling site was established for each watershed near the limits of urbanization, and the pH, conductivity, and discharge were measured at each site bimonthly from February through

June. Field notes were taken at each site to record odors, color of water, macroscopic life, and other conditions on each sampling day. Samples from two dates in June and July were analyzed for ammonia, nitrate, and phosphate. A composite sample for each watershed was created by combining portions of samples which were collected through June and July. The composite samples were analyzed to determine the concentrations of all major ions and selected metals.

Watershed boundaries were drawn to include all areas which contribute to surface runoff at each sampling point. Land uses and soils in the study area were classified, mapped, and digitized to determine the area covered by each class in each zone of each watershed. Watersheds were divided into inner, middle, and outer zones to allow watershed areas to be weighted according to distance from main drainage channels. Sets of distance-weighting factors were applied to the watershed zones, and, for each set, the areas covered by each soil and land use class in each watershed were calculated and expressed as area in units of square kilometers and as percent of the total watershed area.

Water quality constituent concentrations for each watershed were correlated with the watershed variables as calculated with each set of distance-weighting factors. The coefficients of correlation were used to interpret relationships between water quality constituents and land use. Land use variables that produced strong correlations were selected as independent variables in regression analyses of water quality constituent concentrations. Regression equations are reported as models for prediction of dry-weather concentrations of major ions as functions of land use.

As a final component of the study, a numerical model published by the U.S. Geological Survey was used to estimate concentrations and loads of additional water quality constituents in storm runoff as functions of land use and rainfall. Watershed boundaries were drawn to include all points above the confluence of each drainage channel with the receiving river. Estimates were calculated for all watersheds which drain the city of Emporia into the Neosho River and Cottonwood River. Concentrations in both rivers were estimated as functions of rainfall and river discharge. All calculations were made with assumptions that gave high estimates of concentrations in the rivers. Estimates were compared to published data on stormwater runoff in Topeka, Kansas.

The terms and symbols used in this study follow conventions in the field of study but some deserve definition to avoid uncertainty about their use in this thesis:

1. Watershed: the topographic area in which the slope and orientation of the surface will cause surface water to flow through the sampling point, plus any areas which contribute to discharge at the sampling point due to routing design in sub-surface stormwater sewers.

2. Watershed characteristics: used generally to include land use, total area, and other unspecified characteristics of a watershed.

3. Land use: used specifically to mean the dominant class of activity or employment which is designated or encountered in any given parcel of land.

4. Water quality constituent: any measure of water quality, whether specific or bulk, such as temperature, level of suspended solids, zinc concentration, or abundance of bacteria.

5. Analyte: a specific chemical species (e.g. calcium) subject to a chemical analysis.

6. Major ion: any or all of the principal ions typically found in surface waters-- bicarbonate, chloride, sulfate, calcium, sodium, magnesium, ammonium.

7. Concentration: the quantity of an analyte present in a unit volume of water; expressed as milligrams per liter (mg/L) or milliequivalents per liter (meq/L), except hydrogen.

8. (H+): hydrogen ion concentration, taken to be equal to hydrogen ion activity; calculated as 10 raised to the power of the negative of the measured pH, and expressed as moles per liter.

9. Loading: as used with the USGS model, the total mass of pollutant (kg) discharged from a watershed during a discrete discharge event or period of time.

10. Runoff: surficial discharge of water from any source.

11. Stormwater runoff: rapid discharges that follow precipitation events.

12. Dry weather runoff: discharges at fairly constant levels between precipitation events.

Chapter 2: Background and Assumptions of Study

National interest in urban runoff prompted past studies that have important implications for this study. Any attempt to apply the results of this study to other urban areas should be tempered by a due consideration of scope and structure of the study. The economic, geologic, climatic, and land use characteristics of the Emporia area are covered in chapter 3.

2.1 Related Previous Studies

Initial studies of water quality in urban runoff were conducted in the 1960s. Prior to that time, concern with urban runoff focused on flooding problems rather than water contamination. The Federal Water Pollution Control Act Amendments of 1972 recognized urban runoff as one of the potential causes of water contamination, and the Clean Water Act Amendments of 1977 mandated and funded projects to investigate and control pollution in urban runoff. (Portney, 1991).

The Nationwide Urban Runoff Program (NURP) was established in 1978 to assist local and state agencies in the acquisition of data on urban runoff and the cost-effectiveness of control technologies and management practices (EPA, 1983). As a centerpiece of activities, the NURP coordinated data collection and communication between 28 urban runoff projects that involved federal, state, and local agencies. The NURP compiled a database of chemical, land use, and meteorological data for stormwater samples from over 100 sites in the United States.

The NURP database provided a basis for a national assessment of pollution in urban runoff. The database and conclusions drawn from it were presented by the EPA (EPA, 1983). The U.S. Geological Survey selected portions of the NURP database to combine with data from additional USGS sites. The USGS database served for the development of nationwide models for planning-level estimation of loads and concentrations primary stormwater chemical constituents (Driver, 1994). The USGS models are applied to Emporia in chapter 6 of this study.

The U.S. Geological Survey and the Kansas Department of Health and Environment conducted an additional study, outside of the NURP database, of runoff in Shunganunga Creek in

Topeka, Kansas from 1979 to 1981 (Pope and Bevans, 1984). The study included land use analysis of the sub-basins of the creek and continuous sampling of discharge during dry-weather, snowmelt, and rainstorm conditions. Analytes included major nutrients, various metals, and suspended solids. Water quality variations were correlated with land use characteristics. Similarities in climate, soils, and land use between Topeka and Emporia permit comparison of watersheds and water quality (see chapter 6).

2.2 Overview of Chemicals in Urban Runoff and Their Sources

Urban runoff commonly contains a wide variety of chemical constituents, and concentrations may vary widely between watersheds and between storm events or discharge conditions (EPA, 1983). Urban environments include exposed surfaces of many different compositions that are subject to corrosion, weathering, abrasion, and erosion. Urban activities commonly result in emissions of particulates and smoke, discharges of liquids, and spillage or dumping of solids. Contaminants may enter a watershed by atmospheric transport and deposition, or originate from a variety of potential sources related to land use (EPA, 1983; Drever, 1982; Albitton, 1988; Cockerham and Shane, 1994).

In review of data from the Environmental Protection Agency, Pitt (1993) identified the following as the most common potential sources of contamination of urban runoff from residential and commercial areas: sanitary wastewater leakage, effluent from septic tanks, car washes, radiator flushing wastes, engine degreasing wastes, improper oil disposal, leakage of underground gasoline tanks, discharges from launderers and cleaners, and spillage at restaurants and food places. The potential for contamination from industrial sites varies with the nature of the industry and the manner of handling wastes.

As with most surface waters, runoff from any urban watershed will probably contain substantial concentrations of bicarbonate, chloride, sulfate, calcium, sodium, magnesium, and nitrate. All of the major ions are usually present in atmospheric deposition, and all except ammonium and nitrate are common products of the dissolution of bedrock and soil minerals

(Schroeder, 1992). Bicarbonate also forms in natural waters by reaction of carbon dioxide with water to produce carbonic acid. The application of salt to roads during winter adds large quantities of sodium and chloride to runoff (Pope and Bevans, 1984). With exception of nitrate, the major ions are not usually considered pollutants in surface water unless the total concentration of dissolved solids becomes excessive. The EPA has published water quality criteria for aquatic life support for total dissolved solids and alkalinity, which is largely a product of bicarbonate concentrations (EPA, 1976).

The major nutrients--ammonium, nitrate, potassium and phosphate--commonly occur in urban as well as non-urban runoff, and may cause water quality problems by supporting excessive plant and algae growth and eutrophication (Schroeder, 1992). The use and dumping of fertilizers is a common source of contamination (EPA, 1976). Nitrate and phosphate are common in atmospheric deposition, and both may derive from feedlot runoff. Nitrate is a product of natural microbial oxidation of nitrogenous organic waste. Phosphate contamination may occur due to discharges of water with detergent residues (EPA, 1976). Ammonia originates from decomposition of organic material and some industrial discharges. High ammonia concentrations may indicate contamination by bacterial loading or feedlot runoff.

Bacterial contamination of runoff may originate from livestock and grain industries, food industries, residential waste, and leakage of sanitary sewers. These same sources, as well as vegetation, may contribute oxygen-depleting substances to runoff. High suspended sediment loads result from disruption of soils and vegetation and installment of impervious surfaces (Tucker, 1978). Runoff commonly transports grease, oils, and rubber particles from streets and other surfaces as suspended or immiscible material. Detergents and surfactants may be present in some urban watersheds due to industrial or residential discharges, septic sewer leakage, inappropriate cleaners and laundry discharge, and other commercial discharges (Pitt, 1993).

The EPA lists 120 toxic chemicals as priority pollutants. During the NURP study, 121 samples from 61 sites were analyzed for priority pollutants. In these, 77 priority pollutants were detected in urban runoff, including all 14 of the inorganic pollutants and 63 of 106 organic priority pollutants (EPA, 1983). The list of priority pollutants includes the following organic chemicals that have been found in urban runoff: 13 pesticides, PCB-1260, 18 halogenated aliphatics, benzene, two chlorinated forms of benzene, toluene, 6 phenols, 1 cresol, 6 phthalate esters, and 14 polycyclic aromatic hydrocarbons. Pesticides, particularly lindane, may derive from urban lawns. Gasoline and petroleum products contribute benzene, toluene, and organic solvents. Additional sources of organic solvents include plastics manufacturing, paint, glue, and rubber (Cockerham and Shane, 1994). Phenols may originate with distillation of wood, livestock dips, organic waste, degradation of pesticides, and natural sources (EPA, 1983).

Toxic metals were the most prevalent priority pollutants found in the NURP study. Metals that occur in urban runoff include iron, zinc, copper, tin, lead, cobalt, cadmium, mercury, antimony, arsenic, nickel, silver, and aluminum. Copper, lead, and zinc were found in over 90% of all samples in the NURP database, and they were commonly the most concentrated of all contaminants. Copper, lead, and zinc concentrations exceeded freshwater chronic criteria in more than 77% of all samples (EPA, 1983). The principal known sources of metals are fossil fuel combustion, weathering and abrasion of metal alloys, auto tire wear (EPA, 1976), industrial or commercial discharge (Pitt, 1993), pesticides, and fertilizers (Cockerham and Shane, 1994).

The conductivity and pH of runoff depend upon chemical reactions among substances that derive from atmospheric sources and many terrestrial sources. All land uses have the potential to affect pH and conductivity. Conductivity, a measure of the ability of an aqueous solution to conduct an electric current, is a product all of the ions in the water regardless of their source. pH is a measure of the activity of hydrogen ions and is a result of balancing reactions between all acids and bases in the water.

The potential effects of water pollution on the environment are difficult to assess. The various constituents of urban runoff contrast greatly in their capacity to harm humans or biota in the local ecosystem (Cockerham and Shane, 1994). The hazard posed by a contaminant depends upon the types and conditions of organisms that it affects, the concentration of the chemical, time of exposure, the concentrations of other reactive chemicals, and other variables, including temperature and pH. The transport, residence, and fate of a contaminant in discharge depends upon chemical, biological, meteorological, and other conditions.

2.3 Processes That Characterize Urban Runoff

The principal source of stormwater discharge is surface runoff that directly enters drainage channels following precipitation. Dry-weather discharges may contain a small portion of surface runoff that is detained in stormwater sewer structures following precipitation. Other sources of urban runoff include groundwater seepage, intermittent flows of irrigation waters, leakage or discharge from water and sewer lines, leakage or seepage from septic tanks and holding ponds, and discharges from carwashes, laundry facilities, and other commercial or residential land uses (Pitt, 1993). Stormwater discharges may contain components from any of the above sources. Dry-weather runoff contains a smaller relative portion of surface runoff of precipitation and larger relative components of runoff from groundwater and the other sources listed above. The water samples that were collected and analyzed in this study were taken from dry-weather runoff, and modeled estimates were calculated for pollutant concentrations in stormwater runoff.

Urbanized watersheds tend to respond more rapidly to precipitation than non-urban watersheds. Impervious surfaces reduce the detention and infiltration of water that occurs on vegetated lands, and the channelization of drainage systems increases the rates of discharge. Discharges in urban areas following storm events increase more rapidly than in non-urban watersheds, peak storm discharges are higher, and the complete discharge of stormwaters occurs within a shorter period of time (Hirsch, 1990).

The highest concentrations of water quality constituents in urban runoff commonly occur slightly before or during the peak discharge which follows a storm event. During dry conditions, dust, dry precipitation, abraded particles, and weathered materials accumulate on surfaces in urban watersheds. These materials are readily eroded when rainfall occurs, producing what is known as the "first flush" (Pope and Bevans, 1984) or "flushing-out" (Mance and Harmon, 1978) in urban watersheds.

Total loading of pollutants from urban watersheds may be dominated by stormwater discharges due to the combination of high concentrations with high discharges during storm flows. However, Pitt (1991) affirmed that dry-weather flows can contribute a large portion of the total annual load to receiving waters, and pollutant concentrations in dry weather flow can be high enough to cause water quality problems.

Concentrations and total loads of some contaminants in stormwater tend to increase as the length of time between rainfall increases. This rule applies especially to metals that are deposited as dry atmospheric precipitation (Owe, 1984) and to petroleum by-products and suspended solids which are washed from roads and roofs (Pope and Bevans, 1984). Maximum concentrations and chemical loadings during winter months follow periods of snowmelt, especially for sodium and chloride (Pope and Bevans, 1984).

The greatest loading of contaminants occurs during the summer months, when temperature and precipitation are greater. The solubilities of most solids increase as temperature increases, and the increase in biological activity during the warm weather increases the production of oxygen-consuming material and bacteria. Bacterial concentrations during warm weather may be 20 times higher than those found during cold-weather periods (EPA, 1983). Additionally, seasonal warming is accompanied by increases in construction and application of fertilizers and pesticides.

The occurrence of the peak concentration of a chemical in relation to peak discharge may depend upon the source of the chemical in question and the distribution of the source within the watershed. Where agricultural land uses are widespread in an urbanized watershed, for example, peak concentrations of agricultural chemicals may occur after peak discharge due to the higher infiltration capacity of agricultural lands and consequent lag time in delivery of discharge (Pope and Bevans, 1984). Similarly, the distribution of ponds may affect the timing and rate of discharge.

2.4 Assumptions and Limitations of Study

This study, like similar studies in the past, assumes that water quality is a function of land use and related watershed characteristics. Most sources of pollutants are closely linked to specific land uses, and pollution by atmospheric deposition is partially a function of watershed area. Climatic, topographical, and geological factors can also be defined as watershed characteristics. However, the number and complexity of watershed variables makes it difficult to assemble a set of data that will allow accurate numerical descriptions and predictions of water quality.

One of the greatest limitations of this study is the lack of data to adequately represent the full variety of conditions which commonly occur in stormwater runoff. This study has focused on dry-weather conditions from February through July of 1997, and samples were taken approximately every two weeks. Time and equipment were not available to allow continuous sampling in each of the watersheds, and no samples were taken to represent the rapid changes in flows and concentrations during storm events. A more conclusive study would include analysis of runoff from storm events, and span winter as well as summer months.

The use of composite samples imposes a second limitation on the ability of the data from this study to represent recurrent conditions. Time constraints did not permit the determination of analyte concentrations in the samples from each watershed on each sampling date. Composites of samples from several sampling dates were compiled for each watershed so that the results of analyses would represent prevailing differences between watersheds. Consequently, results do not reflect the full degree of fluctuations which occur through time within any given watershed.

A third limitation on this study was the inability to undertake the analysis of all water quality constituents that can cause water quality problems and may be present in runoff from Emporia. The major ions and metals that were analyzed were chosen because their presence was predictably certain, equipment was available for their analysis, and the analytical methods for major ions are relatively fast and easy. Major ions are important components of any water system, yet they generally do not indicate the presence or cause of water quality problems. Important water quality constituents that were not analyzed include bacteria, BOD, and suspended solids.

The pH, conductivity, and discharge in each watershed were monitored throughout the period of study to provide fast and easy monitoring of fluctuations in water quality conditions. However, pH and conductivity do not indicate the presence or concentration of any of the specific chemicals which are of interest, so similar results from different watersheds or different dates do not necessarily indicate similar concentrations of chemicals. Average values and ranges define trends in water quality for each watershed. Unusually low or high results for a given watershed may indicate the presence of undesirable conditions or contamination, and unusually high or low result for a given sampling date can provide evidence of disruption in the watershed. Conductivity and pH indicate the total dissolved solids concentrations and acidity of the samples.

This study and previous studies like it employ a land use classification scheme that lacks sensitivity to the sources of water contaminants. Four principal urban land use divisions were recognized: industrial, commercial, residential, and vegetated. These classes may be distinct from an economic point of view, but they lack applicability in environmental studies such as this. According to the classification scheme, for example, an industrial bakery is in the same land use class as manufacturers of metal products and molded-plastics products, while a commercial bakery is in a separate category with gasoline stations and banks. A more appropriate classification system would group land uses according to the contaminants that they potentially will produce (e.g., those which may produce metals, those which may produce bacteria and BOD).

Additionally, the land use classification scheme does not account for variations in intensity or rate of activity, and the study assumes that chemical loading is directly related to the area of the land use. The analysis assumes, for example, that all streets have the same amount of traffic per unit area and all residential areas have the same population density.

Water quality is affected by factors other than land use that could not be incorporated into this study. Dust and gaseous emissions may be transported from a source in one watershed and deposited in neighboring watersheds. The water quality is a function of spatial variables under such circumstances, but it is not a function of the land use characteristics of the receiving watershed. Subsurface processes and stormsewer design may be important factors but were not analyzed in this study. Some watershed variables, such as population density and average channel slopes, were not considered because they are closely related to other variables (e.g., residential area) that were more easily incorporated into the study.

This study explores the untested premise that the influence of a land use area on water quality is partially a function of distance from the land use area to the sampling point and main drainage channels of the watershed. The premise has its origins in the "contributing-area" and "variable-source" hydrological models which are used for predicting surface runoff. These models assume that surface runoff in vegetated watersheds is generated by limited areas which surround principal drainage channels and expand in response to precipitation. The subsurface waters which become surface flow in contributing areas in the hydrological models are similar to sampled waters in this study that entered the drainage channel as seepage from soil and subsurface materials.

Even if it is assumed that the influence of land use upon water quality varies with distance from the main drainage channel, it is not known if the variation with distance is the same for all land uses or all chemicals, or if the variation with distance is linear, logarithmic, or of some other mathematical form. In this study, a consistent procedure was used to divide each watershed into three zones according to distance from the drainage channels, and weighting factors were applied to each zone. The arrangement of distance-weighting zones and the factors applied to them were created, with no empirical or theoretical basis, for the sake of trial-and-error experimentation.

Chapter 3: Methods and Results of Watershed Analysis

Watersheds, distance-weighting zones in watersheds, land uses, and soils of the study area were mapped on a 1:1200 scale street map of the city of Emporia, then converted into digital format for analysis with a geographic information system. Reclass and addition operations permitted the calculation of the area of each land use class, soil class, and combinations of land use and soil in each distance-weighted zone of each watershed. Watershed analyses were adequately accurate and precise.

3.1 General Description of Study Area

The city of Emporia has a population of 24,936 (Bureau of Census, 1994) and covers 23.6 square kilometers (9.2 square miles) in east-central Kansas, extending 7.2 kilometers (4.5 miles) from east to west and 4.0 kilometers (2.5 miles) from north to south. The local bodies of water which receive urban runoff support wildlife, water-contact recreation, and harvesting of wildlife. The Neosho River and Cottonwood River flow eastward by Emporia to their confluence six miles to the southeast, where they take the name of the Neosho River and enter the Flint Hills National Wildlife Refuge and John Redmond Reservoir twenty miles downstream from Emporia.

Residential areas are distributed throughout the city and predominate in the northern half of the city. Approximately 80 percent of the urban area drains into the Cottonwood River south of the city, and the remainder drains to the north into the Neosho River. A portion of the east side of the city drains into large detention ponds on the floodplain of the Neosho River. The percent of area served by sub-surface stormwater sewer systems is greater in the watersheds that drain into the Cottonwood River than in the watersheds that drain into the Neosho River. See figure 3-1 (map) for depiction of land use distributions.

Emporia hosts 24 manufacturing firms (Bureau of Census, 1994). Industrial activities in Emporia include livestock slaughter and processing, automobile parts manufacturing, industrial baking, molded plastics manufacturing, printing equipment and supplies manufacturing, grain and livestock feed processing, and vegetable oil production. Most industries are located in one of four industrial zones, some of which also include large tracts of vegetated lands. Nearly all industrial areas drain by surface and stormsewer systems into the Cottonwood River. Most of the runoff from the plant of the Iowa Beef Packaging Company is pumped to the company's wastewater treatment facility and treated before release into the Cottonwood River.

Commercial enterprises in Emporia number 339 (Bureau of Census, 1994), including restaurants, automobile service centers, retail stores, and consumer service centers. The central commercial district covers 26 city blocks along Commercial Street between the main railroads and 12th Street. Strip development extends along Commercial Street south of the main railroads, and some commercial enterprises are located in a light industrial zone in the southwest sector of the city. Dense traffic flow and commerce occurs in strip developments along Highway 50 (6th Ave.) throughout Emporia, and along Industrial Avenue north of Highway 50. Most of these areas are drained by surface and sewer into the Cottonwood River. A zone of strip development along East 12th Avenue drains into the Neosho River.

Other prominent land uses in Emporia include a public golf course, several urban parks, the campus of a state university, numerous tracts of open land, and a small municipal zoo. Portions of interstate highways are included in the study area. The municipal water and wastewater treatment plants, the municipal landfill, and the current solid waste transfer station all lie outside of the watersheds that were the principal focus of this study. The municipal wastewater treatment plant borders the Cottonwood River in the southeast sector of the city. Municipal water for the city of Emporia is taken from the Neosho River behind a low-water dam in the northwest sector of the city, above most points of discharge for runoff from Emporia.

3.2 Geomorphology and Climate

Emporia straddles a low ridge that stretches roughly east-west between the Neosho River and the Cottonwood River. Relief in the study area does not exceed 160 feet (49 meters). The Neosho River has shifted southward during recent geological time, encroaching upon the ridge and producing steeper, shorter watersheds on the north side of the drainage divide (Aber, 1997). Average slopes on the north side range from 2.5 to 15 percent, as measured along drainage channels from the drainage divide to the Neosho River. Watersheds on the south side of the drainage divide are more elongate, drainage routes are closer to parallel, and slopes vary less abruptly across the landscape. Average slopes in drainage channels between the drainage divide and the Cottonwood River range from 1.2 to 3.0 percent.

Local bedrock consists of alternating layers of limestone and thicker shale members of the Wabaunsee Group (Upper Pennsylvanian) that are slightly inclined to the west and northwest (O'Connor, 1953). Chert gravel remnants of terrace formations occur in patches on ridgetops, principally in the northwest sector of the study area. Younger, thicker, and siltier terrace formations cover bedrock over most of the southern and eastern areas. Watersheds on both sides of the divide include level or nearly-level areas in their lower reaches that belong to the floodplain and fluvial terrace formations of the Cottonwood and Neosho rivers.

Most soils in the study area are silt loams and silty clay loams, generally with silty clay subsoils (Neill, 1981). Soils on ridgetops and sideslopes range from 27 to 60 inches (69 to 150 cm) in thickness, while soil materials on terraces and floodplains are typically 60 to 100 inches deep (150 to 250 cm). Most soils have very slow to slow permeabilities and slow to medium runoff ratings. Gravelly silt loams, which develop on isolated, ridgetop remnants of chert gravel terraces, can produce rapid runoff. Runoff may also be rapid from Clime-Sogn silty clay soils where they thinly cover bedrock on ridgetops.

Emporia has a humid continental climate with hot summers, moderately cold winters, and precipitation throughout the year. Heaviest precipitation falls as rain between April and June; August and September are commonly the driest months. The maximum 24-hour total rainfall with a 2-year recurrence interval is 3.60 inches (9.1 cm), and an average of 33.0 inches (83.8 cm) of precipitation falls each year (Burns, 1976). July has a mean monthly temperature of 79^0 F (26^0 C), and a mean daily maximum of 91^0 F (32.8^0 C). January has a mean monthly temperature of 29^0 F (-1.7^0 C), and a mean daily minimum of 18^0 F (-7.7^0 C) (Bureau of Census, 1994).

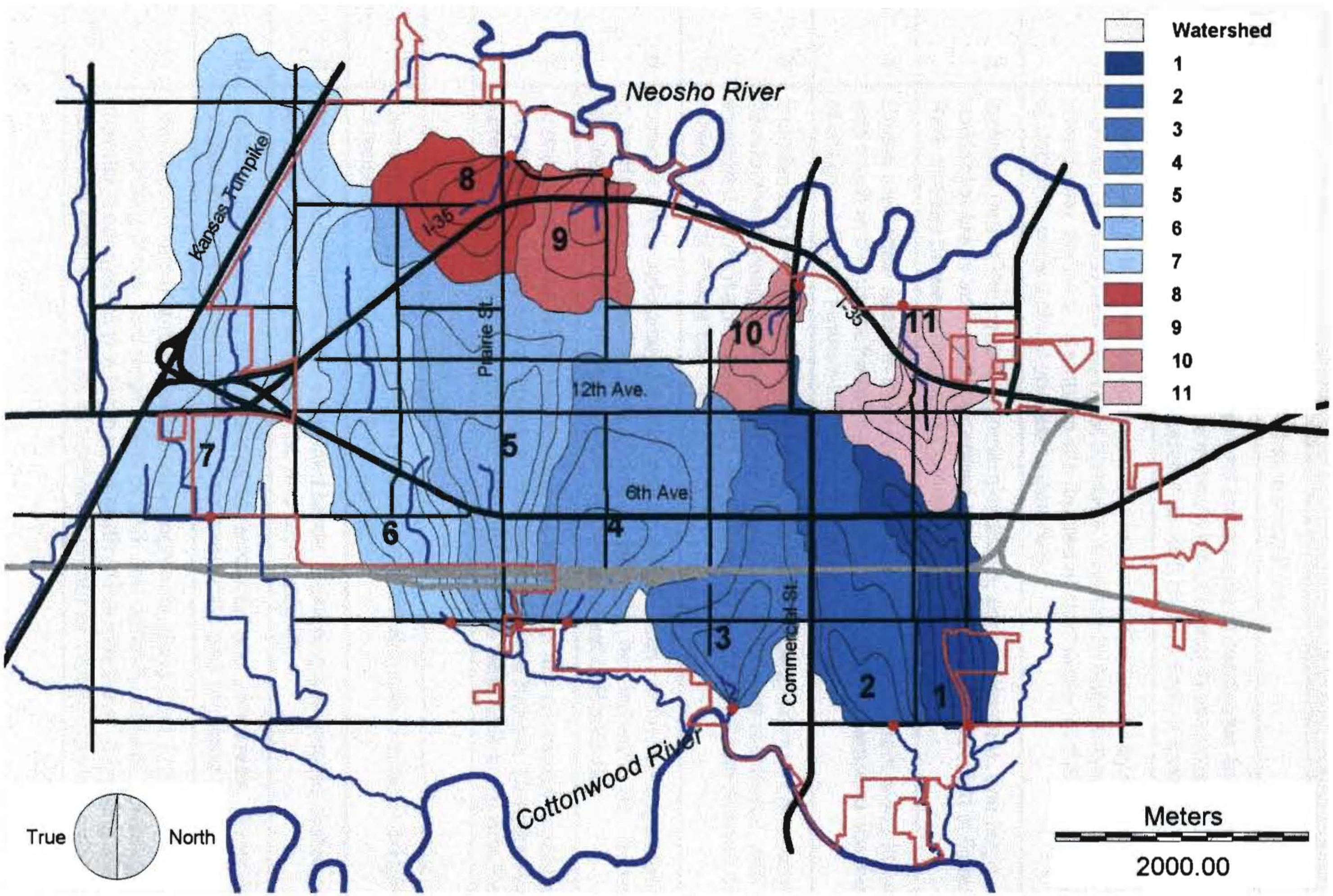
3.3 Delineation of Watersheds and Selection of Sampling Points

The term "watershed" is used here to refer to the land area from which surface water drains through each sampling point. Watershed boundaries were first outlined according to surface elevations as interpreted from 1:24,000 scale topographic maps. Eleven watersheds were chosen for study. Each watershed includes a large percent of urban area, and together the eleven watersheds cover most of the city of Emporia. See figure 3-1 (map). The watersheds range in area from 0.51 to 4.24 square kilometers in watersheds 10 and 7, respectively. The eleven watersheds cover a total area of 19.43 square kilometers.

Sampling sites for each watershed were selected at locations with safe and easy public access near or outside the limits of urbanization. Boundaries for the selected watersheds were modified and refined using ground observations of topography and stormwater sewer designs. Boundaries were drawn to exclude from a watershed all land areas in which the stormwater systems carry runoff into other topographic basins. Groundwater flow was not considered in the delineation of watersheds. See table 3-1 for descriptions of watersheds and sampling sites.

Each watershed was further divided into inner, middle, and outer zones to represent different distances from land use parcels to the principal drainage channels and sampling points. Principal drainage channels were defined as the intermittent streams as presented on the 1:24,000 scale topographic map of Emporia. Transects were drawn on the 1:1200 scale base map across each watershed perpendicular to the main drainage channel at intervals of 300 to 500 meters along each channel, beginning at the sampling point. The distance between the channel stem and the watershed boundary was divided into three portions on each side of the channel, and a point was mapped to mark each division. In watersheds with confluent channels the distance along each channel was measured from the point of confluence to the most distant point of the sub-basin, and the distance was divided into three portions. Likewise, the distance along the drainage divide between the sub-basins was measured from the point of confluence of the channels and divided into three portions. All corresponding points were connected with smooth curves to define the inner, middle, and outer zones of each watershed.

Boundaries and Zones of Urban Runoff Watersheds, Emporia, Kansas



Watersheds in shades of blue drain to Cottonwood River; those in shades of pink drain to Neosho river. Inner, middle, and outer zones of watersheds are shown in thin black lines. Sampling points are red dots. City limits are shown in red lines, streets and highways in black, and railroads in gray.

Figure 3-1: Map of Boundaries and Zones of Urban Runoff Watersheds, Emporia, Kansas.

Table 3-1: Descriptions of Watersheds and Locations of Sampling Sites

Watershed and Site	Description and Location
	Drainage to Cottonwood River
1	Includes several large industries and large tracts of residential and agricultural land. Some agricultural lands are zoned for industrial development. Sampling site located at bridge on East Logan Ave. 400 meters east of East St.
2	Drains most of the central commercial area and includes mostly residential areas. Completely urbanized and most drainage is routed through sub-surface stormsewer systems. Sampling site located at stormwater outfall 50 meters west of Logan Avenue School on East Logan Ave.
3	Includes part of the central commercial district, some industries, and large residential areas and urban vegetated areas. Sampling site located in Peter Pan Park midway between dam and Cottonwood River.
4	Drains residential areas in the core of the city, strip development along 6th Ave., and much of the Santa Fe railroad maintenance facilities. Sampling site located at bridge on South Avenue 500 meters east of Prairie St.
5	Includes two large livestock industries near the sampling site and commercial development along 6th Ave. and Industrial St. Most area is residential, with some vegetated urban tracts. Sampling site located at bridge on South Avenue 50 meters east of Prairie St.
6	Includes many industrial and commercial parcels with connected vegetated areas in southwestern industrial zone and along 6th Ave. and Industrial St. Sampling site located at bridge on South Ave. 400 meters west of Prairie St.
7	Drains lands on the western margin of the city which are principally vegetated or cropland. Includes some industries and facilities of the Kansas Turnpike Assoc. Sampling site located on West 6th Ave. 650 meters west of Graphic Arts Road.
	Drainage to Neosho River
8	Consists of residential and vegetated lands. Sampling site located at bridge on Coronado St. 50 meters east of Prairie St.
9	Consists of residential and vegetated lands. Sampling site located at stormwater outfall at intersection of Lincoln St. and Coronado St.
10	Includes many service areas as well as residential and park areas. Sampling site located at bridge at intersection of Commercial St. and Highland St.
11	Drains commercial and residential developments along East 12th Ave. and surrounding areas, and large tracts of park and agricultural land. Drainage channel is connected to a large pond north of the interstate. Sampling site located at bridge on 18th St. at northwest corner of Trusler Sports Complex.

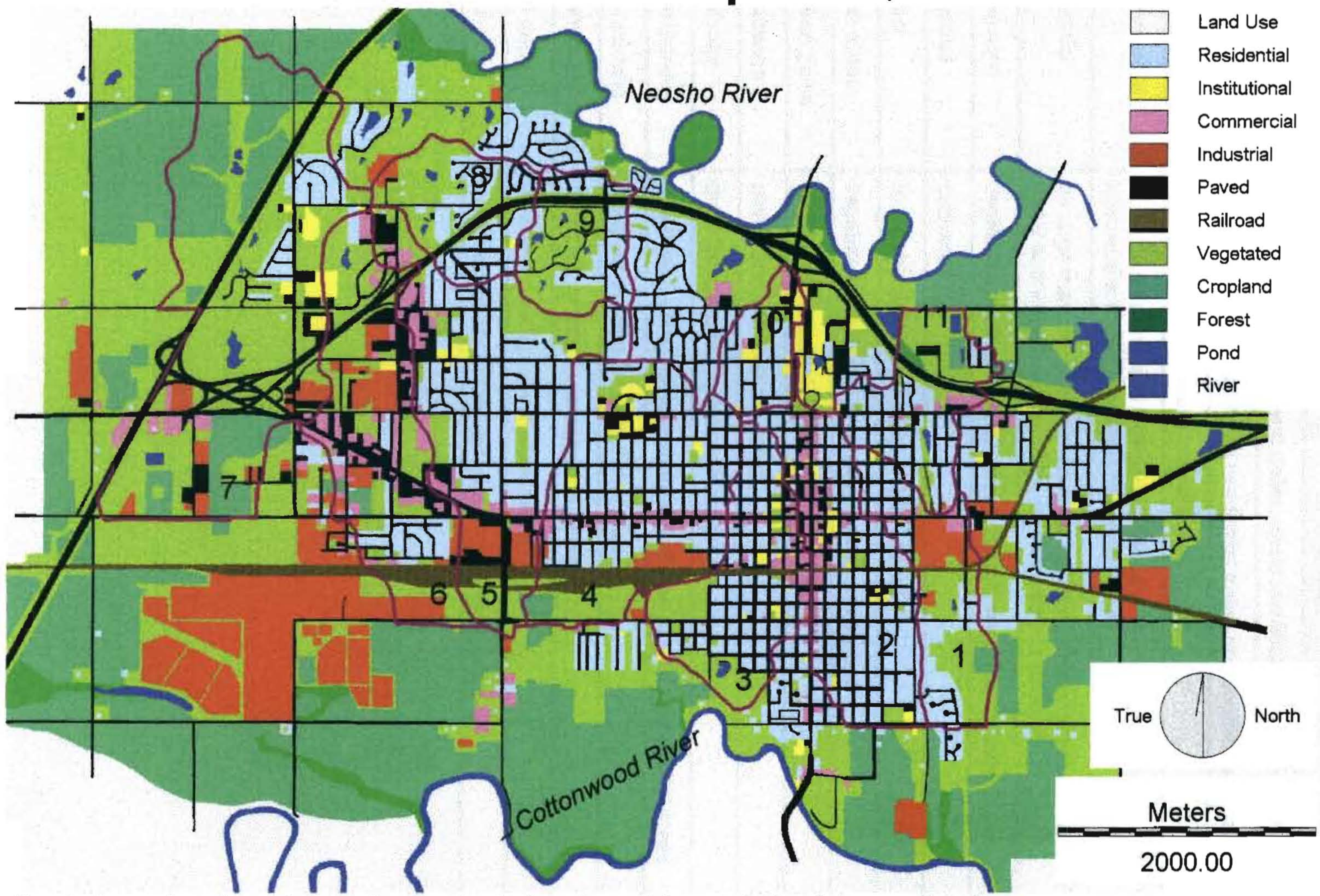
3.4 Land Use Mapping and Analysis

Land uses of the Emporia area were mapped on the 1:1200 base map using 1:9600 scale aerial photographs as the principal source of information. The municipal land use zoning map provided general guidance for mapping, and questionable areas were checked by ground observation. Land use areas were delineated as the smallest mappable units regardless of municipal zoning. Many areas which are zoned residential, commercial, or industrial were broken into parcels of agricultural, vegetated, paved, or other uses. IDRISI © software was used to calculate the area of each land use in each zone of each watershed. See figure 3-2 (map).

All land areas were classified into one of the land use classes which are listed and described in table 3-2. The area covered by each land use in each watershed was initially calculated using the classification scheme outlined in table 3-2. Revised and combined land use classes were formed according to formulae listed in table 3-3 and replaced previous classes for all subsequent analyses. Some land use parcels are included in more than one of the revised or combined classes. For example, commercial parking lots are included in the commercial class as well as the parking and impervious area classes.

The watersheds were divided into inner, middle, and outer zones to permit exploration of the premise that water quality is more greatly influenced by the land use parcels that lie more closely to the drainage channel. When calculating land use values for each watershed, greater weight was given to the land parcels of the inner and middle zones by taking smaller fractions of the middle and outer zones when calculating the land use values for each watershed. For example, the weight of land use areas was shifted towards the inner zone by calculating the area of the land use in the watershed as a sum of the area of the inner zone plus one-half the area of the middle zone and one-fourth of the area in the outer zone. Different sets of fractions yield different relative weights among the zones. The use of distance-weighting variables especially affects the land use values for watersheds that have a concentration of a particular land use class in one zone. For example, if a watershed has a concentration of industrial land use in the inner zone, the calculated percentage of industrial area will be higher with the use of distance-weighting factors.

Land Use at Emporia, Kansas



Purple lines show boundaries of watersheds (numbered) for analysis of dry-weather flow.

Figure 3-2: Map of Land Use at Emporia, Kansas

Table 3-2: Land Use Classification Scheme for Mapping

Land use Class	Description
1 High-Density Res	apartment complexes and trailer courts identifiable on aerial photos
2 Low-Density Res	single-family homes and all residential areas not identified as class 1
3 Institutional	schools, churches, municipal buildings
4 Commercial	all service businesses including automobile service and repair businesses where present in industrial zones
5 Industrial	all large manufacturing enterprises, including animal and grain products; water and wastewater facilities, electric transfer stations
6 Open rural	vegetated rural land, pastures, scrubland, roadway frontage
7 Cropland	cultivated (plowed) land
8 Forest	mappable areas with uninterrupted canopy
9 Open urban	vegetated vacant lots and open space, cemeteries
10 Urban parks	vegetated municipal parks
11 Roadways	paved and unpaved roadways
12 Railroad	main lines, spurs, and service areas
13 Res parking	off-street parking for apartment complexes or other residential areas
14 Inst parking	off-street parking for institutional areas
15 Com parking	off-street parking for commercial areas
16 Ind parking	off-street parking for industrial areas
17 Pond	mappable water bodies detectable on aerial photos

Table 3-3: Revised and Combined Land Use Classes for Watershed Analyses

Land use Class	Formula
Residential	high-density residential + low-density residential + residential parking
Institutional	institutional + institutional parking
Commercial	commercial + commercial parking
Service	commercial + institutional (including parking for both)
Industrial	industrial + industrial parking
Developed	industrial + commercial + institutional +residential + roadways + railroad
Rural	cropland + forest + open rural
Vegetated	cropland + forest + open rural + open urban + park
Paved	roadways + residential parking + institutional parking + commercial parking + industrial parking
Impervious**	(revised residential x 0.38) + (service x 0.85) +(revised industrial x 0.72) + (roadways x 0.95) + (vegetated x 0 .1)

**The coefficients of imperviousness were taken from Pope (Pope, 1984, p.12), in which he cites the U.S. Soil Conservation Service as the original source. The coefficients for streets and vegetated areas were estimated.

Five different sets of land use data were generated by applying five sets of distance-weighting factors (fractions) to the zones of each watershed. (Each set was later correlated with water quality data). The area in each land use class in each watershed were calculated by multiplying the area of the land use in each zone by the factor for the zone and then summing the products, as described in the equation below:

$$A = (AO \times FO) + (AM \times FM) + (AI \times FI)$$

A is the calculated area of the land use in the watershed, AO, AM, and AI are the areas of the land use in the outer, middle, and inner zones, respectively, and FO, FM, and FI are the distance-weighting factors for the outer, middle, and inner zones, respectively. The total area of the watersheds was calculated with the same equation. The percent of area in each land use was calculated by dividing the distance-weighted value for the land use area in the watershed by the distance-weighted value for the total area. See table 3-4 for the sets of distance-weighting factors.

The sets of distance-weighting factors which were applied to the watershed zones are arranged as a series which gives progressively greater weight to the inner zone of each watershed. When a factor of 1.0 was applied to each of the zones (set 1), all land use parcels had equal weight in determination of the land use data for the watershed. The term "standard watershed" is used here to refer to the watersheds when the zones are equally weighted. When factors of 0.0, 0.0, and 1.0 (set 5) were applied to the outer, middle, and inner zones of the watersheds, respectively, the land use parcels in the outer and middle zones had no weight in the determination of land use data; the watersheds were represented by the inner zone only. The intermediate sets of factors allowed the calculation of land use data with different relative weights for each zone.

When the sets of factors were applied as a series from set 1 through set 5, the total area of each watershed and total area in each land use decreased. The percent area in each land use in each watershed increased or decreased through the series, usually giving the maximum value with either set 1 or set 5. The maximum or minimum value in the series was obtained with set 4 for about one tenth of the calculated values. Land use values did not change in the same manner for any given watershed or land use class. For example, the percent land use in vegetated area in watershed 4 increased through the series while that for watershed 5 decreased.

Table 3-4: Sets of Distance-Weighting Factors Applied to Watershed Zones

Set	Outer zone	Middle zone	Inner zone
1	1.0	1.0	1.0
2	0.50	0.75	1.0
3	0.33	0.67	1.0
4	0.0	0.50	1.0
5	0.0	0.0	1.0

When set 1 was applied (standard watershed), the extent of rural area ranged from zero to 8 percent for most watersheds, with 21, 47, and 16 percent in watersheds 1, 7, and 11, respectively. When set 5 was applied (inner zone only), the percent of rural area was lower or the same in all but three watersheds and ranged from zero to 6.0 for most watersheds. The inner zones of watersheds 4 and 11 each had 17 percent rural area and those of watersheds 1 and 7 had 40 percent rural area.

Coverage by vegetated area in the standard watersheds ranged from 3.1 percent in watershed 2 to 72 percent in watershed 7 when set 1 was applied. When set 5 was applied, the values for percent of vegetated area was higher in all but four watersheds and ranged from 7.8 percent in watershed 2 to 76 percent in watershed 7. The percent of pond area ranged from zero to 2.1 percent in the standard watersheds. When set five was applied, the values dropped to zero or nearly zero in watersheds 5, 6, and 9, and more than doubled in watersheds 1, 3, and 7.

Watersheds 1 and 6 had 13 and 17 percent industrial area, respectively, as standard watersheds but 17 and 11 percent, respectively, in their inner zones only. All other watersheds had between zero and 5.9 percent industrial area when either set 1 or set 5 of the distance-weighting factors was applied. With equal weighting of watershed zones, residential areas covered 5.2 to 51 percent of the watersheds, and service uses covered 0.3 to 21 percent of the watersheds. With weighting of the inner zone only, five watersheds had higher values for percent residential area and three watersheds had higher values for percent service area. Residential areas covered 2.9 to 61 percent of the inner zones, and service uses covered zero to 22 percent.

The percent of impervious area in the standard watersheds ranged from 28 to 63 percent, and the percent of paved area ranged from 14 to 35 percent. Values for the inner zones only were modestly higher or lower than those for the standard watersheds, ranging from 24 to 60 percent for impervious area and 4.3 to 32 percent for paved area.

The distance-weighted land use values obtained with sets 1 and 5 are presented in table 3-5 as percent of area for eight land use classes. Actual values for areas, in square meters, are tabulated in Appendix A. As described in chapter 5, evaluation of correlation coefficients between

Table 3-5: Percent of Area in Selected Land Uses for Standard Watersheds and Inner Zones

Water-shed	Weight Factors **	Resid. Area %	Service Area %	Indust Area %	Paved Area %	Veget Area %	Rural Area %	Pond Area %	Total Area sq. km.
1	111	32.9	4.2	13.1	14.5	33.7	21.4	0.20	1.10
	001	14.1	0.0	16.7	4.3	62.1	40.3	0.90	0.26
2	111	48.7	14.5	0.07	35.4	3.1	0.3	0.00	1.77
	001	60.6	0.0	0.0	31.6	7.8	0.4	0.00	0.22
3	111	36.5	11.0	0.2	29.3	21.4	6.3	0.69	1.45
	001	43.4	1.4	0.0	31.4	21.4	0.0	4.17	0.24
4	111	45.3	10.1	3.6	23.2	12.7	7.6	0.00	2.51
	001	34.6	10.3	0.0	20.7	20.7	17.4	0.00	0.32
5	111	39.5	12.9	5.9	23.9	20.5	4.1	0.07	2.84
	001	49.8	6.3	7.4	26.7	10.8	3.6	0.00	0.59
6	111	10.2	21.1	16.5	25.6	32.7	6.0	0.36	2.15
	001	20.4	22.0	10.9	29.3	22.1	6.0	0.00	0.43
7	111	5.2	4.6	5.0	15.0	71.8	47.1	1.28	4.24
	001	3.2	0.3	5.7	14.9	75.7	40.5	3.41	1.21
8	111	39.4	0.4	2.7	18.5	38.2	0.0	1.36	0.97
	001	51.1	0.0	0.0	21.1	26.4	0.0	1.52	0.21
9	111	32.5	0.3	0.0	17.6	48.4	0.0	1.57	0.84
	001	10.8	0.0	0.0	23.8	65.4	0.0	0.01	0.13
10	111	50.7	14.7	0.0	22.1	14.8	0.0	0.00	0.51
	001	28.6	10.2	0.0	29.4	46.1	0.0	0.00	0.08
11	111	37.4	5.8	0.2	23.6	32.7	16.4	2.07	1.05
	001	28.0	7.0	0.0	22.7	47.8	17.3	2.39	0.21

**The distance-weighting factors of 1,1,1 represent the standard watershed (all zones equally weighted), and the factors of 0,0,1 represent the inner zone only (zero weight given to the outer and middle zones.

water quality variables and land use variables permitted selection of sets 1 and 5 and the eight land use classes for interpretation of the relationships between water quality and land use. Results for the other sets of distance-weighting factors and land use classes are not presented here.

3.5 Classification and Mapping of Soils

Fifteen different soil types are presented on aerial photo maps of the study area in "Soil Survey of Lyon County, Kansas" (Neill, 1983). Soils were regrouped into four classes which have similar slopes, permeabilities, runoff rates, and topographic locations (table 3-6). The four soil classes were mapped on the 1:1200 base map and digitized, and the percent area of each watershed was calculated for each soil group. Additional calculations determined the percent of each watershed, by soil class, in impervious, paved, vegetated, or crop land uses (table 3-7).

The amount of area in soil class 1 ranges from zero to 9.0 percent for watersheds on the south side of the drainage divide, while coverage exceeds 40 percent for three of the four watersheds on the north side of the drainage divide. Coincidentally, few industrial sites occupy areas of soil class 1. The total area covered by soil class 1 is smaller than the areas covered by classes 2 and 3. None of lands with soil class 1 are used for cropland, and the soil areas are roughly equally divided between developed and vegetated covers. See figure 3-3 for map of soils.

Class 2 soils, the Ladysmith soils, occupy ridgetop positions like class 1, but class 2 soils have lower slopes. The three northwestern watersheds which contain widespread soils of class 1 contain no soils of class 2. Class 2 soils are most widespread in the southeastern sector of the city, under industrial, commercial, residential, and agricultural uses. Surface ponding is common in areas of class 2 soils on level ridgetop locations, especially where drainage has been disrupted.

Soils of class 3 occupy side-slope positions throughout all watersheds. Class 3 soils cover more area than any other class, from 31 to 69 percent of the watersheds. Areas in soil class 3 are used for the full variety of land uses. In the westernmost watershed (7), 46 percent of the area is covered by vegetated soils of class 3, whereas values range from 1.5 to 21 percent for all other watersheds. The percent area covered by paved soils of class 3 ranges from 3.4 to 13.2.

Table 3-6: Soil Classification Scheme

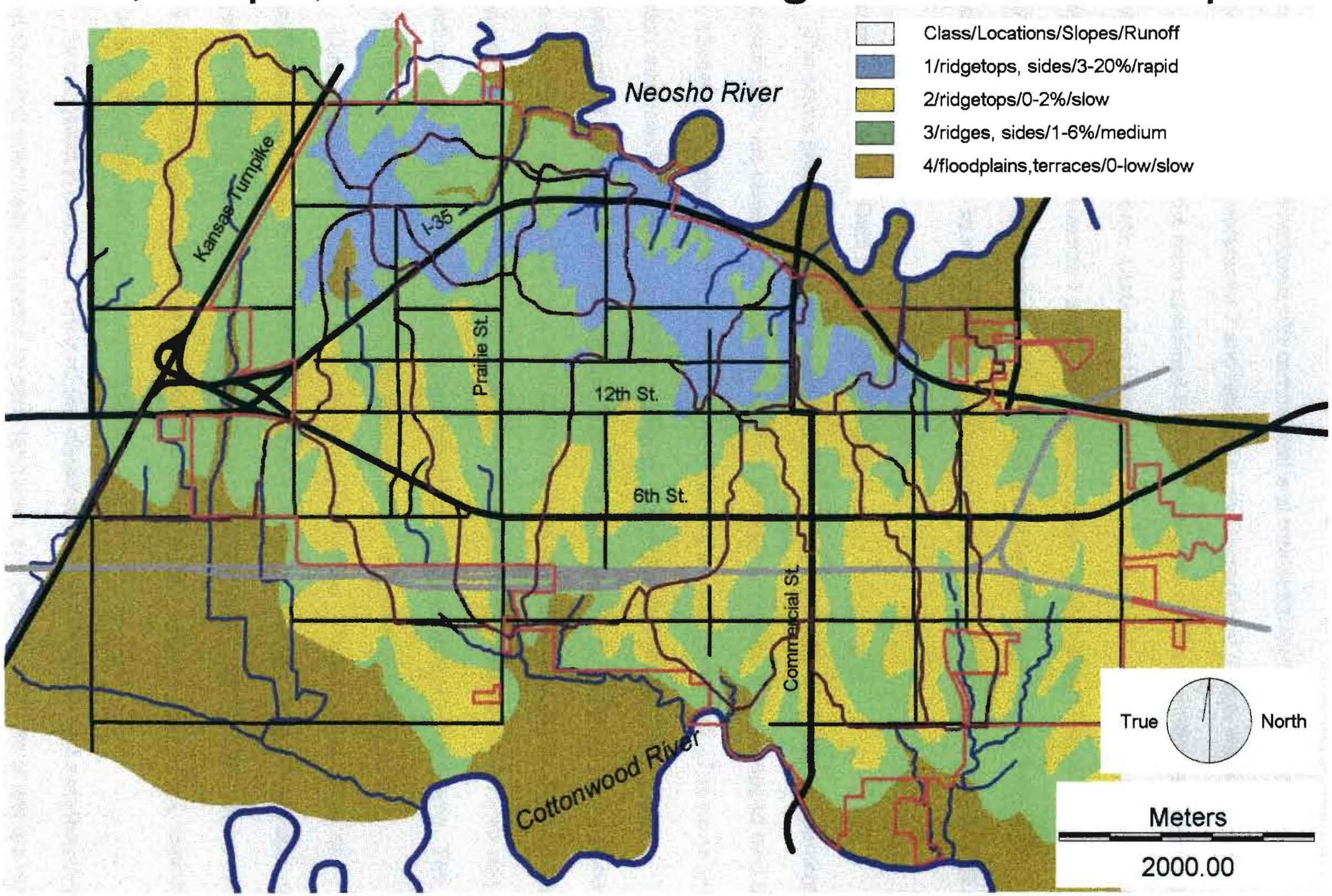
Soil Group	Members*	Locations	Slope	Runoff	Permeability
1	Cd, Oa, Ef	tops and sides of ridges	3-20	rapid	slow
2	Le	ridgetops	0-2	slow	very slow
3	Ka, Kb, Kc, Kd, La, Eb, Ed	ridges, side slopes	1-6	medium	very slow to medium
4	Ia, Ib, Ca, Oc, Ra, Ec	terraces, floodplains	0 to low	slow	very slow to medium

*See Neill (1983) for detailed descriptions of members.

Table 3-7: Percent of Area Covered by Selected Soil Classes in Each Watershed

Water shed	Soil Class 1	Soil Class 2	Soil Class 3	Soil Class 4	Paved Class 3	Paved Class 2+4	Veg. Class 3	Veg. Class 2+4
1	0.0	62.8	37.2	0.0	3.4	11.1	20.1	13.7
2	0.0	60.8	39.2	0.0	13.4	22.0	1.5	1.7
3	0.0	51.9	45.3	2.8	13.6	15.7	10.5	10.9
4	2.1	39.6	55.5	2.8	12.5	10.1	7.6	4.9
5	8.1	21.8	69.2	0.9	16.0	5.4	11.8	5.2
6	8.6	45.3	46.1	0.0	11.2	13.2	15.8	12.2
7	3.1	23.3	63.3	10.3	8.9	5.7	46.3	23.9
8	39.0	0.0	45.4	15.6	12.1	0.5	11.4	8.7
9	60.3	0.0	39.7	0.0	8.9	0.0	20.6	0.0
10	67.5	0.0	30.6	1.9	5.9	1.3	6.9	0.1
11	10.5	20.6	51.1	17.8	13.2	7.4	12.4	18.4

Soil, Slope, and Runoff Rating Classes at Emporia



Watershed are numbered and outlined in purple. City limits are red, streets and highways are black, railroads are gray, and rivers and streams are blue.

Figure 3-3: Map of Soil, Slope, and Runoff Rating Classes

Class 4 soils, found in terrace and floodplain locations, are insignificant in all watersheds except 7 and 11. Watershed 7 is the largest and most vegetated watershed, whereas watershed 11 is much more heavily developed with commercial and residential land uses. Class 4 soils underlie industrial sites in watershed 7 and residential and recreational sites in watershed 11.

Soil classes 2 and 4 were combined to form a fifth class despite the differences between the locations where they form. Class 2+4 represents areas with level to low slope and slow runoff and permeabilities, while classes 1 and 3 have higher slopes runoff ratings. The percent of watershed areas covered by pavement with low slopes and runoff ratings ranged from 1.7 to 24, and the percent coverage by vegetation with low slopes and runoff ratings ranged from 0 to 22.

3.6 Errors and Quality of Data in Watershed Analyses

The errors present in mapping had little effect on final calculations of area and percent area of each land use class in each watershed. The smallest dimension of any mapped land use parcel, 13 meters, is approximately one-fourth the width of a standard city block. The same level of resolution was used throughout mapping procedures, and digitization was performed with a standard error of less than 0.5 meters for the location of control points. The smallest watershed had an area of 0.51 square kilometers, over 3000 times the size of the smallest land use parcel (170 square meters). Some errors may have been introduced by the need to rely on curb-side observations and topographic maps to interpret the layout of sub-surface sewer systems. The areas of uncertainty probably represent less than 1% of the total area of any watershed.

Larger errors were accepted in the mapping of soil areas. The indiscrete nature of boundaries between soil classes ensures that the source for soil mapping has a level of accuracy and precision which is much lower than the level attained in land use mapping in this study. Also, the soil classes in this study provide a poor representation of slope and runoff potential, regardless of the level of accuracy and precision in mapping.

As discussed in chapter 2, the land use classification scheme has limited sensitivity to the types of chemical potentially generated by each land area, and intensity and rate of use are not incorporated into the watershed model. A change in the land use classification scheme could have radically altered the types of land uses which were reported, the areas of land use classes, and the subsequent results of correlations and regression analyses between chemical concentrations and land use variables.

Chapter 4: Methods and Results of Chemical Analyses

The sampling period for this study extended from late winter through mid-summer of the study year. Measurements of pH, conductivity, and discharge were taken to serve as long-term indicators of water quality for each watershed. Samples from two dates were analyzed for ammonia, nitrate, and phosphate. Portions of the last seven samples were composited and analyzed by standard methods for major ions and select metals.

4.1 Collection and Handling of Water Samples

Water samples were collected at each sampling site approximately every two weeks from February through July. Samples were collected in plastic bottles and maintained at ambient temperature until pH and conductivity were analyzed. Samples taken on June 23 and July 19 were filtered and preserved, following measurement of pH and conductivity, for subsequent analyses of major nutrients. Filtration was accomplished with 0.45 micron membrane filters under suction. Samples were preserved with sulfuric acid at pH 2.0 and refrigerated until analysis.

Composite samples were formulated by reserving a prescribed volume of each sample from June 6 through July 29. The composite samples were frozen for preservation; a new portion was added on each sampling day. High discharges on June 22 prevented compilation of a volume-weighted composite. Table 4-1 lists the sampling dates, the volume of each sample which was added to the composite, and the analyses which were performed on each sample.

The composite samples were thawed on the day prior to the first analyses, then 450 ml of each sample was filtered under vacuum with 0.45 micron membrane filters. One half of each filtered sample was preserved at pH 2.0 with sulfuric acid and refrigerated for analysis of nitrate and ammonium. The remaining half of each filtered portion was refrigerated without treatment for analysis of phosphate and sulfate. Of the unfiltered portions, 150 mL was preserved at pH 2.0 with nitric acid and refrigerated for analysis of metals. The remaining 600 mL of the unfiltered portions was refrigerated without treatment for analysis of bicarbonate, chloride, and conductivity.

Table 4.1: Dates of Collection of Samples, and Analyses Performed on Each.

Date	Volume to Composite	Analyses Performed
2-1		pH, conductivity
2-22		pH, conductivity
3-8		pH, conductivity
3-25		pH, conductivity
4-5		pH, conductivity
4-19		pH, conductivity
5-5		pH, conductivity
6-6	100 mL	pH, conductivity
6-12	100 mL	pH, conductivity
6-23	200 mL	pH, conductivity, nitrate, phosphate, ammonia
7-1	200 mL	none
7-14	200 mL	pH, conductivity
7-20	200 mL	pH, conductivity, nitrate, phosphate, ammonia
7-29	200 mL	pH, conductivity
	composite	conductivity, bicarbonate, chloride, sulfate, nitrate, phosphate, sodium, calcium, magnesium, potassium, iron, zinc, lead, copper, tin

4.2 In Situ Observations of Water Quality

Field observations were recorded throughout the sampling period of physical conditions, odors, and macroscopic life at the sampling sites. Extraordinary conditions were consistently present at site 2, including exceptionally clear dry-weather flow, the occasional presence of an oily surface film or surface foam, and persistent emanation of odors from the stormwater outfall. Watershed 2 is entirely urbanized and drains much of central commercial district. Also, most of the area of watershed 2 is served by sub-surface stormwater systems.

Macroscopic life was found repeatedly at all sampling sites except number 2, where no macrophages were encountered on any of the sampling dates. The channel bed at site 2 was often prolifically littered with dead earthworms, unlike the beds at the other sampling sites, indicating an absence of scavenging organisms. On one occasion, the drainage channel at site 2 was followed downstream for a distance of 100 meters, in which no macrophages were found; small fish were found in the stream 500 meters below the sampling site. Dissolved oxygen at site 2 was measured on one occasion and was found to be 10 mg/L, sufficient for aquatic life.

Macrophages which were encountered at other sites include small fishes, crayfish, aquatic insects, leeches, frogs, turtles, and worms. All of the sites, including site 2, exhibited algal growth throughout the sampling period. Unfavorable conditions at other sites occurred sporadically. On one occasion, the runoff at site 4 was thickly clouded with a white powder. Discharge at sampling site 7 had resulted in abnormally high loads of suspended solids on several sampling dates due to construction immediately upstream from the sampling site.

4.3 Monitoring of Conductivity, pH, and Discharge

Discharge was estimated at the time of sample collection by measuring the cross-sectional area of the channel and the surface velocity. A stretch of the drainage channel was identified in which the width, depth, and water velocity were fairly uniform through two feet or more of distance. The width of the wet channel was measured with a meter, and the depth was measured at intervals across the wet channel to provide an approximation of the average depth. The surface velocity of the water was determined by measuring the time required for a marshmallow to travel a measured length along a meter. Three or more measurements of velocity were taken in different parts of the channel if the current was not uniform. The reported value for discharge was the product of the cross-sectional area (width times depth) and the average surface velocity.

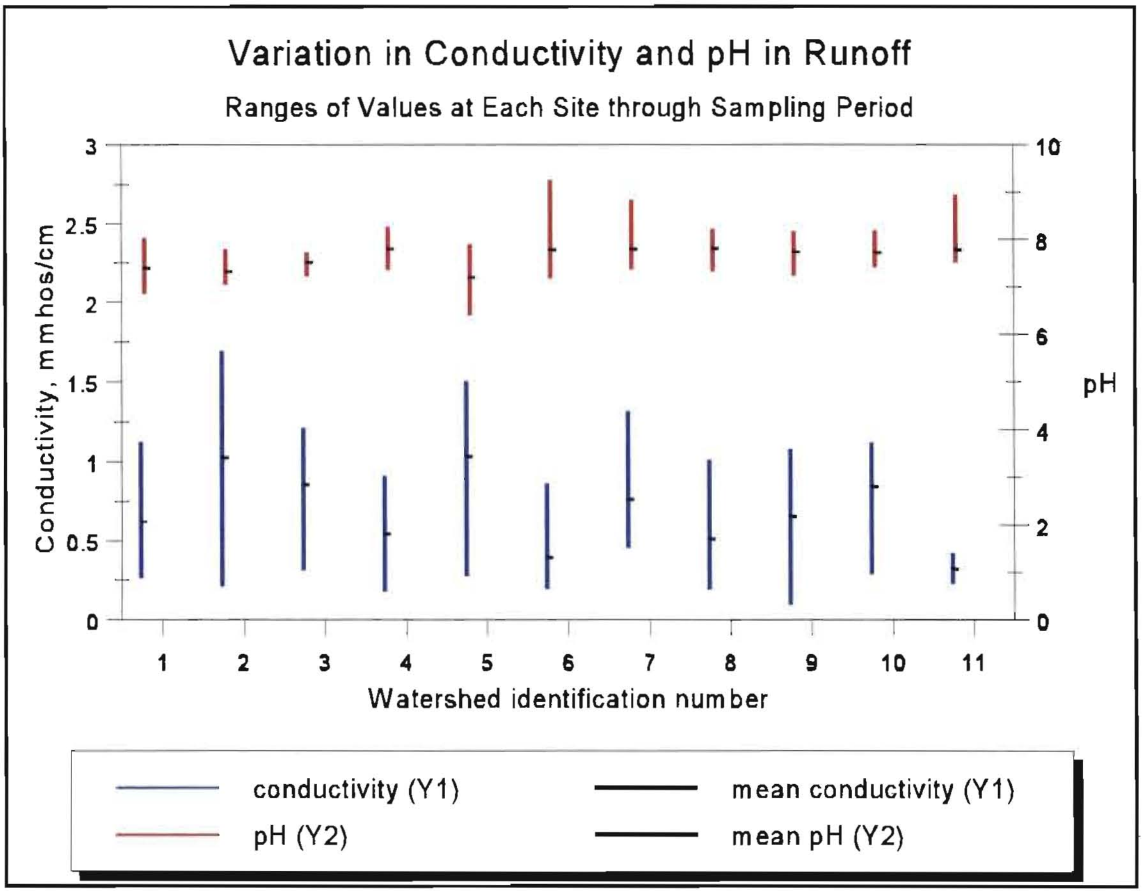
The pH and conductivity of each sample were determined within 2.0 hours and 2.5 hours respectively after collection of the first sample. The temperature of samples was recorded at the time that pH and conductivity were measured, and pH and conductivity values were corrected to 25^0 C (77^0 F) using standard formulae. Average pH values for watersheds, calculated as -log{mean(H+)}, ranged from 7.3 to 7.8, in watersheds 2 and 7, respectively. The lowest and highest temperature-corrected pH values from all samples were 6.4, on Feb. 22, and 9.3, on July 23, in watersheds 2 and 7, respectively. The pH values of natural surface waters usually range from 4 to 9 (APHA, 1985), and values between 7.0 to 8.5 are typical where carbonate minerals are abundant (Schroeder, 1992).

Average conductivities for watersheds ranged from 0.327 mmhos/cm in watershed to 1.03 mmhos/cm in watershed 5. Maximum and minimum recorded values were 0.095 and 1.69 mmhos/cm, in watersheds 9 and 2, on July 20 and May 6, respectively. Potable waters in the United States normally have conductivities between 0.050 and 1.500 mmhos/cm (APHA, 1985). Maximum, minimum and average values for pH and conductivity for each watershed are presented in figure 4.1.

The pH and conductivity values reveal consistent differences in water quality between watersheds, and a tendency for pH to be low when conductivity is high. The ranks of highest conductivities consistently included watersheds 2, 3, and 5, and watersheds 1 and 2 consistently had low pH values. The ranks of lowest conductivities consistently included watersheds 11 and 6. Watershed 11 yielded high pH values during the first half of the study, and the pH in watershed 6 was exceptionally high from late April through the end of the study.

Discharges on three sampling days were much higher than on the others, and low conductivities were measured on those days. Fluctuations in pH through time showed little

Figure 4-1: Range and Mean of Conductivity at Each Site, February through July



connection to variations in pH and discharge. Mean values of pH, conductivity, and discharge for each sampling date are depicted in figure 4.2. Precipitation had fallen within the three days preceding each of the sampling days on which high discharges were recorded. Discharges were declining to base levels, and conductivities were low because the watersheds had been flushed out. Nevertheless, the rate of loading of dissolved solids (mg/s, estimated) were greater on days of high discharge and low conductivity than on days of high conductivity and low discharge.

4.4 Analyses of Phosphate, Nitrate, and Ammonia

The samples which were collected on June 24 and July 19 were analyzed for nitrate, ammonium, and phosphate. These analytes were chosen because of their potential to cause environmental problems by supporting excessive algal growth, their importance as indicators of biological activity and organic waste, and their tendency to vary with weather and vegetative conditions during the growing season. The results of the analyses are presented in table 4-2. All analyses used standard methods as described in section 4.5.

Ammonium, phosphate, and nitrate were all detected in significant quantities in the samples of June 24, and significant quantities of phosphate and nitrate were found in the samples of July 19. Ammonia concentrations did not exceed the State of Kansas criteria for aquatic life support. (Standards depend upon temperature and pH; at pH 7.0 and temperature of 5^0 C the standard is 31.7 mg/L and at pH 8.5 and 25^0 C the standard is 2.91 mg/L (State of Kansas, 1994)). Ammonium levels were exceptionally high in watershed 2, and watersheds 2, 3, and 4 contained substantially larger concentrations of nitrate. A suggested limit for nitrate concentrations for protection of freshwater fish is 5.0 mg/L N (EPA, 1976); four samples from July 29 exceeded the level. Six of the seven samples from June 24 and three of the samples from July 19 contained phosphate in excess of the suggested level for protection of streams, 0.10 mg/L P (EPA, 1976).

The analysis of ammonia on July 19 indicated that all of the samples had less ammonia than the blanks, and the results for the later analysis of ammonia in the composite samples were the same. However, the concentrations of ammonia in the samples of June 24 were sufficiently high that the concentrations would have been measurable even if diluted by a factor of 12, and

Figure 4-2: Variation in pH, Conductivity, and Discharge

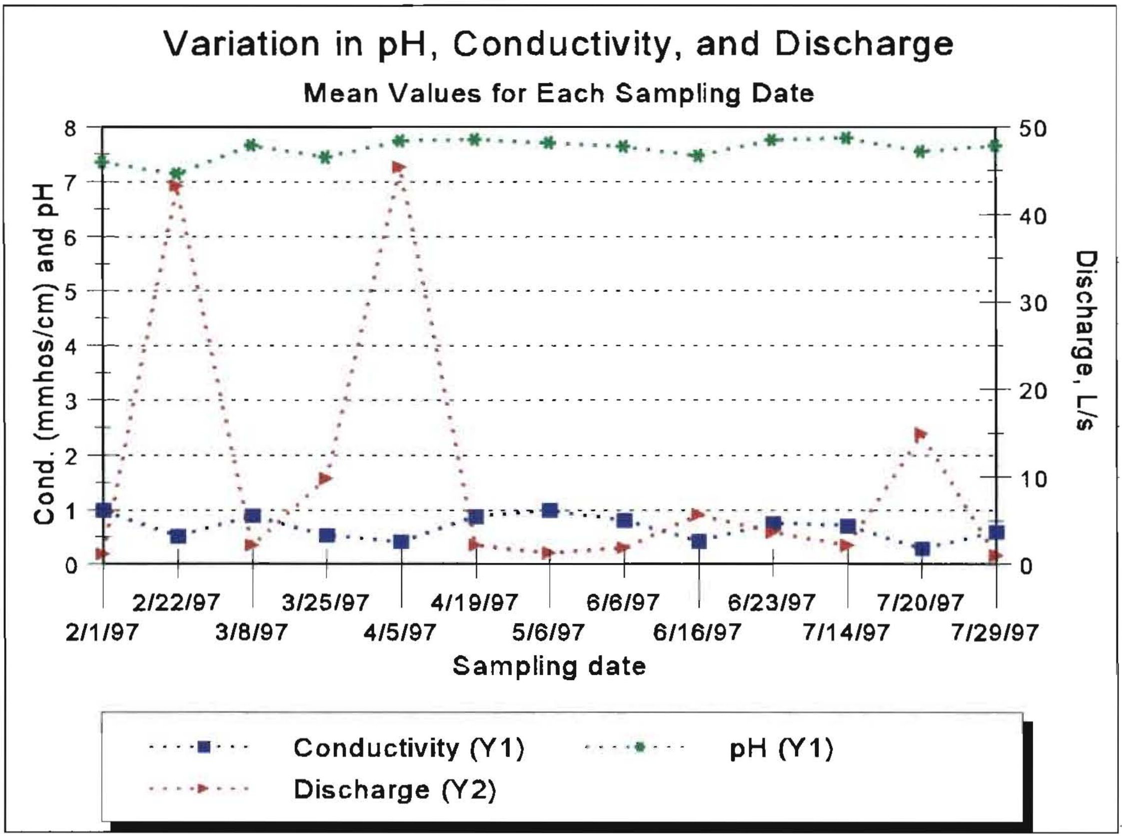


Table 4-2: Phosphate, Nitrate, and Ammonia Concentrations, June 24 and July 19.

Site	Phosphate mg/L P		Nitrate mg/L N		Ammonia mg/L N		Total N from Ammonia and Nitrate, mg/L	
	6-24	7-19	6-24	7-19	6-24	7-19	6-24	7-19
1	0.41	0.04	0.69	0.69	0.15	0.0	0.84	0.69
2	0.29	0.27	4.09	8.18	1.26	0.0	5.35	8.18
3	0.18	0.08	3.52	6.65	0.11	0.0	3.63	6.65
4	0.13	0.07	1.12	9.52	0.39	0.0	1.51	9.52
5	0.22	0.08	2.90	5.01	0.52	0.0	3.42	5.01
6	0.31	0.24	3.12	3.76	0.09	0.0	3.21	3.76
7	na	1.12	na	0.67	na	0.0	na	0.67
8	na	0.03	na	0.65	na	0.0	na	0.65
9	na	0.04	na	0.53	na	0.0	na	0.53
10	na	0.02	na	0.88	na	0.0	na	0.88
11	0.08	0.05	0.23	0.91	0.19	0.0	0.42	0.91

Na: analysis not completed

portions of the June 24 samples constituted 1/12 of the composite samples; ammonia should have been detected in the composite samples. The absence of ammonia in the composite samples, and the samples of July 19, must be attributed to chemical or biological processes which consumed the ammonia after sampling. Preservation techniques and holding times for the samples were inadequate. Nevertheless, the results of June 24 provide strong evidence that ammonia is a common component of runoff from Emporia.

Phosphate levels were highest in watershed 7, followed by watershed 1; watersheds 2 and 6 had substantial concentrations, and all other watersheds had much lower levels. This pattern was repeated in the later analysis of the composite, and yielded distinctive correlations with land uses (see chapter 5). In this respect, the composite samples effectively represent repetitive differences between watersheds. However, the composite samples do not reveal the magnitude of variations that occur with time. Phosphate levels on June 24 were as much as twice those on July 19, and nitrate levels on July 19 were as much as twice the levels on June 24. The levels of total nitrogen, from ammonia and nitrate, were 50 to more than 600 percent higher on July 19 than on June 24.

4.5 Analyses of Composite Samples

The composite samples were analyzed for all major ions and additional metals following procedures described by Schroeder (Schroeder, 1995). Equivalent methods are presented in "Standard Methods of Water and Wastewater Analysis" (APHA, 1985), with exception of the HPLC method for nitrate. Concentrations were calculated using standard formulae. Regression analyses were used to find standardization curves for calculations that were based on Beer's Law.

Results of the analyses are tabulated for the anions and cations in tables 4-3 and 4-4, respectively, and figure 4-3 presents the concentrations of the major ions. Total dissolved solids ranged from 5.0 to 18 milliequivalents per liter, or 157 to 542 mg/L, and averaged 370 mg/L. Seven watersheds had relatively low concentrations-- 5.0 to 10 meq/L-- and the remaining four watersheds had total concentrations of 15 to 18 meq/L.

Table 4-3: Concentrations of Anions in Composite Samples

Site	Concentration of Anion, mg/L				
	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^- *	PO_4^{3+} **
1	126	29.5	16.3	0.90	0.39
2	145	88.4	79.9	6.1	0.19
3	130	107	103	4.5	0.04
4	93.4	18.1	36.2	2.3	0.13
5	137	129	63.5	2.6	0.07
6	77.0	13.1	15.9	2.1	0.17
7	129	63.6	11.3	0.19	0.55
8	91.7	13.3	36.9	0.48	0.05
9	126	20.5	70.0	0.53	0.02
10	140	80.3	74.2	0.56	0.01
11	79.8	17.7	4.90	1.6	0.05
mean	116	52.8	46.5	2.0	0.15
stnd dev, %	22	94	81	71	113

* mg/L N (nitrogen as nitrate)

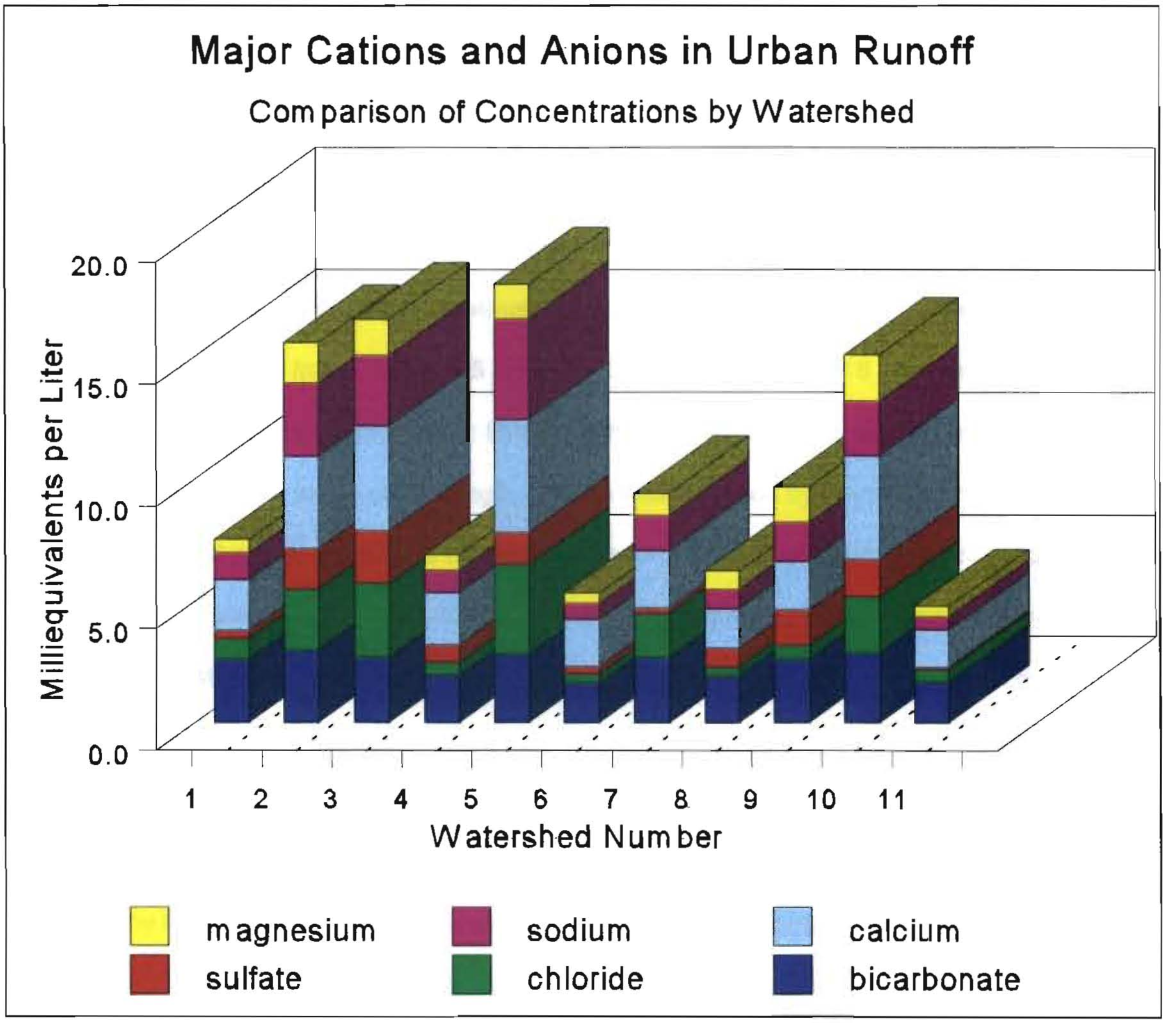
** mg/L P (phosphorus as phosphate)

Table 4-4: Concentrations of Cations in Composite Samples

Site	Concentration of Cation, mg/L					
	K^+	Na^+	Ca^{2+}	Mg^{2+}	Fe^{2+}	Zn^{2+}
1	12.9	25	42	6.6	0.53	0.033
2	5.9	68	76	20	0.20	0.019
3	5.5	66	86	17	0.21	0.016
4	7.5	21	43	7.5	0.37	0.46
5	5.3	94	92	17	0.27	0.008
6	9.1	15	38	5.1	0.37	0.044
7	20.9	33	47	11	0.56	nd
8	5.0	18	33	9.1	0.22	nd
9	4.9	36	40	18	0.23	0.008
10	4.4	51	85	23	0.39	0.008
11	4.5	12	31	5.3	0.50	0.008
mean	7.8	40	56	12.8	0.35	0.056
stnd dev, %	42	51	39	245	67	65

nd: no data (below detection level)

Figure 4-3: Concentrations of Major Ions in Each Watershed



Zinc concentrations in nine watersheds exceeded the state chronic water quality criteria of 0.003 mg/L for waters with hardness of 300 mg/L $CaCO_3$; the highest concentration was 0.46 mg/L. The concentration of nitrate in watershed 1 exceeded the suggested level of 5.0 mg/L N for protection of fish in flowing waters (EPA, 1976). Five of the samples exceeded the suggested level of 0.10 mg/L P for protection of freshwater aquatic life from phosphate.

Bicarbonate was analyzed by titration with hydrochloric acid to the bromocresol green end point. Based on the eleven composite samples, the mean concentration for dry-weather summer flow was found to range from 77.0 to 145 ppm $CaCO_3$, with a mean of 116 ppm as $CaCO_3$. Chloride was analyzed by potentiometric titration with silver nitrate. Concentrations ranged from 13.1 to 130 mg/L, with a mean of 52.8 mg/L. Nitrate was analyzed by injection with a phosphate buffer solution and mobile phase into a reversed-phase HPLC column, with detection at 208 nm (ultraviolet). Concentrations ranged from 0.48 to 6.1 mg/L nitrogen, and averaged 2.0 mg/L.

Phosphate concentrations were determined by spectrophotometric analysis at 882 nm of a complex with molybdate that was reduced by ascorbic acid. Concentrations of phosphate in dry-weather summer run-off ranged from 0.013 to 0.55 mg/L as phosphorus and averaged 0.15 mg/L. Sulfate was analyzed by reaction with barium chloride and spectrophotometric measurement of scattering by the precipitate at 420 nm. Concentrations of sulfate ranged from 4.9 to 103 mg/L and averaged 46.5 mg/L. The spectrophotometric method for ammonia detects the indophenol product, at 630 nm, given by ammonia, phenol, and hypochlorite; ammonia was not detected in any of the samples.

Calcium, sodium, magnesium, iron, zinc, lead, copper, and tin were analyzed by flame atomic absorption methods, and potassium was analyzed by flame atomic emission. Concentrations of calcium ranged from 31 to 92 mg/L, and averaged 55 mg/L. Sodium concentrations ranged from 12 mg/L to 94 mg/L, and averaged 40 mg/L. Magnesium concentrations ranged from 5.1 mg/L to 23 mg/L, and averaged 13 mg/L. Potassium concentrations ranged from 5.3 to 21 mg/L, and averaged 7.8 mg/L. Iron concentrations ranged from 0.20 to 0.56 mg/L, and averaged 0.35 mg/L.

Zinc was detected in nine of the eleven watersheds. Concentrations of zinc ranged from undetectable levels to 0.46 mg/L, and averaged 0.053 mg/L. None of the samples contained detectable concentrations of lead, copper, or tin. The detection limits for the metals were 0.0016 mg/L for zinc, 0.19 mg/L for copper, 0.77 mg/L for lead, and 1.0 mg/L for tin. Pope and Bevans (1984) reported that concentrations of these metals in dry-weather flow in Shunganunga Creek in Topeka ranged from 0.010 to 0.120 mg/L of zinc, non-detectable levels to maxima of 0.060 mg/L lead, and non-detectable levels to 0.020 mg/L for copper; iron and tin were not reported.

4.3 Interpretation of Results

The results of chemical analyses were interpreted by calculating the total of cations and anions for each watershed, in milliequivalents per liter, then expressing the concentration of each analyte in as a percent of the total of anions and cations. Watersheds were ranked in order of increasing concentration or increasing relative abundance of each analyte, and trends among rankings were noted to identify differences among the watersheds. Additionally, the concentrations and relative abundances of all analytes were correlated with each other and with results from previous analyses of pH, conductivity, discharge, nitrate, and phosphate. Correlations are described using the terms that are listed in table 4-5. The same terms will be used in chapter 5 to describe correlations between water quality constituents and land use variables.

The intervals presented in table 4-5 were chosen because a correlation of 0.50 is twice as strong as a correlation of 0.35, a correlation of 0.71 is four times as strong as a correlation of 0.35, and a correlation of 0.87 is six times as strong as one of 0.35. Correlations stronger than $\pm$0.74 are significant at the 0.01 level; correlations stronger than $\pm$0.52 are significant at the 0.10 level.

The mean conductivities for all samples taken from February through July correlate very strongly (0.94) with the conductivities of the composites, suggesting that the composite samples adequately represent the average variations among watersheds for dry-weather flow from February through July. However, conductivities of the composite samples were generally lower than the

Table 4-5: Descriptive Terms for Correlation Coefficients

Description of Coefficient	Range of Values
very weak	0.35 to -0.35
weak	0.35 to 0.50 and -0.35 to -0.50
moderate	0.50 to 0.71 and -0.50 to -0.71
strong	0.71 to 0.87 and -0.71 to -0.87
very strong	0.87 to 1.00 and -.87 to -1.00

mean conductivities, indicating that composite samples underestimate mean concentrations of total dissolved solids and the major ions (table 4-6). Also, the mean discharges for all samples correlated weakly (0.40) with the volume-weighted discharges of the composites.

Weak negative correlations exist between conductivity and discharge for the composite samples and for the averages of all samples. There may be a tendency for watersheds which produce smaller discharges to have higher total dissolved solids during dry weather flow, but factors other than discharge are of equal or greater importance. All of the constituents including hydrogen show weak or very weak negative relationships with discharge; bicarbonate and magnesium have moderate negative correlations.

Conductivities have, predictably, strong positive correlations with the most concentrated ions--bicarbonate, chloride, sulfate, sodium, calcium, and magnesium (all are greater than 0.83). Nitrate has a moderate positive correlation with conductivity. Potassium and phosphate have very weak negative correlations with conductivity, and iron has a moderate negative correlation, revealing a tendency of these ions to have lower concentrations in watersheds which produce larger concentrations of the dominant ions.

The mean concentration of H^+ from February through July correlates strongly (0.70) with the conductivities and total dissolved solids of the composite samples. Watersheds which produce low pH tend to produce high total dissolved load. For the same reason, H^+ concentration shows strong positive correlations with sodium and chloride and moderate positive correlations with bicarbonate and calcium. Surprisingly, pH has weak or very weak correlations with all of conjugate bases of the common acids-- nitrate, sulfate, and phosphate-- except bicarbonate.

The principal anion in dry-weather runoff is bicarbonate, and chloride and sulfate generally rank second and third. Bicarbonate accounted for 14 to 30 percent of the total of anions and cations in the composite samples, with a mean of 22 percent. Chloride accounted for 6 to 18 percent of the total, and exceeded bicarbonate in two watersheds. Sulfate accounted for 2 to 13 percent, exceeding chloride in three watersheds. Nitrate and phosphate are present in significant concentrations, but supplied less than 3 percent of the total of cations and anions.

Table 4-6: Comparison of Conductivities and Discharges for Composites and All Samples.

Site	Conductivity, mmhos/cm				Discharge, L/s			
	Com-posite	All Samples, Feb.-July			Com-posite	All Samples, Feb.-July		
		mean	min	max		mean	min	max
1	0.412	0.618	0.264	1.12	3.2	5.3	0.2	35.0
2	0.772	1.02	0.210	1.69	2.0	5.3	0.1	22.5
3	0.863	0.854	0.314	1.21	7.2	6.9	1.3	24.0
4	0.365	0.543	0.178	0.909	2.4	6.4	0.6	37.5
5	0.884	1.03	0.275	1.51	6.2	11.8	3.1	56.0
6	0.270	0.395	0.194	0.863	5.6	12.8	0.3	57.6
7	0.462	0.764	0.452	1.33	1.5	20.5	0.0	150
8	0.341	0.511	0.190	1.01	6.1	6.4	0.0	41.4
9	0.491	0.655	0.095	1.08	3.2	8.1	0.0	41.3
10	0.709	0.842	0.290	1.12	0.5	1.5	0.1	8.9
11	0.257	0.327	0.228	0.423	10.4	20.9	0.1	130

The principal cations in dry-weather runoff were calcium, sodium, and magnesium, in that order of importance. Calcium constituted 18 to 29 percent of the total of cations and anions, sodium accounted for 9 to 29 percent, and magnesium contributed 6 to 13 percent. When expressed as molarity, sodium concentrations exceeded calcium concentrations in all but three watersheds. Magnesium concentrations, in milliequivalents per liter, exceeded sodium concentrations in four watersheds, but elsewhere were a mere half of sodium concentrations. Potassium was present in significant concentrations in all watersheds but contributed less than 5 percent of the total of cations and anions. Iron accounted for less than 1 percent of the total.

Bicarbonate and chloride both had very strong positive correlations with the principal cations and moderate positive correlations with each other. The correlations of chloride with sodium and calcium (each 0.95) were stronger than those of bicarbonate with sodium and calcium (0.78 and 0.75, respectively). See figure 4-4. Bicarbonate correlated more strongly with magnesium than did chloride. The two dominant anions had moderate positive correlations with sulfate and very weak correlations with the other ions.

A very strong correlation (0.93) occurred between calcium and sodium, and both cations had strong positive correlations with magnesium. Apparently, their concentrations were determined by watershed characteristics in very similar manners. Magnesium correlated more strongly with bicarbonate and sulfate and less strongly with chloride than did calcium and sodium, which suggests that the sources of magnesium were more restricted to carbonate and sulfate minerals.

The percents of total dissolved solids represented by sodium and chloride had strong positive correlations (0.89 and 0.77, respectively) with total dissolved solids (figure 4-5). Conversely, the percentages of total dissolved solids represented by calcium and bicarbonate show weak and very strong negative correlations (-0.47 and -0.95, respectively) with total dissolved solids. Sodium and chloride constituted larger percentages of the more concentrated discharges, and watersheds which produced larger total dissolved solids may have had more active or extensive sources of sodium and chloride (figure 4-5). The percentages of total dissolved solids represented by magnesium and sulfate had weak positive correlations with total dissolved solids.

Figure 4-4: Variation of Calcium and Sodium in Relation to Chloride

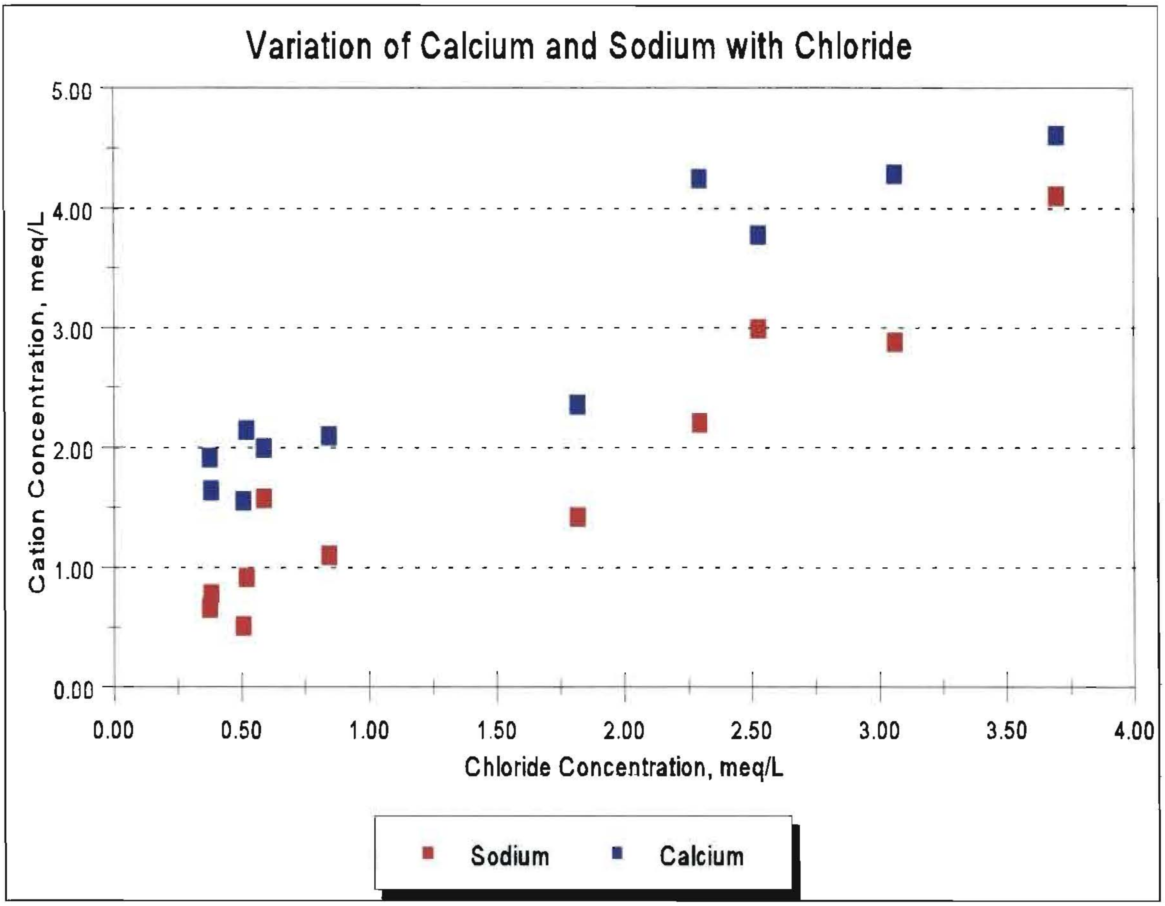
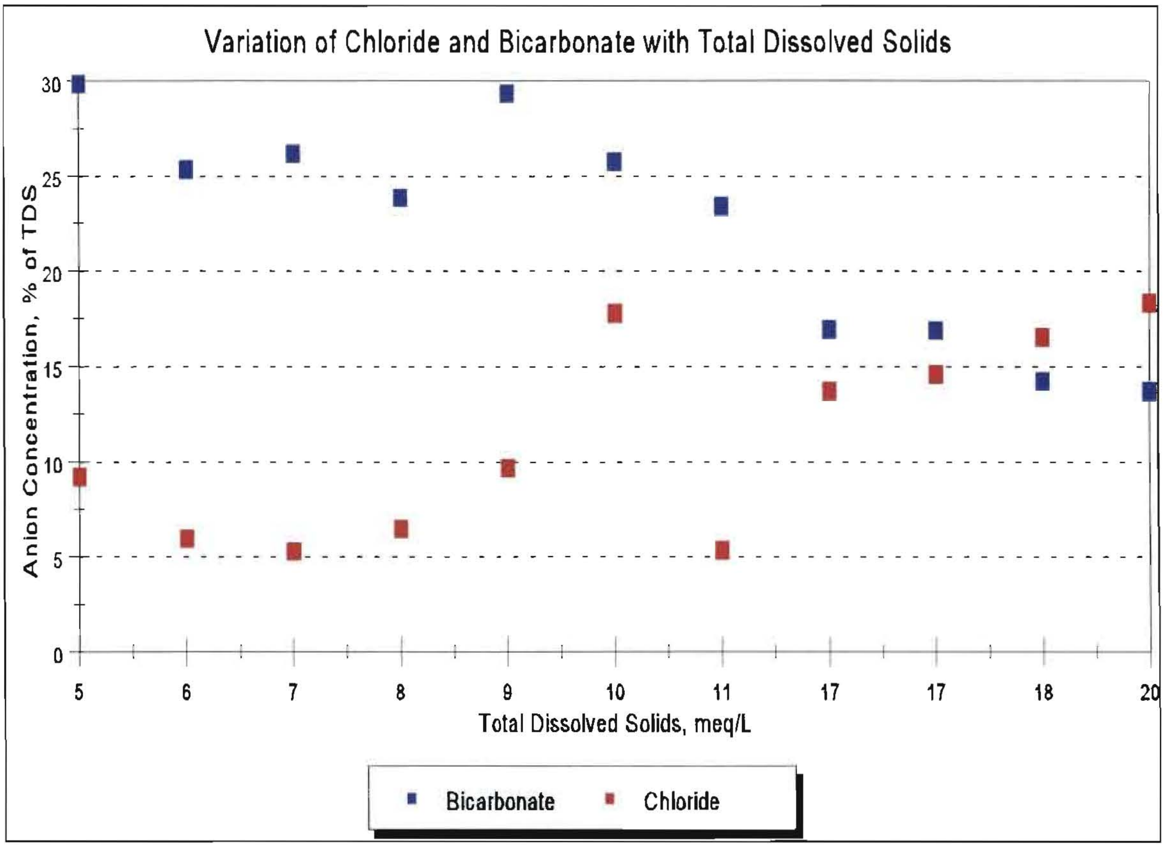


Figure 4-5: Variation of Chloride and Bicarbonate as Percent of Total Dissolved Solids



Watersheds 5, 3, and 2 consistently had the highest concentrations of the major ions, followed by watersheds 10, 7 and 9, but not necessarily in that order. Watershed 5 had an exceptionally high concentration of sodium the highest and second-highest concentrations of calcium and magnesium, respectively. The lowest concentrations of sodium, calcium, and sulfate were found in watershed 11, and watershed 8 also had low concentrations of most major ions. The lowest concentrations of bicarbonate, chloride, and magnesium were found in watershed 6, which also had outstanding high pH values.

Sulfate had a moderate positive correlations with nitrate, and correlations with other analytes follow similar patterns--positive correlations with the three principal cations, weaker positive correlations with bicarbonate and chloride, and negative correlations with potassium and phosphate. Coefficients with sulfate are generally stronger than those with nitrate, and a very strong (0.87) correlation exists between sulfate and magnesium. The correlation of sulfate with iron is strongly negative, suggesting that the land uses which gives rise to sulfate compete for space with the land uses which give rise to iron.

The concentrations of total nitrogen from ammonia and nitrate compare favorably with those from the samples of June 24 and July 19. The concentrations of total nitrogen from nitrate and ammonia were higher on July 19 than on June 24, by less than 100%. Concentrations in composite samples were between those for July 19 and June 24 for all watersheds except watershed 11, which yielded higher results in the composite sample than on either June 24 or July 19. Highest concentrations of nitrogen were generally found watershed 2, followed by watersheds 3, 4, 5, and 6.

The concentrations of major ions in the samples from watersheds 1 and 7 ranked in the middle among concentrations from all watersheds. However, the pattern of phosphate concentrations that was found in samples from June 24 and July 19 was repeated in the composite sample for phosphate and potassium. Exceptionally high concentrations of each analyte were found in watershed 7, and watershed 1 ranked second for each chemical. Watersheds 5, 4, and 2 followed, but not necessarily in that order.

Potassium and phosphate correlate very strongly with each other and show similar patterns of correlation with the other ions. Iron concentrations have moderate positive correlations with potassium and phosphate, suggesting that the chemicals derive from similar land uses. Correlations of potassium, phosphate, and iron with all other ions are weakly to moderately negative. The percents of total dissolved solids given by potassium and phosphate have negative correlations with total dissolved solids; their highest concentrations do not occur in the discharges that have the highest total concentrations.

The highest iron concentrations were also found in watersheds 7 and 1, but the distribution of concentrations was not elsewhere similar to those of potassium and phosphate. Watershed 11, which had the lowest total dissolved solids, ranked third for iron concentrations. The percent of total dissolved solids given by iron has a very strong negative correlation (-0.81) with total dissolved solids, which may reflect decreasing iron solubility with increasing concentrations of other species. Iron concentrations were low in all watersheds compared to the major ions, which derive from many sources, so any correlation coefficients do not serve to illuminate connections between iron and major ions, if any connections exist.

The high pH values in watershed 6 during the summer months suggest the occurrence of excessive algal growth and possible pollution by the major nutrients--nitrate, phosphate, and potassium. However, concentration of the nutrients in several other watersheds exceeded those of watershed 6. Also, the weathering of carbonate minerals of calcium and magnesium may cause pH to rise, yet the concentrations of all major cations in watershed 6 were surprisingly low, and bicarbonate constituted a high (26) percent of the total of cations and anions. The cause of the high pH values remains uncertain.

4.6 Errors in Chemical Analyses

The mean concentrations of the major cations may be reported with only two significant digits and the accuracy of the means remains questionable, for reasons described below. Results for nitrate are questionable; the precision of the analyses permit the use of three significant digits for mean concentrations, but the determined levels of nitrate may not have been present originally in the samples. All other values for mean concentrations may be reported with three significant digits. Two significant digits are adequate for the application of water quality standards and regression analyses of the constituent concentrations.

Ammonia was not detected in any of the samples due to bacterial consumption, and analysis of ammmonia as a function of land use could not be completed. If the nitrogen in the ammonia was oxidized to nitrate, then the descriptions of nitrate concentrations as functions of land use actually represent total nitrogen concentrations. Results for nitrate may be low, particularly for watersheds 7 through 11, due to drifting baseline in the HPLC instrument during analysis; any errors were less than 10 percent of the total.

Results for bicarbonate, chloride, potassium, phosphate, and iron were accepted without suspicion of significant error. The concentration of zinc was exceptionally high in one watershed; contamination of the sample should be regarded as a possible cause of the skewed distribution. Results for sulfate may be low, by less than 5%, due to irregularities in the rates of formation and settling of the barium sulfate colloid which was used in the colorimetric analysis.

When ionic concentrations are expressed as milliequivalents per liter, the total concentration of anions in each sample should equal the total concentration of cations, within a range of error which increases as the total concentration increases (APHA, 1985). The balance between cations and anions did not agree within the acceptable range of error in any of the composite samples, and in all cases the total anions were less than the total cations.

Also, the theoretical conductivity of each sample was determined by calculating the activity of each ion, then multiplying the activity of each ion by its appropriate factor of conductivity to yield the expected contribution of each ion to the total conductivity. The calculated conductivities of the ions were added to give the calculated conductivity of each sample. The calculated conductivity of each sample should approximately equal the measured conductivity of each sample. The calculated conductivities of the composite samples were lower than the observed conductivities in all but one sample.

The low results for measured anions and calculated conductivities indicate that an anion was present is fairly substantial quantities in all of the samples and escaped analysis. The unknown anion may be the conjugate base of one or more organic acids which commonly occur in wastewaters. Table 4.7 shows the quantities of additional anion, in milliequivalents per liter, which are lacking from the cation-anion balance for each watershed.

The values presented provide only approximations of the direction and magnitude of error because of uncertainties in the calculation of conductivity by summation. It was presumed that the unknown anion had an ionic charge of 1^-, an activity coefficient of 0.40, and a conductivity coefficient of 0.050 mmhos/cm/meq/L, all of which affected the calculated adjustments to cations and anions. Also, the measurement of conductivity is subject to error, and any errors in the analyses of the different analytes cause corresponding errors in the adjustments to the balance of ions and calculated conductivities.

The analyses of sodium, calcium, and magnesium suffered two major sources of error. Gross errors during analysis revealed contamination of samples by all three cations in two batches of dilutions that were then discarded. Smaller levels of contamination were probably present in blanks, standards or other samples. Also, the results which were obtained with different factors of dilution varied considerably (but by less than 10 percent in most cases). The poor agreement among different dilutions may have resulted from differing levels of activity by contaminants and interferences at the different levels of dilution. The results reported for the major metals are means from three trials for the least dilute samples.

When the cation-anion balances and calculated conductivities for each sample were adjusted with the unknown anion, significant adjustments of cation concentrations were necessary in order to balance results. Subtraction of cations was necessary in four watersheds, suggesting that contamination of those samples affected the analyses. Again, several uncertainties in the calculation of the adjustments disallow full confidence in their validity.

It is not known whether the calculated adjustments should be attributed to error in the analyses of one or all of the principal cations. If the full adjustment was due to error with only one

Table 4.7: Total Concentrations of Cations and Anions, and Adjustments Needed for Balance

Site	Total Anions Plus Cations, meq/L	Adjustment to Anions, meq/L	Adjustment to Cations, meq/L
1	7.94	0.76	0.50
2	16.2	1.1	0.10
3	16.9	1.5	0.92
4	7.26	0.70	0.15
5	18.2	1.9	-0.40
6	5.7	0.52	-0.29
7	10.0	0.2	-.31
8	6.37	0.76	0.50
9	9.81	1.1	0.56
10	15.2	1.5	-0.28
11	5.00	0.48	0.20

cation, significant errors may have been introduced into the subsequent correlations of concentrations with land use variables. The development of predicative models through regression analyses likewise would have suffered mistakes and error. The detection of errors in the analyses give reason to believe that the adjustments should be distributed among the cations; if so, the error with each cation in each watershed may be greater than or less than the calculated adjustment. For some watersheds, the calculated adjustment in cation concentrations was greater than the error obtained by the predicative models for estimation of dry-weather concentrations.

In order to asses the possible effects of the error on the development of predicative models, an adjusted concentration of each cation was calculated by adding the full measure of error to the determined concentration. Both the determined and the adjusted concentrations were correlated with land use variables for the watersheds. Differences between correlation coefficients were generally insignificant; the strongest correlations remained essentially unchanged.

The calculated concentrations of the unknown anion have a very strong positive correlation with conductivity, which may be a result of increasing disparity between analytical results for cations and anions as total dissolved solids increase. The unknown anion has a moderate positive correlation with hydrogen ion, which gives no reason to doubt that an organic acid is the source of the unknown. Like most of the known ions, the unknown anion has a negative correlation with discharge (-0.55). The purported anion shows moderate to strong positive correlations with all of the major ions, and a weak positive correlation with nitrate. Moderate negative correlations exist with potassium, phosphate, and iron.

Chapter 5: Relationships of Runoff Quality to Watershed Characteristics

Water quality constituent concentrations from each watershed were correlated with land use variables to search for relationships between them. Land uses in watersheds were expressed as areas and percent areas, and chemical quantities were expressed as concentrations and as rates of loading. Correlation coefficients were used to select the best form of expression of land use and water quality variables with which to perform regression analyses. Predictive models of dry-weather concentrations are presented below.

5.1 Procedures

The watershed analyses described in chapter 3 provided ten sets of land use data, two sets (area and percent area) for each of the five sets of distance-weighting factors that were used. Two sets of water quality data were generated for use in correlations: analyte concentrations, and analyte loading rates as determined by multiplying the concentration of each analyte in each sample by the appropriate discharge value for the watershed. Mean discharge rates, mean hydrogen ion concentrations, and total dissolved solids concentrations (from the composite samples) were included in the water quality data sets for correlation with land use values. Total dissolved solids concentrations and H+ concentrations were also expressed as loadings (mass per unit time) as for the analytes. Discharge was expressed as rate of discharge (liters per second).

Twenty sets of correlation coefficients were produced by the combination of each of the two chemical data sets with each of the land use data sets. Additionally, the data sets for coverage by soil class were correlated with the water quality data sets of concentrations and loadings. The correlations between concentrations and standard (unweighted) land use percentages were computed first and used as a reference for comparing the correlations between values in the other data sets.

Comparisons among the sets of correlations justified simplification of the study by elimination of all but four sets of coefficients. The sets of correlations were arranged in the order of the sets of distance-weighting factors that were applied to the watersheds, and the correlations coefficients were compared. It was found that the strongest correlations generally occurred when the land use areas or percent areas were calculated with the first set of distance-weighting factors (1,1,1), which gave equal weight to the three zones, or with the last set of factors (0, 0, 1), which gave weight to the inner zone only. In some cases, the strongest correlations were obtained with intermediate sets of distance-weighting factors which gave some weight to the outer and middle zones. In those cases, however, the land use variable was usually one that has widespread distribution such as vegetated or impervious area. Consequently, the difference between the strongest coefficient and the coefficient obtained with the first or last set of factors was insignificant, usually less than 0.05. On this basis, only the data sets based on the first and last sets of distance-weighting factors were retained.

Secondly, it was found by comparison of data sets that few of the correlations between land use and loading were stronger than the correlations obtained between land use and concentration. Loading functions were not included in the regression models. Also, most correlations between water quality data and soils data were weak, and the few correlations that were strong merely echoed strong correlations that existed with land use data. For example, potassium concentrations correlated strongly with the percent of area covered by vegetation and less strongly with the percent of vegetated area in each of soil classes 2, 3, and 4. The soil data sets were excluded from use in the regression models.

Four data sets remained for use in generating regression models-- the correlations between concentration values and each of four sets of land use data (land use area in the standard watersheds, percent land use in the standard watersheds, land use area in the inner zones, and percent land use in the inner zones). These sets of correlation coefficients were used to guide the selection of land use variables for modeling of chemical concentrations. For each water quality constituent, a comparison was made of the four coefficients of correlation that had been calculated between the constituent concentration and each expression of the watershed variables. The strongest coefficients from among the four was taken as an indicator of the best manner in which to express the land use variable. The coefficients calculated with standard watershed land use values were often substantially larger or smaller than the coefficients calculated with land use values for the inner zone only. However, there were generally much greater differences between the coefficients calculated using land use values in units of area and those calculated using land use values as percent area. In many instances, the selection of the best expression of the watershed variable was based upon insignificant differences in correlation coefficients.

Values for twelve land use classes were available as results of the land use analyses described in chapter 3, and additional classes were formed by combinations of the urban land use classes (e.g. industrial plus commercial area). Correlations with all land use classes were evaluated, and eight land use classes were selected for development of the regression models. The institutional land uses occupied relatively little total area and were comparable to both residential and commercial areas. Correlations with water quality data were computed for commercial area, residential area, commercial plus institutional area, and residential plus institutional area. Comparison of results showed that the pairs of coefficients gained with residential as one class and commercial plus institutional as another class were generally better than the coefficients gained with commercial as one class and residential plus institutional as the other. The models incorporate residential land use and commercial plus institutional land use (service) as two separate variables.

Few strong correlations were obtained with total area, but the factor was retained for modeling because it is distinct from other variables. Likewise, few strong correlations resulted with industrial land use, but the correlations were frequently different from those with other land use classes so the class was included as an independent variable in the models. Several strong correlations were obtained with the pond class, and it was included in the model. Strong correlations were also obtained with the impervious area class, but it was excluded from the model because the paved land use class is comparable and generally returned stronger correlations. The vegetated land use class was chosen over the crop land use class because of their similarities and the stronger coefficients which were obtained with the vegetated class.

Correlation coefficients were also computed for combinations of residential, institutional, commercial, and industrial areas, and each of those combinations plus paved area or impervious area. The correlations obtained with the combined classes were often ambiguous and masked the differences between the variables. For this reason, the models included residential, service, industrial, and paved land use classes as separate variables, and the totality of urbanized area was represented in a negative manner by the rural land use class. Zinc correlated weakly with all land use classes except railroad, so the railroad class was included in the model for zinc only.

5.2 Correlations Between Land use Variables and Water Quality Variables

Correlation coefficients are described below with the same terms that were presented in chapter 4 (table 4-5). As before, the coefficients stronger than ± 0.74 are statistically significant at the 0.05 level, and those stronger than ± 0.52 are significant at the 0.10 level. The presence of a strong correlation between a watershed variable and an analyte concentration suggests a causal relationship between the two. However, the relationship may be indirect or the watershed variable may correlate strongly with the analyte if the watershed variable and the true determining variable are distributed among the watersheds in similar patterns. Also, a weak correlation between an analyte and a watershed variable does not indicate the absence of a causal relationship because the contribution of the watershed variable to the analyte concentration may be masked by the effects of other determining factors. Correlations which are statistically significant at the 0.1 level or less are listed in table 5-1.

Hydrogen ion concentrations had strong positive correlations (0.72) with the residential area in the inner zone and moderate negative correlations with percent pond area and percent vegetated area (-0.51 and -0.43, respectively). Correlations with all other land use variables were weak. The correlation with residential area, if valid, suggests that residential areas contribute acidity to runoff more strongly than do other land uses and their influence increases with proximity to the drainage channel. The other correlations suggest a tendency for ponds and vegetated areas to produce less acidic discharges than urbanized areas.

Table 5-1: Watershed and Water Quality Variables that Correlate Strongly.**

Water Quality Variable	Coefficients of Correlation with Watershed Variables Text denotes Area (A) or Percent Area (%), and Total Watershed or Inner Zone							
	Total	Res.	Service	Indust.	Paved	Veg.	Rural	Pond
Discharge	0.65 A Inner	-0.66 %Total			0.59 A Inner	0.66 A Total	0.67 %Total	***0.77*** A Total
pH as (H+)		0.72 A Inner						0.52 %Total
Total Dis. Solids								
Bicarbonate			-0.54 %Inner					
Chloride		0.56 A Inner						
Nitrate		0.70 %Inner	0.52 %Total		***0.93*** %Total	-0.73 %Inner		
Sulfate		0.55 %Total		-0.55 %Total	0.64 %Total		-0.70 %Inner	
Phosphate	***0.75*** A Inner	-0.63 %Total		***0.77*** A Inner	-0.65 %Inner	***0.82*** A Inner	***0.87*** A Inner	***0.72*** A Inner
Potassium	***0.83*** A Inner	***-0.75*** %Total		***0.80*** A Inner	-0.62 %Inner	***0.91*** A Inner	***0.94*** A Inner	***0.82*** A Inner
Sodium		0.64 A Inner						
Calcium					0.54 %Inner	-0.53 %Total		-0.58 %Total
Magnesium				-0.59 %Total	0.55 %Inner		-0.55 %Inner	
Iron		-0.72 %Inner		0.55 A Inner	-0.67 %Inner	0.66 %Inner	0.87 %Inner	
Zinc	Correlates weakly with all variables except Railroad Area. The strongest correlation, ***0.93***, is with the percent railroad area in the inner zone.							

**Coefficients in bold italics are significant at 0.05 level; all others are significant at 0.10 level.

Correlations with total dissolved solids concentrations followed a pattern similar to that of hydrogen ion concentrations. The strongest positive correlations were obtained with residential area in the inner zone (0.45) and percent paved area (0.47) and the strongest negative correlations were obtained with percent vegetated area (-0.42) and percent ponded area (-0.49). Urbanized areas seemingly yield greater total dissolved solids concentrations. See figures 5-1 and 5-2.

Average discharge showed moderate positive correlations with rural area and vegetated area in the inner zone (0.67 and 0.66, respectively), indicating a tendency for vegetated lands to sustain greater dry-weather flows. Discharge had a moderate positive correlation with total area (0.54) because larger watersheds tend to produce larger discharges. The correlation was slightly stronger with the area of the inner zone (0.65), which may reflect the generation of dry-weather flow by seepage in the inner zone. Discharge also had positive correlations with the percents of area in soil class 3 (0.60) and 4 (0.77), which may reflect a greater production of dry-weather flow from low-slope areas. Discharge had a strong positive correlation (0.77) with pond area due to the location of detention ponds in watersheds that produce larger discharges. Discharge had a moderate negative correlation with the percent residential area (-0.66) but not with industrial or commercial areas, despite the relatively low impermeability of residential areas and the contribution of lawn waters to soil moisture. (Class 3 soils have moderate slopes, slow to moderate runoff ratings, and side slope locations, and class 5 soils have low to level slopes, very slow to slow runoff ratings, and floodplain and terrace locations).

Bicarbonate and chloride showed no strong correlations with any of the land use categories. Both ions had moderate negative correlations with ponded area (-0.39 and -0.44, respectively), and bicarbonate had a moderate negative correlation with service area in the inner zone (-0.54). Chloride had a moderate positive correlation with residential area in the inner zone (0.56), and a weak positive correlation with percent paved area (0.44), and bicarbonate had very weak positive correlations with both classes. The high concentrations and poor correlations of these two analytes probably result from their widespread origins in multiple land use classes as well as precipitation. There is a slight tendency for concentrations to increase as urbanized areas

Figure 5-1: Variation of pH and Total Dissolved Solids with Percent Vegetated Area

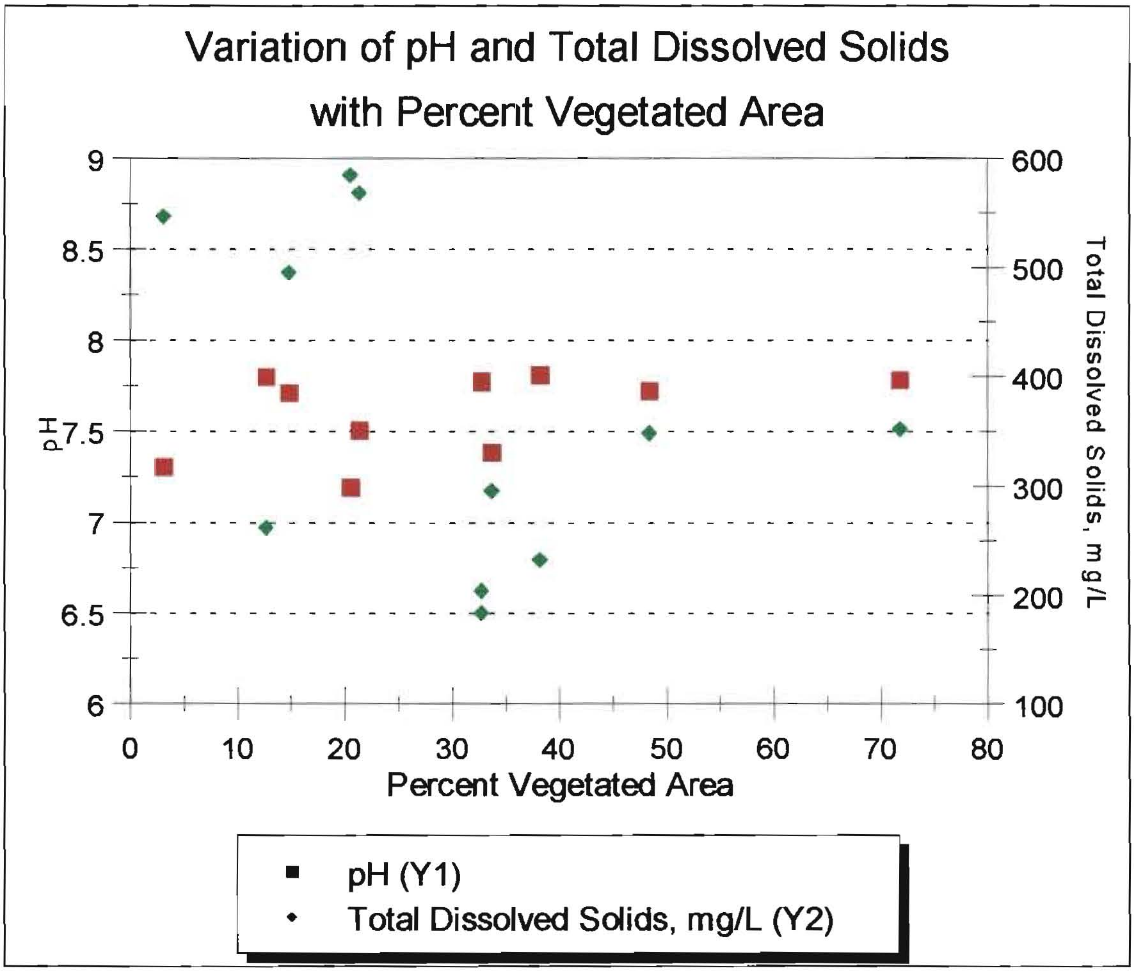
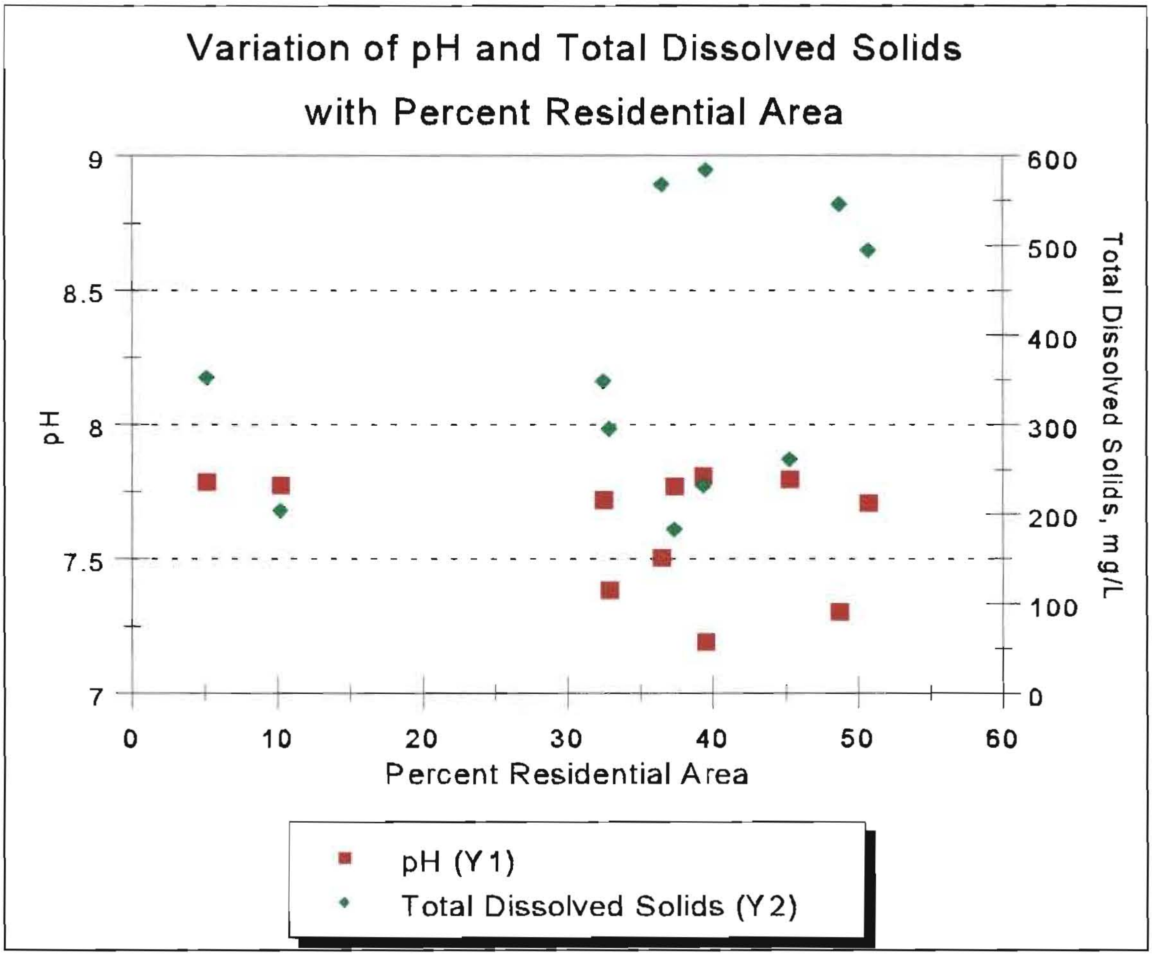


Figure 5-2: Variation of pH and Total Dissolved Solids with Percent Residential Area



replace vegetated areas, and chloride may have an important source in automobile traffic, road salt and dirt, or pavement. Correlations with percent of total ions showed that the percent contributed by bicarbonate tends to decline as the percents of paved area and urbanized area increase.

The dominant cations correlated strongly with each other and had patterns of correlation that were similar to those of bicarbonate and chloride. Calcium and sodium had moderate and weak negative correlations with percent pond area (-0.58 and -0.47, respectively) and percent vegetated area (-0.53 and -0.41, respectively). Both ions had moderate positive correlations with percent paved area (figure 5-3), and weak and moderate positive correlations with residential area in the inner zone (0.49 and 0.64, respectively). Like bicarbonate and chloride, the principal cations have high concentrations that derive from a variety of land uses as well as precipitation, and result in weak correlations with individual land use classes. Concentrations tend to be slightly higher in urbanized areas. The principal anions and cations had high concentrations in fully-urbanized areas, lowest concentrations in watersheds with 5 to 10 percent of rural area, and higher concentrations as the percent of rural land increased. See figures 5-3 and 5-4.

Correlations with magnesium were all very weak to moderate, and followed a pattern like those for calcium and sodium. Magnesium had a moderate positive correlation with paved area in the inner zone, a weak positive correlation with percent residential area, and weak or moderate negative correlations with percents of vegetated, rural, and pond area. Magnesium correlated more strongly with percent industrial area in the inner zone (-0.59) than did sodium and calcium. The pattern suggests that sodium and calcium have more urban sources than does magnesium.

The pattern of correlations with sulfate was similar to those of the other major ions, but correlations tended to be slightly stronger. Concentrations had moderate negative correlations with percent rural area in the inner zone (-0.70) and percent vegetated area (-0.51), and moderate positive correlations with percent paved area in the inner zone (0.64) and percent residential area (0.55). As with magnesium, the negative correlation with percent industrial area was moderately strong (-0.55). Overall, there is a trend for sulfate concentrations to be higher in urbanized areas, and to be lower in areas with greater abundance of vegetation and ponds, as with chloride, sodium,

Figure 5-3: Variation of Principal Ions with Percent Paved Area

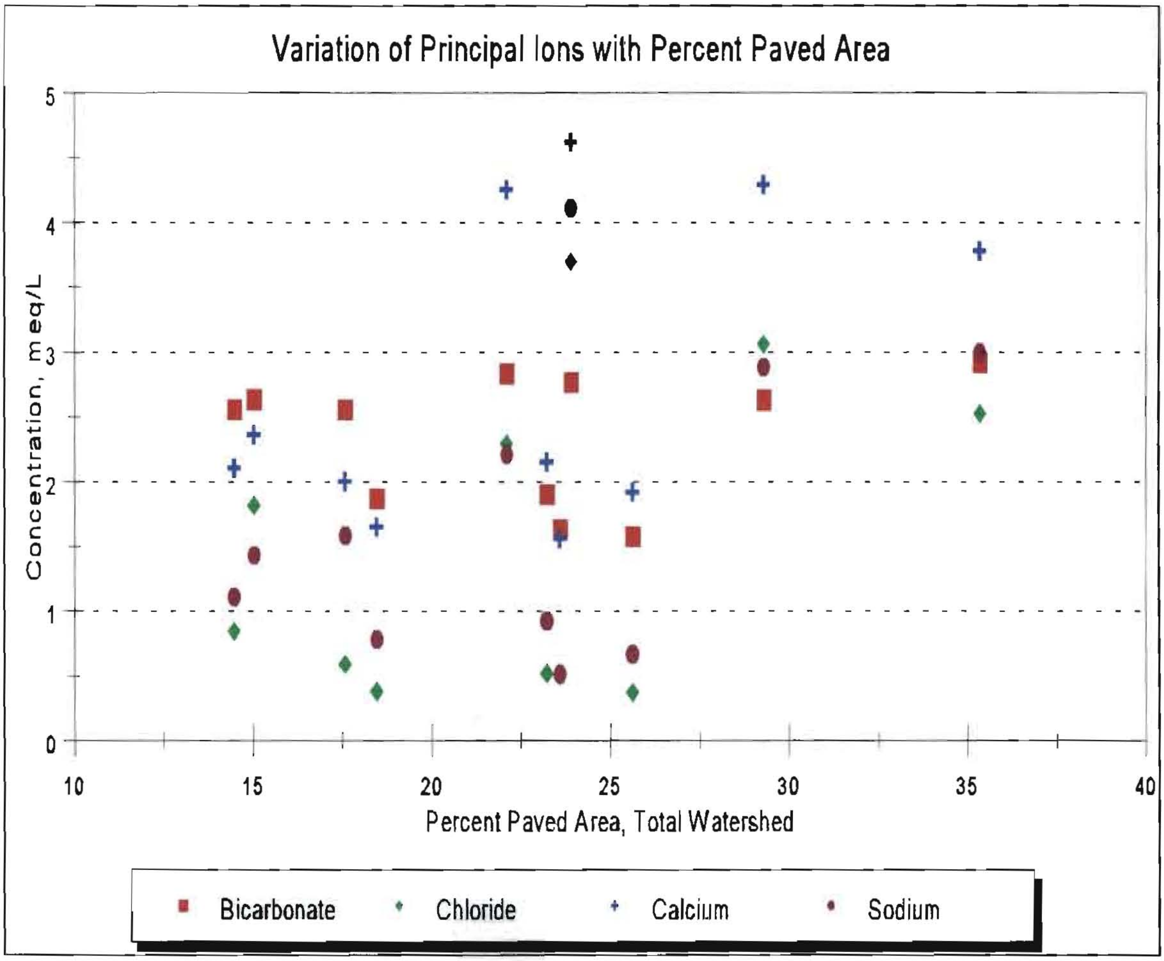
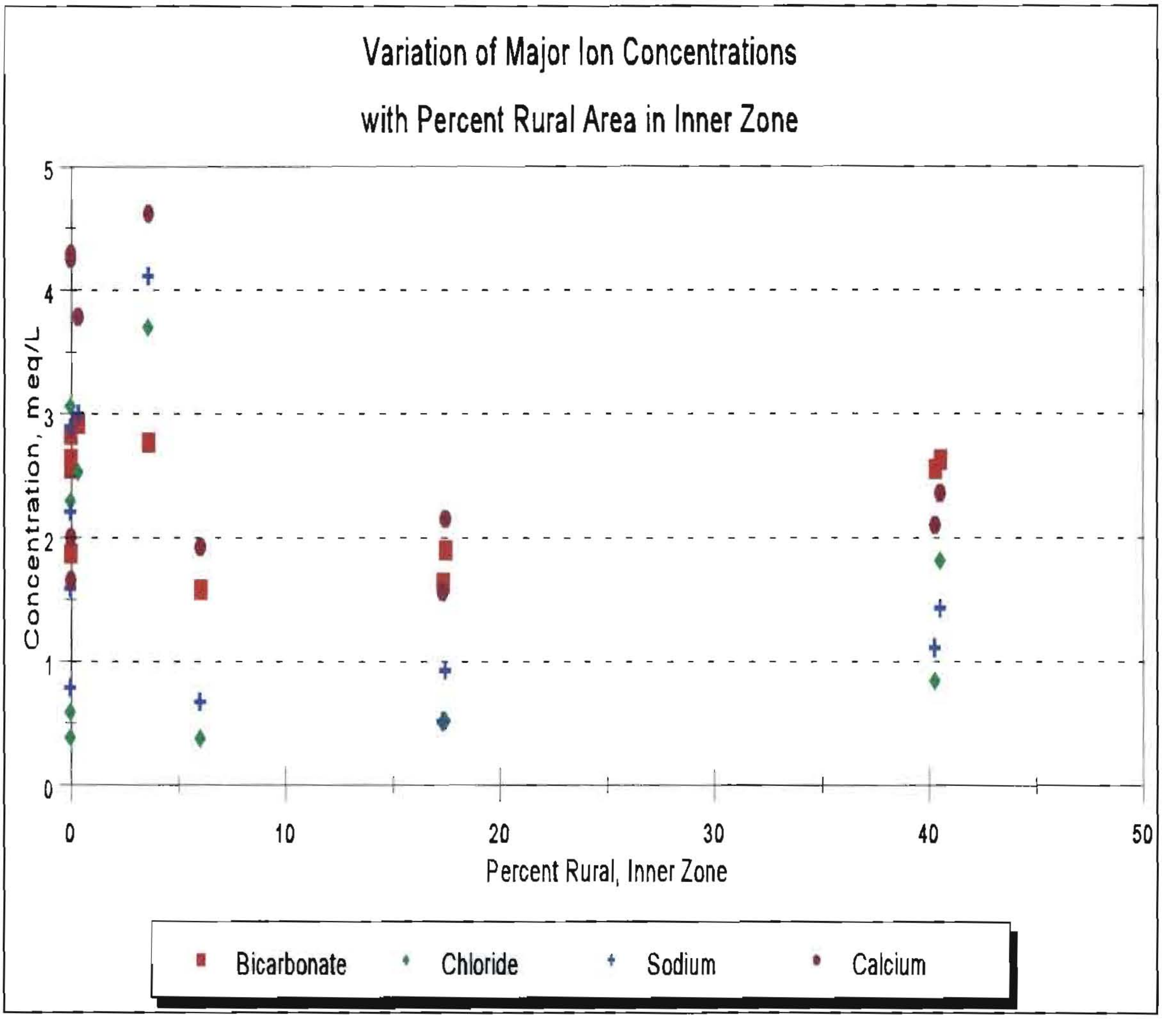


Figure 5-4: Variation of Principal Ions with Percent Rural Area



and the other major ions. No explanation is offered for the moderately strong negative correlations of sulfate and magnesium with industrial land use areas, or the very weak correlations of the other major ions with industrial land use areas.

Correlations with nitrate more clearly showed a trend for urbanized areas to produce higher concentrations. Nitrate had a very strong positive correlation with the percent of paved area (0.93, see figure 5-5), a strong positive correlation with the percent of residential area in the inner zone (0.70), and a weak positive correlation with percent service area (0.52). Negative correlations were obtained with percent vegetated area in the inner zone (-0.73), and percents of rural and vegetated areas (-0.39 and -0.73, respectively). Atmospheric deposition is a major source of nitrate, and the correlations suggest that consumption of nitrate by vegetation reduces concentrations in runoff. Urban sources of nitrate, such as from gasoline engines, may also contribute to higher concentrations in more urbanized areas. Nitrate had a moderate positive correlation with class 2 soils (0.66) and a moderate negative correlation with class 1 soils (-0.52), which suggests that nitrate concentrations are influenced by slopes and permeabilities more than are other analyte concentrations. (Class 2 soils have low to level slope, slow runoff, floodplain and terrace locations, and class 1 soils have 3-20% slope, rapid runoff, and ridgetop locations).

Potassium and phosphate had patterns of correlation which were very similar to each other and distinct from the other analytes. The two ions had very strong positive correlations with percent rural area in the inner zone (0.94 and 0.87, respectively) and with percent vegetated area in the inner zone (0.91 and 0.82, respectively). See figure 5-6. Comparably strong correlations were obtained with cropland areas. Correlations with paved area were moderately negative, and correlations with percent residential area were moderately to strongly negative (-0.75 and -0.63, respectively), but both chemicals had strong positive correlations (0.80 and 0.77, respectively) with percent industrial area in the inner zone. Potassium and phosphate were the only analytes that showed notable correlations with total area; correlations were strongly positive for both chemicals (0.75 and 0.83, respectively). In summary, potassium and phosphate concentrations are higher in discharge from vegetated areas, which may be due to the application of fertilizers. Concentrations

Figure 5-5: Variation of Nitrate with Paved Area

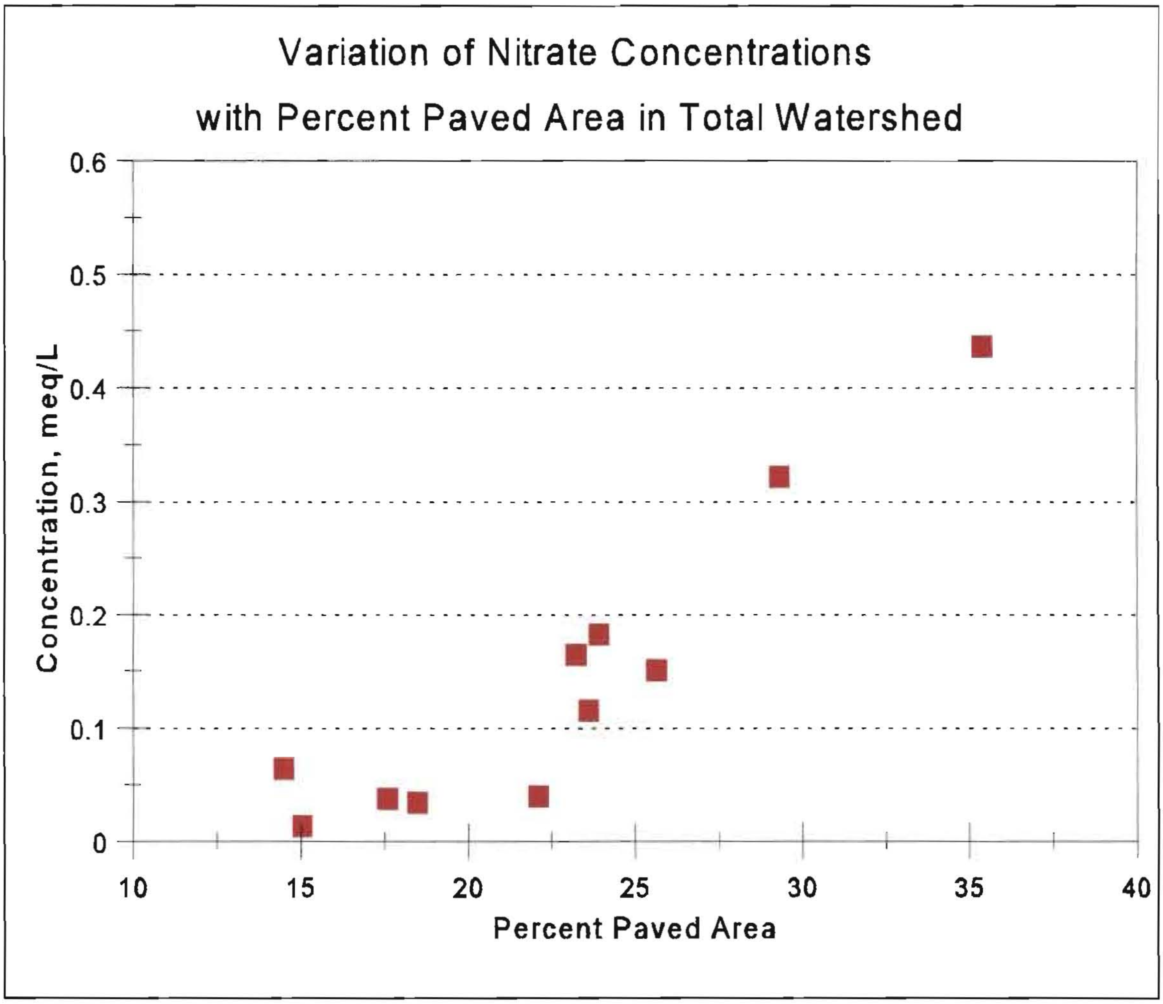
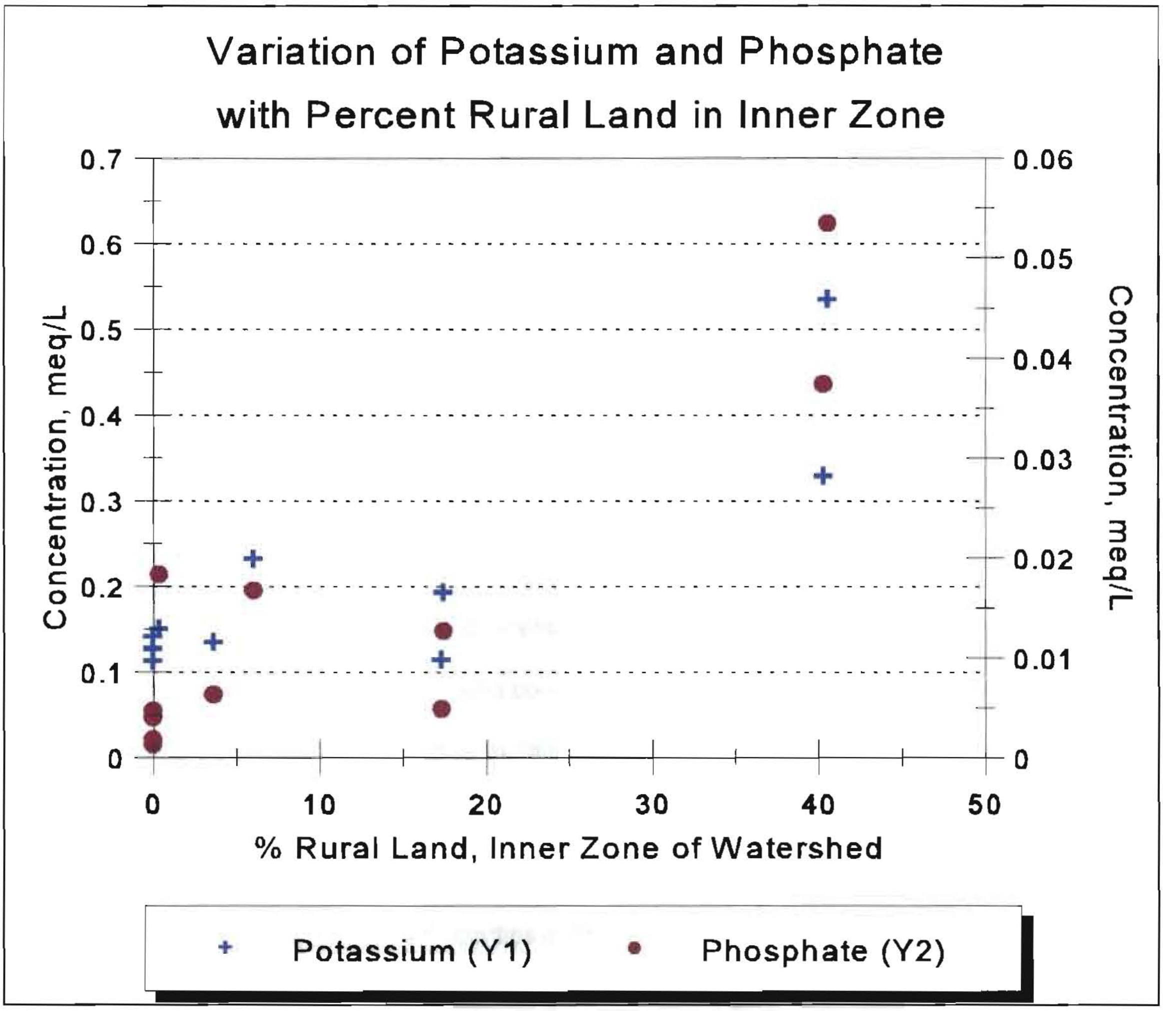


Figure 5-6: Variation of Potassium and Phosphate with Percent Rural Area in Inner Zone



are lower in urban areas, except where industrial areas are located near the drainage channel; livestock and grain industries are possible sources.

Like potassium and phosphate, iron concentrations were higher in discharges from rural areas and industrial areas. Correlations also suggested that conditions in the inner zone influence iron concentrations more strongly than any of the other water quality constituents. Iron concentrations correlated very strongly (0.87) with the percent of rural area in the inner zone (figure 5.7, and likewise had moderate positive correlations with industrial area in the inner zone (0.55) and the percent of vegetated area in the inner zone (0.66). Iron had a strong negative correlation with the percent of residential area in the inner zone (-0.72) and a moderate negative correlation with the percent of paved area in the inner zone (-0.67). See figure 5-8. Sources of iron may include pesticides and fertilizers in rural areas, and corrosion or abrasion in industrial areas.

The correlations between zinc concentrations and all land use classes were weak or very weak with exception of a moderate positive correlation with residential area (0.56)and a very strong correlation with the percent of area used by railroads in the inner zone. Correlation coefficients were greater than 0.80 for all expressions of railroad area-- area or percent of area in the standard watershed or the inner zone only. If the correlation is valid, zinc may have a source in combustion, dumping, materials storage, or other activities in the railroad areas. However, the correlation was heavily influenced by a high concentration in watershed 4 that may be caused by a local source other than railroads. (Correlations between railroad area and bicarbonate were weakly positive, and correlations with all other analytes were very weak).

5.3 Regression Models for Prediction of Chemical Concentrations

Multivariate regression analyses were performed to provide coefficients with which to predict the concentrations of the water quality constituents in dry-weather conditions. The eight land use classes identified above were used as the independent variables for each analyte, and the area of each watershed covered by the land use area was expressed in the manner which was found to return the strongest correlation coefficient.

Figure 5-7: Variation of Iron and Sulfate with Percent Vegetated Area

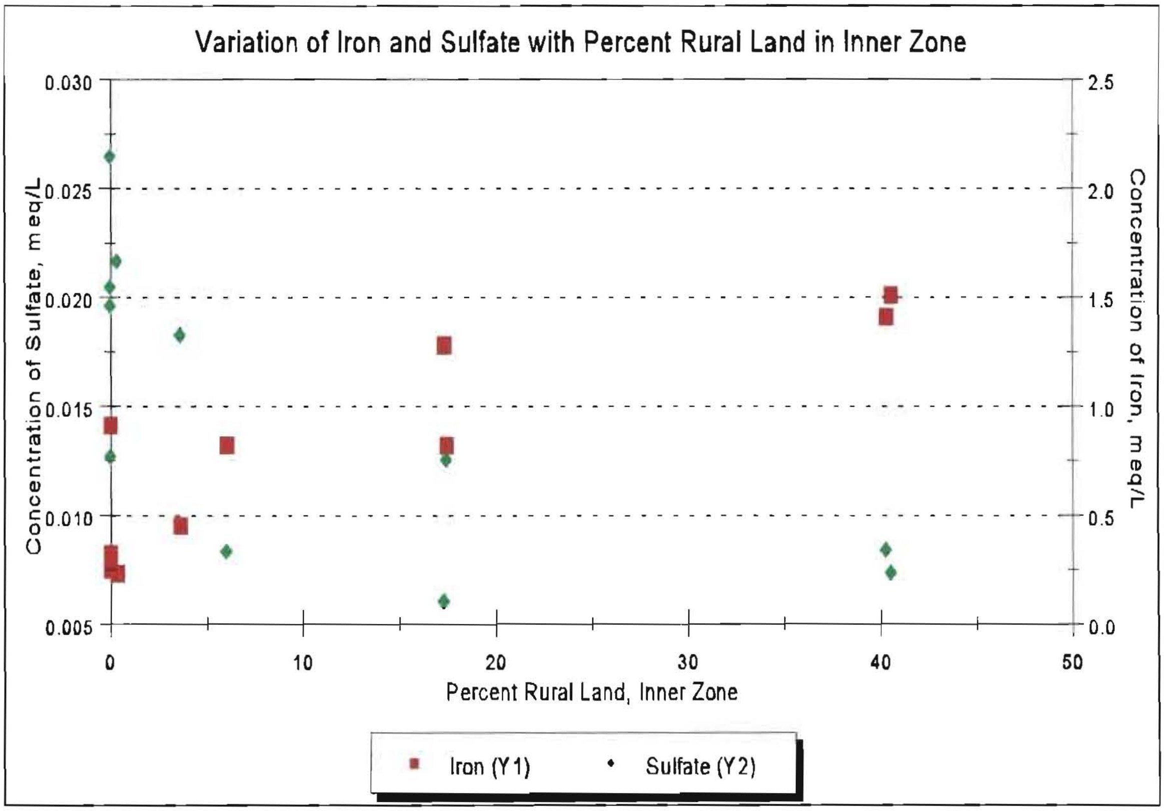
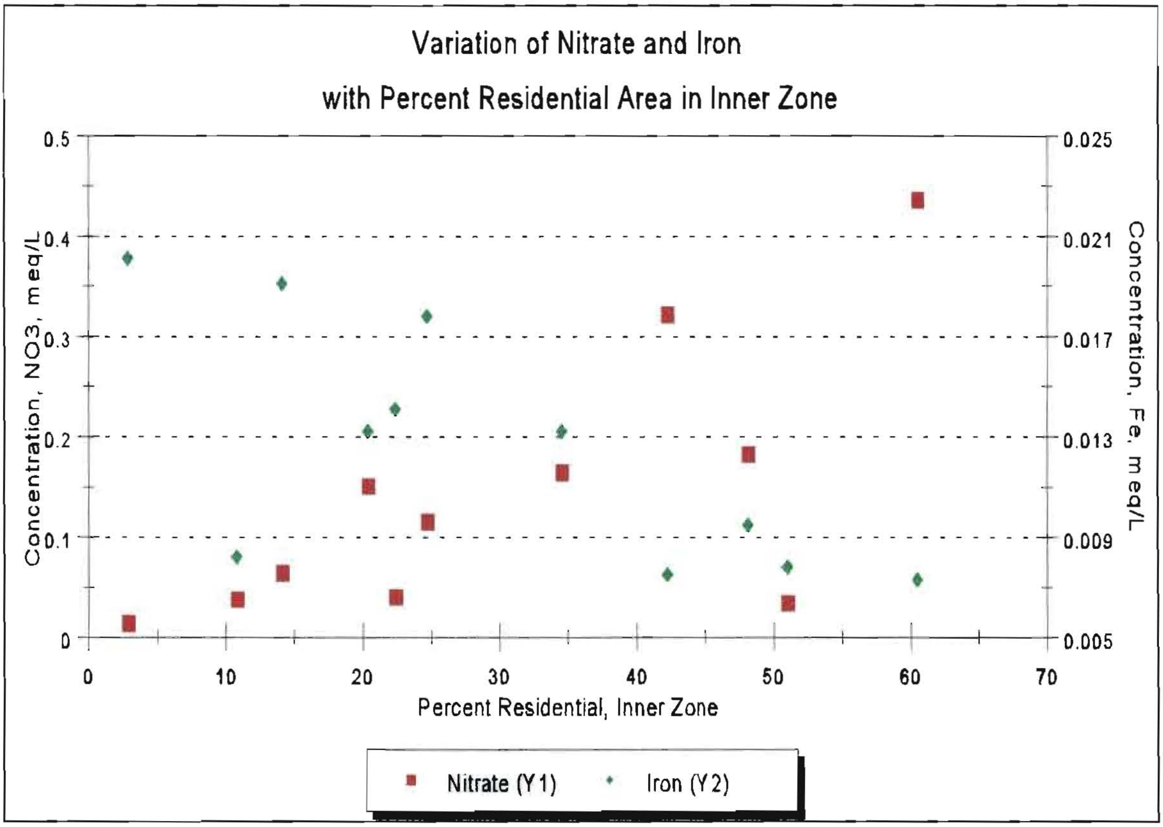


Figure 5-8: Variation of Nitrate and Iron with Percent Residential Area



The regression models take the following form:

$$Z = (A \times a) + (B \times b) + (C \times c) + (D \times d) + \ldots (H \times h) + Y$$

Z represents the concentration of the water quality constituent in units as listed in table 5-2. A, B, C, etc. represent distance-weighted values for each of eight land use variables. The values a, b, c, etc. are the coefficients for each land use variable in the model for each water quality constituent, and Y is the intercept of the regression line.

The regression models were tested by predicting constituent concentrations in the watersheds using the land use data of the watersheds with which the models were derived. The error of prediction was taken as the difference between the predicted concentration and the concentration that was determined for the composite samples, and the standard deviations of error were expressed as percents of the mean concentrations. Tables 5-3 and 5-4 summarize the levels of error obtained with each model.

The model for prediction of zinc concentrations returned a standard error of less than 1 percent, the models for calcium and iron had standard errors of less than 5 percent, and the models for total dissolved solids, bicarbonate, and nitrate returned standard errors of less than 10 percent. Three models, those for pH (as hydrogen ion concentration), chloride, and phosphate had standard errors of greater than 20 percent.

The models for total dissolved solids, discharge, bicarbonate, nitrate, sulfate, sodium, and magnesium produced errors which did not exceed 50 percent for any of the watersheds, and the model for potassium had a comparable level of error. The model for pH (H+ concentration) returned one estimate with an error of over 80 percent, but errors for other watersheds were less than 25 percent. The model for phosphate returned three estimates with errors in excess of 50 percent, one of which exceeded 100 percent. The model for chloride is the least reliable; it returned three estimates in excess of 100 percent, and a standard error of 36 percent.

The models generally produced modest errors with fairly even distribution of errors among the watersheds. However, several models returned one, two, or more estimates that had substantially higher errors than the other estimates. In particular, errors of estimation in some

Table 5-2: Models of Water Quality Constituent Concentrations in Dry-Weather Runoff. E indicates scientific notation; the coefficient of ten of follows.

Water Qual. Const.	Watershed Variable Text denotes Area (A) or Percent Area (%), and Total watershed or Inner zone								Inter-cept
	Total	Resid.	Service	Indust.	Paved	Veg	Rural	Pond	Y
Disch. (L/s)	2.478 E 1 %Inner	1.509 E -1 %Total	1.310 E 2 A Inner	9.477 E 3 A Inner	-9.655 A Inner	-2.172 E 1 Total	1.061 E -1 %Total	9.878 E 2 Total	-6.337
pH as (H+)	-3.740 E -8 %Total	2.151 E -7 A Inner	-8.944 E -8 A Total	1.361 E -9 %Inner	1.463 E -7 A Total	3.462 E -10 %Total	2.803 E -8 A Total	-1.041 E -8 %Total	1.660 E -8
Total Solids mg/L	1.94 E 2 A Total	2.165 E 3 A Inner	1.275 E 1 %Total	-3.399 E 1 %Total	2.027 E 1 %Total	1.963 E 1 %Total	6.784 %Inner	-3.237 E 2 %Total	-3.872 E 2
Bicar-bonat. meq/L	-1.963 E -1 A Inner	2.185 E -2 %Total	-2.715 E -2 %Inner	-2.989 E -2 %Inner	5.568 E -2 %Total	5.206 E 3 %Total	-4.916 E -1 A Inner	-9.514 E -1 %Total	-1.889 E -1
Chlor. meq/L	-2.750 E -2 Total	17.80 A Inner	3.845 E -2 %Total	-8.002 E -2 %Total	1.179 E -1 %Total	7.483 E -2 %Inner	-1.215 E -2 %Inner	-7.596 E -1 %Total	-4.796
Nitrat. meq/L N	-5.467 E-2 A Inner	-3.044 E-3 %Inner	-1.860 E-2 %Total	2.141 A Inner	3.486 E-2 %Total	-1.87 E-3 %Inner	6.6 E-4 %Inner	-6.2 E-2 %Inner	-3.012 E -1
Sulfat. meq/L	1.313 A Inner	-5.725 E-2 %Total	-21.96 A Inner	-9.364 E-2 %Total	6.725E -2 %Inner	1.251 E-2 %Total	7.599 E-3 %Inner	-91.62 A Total	2.269
Phos. meq/L P	-4.172 E-2 A Inner	-7.210 E-4 %Total	-1.145 E-3 %Inner	2.712 E -1 A Inner	9.796 E-4 %Inner	-2.721 E -1 A Inner	6.456 E -1 A Inner	-6.316 E -1 A Inner	3.359 E -2
K meq/L	-8.901 E-2 A Total	-5.854 E -3 %Total	-1.620 E-2 %Total	3.386 A Inner	2.016 E-2 %Inner	-3.876 A Inner	7.954 A Inner	-2.393 A Inner	2.352 E -1
Na meq/L	-5.001 E-3 A Total	18.76 E -2 A Inner	-3.947 E-2 %Total	-2.103 E-2 %Total	1.662 E -1 %Total	8.614 E -2 %Inner	-3.802 E -2 %Inner	-1.033 %Total	-5.265
Ca meq/L	-1.866 A Total	19.24 A Inner	-1.365 E -1 %Total	-1.011 E -1 %Total	4.318 E -1 %Inner	1.008 E -1 %Total	1.983 E -1 %Inner	-2.842 %Total	-7.333
Mg meq/L	-2.819 E -1 A Inner	5.534 E-2 %Total	-13.73 A Inner	6.449 E -2 %Total	1.328 E -1 %Inner	5.507 E-2 %Total	2.417 E-2 %Inner	-6.106 E -1 %Total	-5.381
Fe meq/L	-1.506 E-3 A Inner	3.334 E-4 %Inner	5.692 E-4 %Inner	1.072 E-2 A Inner	2.779 E-4 %Inner	3.314 E-4 %Inner	3.881 E-4 %Inner	-4.073 E-2 A Inner	-2.308 E -2
Zn* meq/L	1.176 E -2 A Total	-1.765 E -3 A Total	-6.064 E-5 %Inner	-1.509 E -1 A Total	-2.082 E -3 A Total	-2.823 E-5 %Total	1.917 E-5 %Inner	-4.728 E -3 A Total	4.25 E -2

*The model for zinc includes percent area railroad in the inner zone, with a coefficient of 8.705 E-4.

Table 5-3: Error in Prediction of Water Quality Constituent Levels, part 1.

Watershed	Error in Prediction of Water Quality Constituent Levels, Percent							
	Dis-charge	pH as (H+)	Total Solids, mg/L	Bicar-bonate	Chloride	Sulfate	Nitrate	Phos-phate
1	1.7%	0.8%	-2.5%	-5.9%	-21%	-4.4%	-6.7%	0.9%
2	0.5	-2.2	6.0	1.3	12	16	3.3	-12
3	18	10	-8.3	-1.2	-38	-13	-9.4	54
4	-9.4	19	-6.9	**20**	**150**	-6.0	3.5	10
5	-7.8	-10	-1.9	-8.4	1.3	-1.1	0.9	20
6	4.5	24	0.8	3.6	35	9.5	2.4	-6.8
7	0.6	-0.6	4.2	0.5	-20	3.7	-5.4	-0.4
8	**35**	**81**	**22**	**22**	**105**	-4.6	-1.0	**-93**
9	**-35**	-47	-10	-2.1	**110**	8.5	23	**160**
10	**48**	-18	3.7	-7.2	-8.0	-5.5	-6.0	3.2
11	-3.2	-18	1.1	-13	**77**	**45**	3.4	0.7
standard deviat. of error, %	14	21	7.7	9.3	36	14	8.0	29

Table 5-4: Error in Prediction of Water Quality Constituent Levels, part 2.

Water-shed	Error in Prediction of Water Quality Constituent Levels, Percent					
	Calcium	Sodium	Magne-sium	Potassium	Iron	Zinc
	0.9	-9.2	-11	-3.3	-0.4	0.3
2	5.4	6.6	-1.4	-10	**14**	-3.2
3	-3.7	-24	-0.3	-11	-8.7	6.5
4	-5.0	**45**	8.3	-2.2	-0.02	-0.00
5	-0.2	0.6	-13	11	-9.9	-1.5
6	0.2	11	11	-0.4	5.2	-0.1
7	1.0	-13	6.0	-0.4	0.9	nd
8	0.4	-25	**31**	-8.3	3.8	nd
9	1.8	21	-14	-11	5.0	-1.9
10	-0.6	-4.0	5.8	-1.5	-4.2	-1.1
11	0.3	**42**	-5.5	**52**	-1.8	-0.3
standard deviat. of error, %	3.2	18	12	11	4.7	0.7

Nd: no data

models were exceptionally high for watersheds 3, 4, 8, 9, and 11. The models for discharge, (H+), total dissolved solids, bicarbonate, chloride, sodium, magnesium, and phosphate produced unusually high errors in their estimates of constituent levels in watershed 8. Apparently, the eight watershed variables do not adequately describe the factors which determine water quality in watershed 8. Likewise, the models do not incorporate important factors which influence the concentrations of chloride in watersheds 4 and 9, sulfate in watershed 11, phosphate in watersheds 3 and 9, and sodium in watersheds 3, 4, and 11.

The accuracy of the predicted models depends in part upon how well the composite samples represent average conditions. It was determined earlier (section 4-3) that the conductivities of the composite samples were generally lower than the mean conductivities of all samples taken from February through July. Conductivity values may be used to estimate total dissolved solids concentrations by multiplying conductivity by a factor, usually between 0.55 and 0.70, that expresses the typical concentration of dissolved solids (mg/L) per unit of conductivity observed (mmhos/cm) (APHA, 1985). A constant was calculated for each watershed by dividing the determined concentration by the observed conductivity of the composite sample. The constants were then used to calculate the mean and standard deviation of estimated mean total dissolved solids concentrations for each watershed from February through July (table 5-5). The estimated values for mean and percent standard deviation were compared with the predicted values and the determined values from the composite samples. A ratio was calculated to compare the estimated mean concentration with each of the determined and predicted concentrations.

The results show the estimated mean total dissolved solids concentrations are higher than the determined and estimated total dissolved solids by a mean factor of 24 percent. The determined value for watershed 3 is 2 percent higher than the estimated mean value, but predicted and determined values for all other watersheds are below the estimated means by as much as 40 percent. The predicted and determined values for total dissolved solids probably underestimate the true mean value. A correction of 20 to 30 percent would give a better estimate of the true mean concentration in most instances.

Table 5-5: Comparison of Mean, Composite, and Predicted Total Dissolved Solids

Site	Estimated Total Dis. Solids, Feb - July		Total Dissolved Solids, Composite		Predicted Total Dissolved Solids	
	Mean, mg/L	% Stand. Deviation	mg/L	(mean-comp) ÷mean, %	mg/L	(mean-pred) ÷mean, %
1	380	51%	261	31%	250	34%
2	750	42	490	35	523	30
3	510	39	521	-2.1	474	7.1
4	340	46	230	33	213	37
5	620	45	542	13	532	14
6	260	45	176	32	178	32
7	520	40	318	39	331	36
8	310	38	208	33	255	18
9	420	45	317	25	283	33
10	540	31	459	15	477	17
11	200	21	157	22	160	20
mean	440	40	334	24	334	24

Nevertheless, the determined and predicted values for total dissolved solids are probably within the range that defines the average conditions for the watersheds. All of the predicted and determined values lie within one standard deviation of the estimated mean, with exception of the determined value for watershed 11. In most watersheds, the standard deviation of conductivities (estimated total dissolved solids) was 38 to 51 percent of the mean, and the average standard deviation for all watersheds was 40 percent of the mean.

Chapter 6: Estimation of Pollutant Concentrations in Storm Runoff and Receiving Rivers

Models presented by the U.S. Geological Survey (Driver, 1994) were used for estimating mean storm concentrations, total storm loads, and total storm discharges for selected pollutants in storm runoff. The land use data for the Emporia area were adapted for use in the models, and estimates were made of pollutant levels in all of the watersheds which drain Emporia. Estimates were compared to concentrations in stormwater in Topeka, Kansas as reported by Pope and Bevans (1984); all references below to Shunganunga Creek were taken from their work. The estimates of total storm loads and volumes were used to model concentrations of the pollutants in receiving rivers as functions of rainfall, river discharge, and initial pollutant concentrations. Assumptions in calculations favored larger estimates.

6.1 Procedures for Estimation of Mean Storm Concentrations, Loads, and Runoff

The USGS models allowed estimation of chemical oxygen demand, total dissolved solids, total nitrogen, total Kjeldahl nitrogen, total phosphorus, dissolved phosphorus, total recoverable cadmium, copper, lead, and zinc. The standard errors of estimate for each model are listed in table 6-1, as reported by Driver (1994). The models are most accurate with rainfall values between 0.10 and 1.00 inches (0.25 and 2.54 cm) and total watershed areas between 0.01 and 1.00 square miles (0.026 and 2.56 square kilometers) (based upon figure 4 in Driver).

The USGS models were based upon logarithmic expressions of concentrations and independent variables. Estimates for mean storm concentrations, total discharge, and total loading per storm are calculated with equations of the following form (Driver, 1994):

$$Y = (Bo) \times (X_1^{B1}) \times (X_2^{B2}) \times (X_3^{B3}) \times \ldots . BCF$$

Bo is the intercept of the regression model, and BCF is a bias correction factor. The variables X_1, X_2, etc., are meteorological variables and land use variables. The model for each pollutant includes only those variables which were found to be significant in the analysis of the database. Exponential values b1, b2, etc. are coefficients for the variables.

Table 6-1: Standard Prediction Error for USGS Models of Total Storm Loads and Volumes*

	Water Quality Constituent					
	Total Dis. Solids	Chemical Oxygen D.	Kjeldahl Nitrogen	Total Nitrogen	Dissolved Phosph.	Total Phosph.
Standard Error, %	77	98	87	86	169	96
	Cadmium	Copper	Lead	Zinc	Discharge	
Standard Error, %	87	117	126	138	69	

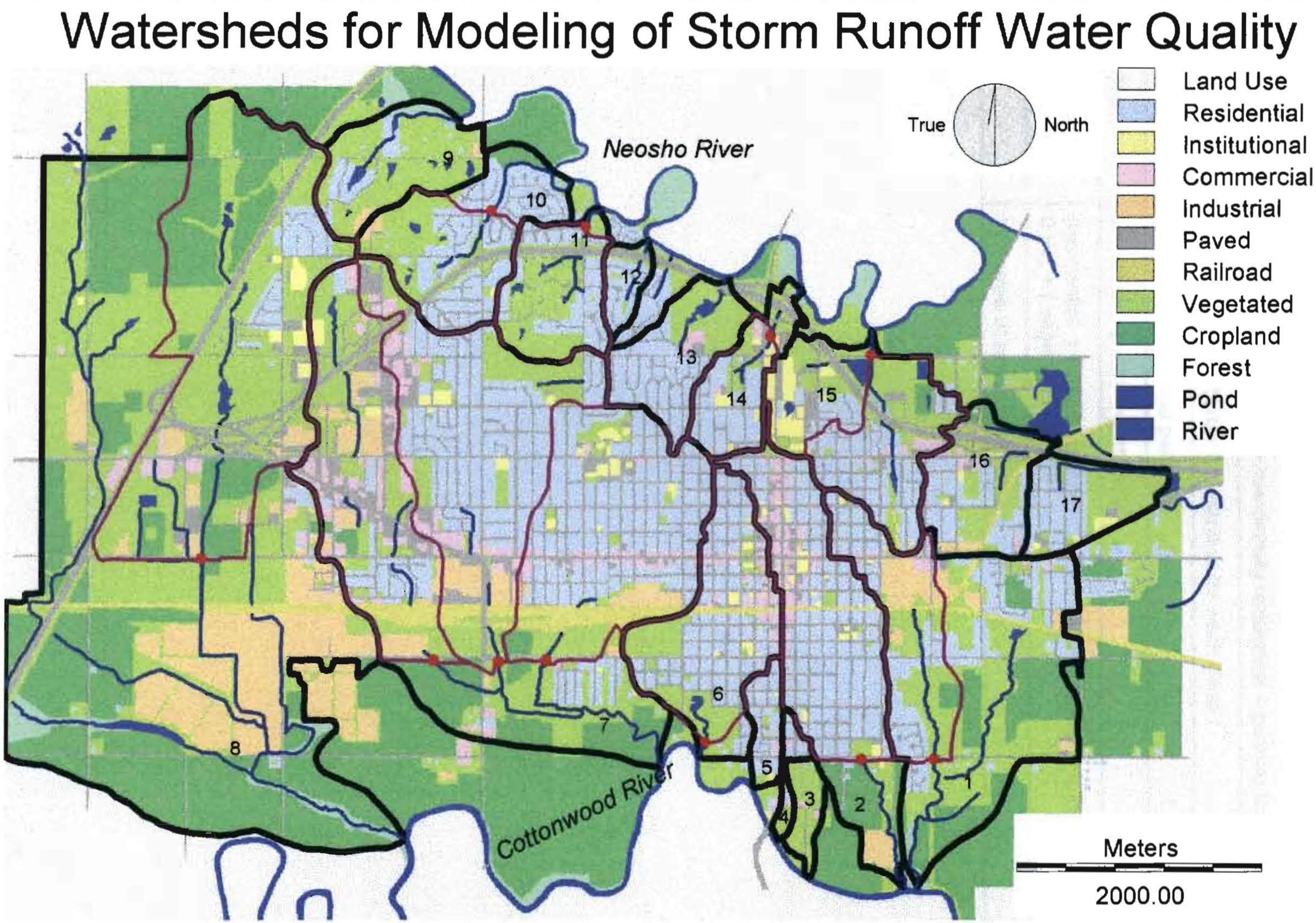
*Taken from table 2 in Driver (1994).

Other variables required by the model besides land use are total amount of rainfall, mean annual nitrogen loading in precipitation, the maximum 24-hour rainfall with a 2-year recurrence interval, mean annual precipitation, and the mean minimum January temperature. A series of 13 values were used for total rainfall, ranging from 0.1 to 4.0 inches (0.25 to 10 centimeters). The values used for the other three variables were 14.7 pounds per acre (8008 kg/sq. km.) of nitrogen for mean loading (Albritton, 1988), 3.6 inches (9.1 cm.) for maximum 2-year 24-hour rainfall, 33 inches (84 cm) for mean annual precipitation, and 20 degrees Fahrenheit (-6.7^0 C) for mean January temperature (Burns, 1976).

The watersheds used in the earlier part of this study were expanded to include the total area of each watershed that contributes to runoff at the point of confluence of each drainage channel with the receiving river. Watersheds were combined into larger units if their drainage channels join before confluence with the receiving river. Additional watersheds were delineated to provide nearly complete coverage of the urban area of Emporia with a total of 17 watersheds. See figure 6-1 (map) for locations of watersheds. Results for two watersheds which drain into large detention ponds on floodplains are not reported. The westernmost portion of watershed 8 was truncated due to its extension beyond the mapped area.

Six land use variables are required by the model: total drainage area, impervious area, percent residential area, percent commercial area, percent industrial area, and percent non-urban area. The land use classes on the land use map for Emporia were recombined, as presented in table 6-2, to provide the necessary six values for each watershed. Wastewater treatment plants and municipal waste and water facilities were classified as industrial areas, and the percent impervious area was calculated as described in chapter 3.

The USGS presentation of the models does not provide specifications for the classification of land uses or the level of mapping resolution that should be used when generating land use data for the models. This study treated small parcels of vegetated land within industrial, commercial, or residential areas as separate land use areas. The use of the city zoning map or a less detailed level of resolution in mapping of land uses would have given much higher percentages of industrial



Black lines show watersheds (numbered) for modeling of pollutants in storm runoff. Red lines and dots show watersheds and sampling points for analysis of dry-weather flow. The western portion of watershed 8 was truncated. Watersheds 16 and 17 drain into detention ponds and were excluded from modeling of pollutants in the Neosho River.

Figure 6-1: Map of Watersheds and Land Use Areas for Modeling of Storm Runoff Quality

Table 6-2: Land Use Classification for Use in Estimating Storm Runoff Quality

Land use	Description
residential	high-density residential + low-density residential + parking for each class
commercial	commercial + institutional + parking for each class
industrial	industrial + industrial parking
non-urban	cropland + forest + open rural
impervious	(residential x 0.38) + (commercial x 0.85) +(industrial x 0.72) + (roadways x 0.95) + (vegetated x 0 .1)
total	total area of watershed, square miles

area in several watersheds, and slightly higher percentages for commercial and residential areas. Estimates of pollutant loads and concentrations would generally have been slightly higher. The wastewater treatment plants of the Iowa Beef Processing Company cover large areas in watershed 8 and were classified as industrial areas although the plants probably do not contribute to pollutant loads in runoff in a manner similar to other industrial areas. The municipal zoo and the water, wastewater, and solid waste facilities were also classified as industrial areas.

Total areas and percent areas by land use for each watershed are presented in table 6-3. The watersheds that drain into the Cottonwood River cover substantially more total area than those that drain into the Neosho River, and they drain most of the city of Emporia. Two watersheds, numbers 7 and 8, are much larger than the others and contain larger percentages of industrial area. The watersheds that drain into the Neosho River are generally smaller than those that drain into the Cottonwood River. Among those that drain into the Neosho River, watershed 15 covers the most area and includes the largest tracts of commercial and residential land. Watersheds 3, 4, and 12 each cover little more area than several city blocks. The loads that were estimated for the small watersheds were included in the calculations of total loads for each receiving river.

The estimated mean storm concentrations of pollutants for runoff from Emporia were compared with reported concentrations for five sub-basins of Shunganunga Creek in Topeka. The watershed characteristics of the two study areas are substantially different, especially in measures of total size, percent agricultural land use, and coverage by lakes (table 2 in Pope and Bevans, 1978). The sub-basins of Shunganunga Creek range in size from 4.65 to 60.3 square miles (11.9 to 154 sq. km.) but the largest watershed of Emporia covers 4.94 square miles (12.6 sq. km.). The percent of agricultural land in the sub-basins of Shunganunga Creek ranged from 51.1 to 85.9 percent, whereas the percent of non-urban land use in the watersheds of Emporia ranged from 8.7 to 76.6 percent. Lakes larger than 5 surface acres covered 0.0 to 4.1 percent of the sub-basins of Shunganunga Creek but none of the watersheds of Emporia include lakes of such size.

Residential areas covered 3.1 to 26.7 percent of the sub-basins of Shunganunga Creek and 2.4 to 75 percent of the watersheds of Emporia. Commercial areas covered 0.2 to 11.0

Table 6-3: Land Use Values Used for Estimation of Storm Runoff Quality

Water-shed	Total Area, sq. mi.	Impervious Area	Industrial Area	Commerc. Area	Residential Area	Non-Urban Area
Watersheds of Cottonwood River						
1	1.30	29.6%	8.9%	1.7%	24.1%	59.8%
2	0.85	61.8	1.9	16.6	49.9	18.9
3	0.08	17.9	0.3	12.8	2.8	81.1
4	0.05	58.4	1.0	10.1	51.5	22.5
5	0.10	69.9	0.0	9.1	71.7	8.7
6	0.60	57.5	2.6	12.2	45.1	24.8
7	3.42	53.7	12.3	13.6	34.3	31.6
8	4.94	15.0	6.0	2.3	2.4	74.2
Watersheds of Neosho River						
9	0.36	13.6%	4.5%	0.0%	14.5%	76.6%
10	0.34	40.3	3.6	0.5	20.7	53.1
11	0.34	34.7	0.0	0.3	37.2	49.7
12	0.08	53.3	0.0	0.0	75.0	16.6
13	0.31	43.1	0.0	5.4	54.4	30.3
14	0.24	61.1	0.0	14.2	51.2	23.0
15	0.64	51.2	0.6	15.0	34.6	36.2

percent of the sub-basins of Shunganunga Creek and 0.0 to 17 percent of the watersheds of this study. Industrial land uses covered 0.0 to 10.2 percent of the sub-basins of Shunganunga Creek and 0.0 to 12.3 percent of the watersheds of Emporia. Impervious areas covered 8.0 to 22 percent of the sub-basins of Shunganunga Creek and 15.0 to 69.9 percent of the watersheds of Emporia.

6.2 Estimates of Pollutant Concentrations in Storm Runoff

Estimated mean concentrations of all pollutants in storm runoff, except total recoverable cadmium, declined as total rainfall values increased (figures 6-2 and 6-3). For several pollutants, the estimated mean storm concentrations were higher in the smaller watersheds than in the larger watersheds. All estimates of total loads increased with increasing rainfall (figures 6-4 and 6-5). Estimated total loads per storm were consistently highest for watershed 7, except estimated total loads for cadmium and lead, which are highest in watershed 8. The estimated total loads from watershed 7 accounted for 1/7 of the total estimated pollutant loads of lead from all watersheds and approximately 1/4 to 1/2 of the total loads for all other pollutants. Watersheds 2, 1, 6, and 15 also produced substantial estimated loads.

Estimated mean concentrations of total dissolved solids were comparable to those reported by Pope and Bevans in Topeka and indicated no threat of salinization to the aquatic communities. Estimated concentrations resulting from 0.10 inches (0.25 cm) of rain were 740 and 500 mg/L in watersheds 7 and 8, respectively, and less than 400 mg/L for all other watersheds. With 3.0 inches (7.6 cm) of rain, estimated mean concentrations for watersheds 7 and 8 were 500 and 340 mg/L, respectively, and less than 260 mg/L for the other principal watersheds. Pope and Bevans reported mean storm concentrations in the sub-basins of Shunganunga Creek between 109 and 774 mg/L and mean site values between 284 and 379 mg/L. Freshwater life may be tolerant of dissolved solids up to concentrations of 10,000 mg/L or more, and 15,000 mg/L has been suggested as the limit for freshwater communities (EPA, 1976).

Estimated COD concentrations in storm runoff from the watersheds ranged from 120 to 160 mg/L with 0.1 inches (0.25 cm) of rain and 47 to 65 mg/L with 3.0 inches (7.6 cm) of rain.

Figure 6-2: Mean Estimated Concentrations of Nutrients in Storm Runoff

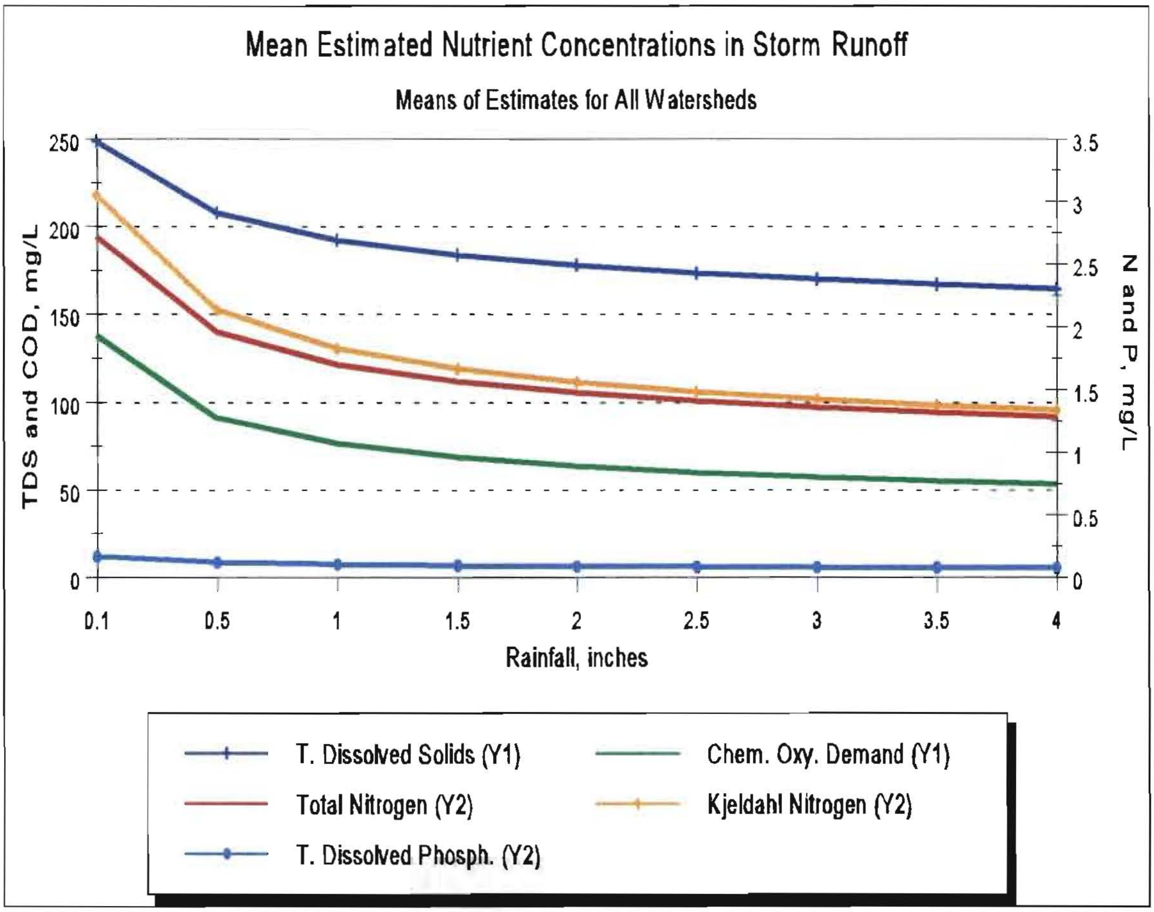


Figure 6-3: Mean Estimated Concentrations of Metals in Storm Runoff

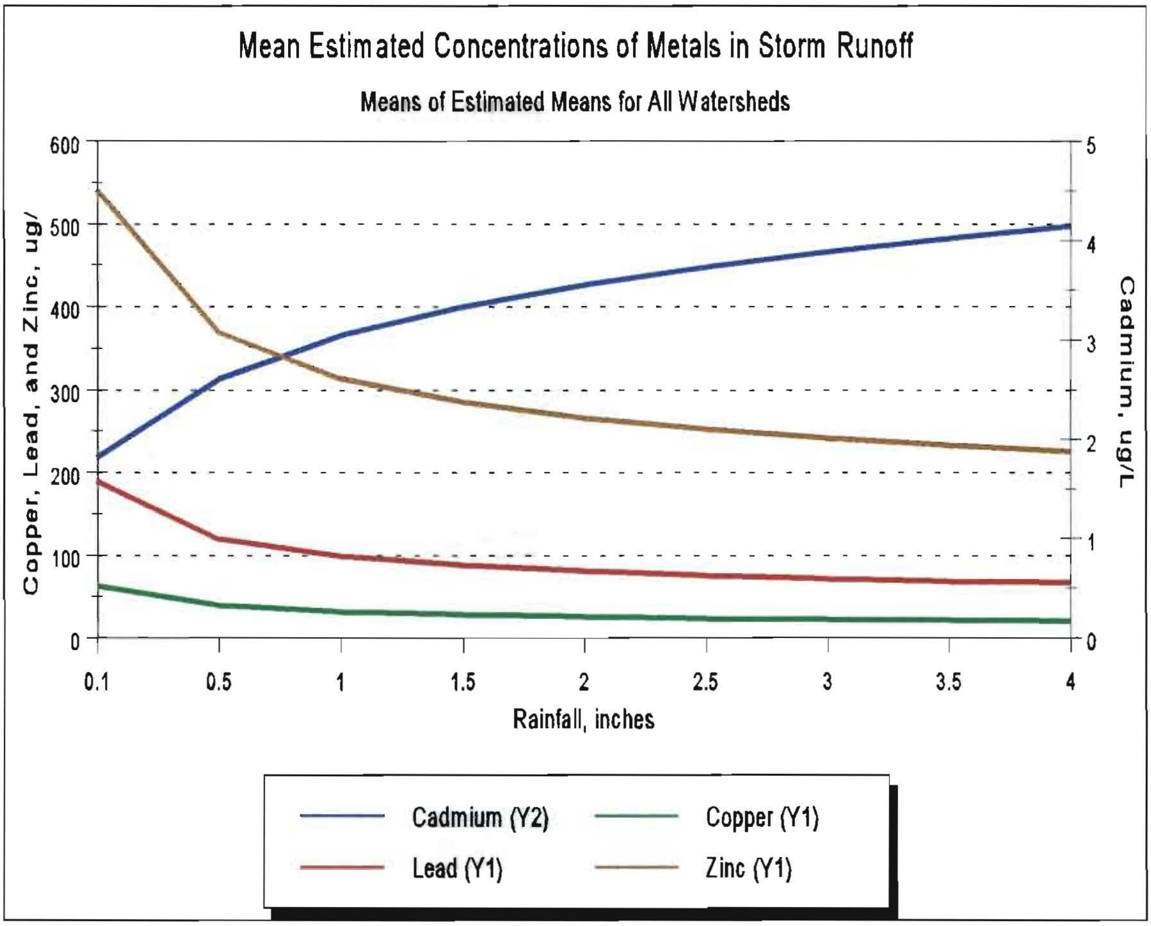


Figure 6-4: Estimated Total Loads of Nutrients in Storm Runoff

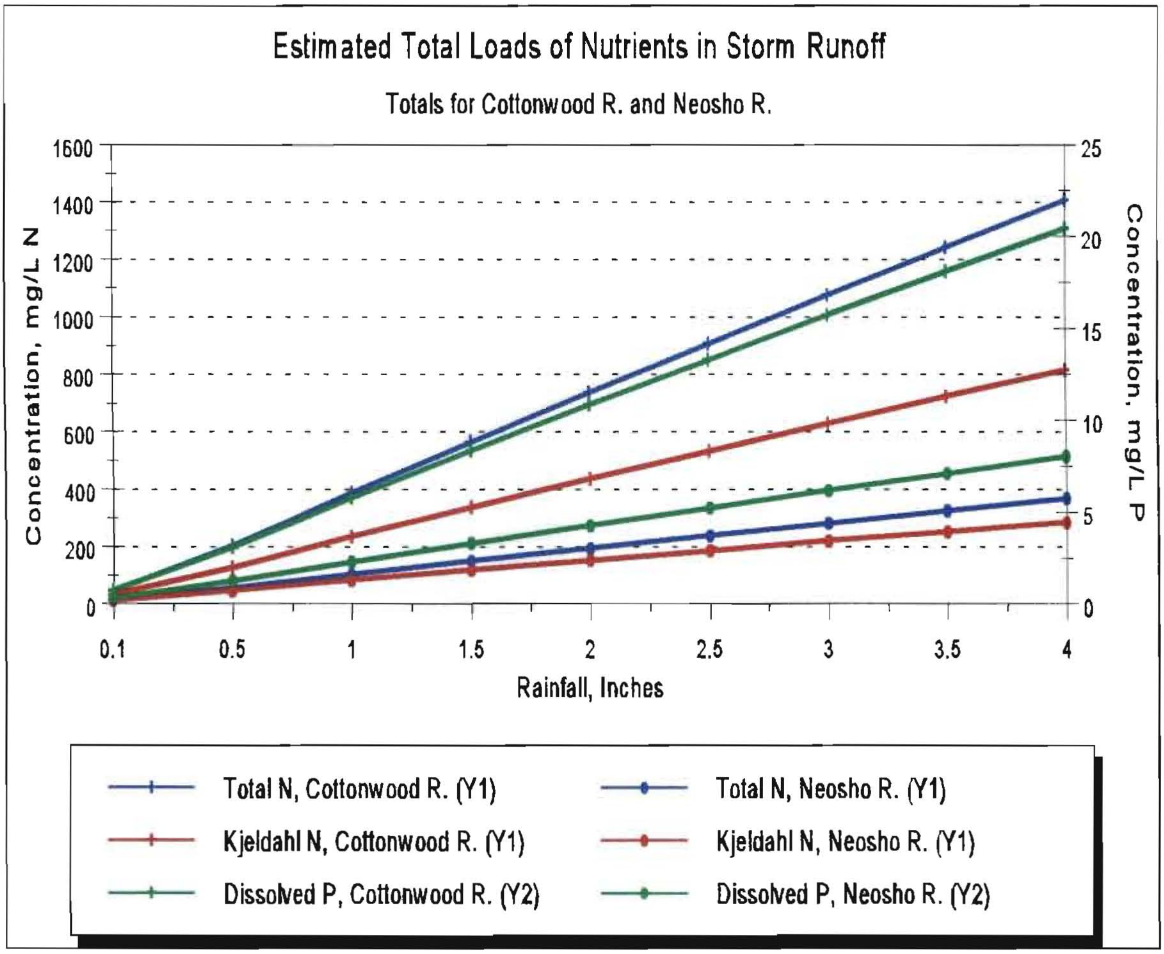
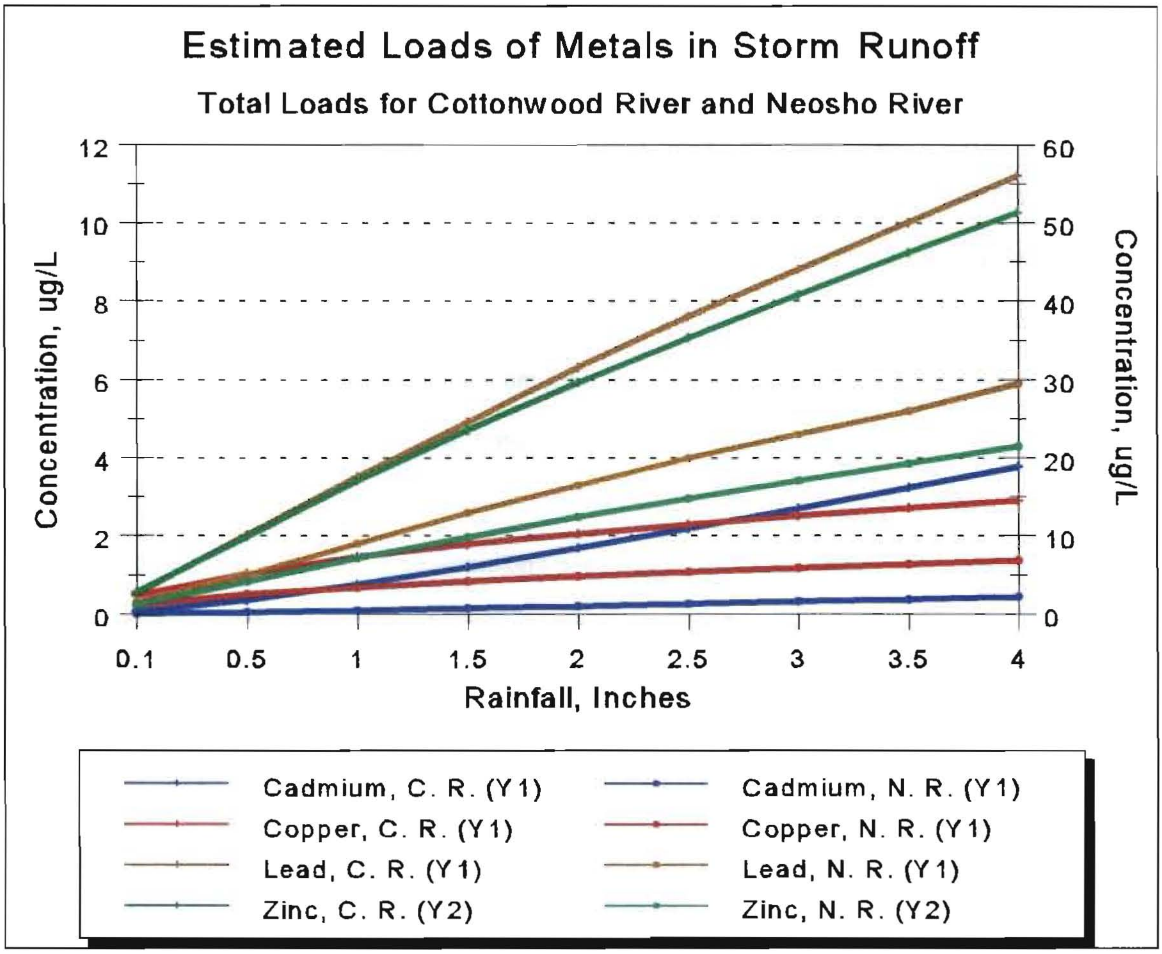


Figure 6-5: Estimated Total Loads of Metals in Storm Runoff



Highest mean concentrations were estimated for the smallest watersheds. The estimates are comparable to those found in Topeka. Pope and Bevans reported mean concentrations between 8 and 400 mg/L, and mean values between 46 and 66 mg/L for the different sites.

Estimated mean storm concentrations of total nitrogen in storm runoff were comparable to values found in Topeka and did not exceed recommended limits, 5.0 mg/L N, for the protection of fish from nitrate (EPA, 1976). Mean concentrations of total nitrogen in the different watersheds were estimated at 2.2 to 3.3 mg/L N with 0.1 inches (0.25 cm) of rain and 1.1 to 1.6 mg/L N with 3.0 inches (7.6 cm) of rain. Concentrations of nitrogen from nitrate and nitrite in Shunganunga Creek ranged from non-detectable levels to 4.2 mg/L, and mean values at different sites ranged from 0.7 to 1.6 mg/L N.

Estimated storm runoff concentrations of Kjeldahl nitrogen, from ammonia and organic nitrogen, were comparable to those found in stormwater in Shunganunga Creek and exceeded state water quality standards for unusual conditions of high pH or high temperature. Estimated concentrations ranged from 2.5 to 3.5 mg/L N with 0.1 inches (0.25 cm) of rain and 1.2 to 1.6 mg/L with 3.0 inches (7.6 cm) of rain. Water quality standards range through 31.7 mg/L at pH 7.0 and temperature of 5^{0}C and 2.91 mg/L at pH 8.5 and 25^0 C. The mean of estimated concentrations with 0.1 inches (0.25 cm) of rain, 3.0 mg/L, exceeded water quality standards for pH of 8.5 or above. Values in Shunganunga Creek ranged from 0.26 to 4.5 mg/L N, and mean values ranged from 1.6 to 2.4 mg/L.

Estimated mean concentrations of total dissolved phosphorus from phosphate were lower than those found in stormwater in Shunganunga Creek and exceeded suggested water quality standards. Estimated concentrations in runoff varied from 0.079 to 0.24 mg/L P with 0.1 inches (0.25 cm) of rain and 0.039 to 0.12 mg/L with 3.0 inches (7.6 cm) of rain. A suggested limit is 0.10 mg/L total phosphorus (EPA, 1976). Total dissolved phosphorus in Shunganunga Creek ranged from 0.13 to 5.8 mg/L P, and means ranged from 0.47 to 1.2 mg/L. Estimated concentrations of total phosphorus ranged from 0.55 to 1.02 mg/L P with 0.1 inches (0.25 cm) of rain and 0.30 to 0.56 mg/L with 3.0 inches (7.6 cm) of rain.

Estimated mean concentrations of cadmium in runoff were generally below state water quality standards. Estimated concentrations varied from 0.0012 to 0.0029 mg/L with 0.10 inches (0.25 cm) of rain and 0.0026 to 0.0062 mg/L with 3.0 inches (7.6 cm) of rain. With 1.5 inches (3.8 cm) of rain or more, the estimates for watersheds 7 and 8 surpassed the state acute water quality standard of 0.005 mg/L for waters with hardness of 100 mg/L as calcium carbonate. No estimated concentrations surpassed the state standard of 0.016 mg/L for waters with hardness of 300 mg/L as calcium carbonate. Pope and Bevans did not report concentrations of cadmium in Shunganunga Creek. Unlike the other metals, the estimated mean concentrations of cadmium increased with increasing values for precipitation.

Estimated mean storm concentrations of copper in runoff were higher in the smaller watersheds than in the larger ones. Estimates ranged from 0.035 to 0.087 mg/L with 0.1 inches (0.25 cm) of rain and 0.013 to 0.031 mg/L with 3.0 inches (7.6 cm) of rain (figure 6-4). With 3.0 inches (7.6 cm) of rain or less, the mean of estimated concentrations for the watersheds exceeded the state acute water quality standards of 0.06 mg/L for waters with 100 mg/L calcium carbonate. With rainfall of 0.10 inches (0.25 cm), the mean of estimated concentrations exceeded the acute standard of 0.06 mg/L for waters with hardness of 300 mg/L as calcium carbonate. The values are closely comparable to those reported by Pope and Bevans. Stormwater concentrations in Shunganunga Creek ranged from undetectable levels to 0.200 mg/L, and median values for sites ranged from 0.010 to 0.020 mg/L.

Estimated mean concentrations of lead in storm runoff were also comparable to the concentrations reported by Pope and Bevans. Estimated concentrations varied from 0.045 to 0.410 mg/L with 0.1 inches (0.25 cm) of rain and 0.017 to 0.15 mg/L with 3.0 inches (7.6 cm) of rain. None of the estimates surpassed state acute water quality standards of 0.66 mg/L for waters with hardness of 300 mg/L as calcium carbonate. The mean of estimates for 0.1 inches (0.25 cm) of rain, 0.189 mg/L, surpassed the standard for waters with hardness of 100 mg/L calcium carbonate. Values in Shunganunga Creek were as high as 0.80 mg/L, and median values for sites ranged from 0.010 to 0.070 mg/L.

Estimated mean concentrations for zinc in storm runoff were higher than the results reported by Pope and Bevans, and nearly all estimates surpassed state water quality standards. Estimated concentrations varied from 0.63 to 2.3 mg/L with 0.1 inches (0.25 cm) of rain and 0.43 to 1.0 mg/L with 3.0 inches (7.6 cm) of rain. The state acute water quality standard is 0.356 mg/L for waters with hardness of 300 mg/L as calcium carbonate. The means for estimates surpassed the standard for all rainfall values to 3.0 inches (7.6 cm); estimates for watershed 8 were below the standard given rainfall in excess of 1.25 inches (3.2 cm). Zinc concentrations in Shunganunga Creek ranged from 0.0077 and 0.520 mg/L, and means ranged from 0.048 to 0.140 mg/L.

6.3 Modeling of Pollutant Concentrations in Receiving Rivers

The estimates of total storm pollutant loads and total storm discharge were used to model pollutant concentrations in receiving rivers as functions of rainfall and river discharge. The calculations that were performed grossly oversimplify the complex chemical and hydrological processes that control pollutant transport, mixing, and availability as urban runoff mixes with the waters of the receiving river. The models treat the total storm loads and discharges as if all of the urban watersheds discharged into their receiving rivers at the same point and produced a uniform concentration of each pollutant in the receiving river at the discharge point. Also, the calculations assume that loading and mixing occur uniformly over a period of time (time of loading) that is a linear function of the amount of total rainfall.

The model for discharge was used to estimate the total volume of water discharged by each watershed for each given value of rainfall. A sum was calculated of the estimated total discharge from each watershed which drains into the Cottonwood River, and the sum was multiplied by 0.50 to compute a value for the total volume of runoff that would be delivered to the river from Emporia during the time of loading. The total volume of water supplied from upstream was calculated as the product of the river discharge and the time of loading. The total volume of runoff was added to the total volume of river discharge from upstream to give a total volume of water in the channel during time of loading. The calculations were repeated with each of the values for each of four values for initial river discharge, and equivalent calculations for the Neosho River were completed with river discharge values pertaining to the Neosho River. It was assumed that no other sources contributed to river discharge during the time of loading.

The total mass of pollutant that was present in the river channel during time of loading was calculated as the sum of pollutant mass in the river and total pollutant mass from runoff for each value of rainfall. The estimated masses of pollutant loading from each watershed were added to give a total load for each receiving river, and the sum was multiplied by 0.95 to provide an estimate of the mass of pollutant delivered to the river during the time of loading. A background value of pollutant concentration was assumed for the river (zero in some cases) and was multiplied by the discharge of the river to give a value for the rate of supply of pollutant from upstream. The rate value was multiplied by the time of loading to give a total mass of pollutant supplied from upstream. The total mass in the river was added to the total mass discharged from Emporia, and was divided by the total volume of discharge during the time of loading.

The calculations that were performed are described by the equation below, in which MPC is the modeled pollutant concentration in the river:

$$MPC = [(RQ \times RC \times DL) + (ETL \times 0.95)] \div [(RQ \times DL) + (ER \times 0.5)]$$

RQ is the river discharge, RC is the assumed initial river concentration, and DL is the time (duration) of loading. ETL is the estimated total load of pollutant, and ER is the estimated total runoff. Appropriate factors for conversion of units were included in the calculations.

Values for rainfall were the same as those used with the USGS models. It was assumed that the loading would occur over a time span equal to 0.5 hours plus 0.5 hours per inch of rainfall. Values for river discharge were mean values for the 1963 to 1995 water years of the discharge exceeded by 10 percent of all flows, discharge exceeded by 50% of all flows, mean discharge, and discharge exceeded by 90% of all flows (USGS, 1997) for the Neosho River at Americus, Kansas, and the Cottonwood at Plymouth, Kansas. See table 6-4 for discharge values for each river.

State water quality criteria for cadmium, copper, lead, and zinc are based upon hardness and the water-effect ratio of the body in question. The standards that are used in this study were

Table 6-4: Discharge Values Used for Estimation of River Concentrations

River	Discharge, cubic feet per second			
	90% Exceed	50% Exceed	Mean	10% Exceed
Cottonwood	43	250	882	1880
Neosho	10	64	328	868

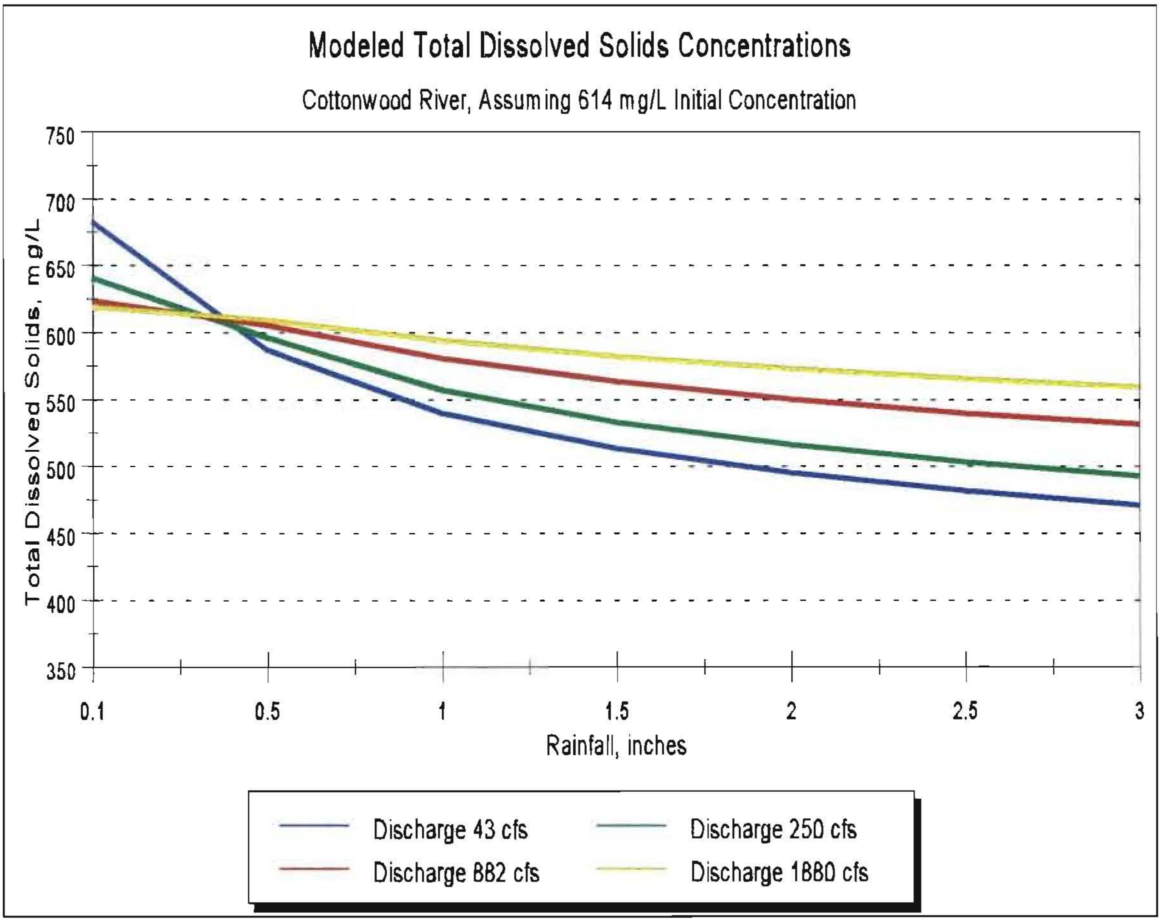
calculated with the assumption that the water-effect ratio is one (1.0), and hardness values for each river were obtained from the 1968 water quality records (USGS, 1968). Recorded values for hardness in the Neosho River in 1968 averaged 200 mg/L as calcium carbonate and had a lowest value of 94 mg/L as calcium carbonate. The lowest recorded value for the Cottonwood River was 300 mg/L and the mean was 490 mg/L as calcium carbonate.

Modeled concentrations of pollutants in the rivers are generally higher for the Cottonwood River than in the Neosho River, with some exceptions. Modeled concentrations of Kjeldahl Nitrogen are higher for the Neosho River for most values of rainfall when discharge is at 50% exceedance levels or lower. Modeled concentrations of total dissolved phosphorus and zinc are higher for the Neosho River for all values of rainfall and the three lowest river stages. Modeled copper concentrations are higher for the Neosho River for all values of rainfall and river stage.

The modeled concentrations indicated that the Neosho and Cottonwood Rivers are not threatened by total dissolved solids in runoff from Emporia. The highest total dissolved load recorded for the Cottonwood River in 1968 was 614 mg/L, and the highest value for the Neosho River was 329 mg/L (USGS, 1968). When these values are taken as the background values for the rivers, the highest estimated total dissolved solids concentrations are 682 and 331 mg/L, respectively, which were calculated with the lowest rainfall and discharge values (figure 6-6). Estimates for the Cottonwood River show a greater magnitudes of increase over background values, and a broader range of discharge and rainfall values in which increases occur.

COD concentrations were modeled with background values of 100 and 300 mg/L for the Neosho River and 100 mg/L and 600 mg/L for the Cottonwood River. When the background values of 100 mg/L were applied, modeled estimates for both rivers were as high as 150 mg/L but were less than 100 mg/L given all rainfall values above 1.0 inches (2.54 cm). When the higher background values were assumed, the modeled concentrations for both rivers declined after loading with storm runoff. The modeled estimates indicated that storm runoff poses little threat of raising COD concentrations above background levels.

Figure 6-6: Modeled Total Dissolved Solids in Cottonwood River after Storm Runoff



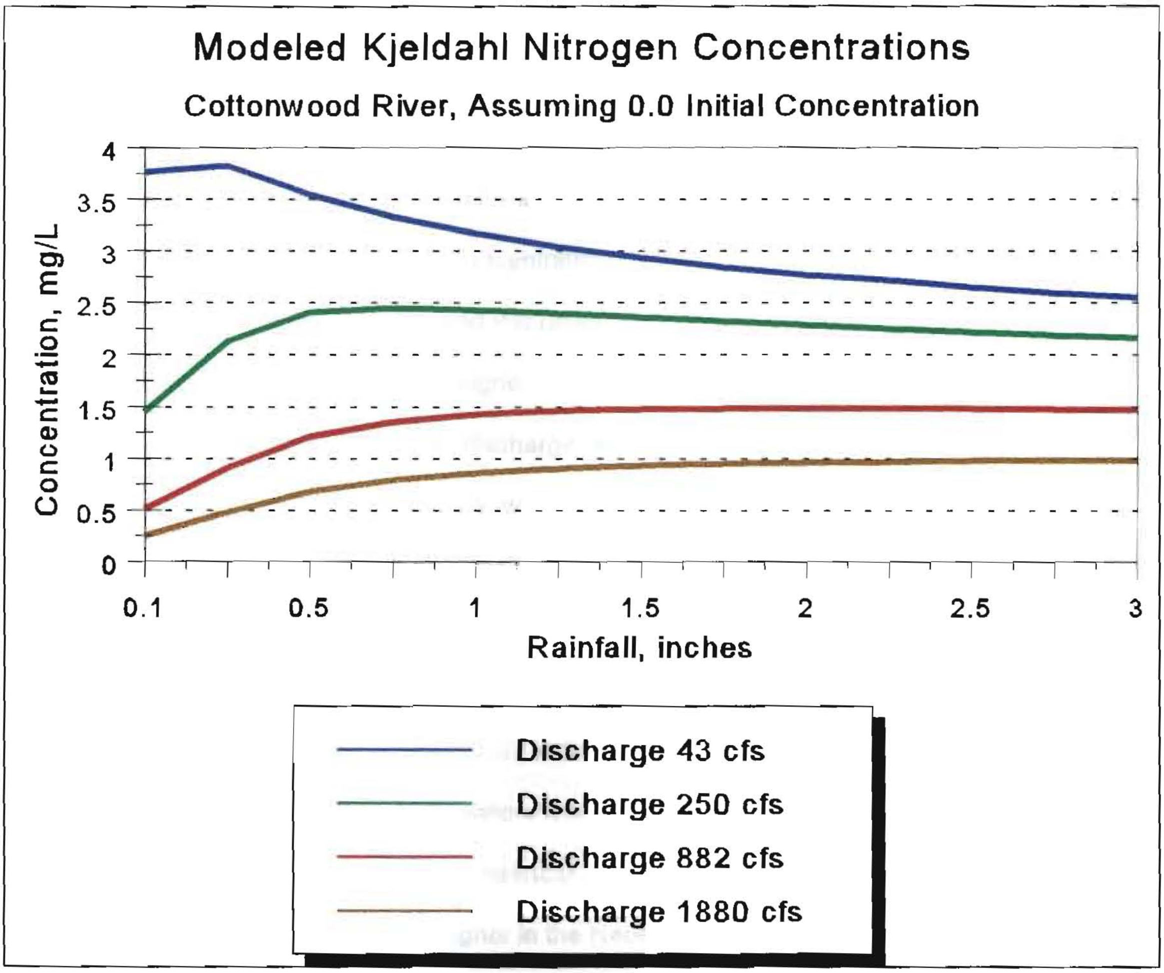
The modeled concentrations of Kjeldahl nitrogen in the rivers exceeded state water quality standards under the low-probability conditions of low discharge, low rainfall amounts, and unusually high pH in the receiving rivers (8.5 or above). Assuming a background value of 0.0 mg/L and 90% exceedance flow, modeled concentrations in the Cottonwood River range from 3.8 mg/L with 0.1 inches (0.25 cm) of rain to 2.6 mg/L with 3.0 inches (7.6 cm) of rain (figure 6-7). Under the same conditions, modeled concentrations in the Neosho River range from 4.5 mg/L to 2.8 mg/L. At pH 7.5, water quality standards range from 20.7 mg/L at 0^oC to 12.6 mg/L at 30^o C.

Total nitrogen concentrations from nitrate were modeled in the rivers using values of 0.056 and 0.050 mg/L as background values for the Cottonwood River and the Neosho River, respectively, which were the maximum values recorded in each river during 1968 (USGS, 1968). Modeled concentrations of nitrate levels in the rivers after runoff showed increases of 20 to 100 times the background values but were generally less than one half of the recommended limit. Given mean discharge and 1.0 inches (2.54 cm) of rain, the estimated concentrations were 2.4 mg/L and 1.8 mg/L for the Cottonwood River and the Neosho River, respectively.

Modeled estimates of total dissolved phosphorus in the rivers after loading were all below the recommended level of 0.10 mg/L (EPA, 1978) but higher than typical values for the rivers. Maximum recorded phosphorus concentrations in 1968 were 0.0063 and 0.0053 mg/L P for the Cottonwood River and Neosho River, respectively (USGS, 1968). When background concentrations were assumed to be 0.0 mg/L, modeled concentrations were 10 to 30 times greater than the maximum 1968 concentrations. With mean river discharge, modeled concentrations in the Cottonwood River ranged from 0.015 mg/L P with 0.1 inches (0.25 cm) of rain to 0.038 mg/L with 3.0 inches (7.6 cm) of rain and concentrations in the Neosho River ranged from 0.016 mg/L with 0.1 inches (0.25 cm) of rain to 0.043 mg/L with 3.0 inches (7.6 cm).

Modeled concentrations of cadmium were approximately three times greater in the Cottonwood River than in the Neosho River, but estimates generally were below state water quality standards. With mean discharge, modeled concentrations in the Cottonwood River ranged from 0.0009 mg/L to 0.0063 mg/L with 0.1 to 3.0 inches (0.25 to 7.6 cm) of rain, respectively, and

Figure 6-7: Modeled Kjeldahl Nitrogen Concentrations in Cottonwood River after Storm Runoff

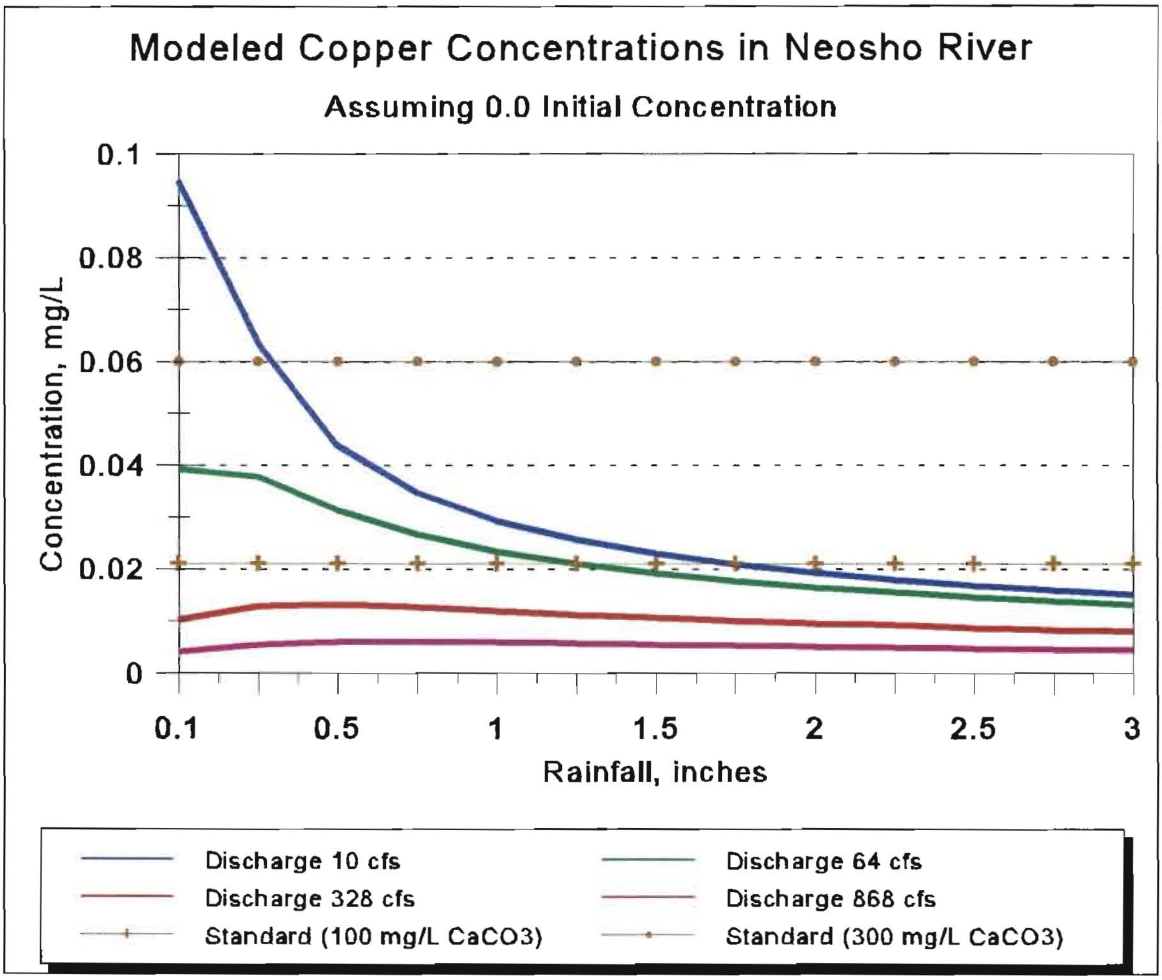


analogous concentrations in the Neosho River ranged from 0.0003 mg/L to 0.0022 mg/L. None of the estimates surpassed the state acute water quality standard of 0.016 for waters with hardness of 300 mg/L as calcium carbonate. The standard of 0.005 mg/L for waters with hardness of 100 mg/L as calcium carbonate was not surpassed by any of the estimates for the Neosho River but was surpassed by most estimates for the Cottonwood River at mean discharge levels or lower.

Modeled estimates of copper concentrations in the rivers after loading may exceed state standards for low levels of discharge and low rainfall events, depending upon the hardness of the waters. Modeled concentrations were higher for the Neosho River than for the Cottonwood River, especially under conditions of low river discharge, assuming 0.0 mg/L initial concentration. The highest estimate for the Cottonwood River was 0.059 mg/L and the highest estimate for the Neosho River was 0.095 mg/L, each at the low stage with 0.1 inches (0.25 cm) of rain (figure 6-8). Water quality standards are 0.021 mg/L with 100 mg/L calcium carbonate, 0.060 mg/L with 300 mg/L calcium carbonate, and 0.097 mg/L with 500 mg/L calcium carbonate.

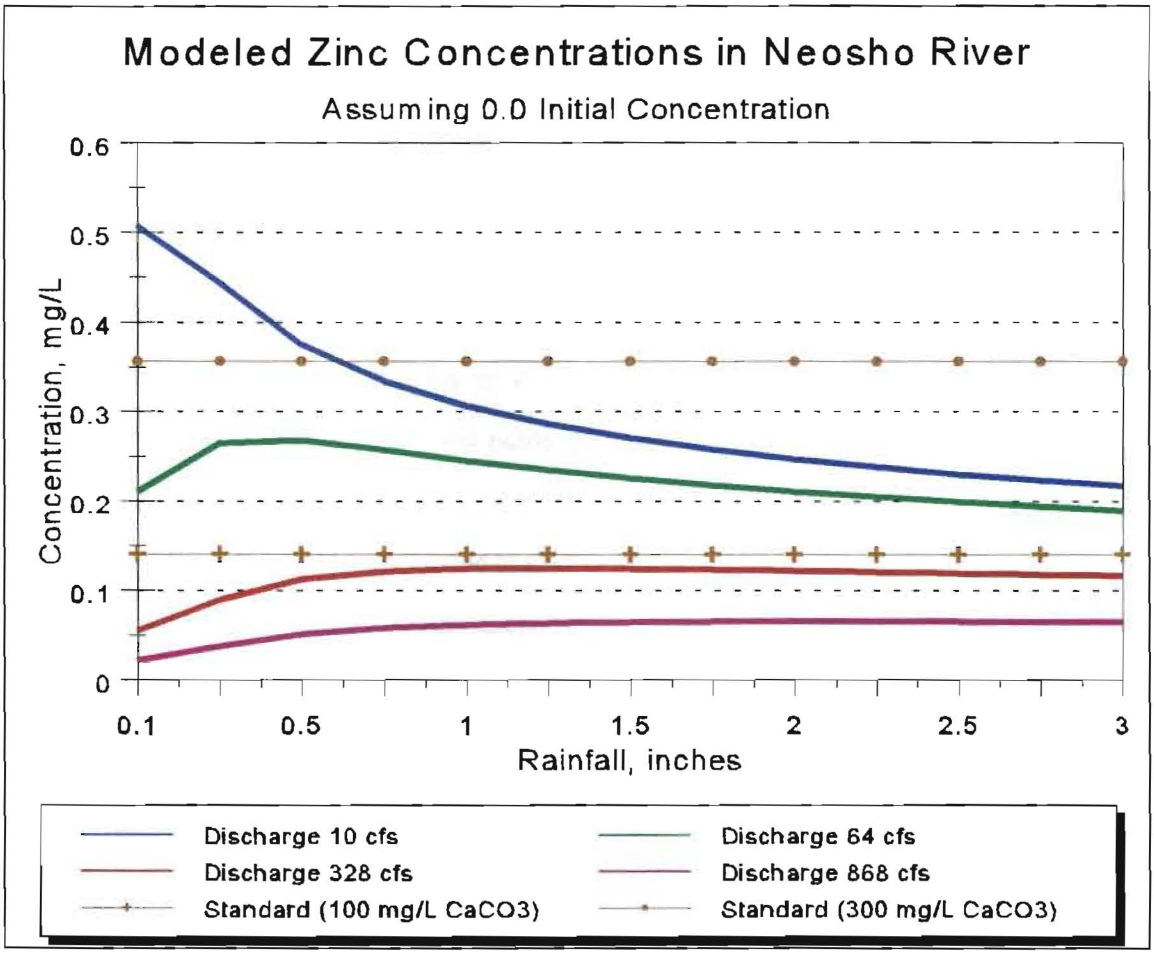
The modeled concentrations of lead in the rivers were generally less than one fifth the acute state standard of 0.661 mg/L for waters with hardness of 300 mg/L as calcium carbonate, and none of the estimates surpassed the standard of 0.163 mg/L for waters with hardness of 100 mg/L. Modeled concentrations were higher in the Neosho River than in the Cottonwood River and were nearly double those of the Cottonwood River under conditions of low discharge, assuming 0.0 mg/L initial concentration. As with the zinc concentrations (figure 6-8), the peak estimates of lead concentrations occurred at higher rainfall values as discharge values increased. For the Neosho River, the highest estimate given low discharge was 0.12 mg/L with 0.1 inches (0.25 cm) of rain, the highest estimate with 50% exceedance discharge was 0.68 mg/L with 0.5 inches (1.3 cm) of rain, the highest estimate with mean discharge was 0.033 mg/L with 1.5 inches (3.8 cm) of rain, and the highest estimate with 10% exceedance discharge was 0.018 mg/L with 2.5 inches (6.4 cm) of rain. Estimated concentrations in the Cottonwood River ranged from 0.068 mg/L with low discharge and 0.1 inches (0.25 cm) of rain to 0.014 mg/L with the 10% exceedance discharge value and 2.0 inches (5.1 cm) of rain.

Figure 6-8: Modeled Copper Concentrations in Neosho River after Storm Runoff



Concentrations of zinc in the rivers were estimated to exceed state standards in the Neosho River with most levels of rainfall when the discharge was equal to or less than the 50% exceedance level, assuming a hardness of 200 mg/L as calcium carbonate and water quality standard of 0.253 mg/L (figure 6-9). Estimates for the Cottonwood River were lower than those for the Neosho River, ranging from 0.048 mg/L to 0.096 mg/L with mean discharge and variation of rainfall from 0.1 to 3.0 inches (0.25 to 7.6 cm). Calculations assumed that the initial concentrations in the rivers were 0.0 mg/L. See figure 6-9.

Figure 6-9: Modeled Zinc Concentrations in Neosho River after Storm Runoff



Chapter 7: Conclusions

Water quality variables in urban runoff were successfully analyzed and described as functions of watershed variables. Monitoring of pH, conductivity, and runoff provided a database for description of repetitive differences between watersheds in the water quality of the dry-weather runoff they produce. Composite samples of dry-weather flow successfully reproduced prevailing differences between watersheds, but the concentrations of major ions in the composites were probably 20 to 30 percent lower than the mean long-term concentrations. Mean concentrations were determined for the major ions, major nutrients, iron, and zinc. Copper, lead, and tin were not detected in any composite samples.

A water quality problem was found to exist in watershed 2 based upon field observations at the sampling point. Macroscopic life was absent at the site throughout the sampling period, and the site was notable for odors and surface pollutants. Runoff from watershed 2 had exceptionally high ammonia concentrations and low pH values. Runoff from watershed 6 some pH values above 9.0; water quality problems may occur in the watershed, particularly during summer months. Heavy sediment loading occurred in watershed 7 on several dates due to construction near the drainage channel. Runoff from watershed 7 had exceptionally high concentrations of phosphate and potassium. Dumping in watershed 4 resulted in turbid conditions in runoff on one date.

Nitrate and phosphate concentrations varied substantially between sampling dates and exceeded suggested water quality standards in samples from several watersheds. Ammonia was detected in all analyzed samples from June 24 and did not exceed state water quality standards. Samples from several watersheds contained zinc in excess of state acute water quality standards.

Land use variables correlated more strongly with concentrations of water quality constituents than with rates of loading of water quality constituents. Water quality variables correlated more strongly with land use variables than with soil classes. Water quality constituent concentrations correlated more strongly with distance-weighted land use variables when equal weight was given to all land use parcels or when weight was given to the inner zone only.

The urban land uses at Emporia produce slightly higher concentrations of the major ions than do non-urban land uses, but no particular land use was identified as a leading source of major ions. Total dissolved solids and the major ions showed weak or moderate correlations with all land use classes, probably due to their derivation from a variety of land uses as well as precipitation. The concentrations of major ions tended to be lower in watersheds with greater areas of ponds and vegetation. Urban land uses contribute to concentrations of chloride more strongly than to bicarbonate. Calcium and sodium concentrations correlated more strongly with chloride than with bicarbonate. Runoff was less acidic in watersheds with larger areas of ponds and vegetation.

Very strong correlations between potassium and phosphate indicated that they have common sources in vegetated and rural land uses, and possible sources in industries near the drainage channels. Nitrate showed no clear relationships with the other ions but showed a strong tendency to be higher in urbanized and paved watersheds, due perhaps to the consumption of nitrate by vegetation or the production of nitrate in urban sources such as combustion engines.

Iron concentrations correlated positively with vegetated areas and negatively with industrial areas. Correlations indicated that iron concentrations are strongly controlled by land use areas which lie near the drainage channels. The land uses that contribute iron to runoff apparently compete for space with the sources of sulfate. Zinc concentrations correlated very strongly with railroad land uses and weakly with all other land use classes.

Predicative models that were generated from the chemical and land use databases showed modest standard errors of prediction for each constituent concentration. However, exceptionally high errors occurred in some cases and indicated that the predictive models lack important factors to adequately describe particular water quality constituent concentrations in some watersheds. The models probably underestimate mean concentrations because they were generated with data from the composite samples.

The mapping operations by which the land use data were generated were adequately precise and accurate, but the land use classification scheme was found to be insensitive to the differences and similarities among sources of the water quality constituents. The accuracy of results for chemical analyses are questionable for nitrate and ammonia, due to possible oxidation of ammonia to nitrate after collection of the samples. The analyses of calcium, sodium, and magnesium suffered contamination and other sources of error. Cation concentrations exceeded anion concentrations in most samples, possibly due to the presence of organic acids.

Models from the USGS provided estimates of pollutant concentrations and loads in storm runoff that compared favorably with reported concentrations from watersheds in Topeka, Kansas. Estimated mean storm concentrations of zinc, copper, and Kjeldahl nitrogen surpassed State of Kansas water quality standards for low values of total rainfall (generally 0.5 inches or less). Some estimated concentrations of total dissolved phosphorus exceeded recommended levels.

The estimates of total storm pollutant loading and discharge were used to model pollutant concentrations in receiving rivers using assumptions that favored overestimation of concentrations. Total dissolved solids and COD loads were estimated at levels that pose no threat to the water quality of either the Cottonwood River or the Neosho River. The estimated total dissolved solids load that is delivered to the Cottonwood River is greater than the load that is delivered to the Neosho River, and the estimated concentrations of pollutants in the Cottonwood River following loading were higher than those for the Neosho River under most conditions.

Storm runoff endangers the water quality of the Neosho River more than the water quality of the Cottonwood River, particularly under conditions of low discharge and rainfall amounts of one inch or less. Water quality criteria are lower for the Neosho River because it usually has lower hardness values than the Cottonwood River, and the lower discharge of the Neosho River provides less capacity for dilution of runoff. Modeled concentrations of Kjeldahl nitrogen, copper, and zinc in the Neosho River approached or exceeded water quality standards under conditions of low discharge and low rainfall. Modeled concentrations of total dissolved nitrogen and total dissolved phosphorus in the rivers following runoff did not exceed water quality criteria but were much higher than the maximum background concentrations that were recorded in 1968.

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Appendix A: Landuse by Zone and Soil Class of Watersheds

Abbreviations used in column headings:

- Shed: Watershed number
- Zone: Inner zone (1), middle zone (2), outer zone (3)
- Soil: Soil class
- Total: Total area, square kilometers
- Res: Percent residential area
- Com: Percent commercial area
- Ind: Percent industrial area
- Veg: Percent vegetated area
- Crop: Percent cropland area
- Paved: Percent paved area
- Pond: Percent ponded area
- Imp: Percent impervious area
- Rural: Percent rural area
- Rail: Percent railroad area

Shed	*Zone*	*Soil*	*Total*	*Res*	*Inst*	*Com*	*Ind*	*Veg*	*Crop*	*Paved*	*Pond*	*Imp*	*Rural*	*Rail*
1	1	1	0.0											
		2	0.4167	45	1	5	7	19	5	20	0	51	9	2
		3	0.0738	44	0	0	0	34	1	23	0	40	34	0
		4	0.0											
	2	1	0.0											
		2	0.2714	27	1	6	26	25	4	14	0	52	13	2
		3	0.0697	43	0	0	0	45	4	12	0	25	45	0
		4	0.0											
	3	1	0.0											
		2	0.0005	100	0	0	0	0	0	0	0	38	0	0
		3	0.2637	14	0	0	17	62	0	4	1	24	40	2
		4	0.0											
total			1.0959	33	1	4	13	34	3	14	0	44	21	2

Shed	*Zone*	*Soil*	*Total*	*Res*	*Inst*	*Com*	*Ind*	*Veg*	*Crop*	*Paved*	*Pond*	*Imp*	*Rural*	*Rail*
2	1	1	0.0005	0	16	0	0	0	0	100	0	93	0	0
		2	0.8263	44	2	14	0	3	0	37	0	65	0	2
		3	0.1960	41	11	14	0	2	0	40	0	67	1	0
		4	0.0											
	2	1	0.0											
		2	0.2363	55	9	5	0	1	0	32	0	62	0	1
		3	0.2858	52	6	9	0	2	0	32	0	63	0	2
		4	0.0											
	3	1	0.0											
		2	0.0097	65	1	0	0	3	0	31	0	55	0	0
		3	0.2104	60	0	0	0	8	0	32	0	54	0	0
		4	0.0											
total			1.7651	49	5	10	0	3	0	35	0	63	0	1

Shed	*Zone*	*Soil*	*Total*	*Res*	*Inst*	*Com*	*Ind*	*Veg*	*Crop*	*Paved*	*Pond*	*Imp*	*Rural*	*Rail*
3	1	1	0.0											
		2	0.5549	35	2	15	1	19	0	29	0	57	14	3
		3	0.1949	31	3	4	0	36	0	28	0	46	6	0
		4	0.0103	0	0	0	0	100	0	0	0	10	0	0
	2	1	0.0											
		2	0.1930	45	4	8	0	7	0	34	0	62	0	3
		3	0.2448	35	8	5	0	20	0	28	0	56	0	6
		4	0.0083	0	0	0	0	100	0	0	0	10	0	0
	3	1	0.0											
		2	0.0031	67	0	0	0	2	0	30	0	55	0	0
		3	0.2152	46	1	0	0	15	0	34	4	52	0	0
		4	0.0212	0	0	0	0	89	0	0	11	9	0	0
total			1.4607	36	3	8	0	21	0	29	1	54	6	3

Shed	*Zone*	*Soil*	*Total*	*Res*	*Inst*	*Com*	*Ind*	*Veg*	*Crop*	*Paved*	*Pond*	*Imp*	*Rural*	*Rail*
4	1	1	0.0519	60	0	1	0	8	0	30	0	53	0	0
		2	0.5789	36	7	6	10	7	0	25	0	65	4	13
		3	0.7131	52	9	2	0	15	4	24	0	52	6	2
		4	0.0032	0	0	2	0	97	0	1	0	13	97	0
	2	1	0.0											
		2	0.3541	50	4	7	8	5	0	24	0	59	1	4
		3	0.4661	52	0	5	0	13	1	22	0	53	9	8
		4	0.0207	0	0	0	0	92	20	7	0	16	92	0
	3	1	0.0											
		2	0.0620	48	0	22	0	0	0	33	0	65	0	0
		3	0.2158	38	0	9	0	11	0	20	0	63	6	26
		4	0.0468	0	0	0	0	92	0	8	0	16	92	0
total			2.5395	45	5	5	4	13	2	23	0	56	8	8

Shed	*Zone*	*Soil*	*Total*	*Res*	*Inst*	*Com*	*Ind*	*Veg*	*Crop*	*Paved*	*Pond*	*Imp*	*Rural*	*Rail*
5	1	1	0.2297	16	2	24	0	43	0	30	0	46	0	0
		2	0.3771	18	1	23	15	22	1	25	0	60	8	7
		3	0.7293	39	1	11	0	32	1	18	0	44	3	1
		4	0.0038	0	0	0	0	98	0	2	0	12	98	0
	2	1	0.0											
		2	0.2259	32	1	7	20	19	0	22	0	55	6	6
		3	0.6760	55	4	8	3	8	0	25	0	55	3	2
		4	0.0062	0	0	0	0	53	0	47	0	50	53	0
	3	1	0.0											
		2	0.0162	50	0	0	29	0	0	28	0	60	0	0
		3	0.5586	50	2	5	7	9	0	27	0	57	1	3
		4	0.0164	0	0	0	0	89	0	11	0	19	89	0
total			2.8391	40	2	11	6	21	0	24	0	52	4	3

Shed	Zone	Soil	Total	Res	Inst	Com	Ind	Veg	Crop	Paved	Pond	Imp	Rural	Rail
6	1	1	0.1852	10	8	17	0	55	0	14	0	40	0	0
		2	0.5126	5	1	30	20	25	2	26	0	63	5	5
		3	0.3814	1	7	10	15	44	2	35	2	49	7	2
		4	0.0											
	2	1	0.0											
		2	0.3557	13	0	21	18	29	6	29	0	56	7	1
		3	0.2842	12	0	5	29	37	1	10	0	49	9	9
		4	0.0											
	3	1	0.0											
		2	0.1030	3	0	41	6	30	5	45	0	62	5	0
		3	0.3230	26	0	16	12	20	0	24	0	59	6	10
		4	0.0											
total			2.2288	10	2	18	16	31	2	25	0	53	6	4

Shed	Zone	Soil	Total	Res	Inst	Com	Ind	Veg	Crop	Paved	Pond	Imp	Rural	Rail
7	1	1	0.1333	20	23	0	0	52	0	13	0	38	4	0
		2	0.7281	0	0	1	13	72	46	16	0	30	55	0
		3	0.7780	8	8	3	2	67	16	15	2	30	49	0
		4	0.1266	0	0	0	12	76	9	13	0	28	76	0
	2	1	0.0											
		2	0.2349	8	1	0	1	69	30	20	0	31	44	0
		3	0.9844	8	4	3	1	72	27	13	0	24	49	0
		4	0.0449	0	0	0	0	88	60	12	0	20	88	0
	3	1	0.0											
		2	0.0223	0	17	0	0	76	11	17	0	29	11	0
		3	0.9189	4	0	0	2	79	24	14	2	13	41	0
		4	0.2650	0	0	0	17	64	33	19	9	28	43	0
total			5.1022	4	3	1	4	60	22	12	1	23	39	0

Shed	Zone	Soil	Total	Res	Inst	Com	Ind	Veg	Crop	Paved	Pond	Imp	Rural	Rail
8	1	1	0.3361	27	1	0	7	50	0	15	1	35	0	0
		2	0.0											
		3	0.1591	45	0	0	1	36	0	17	1	34	0	0
		4	0.0											
	2	1	0.0383	71	0	0	0	17	0	11	2	39	0	0
		2	0.0											
		3	0.2249	38	0	0	0	37	0	23	2	26	0	0
		4	0.0											
	3	1	0.0027	8	0	0	0	31	0	61	0	64	0	0
		2	0.0											
		3	0.1594	55	0	0	0	20	0	23	2	29	0	0
		4	0.0453	40	0	0	0	49	0	11	0	30	0	0
total			1.3226	29	0	0	2	28	0	13	1	28	0	0

Shed	Zone	Soil	Total	Res	Inst	Com	Ind	Veg	Crop	Paved	Pond	Imp	Rural	Rail
9	1	1	0.2125	54	1	0	0	29	0	14	3	36	0	0
		2	0.0											
		3	0.2216	25	0	0	0	58	0	16	1	29	0	0
		4	0.0											
	2	1	0.1853	33	0	0	0	52	0	12	3	29	0	0
		2	0.0											
		3	0.0905	29	0	0	0	37	0	34	0	38	0	0
		4	0.0											
	3	1	0.1099	12	0	0	0	68	0	20	0	30	0	0
		2	0.0											
		3	0.0215	5	0	0	0	52	0	43	0	9	0	0
		4	0.0											
total			0.8942	31	0	0	0	46	0	17	1	32	0	0

Shed	Zone	Soil	Total	Res	Inst	Com	Ind	Veg	Crop	Paved	Pond	Imp	Rural	Rail
10	1	1	0.1896	59	7	6	0	8	0	20	0	53	0	0
		2	0.0											
		3	0.0631	44	12	5	0	20	0	22	0	45	0	0
		4	0.0081	0	16	0	0	6	0	78	0	88	0	0
	2	1	0.1171	53	21	2	0	7	0	20	0	57	0	0
		2	0.0000											
		3	0.0562	71	1	3	0	9	0	16	0	32	0	0
		4	0.0010	0	68	0	0	0	0	32	0	88	0	0
	3	1	0.0387	13	11	7	0	45	0	38	0	47	0	0
		2	0.0											
		3	0.0375	32	0	1	0	47	0	20	0	18	0	0
		4	0.0006	0	87	0	0	0	0	13	0	86	0	0
total			0.6009	43	9	4	0	13	0	19	0	44	0	0

Shed	Zone	Soil	Total	Res	Inst	Com	Ind	Veg	Crop	Paved	Pond	Imp	Rural	Rail
11	1	1	0.0567	58	0	0	0	11	0	31	0	53	2	0
		2	0.2070	43	3	8	1	19	1	27	0	53	10	2
		3	0.1851	56	0	8	0	12	1	27	0	52	5	2
		4	0.0770	5	0	0	0	68	17	8	18	17	62	0
	2	1	0.0398	62	0	0	0	12	0	25	0	49	5	0
		2	0.0086	11	0	0	0	43	0	46	0	53	34	0
		3	0.2063	40	0	3	0	31	4	25	1	45	19	1
		4	0.0551	0	7	0	0	91	14	8	1	16	22	0
	3	1	0.0136	2	0	0	0	70	0	29	0	35	56	0
		2	0.0											
		3	0.1441	36	0	5	0	31	0	26	4	44	16	0
		4	0.0543	0	13	0	0	87	0	13	0	20	11	0
total			1.05	37	2	4	0	33	3	24	2	43	16	1

Appendix B: Record of Discharge, Conductivity, and pH

Discharge, L/s

Date	Watershed											
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*mean*	*stds*
2-1	0.3	0.1	3.2	0.8	4.5	1.4	0.3	0.9	0.8	0.2	0.7	1.2	1.4
2-22	14.0	22.5	10.0	25.5	29.3	33.5	113.0	16.7	40.7	8.9	130.0	40.3	41.4
3-8	0.2	0.4	4.6	2.3	4.8	3.2	3.4	2.4	1.2	1.4	0.9	2.2	1.6
3-25	0.9	2.0	6.8	3.6	20.0	38.7	8.8	2.3	4.8	0.8	19.8	9.9	11.8
4-5	35.0	19.5	13.1	37.5	56.0	57.6	150.0	18.0	41.3	5.3	66.7	45.5	39.9
4-19	0.9	1.3	4.2	2.2	3.6	2.5	0.8	6.5	2.0	0.9	1.5	2.4	1.7
5-6	0.2	1.0	4.2	1.0	3.3	3.0	0.7	0.2	0.2	0.2	1.1	1.4	1.4
6-6	0.3	1.3	5.3	1.1	3.8	0.3	0.2	0.0	0.0	0.1	9.0	1.9	2.9
6-16	0.2	1.0	4.2	1.0	3.3	3.0	0.7	0.2	0.2	0.2	49.5	5.8	14.6
6-23	0.7	1.2	24.0	1.50	4.4	1.5	0.5	0.0	0.0	0.2	6.9	3.7	7.1
7-1	1.2	0.6	1.3	1.1	3.1	1.2	1.4	0.7	0.0	0.1	1.9	1.1	0.9
7-14	2.0	0.7	5.7	1.4	6.5	1.2	2.5	0.3	0.0	0.3	3.6	2.2	2.2
7-20	17.9	8.3	6.0	10.2	19.4	30.2	5.4	41.4	22.0	2.3	1.5	15.0	12.6
7-29	0.4	0.9	4.0	0.6	3.1	1.5	0.0	0.3	0.0	0.1	0.1	1.0	1.3
mean	4.9	4.6	7.4	7.0	12.4	13.3	25.4	4.4	8.3	1.7	26.2		
stds	10.8	8.2	6.4	12.4	16.8	20.1	53.1	6.7	16.2	2.9	41.0		

Temperature-Corrected Conductivity, mmhos/cm

Date	Watershed											
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*mean*	*stds*
2-1	1.226	1.633	1.131	0.986	1.443	0.941	1.294	0.587	1.175	1.132	0.451	1.091	0.34
2-22	0.412	0.801	0.345	0.595	0.788	0.447	0.579	0.694	0.428	0.888	0.339	0.574	0.20
3-8	0.966	1.572	1.117	0.845	1.507	0.492	0.908	0.406	0.985	1.176	0.442	0.947	0.39
3-25	0.375	0.557	0.631	0.339	0.606	0.274	1.290	0.455	0.870	0.650	0.387	0.585	0.29
4-5	0.271	0.447	0.473	0.380	0.355	0.316	0.669	0.600	0.515	0.507	0.320	0.441	0.13
4-19	1.001	1.468	1.108	0.893	1.298	0.443	0.716	0.645	0.756	0.987	0.423	0.885	0.33
5-6	1.002	1.677	1.035	0.753	1.405	0.402	1.310	0.999	0.876	1.075	0.370	0.991	0.39
6-6	0.552	1.594	1.070	0.602	1.562	0.423	0.741	0.615	0.740	1.128	0.311	0.849	0.43
6-16	0.325	0.554	0.467	0.458	0.526	0.293	0.461	0.453	0.436	0.600	0.276	0.441	0.10
6-23	0.521	1.166	1.208	0.314	1.485	0.461	0.564	0.439	0.970	0.939	0.287	0.759	0.41
7-14	0.461	1.168	1.078	0.631	1.330	0.345	0.542	0.470	0.642	0.961	0.229	0.714	0.36
7-20	0.818	0.215	0.346	0.183	0.283	0.199	0.469	0.196	0.098	0.299	0.273	0.307	0.2
7-29	0.329	0.816	1.070	0.296	1.195	0.278	0.742	0.297	0.344	0.938	0.291	0.600	0.36
mean	0.635	1.051	0.852	0.560	1.060	0.409	0.791	0.527	0.680	0.868	0.338		
stds	0.323	0.514	0.338	0.255	0.476	0.183	0.314	0.200	0.304	0.271	0.071		

Temperature-Corrected pH

Date	Watershed											
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***mean***
2-1	6.85	7.04	7.44	7.71	7.18	7.24	7.73	8.08	8.02	7.83	8.12	7.37
2-22	7.43	7.24	7.48	7.59	6.40	7.17	7.36	7.57	7.51	7.45	8.01	7.15
3-8	8.04	7.28	7.60	8.02	7.39	8.53	7.70	7.88	7.83	7.40	8.14	7.67
3-25	7.47	7.17	7.21	7.35	7.19	7.38	7.72	7.90	7.97	7.70	7.97	7.45
4-5	7.34	7.35	7.61	8.14	7.71	8.06	8.84	8.04	8.10	7.73	8.15	7.75
4-19	7.47	7.42	7.60	8.05	7.47	8.54	7.96	7.89	8.17	7.97	8.94	7.77
5-6	7.48	7.33	7.68	7.89	7.63	8.65	8.33	7.59	7.82	7.92	7.87	7.72
6-6	7.48	7.34	7.49	8.20	7.52	8.32	7.84	7.90	7.72	7.66	7.56	7.65
6-16	7.19	7.14	7.49	7.70	7.41	8.45	8.10	7.33	7.55	7.64	7.53	7.48
6-23	7.69	7.44	7.72	8.26	7.48	9.26	7.69	8.22	7.65	8.19	7.70	7.76
7-14	7.50	7.51	7.67	8.19	7.90	9.17	7.99	7.91	7.82	8.08	7.60	7.80
7-20	7.52	7.33	7.32	7.65	7.51	7.63	7.60	8.11	8.14	7.48	7.52	7.55
7-29	7.63	7.79	7.63	7.75	7.43	9.03	7.78	8.15	7.23	8.02	7.51	7.66
mean	7.38	7.30	7.50	7.80	7.19	7.77	7.78	7.81	7.72	7.71	7.77	

Appendix C: Values of Variables Used for Modeling of Storm Runoff Quality

Watershed	DA	IA+1	LUI+1	LUC+1	LUR+1	LUN+2	INT	MAR	MNL	MJT
1	1.301	30.6	9.9	2.7	25.1	60.8	3.6	33	14.7	33.0
2	0.852	62.8	2.9	18.3	50.9	19.9	3.6	33	14.7	33.0
3	0.079	18.9	1.3	13.8	3.8	82.1	3.6	33	14.7	33.0
4	0.048	59.4	2.0	11.2	52.5	23.5	3.6	33	14.7	33.0
5	0.095	70.9	1.0	11.1	72.7	9.7	3.6	33	14.7	33.0
6	0.597	58.5	3.6	13.9	46.1	25.8	3.6	33	14.7	33.0
7	3.420	54.7	13.3	14.8	35.3	32.6	3.6	33	14.7	33.0
8	4.935	16.0	7.0	3.3	3.4	75.2	3.6	33	14.7	33.0
9	0.361	14.6	4.5	1.0	15.5	76.6	3.6	33	14.7	33.0
10	0.343	41.3	4.6	1.6	21.7	55.0	3.6	33	14.7	33.0
11	0.339	35.7	1.0	1.3	38.1	51.7	3.6	33	14.7	33.0
12	0.082	54.3	1.0	1.0	76.0	18.6	3.6	33	14.7	33.0
13	0.307	44.1	1.0	5.4	55.4	32.3	3.6	33	14.7	33.0
14	0.243	62.1	1.0	17.2	52.3	23.0	3.6	33	14.7	33.0
15	0.642	52.2	1.6	17.6	35.6	36.2	3.6	33	14.7	33.0
16	0.349	50.5	9.2	7.8	37.3	38.1	3.6	33	14.7	33.0
17	0.245	39.6	1.0	8.5	41.9	44.6	3.6	33	14.7	33.0

DA: drainage area, square miles
IA+1: percent impervious area + 1
LUI+1: percent industrial area + 1
LUC+1: percent commercial area + 1
LUN+2: percent non-urban landuse + 2
INT: (rainfall intensity) maximum 24-hour rainfall with 2-year recurrence interval, inches
MAR: mean annual rainfall, inches
MNL: mean loading of nitrogen from rainfall, lbs. N per acre
MJT: mean minimum January temperature, degrees Fahrenheit

Appendix D: Estimated Stormwater Pollutant Loads and Concentrations

Shed: Watershed
C.R.: Cottonwood River
N.R.: Neosho River

Chemical Oxygen Demand, Estimated Total Storm Load, kg

Shed	*Rainfall, inches*											
	0.1	*0.25*	*0.5*	*0.75*	*1*	*1.25*	*1.5*	*2*	*2.5*	*3*	*3.5*	*4*
1	92	206	379	541	696	847	994	1279	1556	1826	2091	2351
2	110	246	453	646	832	1012	1187	1529	1859	2182	2498	2809
3	17	38	70	100	129	157	184	237	288	338	387	435
4	13	28	52	74	95	116	136	175	213	250	286	322
5	20	45	83	118	152	185	218	280	341	400	458	515
6	80	179	329	469	604	735	863	1111	1351	1585	1815	2041
7	297	665	1222	1745	2246	2732	3207	4128	5022	5894	6748	7587
8	236	527	968	1382	1779	2163	2539	3269	3976	4666	5343	6007
9	27	61	111	159	205	249	292	376	458	537	615	692
10	30	67	123	176	226	275	323	416	506	594	680	765
11	25	57	105	149	192	234	274	353	430	504	577	649
12	9.0	21	39	55	71	86	101	130	159	186	213	240
13	35	79	146	208	268	326	383	492	599	703	805	905
14	42	93	171	244	314	382	448	577	701	823	942	1060
15	83	185	340	486	626	761	893	1150	1399	1642	1880	2113
16	50	111	204	291	374	455	534	688	837	982	1125	1264
17	34	75	138	197	253	308	361	465	566	664	760	855
Total	1200	2683	4931	7040	9063	11024	12938	16656	20260	23778	272244	30610
C.R.	865	1934	3555	5075	6533	7947	9327	12007	14606	17142	19626	22067
N.R.	252	563	1035	1477	1902	2313	2715	3495	4252	4990	5713	6423

Chemical Oxygen Demand, Estimated Mean Concentration, mg/L

Shed	*Rainfall, inches*											
	0.1	*0.25*	*0.5*	*0.75*	*1*	*1.25*	*1.5*	*2*	*2.5*	*3*	*3.5*	*4*
1	122.8	96.8	80.9	72.8	67.6	63.8	60.9	56.5	53.3	50.9	48.9	47.2
2	136.2	107.4	89.8	80.8	75.0	70.8	67.5	62.7	59.2	56.4	54.2	52.4
3	146.4	115.5	96.5	86.9	80.6	76.1	72.6	67.4	63.6	60.7	58.3	56.3
4	156.1	123.1	102.9	92.6	86.0	81.1	77.4	71.8	67.8	64.7	62.1	60.0
5	154.5	121.9	101.9	91.7	85.1	80.3	76.6	71.1	67.1	64.0	61.5	59.4
6	136.8	107.9	90.2	81.2	75.3	71.1	67.8	63.0	59.4	56.7	54.5	52.6
7	124.2	98.0	81.9	73.7	68.4	64.6	61.6	57.2	54.0	51.5	49.5	47.8
8	113.8	89.8	75.0	67.6	62.7	59.2	56.4	52.4	49.5	47.2	45.3	43.8
9	127.0	100.2	83.7	75.4	70.0	66.0	63.0	58.5	55.2	52.6	50.6	48.9
10	130.2	102.7	85.8	77.3	71.7	67.7	64.6	59.9	56.6	54.0	51.9	50.1
11	129.4	102.0	85.3	76.8	71.3	67.3	64.2	59.6	56.2	53.6	51.5	49.8
12	143.5	113.2	94.6	85.2	79.1	74.6	71.2	66.1	62.4	59.5	57.2	55.2
13	136.9	108.0	90.3	81.3	75.4	71.2	67.9	63.0	59.5	56.7	54.5	52.7
14	144.3	113.8	95.1	85.6	79.5	75.0	71.6	66.4	62.7	59.8	57.5	55.5
15	135.2	106.6	89.1	80.2	74.5	70.3	67.0	62.2	58.7	56.0	53.8	52.0
16	137.4	108.4	90.6	81.5	75.7	71.4	68.1	63.2	59.7	56.9	54.7	52.9
17	138.7	109.4	91.4	82.3	76.4	72.1	68.8	63.8	60.3	57.5	55.2	53.4
mean	136	107	90	81	75	71	67	63	59	56	54	52

Dissolved Solids, Estimated Total Storm Load, kg

Shed	Rainfall, inches											
	0.1	*0.25*	*0.5*	*0.75*	*1*	*1.25*	*1.5*	*2*	*2.5*	*3*	*3.5*	*4*
1	273	683	1366	2049	2732	3415	4099	5465	6831	8197	9563	10929
2	418	1044	2088	3132	4176	5220	6264	8352	10440	12528	14616	16705
3	4.0	10	20	29	39	49	59	78	98	117	137	156
4	10	24	48	72	96	120	144	193	241	289	337	385
5	29	73	146	220	293	366	439	586	732	878	1025	1171
6	241	601	1203	1804	2405	3007	3608	4810	6013	7216	8418	9621
7	2070	5176	10351	15527	20702	25878	31053	41405	51756	62107	72458	82809
8	630	1576	3152	4729	6305	7881	9457	12610	15762	18914	22067	25219
9	19	49	97	146	195	243	292	389	486	584	681	778
10	74	185	369	554	739	923	1108	1477	1846	2216	2585	2954
11	60	149	298	447	596	745	894	1192	1490	1788	2086	2384
12	17	42	85	127	170	212	255	339	424	509	594	679
13	70	175	350	525	701	876	1051	1401	1752	2102	2452	2802
14	82	206	411	617	823	1028	1234	1645	2056	2468	2879	3290
15	227	566	1133	1699	2265	2832	3398	4531	5663	6796	7929	9061
16	99	247	494	742	989	1236	1483	1978	2472	2967	3461	3956
17	45	113	226	340	453	566	679	906	1132	1359	1585	1812
Total	4368	10920	21839	32759	43678	54598	65517	87356	109195	131034	152873	174712
C.R.	3675	9187	18375	27562	36749	45936	55124	73498	91873	110247	128622	146996
N.R.	549	1372	2744	4115	5487	6859	8231	10974	13718	16461	19205	21949

Dissolved Solids, Estimated Mean Concentration, mg/L

Shed	Rainfall, inches											
	0.1	*0.25*	*0.5*	*0.75*	*1*	*1.25*	*1.5*	*2*	*2.5*	*3*	*3.5*	*4*
1	340	307	284	271	263	256	251	243	237	232	228	225
2	382	345	319	305	295	288	282	273	266	261	257	253
3	63	57	53	51	49	48	47	45	44	43	43	42
4	84	76	70	67	65	63	62	60	58	57	56	55
5	129	117	108	103	100	98	96	93	90	88	87	86
6	307	277	257	245	238	232	227	220	214	210	206	203
7	737	665	616	588	570	556	544	527	514	504	495	488
8	501	452	418	400	387	378	370	358	349	342	336	331
9	124	112	103	99	96	93	91	88	86	85	83	82
10	196	177	164	156	151	148	145	140	137	134	132	130
11	182	164	152	145	140	137	134	130	127	124	122	120
12	106	96	88	85	82	80	78	76	74	72	71	70
13	191	172	159	152	147	144	141	136	133	130	128	126
14	198	179	166	158	153	150	146	142	138	136	133	131
15	303	273	253	242	234	228	224	216	211	207	203	200
16	217	196	181	173	168	164	160	155	151	148	146	144
17	161	146	135	129	125	122	119	115	113	110	108	107
mean	248	224	207	198	192	187	183	178	173	170	167	164

Total Kjeldahl Nitrogen, Estimated Total Storm Load, kg N

Shed	*Rainfall, inches*											
	0.1	*0.25*	*0.5*	*0.75*	*1*	*1.25*	*1.5*	*2*	*2.5*	*3*	*3.5*	*4*
1	3.6	8.2	15	22	29	35	41	54	66	78	89	101
2	3.8	8.7	16	24	31	37	44	57	70	83	95	108
3	0.3	0.7	1.4	2.0	2.6	3.1	3.7	4.8	5.9	6.9	8.0	9.0
4	0.4	0.9	1.7	2.5	3.3	4	4.7	6.1	7.5	8.8	10	11
5	0.8	1.7	3.2	4.7	6.1	7.4	8.7	11	14	16	19	21
6	2.8	6.4	12	17	22	27	32	42	51	61	70	79
7	10	24	44	64	83	101	119	155	189	224	257	290
8	7	16	30	43	56	68	81	105	128	151	174	196
9	0.9	2.0	3.8	5.5	7.2	8.8	10	13	16	19	22	25
10	1.5	3.5	6.5	9.3	12	15	18	23	28	33	38	43
11	1.4	3.2	5.9	8.5	11	14	16	21	25	30	34	39
12	0.6	1.3	2.5	3.6	4.7	5.7	6.8	8.8	11	13	15	16
13	1.4	3.3	6.2	8.9	12	14	17	22	26	31	36	41
14	1.4	3.3	6.2	9.0	12	14	17	22	27	31	36	41
15	2.8	6.3	12	17	22	27	32	42	51	60	69	78
16	1.7	3.9	7.3	11	14	17	20	26	31	37	43	48
17	1.1	2.6	4.9	7.1	9.2	11	13	17	21	25	28	32
Total	42	96	179	259	335	411	484	629	770	908	1044	1178
C.R.	29	66	124	179	232	284	335	435	532	628	722	815
N.R.	10	23	43	62	81	99	116	151	185	218	250	283

Total Kjeldahl Nitrogen, Estimated Mean Concentration, mg/L N

Shed	*Rainfall, inches*											
	0.1	*0.25*	*0.5*	*0.75*	*1*	*1.25*	*1.5*	*2*	*2.5*	*3*	*3.5*	*4*
1	2.8	2.3	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.2
2	2.9	2.4	2.0	1.9	1.7	1.7	1.6	1.5	1.4	1.4	1.3	1.3
3	3.3	2.7	2.3	2.1	1.9	1.9	1.8	1.7	1.6	1.5	1.5	1.4
4	3.5	2.9	2.5	2.2	2.1	2.0	1.9	1.8	1.7	1.6	1.6	1.5
5	3.4	2.8	2.4	2.2	2.0	1.9	1.9	1.7	1.7	1.6	1.5	1.5
6	3.0	2.4	2.1	1.9	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3
7	2.7	2.2	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.2
8	2.5	2.0	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1
9	2.9	2.4	2.0	1.9	1.7	1.7	1.6	1.5	1.4	1.4	1.3	1.3
10	3.1	2.5	2.1	1.9	1.8	1.7	1.7	1.6	1.5	1.4	1.4	1.3
11	3.0	2.5	2.1	1.9	1.8	1.7	1.7	1.6	1.5	1.4	1.4	1.3
12	3.4	2.8	2.4	2.2	2.0	1.9	1.8	1.7	1.6	1.6	1.5	1.5
13	3.1	2.5	2.2	2.0	1.8	1.8	1.7	1.6	1.5	1.4	1.4	1.3
14	3.2	2.6	2.2	2.0	1.9	1.8	1.7	1.6	1.5	1.5	1.4	1.4
15	3.0	2.4	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.3
16	3.1	2.5	2.1	2.0	1.8	1.7	1.7	1.6	1.5	1.4	1.4	1.3
17	3.1	2.5	2.2	2.0	1.9	1.8	1.7	1.6	1.5	1.5	1.4	1.4
mean	3.0	2.5	2.1	1.9	1.8	1.7	1.7	1.6	1.5	1.4	1.4	1.3

Total Nitrogen, Estimated Total Storm Load, kg N

Shed	*Rainfall, inches*											
	0.1	*0.25*	*0.5*	*0.75*	*1*	*1.25*	*1.5*	*2*	*2.5*	*3*	*3.5*	*4*
1	5.0	12	22	33	43	53	62	82	100	119	138	156
2	5.4	13	24	35	46	57	68	89	109	130	150	170
3	0.3	0.6	1.2	1.7	2.2	2.7	3.3	4.3	5.2	6.2	7.2	8.1
4	0.3	0.8	1.6	2.3	3.0	3.7	4.4	5.7	7.1	8.4	10	11
5	0.7	1.8	3.4	4.9	6.4	7.9	9.4	12	15	18	21	23
6	3.7	8.7	17	24	32	39	46	61	75	89	102	116
7	18	43	82	119	156	192	228	299	368	436	504	571
8	11	26	50	74	96	119	141	184	227	269	311	352
9	0.9	2.1	4.1	6	8	10	11	15	18	22	25	28
10	1.7	4.1	7.8	11	15	18	22	29	35	42	48	55
11	1.6	3.7	7.0	10	13	16	20	26	31	37	43	49
12	0.5	1.3	2.4	3.6	4.7	5.8	6.8	8.9	11	13	15	17
13	1.6	3.8	7.4	11	14	17	21	27	33	39	45	51
14	1.7	3.9	7.4	11	14	18	21	27	33	40	46	52
15	3.7	8.6	16	24	31	39	46	60	74	88	102	115
16	2.0	4.7	9.1	13	17	21	25	33	41	48	56	63
17	1.2	2.9	5.5	8.1	11	13	15	20	25	30	34	39
Total	60	140	269	392	513	632	750	981	1209	1434	1656	1876
C.R.	45	105	201	294	385	474	562	736	907	1075	1242	1407
N.R.	12	27	53	77	100	124	147	192	237	281	324	367

Total Nitrogen, Estimated Mean Concentration, mg/L N

Shed	*Rainfall, inches*											
	0.1	*0.25*	*0.5*	*0.75*	*1*	*1.25*	*1.5*	*2*	*2.5*	*3*	*3.5*	*4*
1	2.8	2.3	2.0	1.8	1.7	1.7	1.6	1.5	1.4	1.4	1.3	1.3
2	3.1	2.5	2.2	2	1.9	1.8	1.8	1.7	1.6	1.5	1.5	1.4
3	2.1	1.8	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0
4	2.5	2.1	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2
5	2.7	2.3	2.0	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3
6	3.0	2.5	2.1	2.0	1.9	1.8	1.7	1.6	1.5	1.5	1.4	1.4
7	3.3	2.7	2.4	2.2	2.0	2.0	1.9	1.8	1.7	1.6	1.6	1.5
8	2.7	2.2	1.9	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3
9	2.2	1.9	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1
10	2.7	2.2	1.9	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.3
11	2.6	2.2	1.9	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2
12	2.6	2.1	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2
13	2.7	2.2	1.9	1.8	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.3
14	2.8	2.3	2.0	1.9	1.8	1.7	1.6	1.5	1.5	1.4	1.4	1.3
15	2.9	2.4	2.1	1.9	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4
16	2.8	2.3	2.0	1.8	1.7	1.7	1.6	1.5	1.4	1.4	1.3	1.3
17	2.6	2.2	1.9	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2
mean	2.7	2.2	2.0	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3

Total Phosphorus, Estimated Total Storm Load, kg P

Shed	*Rainfa ll, inches*											
	0.1	*0.25*	*0.5*	*0.75*	*1*	*1.25*	*1.5*	*2*	*2.5*	*3*	*3.5*	*4*
1	0.47	1.2	2.3	3.4	4.5	5.7	6.8	9.0	11.2	13.4	15.6	17.8
2	0.5	1.2	2.5	3.7	4.9	6.1	7.3	9.6	12	14.4	16.8	19.1
3	0.06	0.15	0.3	0.44	0.59	0.7	0.9	1.2	1.4	1.7	2.0	2.3
4	0.08	0.19	0.37	0.55	0.73	0.9	1.1	1.5	1.8	2.2	2.5	2.9
5	0.13	0.32	0.63	0.94	1.2	1.5	1.9	2.5	3.1	3.7	4.3	4.9
6	0.39	1.0	1.9	2.8	3.7	4.7	5.6	7.4	9.2	11	12.9	14.7
7	1.2	2.9	5.7	8.5	11.2	14	16.8	22.3	27.7	33.2	38.7	44.1
8	0.82	2.0	4.0	6.0	7.9	9.9	11.8	15.7	19.5	23.4	27.2	31
9	0.14	0.35	0.7	1.1	1.4	1.7	2.1	2.8	3.4	4.1	4.8	5.4
10	0.23	0.56	1.1	1.7	2.2	2.8	3.3	4.4	5.5	6.5	7.6	8.7
11	0.21	0.52	1.0	1.5	2.0	2.5	3.1	4.0	5.0	6.0	7.0	8.0
12	0.1	0.25	0.5	0.7	0.99	1.2	1.5	2.0	2.5	2.9	3.4	3.9
13	0.22	0.54	1.1	1.6	2.1	2.6	3.2	4.2	5.2	6.3	7.3	8.3
14	0.22	0.55	1.1	1.6	2.1	2.7	3.2	4.3	5.3	6.3	7.4	8.4
15	0.38	0.95	1.9	2.8	3.7	4.6	5.5	7.4	9.2	11	12.8	14.6
16	0.25	0.63	1.2	1.9	2.5	3.1	3.7	4.9	6.1	7.3	8.5	9.6
17	0.18	0.44	0.88	1.3	1.7	2.2	2.6	3.4	4.3	5.1	6.0	6.8
Total	5.5	13.7	27.1	40.4	53.7	66.9	80.1	106.3	132.5	158.6	184.6	210.6
C.R.	3.6	8.9	17.6	26.3	34.9	43.4	52.0	69.1	86.1	103	119.9	136.8
N.R.	1.5	3.7	7.4	11.0	14.6	18.2	21.8	29.0	36.1	43.2	50.3	57.3

Total Phosphorus, Estimated Mean Concentration, mg/L P

Shed	*Rainfall, inches*											
	0.1	*0.25*	*0.5*	*0.75*	*1*	*1.25*	*1.5*	*2*	*2.5*	*3*	*3.5*	*4*
1	0.66	0.56	0.50	0.46	0.44	0.42	0.41	0.39	0.37	0.36	0.35	0.34
2	0.70	0.59	0.53	0.49	0.47	0.45	0.43	0.41	0.4	0.38	0.37	0.36
3	0.95	0.81	0.72	0.67	0.63	0.61	0.59	0.56	0.54	0.52	0.51	0.50
4	1.02	0.87	0.77	0.72	0.68	0.66	0.63	0.60	0.58	0.56	0.55	0.53
5	0.94	0.80	0.71	0.66	0.62	0.6	0.58	0.55	0.53	0.51	0.50	0.49
6	0.73	0.62	0.55	0.51	0.49	0.47	0.45	0.43	0.41	0.40	0.39	0.38
7	0.58	0.49	0.44	0.41	0.39	0.37	0.36	0.34	0.33	0.32	0.31	0.30
8	0.55	0.47	0.41	0.38	0.37	0.35	0.34	0.32	0.31	0.30	0.29	0.29
9	0.78	0.66	0.58	0.54	0.52	0.50	0.48	0.46	0.44	0.43	0.41	0.40
10	0.79	0.67	0.59	0.55	0.52	0.50	0.49	0.46	0.45	0.43	0.42	0.41
11	0.79	0.67	0.59	0.55	0.52	0.50	0.49	0.46	0.45	0.43	0.42	0.41
12	0.95	0.81	0.72	0.67	0.63	0.61	0.59	0.56	0.54	0.52	0.51	0.50
13	0.80	0.68	0.60	0.56	0.53	0.51	0.50	0.47	0.45	0.44	0.43	0.42
14	0.83	0.70	0.62	0.58	0.55	0.53	0.51	0.49	0.47	0.45	0.44	0.43
15	0.73	0.62	0.55	0.51	0.48	0.46	0.45	0.43	0.41	0.40	0.39	0.38
16	0.79	0.67	0.59	0.55	0.52	0.50	0.49	0.46	0.45	0.43	0.42	0.41
17	0.82	0.70	0.62	0.58	0.55	0.53	0.51	0.48	0.47	0.45	0.44	0.43
mean	0.79	0.67	0.59	0.55	0.52	0.50	0.49	0.46	0.45	0.43	0.42	0.41

Total Dissolved Phosphorus, Estimated Total Storm Load, kg P

Shed	*Rainfall, inches*											
	0.1	*0.25*	*0.5*	*0.75*	*1*	*1.25*	*1.5*	*2*	*2.5*	*3*	*3.5*	*4*
1	0.09	0.20	0.38	0.54	0.71	0.87	1.03	1.33	1.64	1.93	2.22	2.51
2	0.10	0.24	0.45	0.65	0.84	1.03	1.22	1.58	1.94	2.29	2.64	2.98
3	0.01	0.02	0.04	0.06	0.07	0.09	0.11	0.14	0.17	0.20	0.23	0.26
4	0.01	0.03	0.06	0.08	0.11	0.13	0.16	0.20	0.25	0.30	0.34	0.39
5	0.02	0.06	0.10	0.15	0.20	0.24	0.28	0.37	0.45	0.53	0.61	0.69
6	0.08	0.18	0.33	0.48	0.63	0.77	0.91	1.18	1.44	1.71	1.96	2.22
7	0.25	0.57	1.08	1.56	2.03	2.49	2.94	3.82	4.69	5.54	6.37	7.20
8	0.14	0.33	0.63	0.91	1.18	1.44	1.71	2.22	2.72	3.22	3.70	4.18
9	0.02	0.05	0.09	0.14	0.18	0.22	0.26	0.34	0.41	0.49	0.56	0.64
10	0.04	0.10	0.18	0.26	0.34	0.42	0.49	0.64	0.78	0.92	1.06	1.20
11	0.04	0.09	0.16	0.23	0.31	0.37	0.44	0.57	0.71	0.83	0.96	1.08
12	0.02	0.04	0.08	0.11	0.15	0.18	0.22	0.28	0.34	0.41	0.47	0.53
13	0.04	0.09	0.17	0.25	0.33	0.40	0.47	0.62	0.76	0.89	1.03	1.16
14	0.04	0.10	0.18	0.27	0.35	0.43	0.50	0.65	0.80	0.95	1.09	1.23
15	0.07	0.17	0.32	0.47	0.61	0.75	0.89	1.15	1.41	1.67	1.92	2.17
16	0.05	0.11	0.21	0.30	0.39	0.48	0.57	0.74	0.90	1.07	1.23	1.39
17	0.03	0.07	0.14	0.20	0.26	0.32	0.38	0.49	0.60	0.71	0.82	0.93
Total	1.06	2.44	4.6	6.66	8.66	10.62	12.55	16.32	20.02	23.65	27.22	30.76
C.R.	0.7	1.6	3.1	4.4	5.8	7.1	8.3	10.8	13.3	15.7	18.1	20.4
N.R.	0.3	0.6	1.2	1.7	2.3	2.8	3.3	4.3	5.2	6.2	7.1	8.0

Total Dissolved Phosphorus, Estimated Mean Concentration, mg/L P

Shed	*Rainfall, inches*											
	0.1	*0.25*	*0.5*	*0.75*	*1*	*1.25*	*1.5*	*2*	*2.5*	*3*	*3.5*	*4*
1	0.117	0.096	0.083	0.077	0.072	0.069	0.066	0.062	0.060	0.057	0.056	0.054
2	0.150	0.124	0.107	0.098	0.093	0.088	0.085	0.080	0.077	0.074	0.071	0.069
3	0.169	0.140	0.121	0.111	0.104	0.100	0.096	0.090	0.086	0.083	0.080	0.078
4	0.244	0.201	0.174	0.160	0.151	0.144	0.139	0.130	0.124	0.120	0.116	0.113
5	0.226	0.187	0.162	0.149	0.140	0.134	0.129	0.121	0.116	0.111	0.108	0.105
6	0.157	0.130	0.112	0.103	0.097	0.093	0.089	0.084	0.080	0.077	0.075	0.073
7	0.114	0.094	0.081	0.075	0.070	0.067	0.065	0.061	0.058	0.056	0.054	0.053
8	0.079	0.065	0.056	0.052	0.049	0.047	0.045	0.042	0.040	0.039	0.038	0.037
9	0.122	0.101	0.087	0.080	0.075	0.072	0.069	0.065	0.062	0.060	0.058	0.056
10	0.159	0.131	0.113	0.104	0.098	0.094	0.090	0.085	0.081	0.078	0.075	0.073
11	0.153	0.127	0.110	0.101	0.095	0.090	0.087	0.082	0.078	0.075	0.073	0.071
12	0.217	0.180	0.155	0.143	0.134	0.128	0.123	0.116	0.111	0.107	0.103	0.101
13	0.164	0.136	0.117	0.108	0.102	0.097	0.093	0.088	0.084	0.081	0.078	0.076
14	0.186	0.154	0.133	0.122	0.115	0.110	0.106	0.099	0.095	0.091	0.089	0.086
15	0.151	0.124	0.108	0.099	0.093	0.089	0.086	0.081	0.077	0.074	0.072	0.070
16	0.166	0.137	0.119	0.109	0.103	0.098	0.094	0.089	0.085	0.082	0.079	0.077
17	0.166	0.137	0.119	0.109	0.103	0.098	0.095	0.089	0.085	0.082	0.079	0.077
mean	0.161	0.133	0.115	0.106	0.100	0.095	0.092	0.086	0.082	0.079	0.077	0.075

Recoverable Cadmium, Estimated Total Storm Load, kg

Shed		*Rainfall, inches*										
	0.1	*0.25*	*0.5*	*0.75*	*1*	*1.25*	*1.5*	*2*	*2.5*	*3*	*3.5*	*4*
1	0.005	0.014	0.031	0.049	0.069	0.090	0.111	0.133	0.201	0.249	0.298	0.349
2	0.003	0.008	0.018	0.029	0.040	0.052	0.065	0.078	0.118	0.146	0.175	0.204
3	0.000	0.000	0.001	0.001	0.002	0.003	0.003	0.004	0.006	0.007	0.009	0.010
4	0.000	0.000	0.000	0.001	0.001	0.001	0.002	0.002	0.003	0.004	0.005	0.005
5	0.000	0.000	0.001	0.002	0.003	0.003	0.004	0.005	0.007	0.009	0.011	0.013
6	0.002	0.005	0.011	0.018	0.026	0.033	0.041	0.050	0.075	0.093	0.111	0.130
7	0.016	0.046	0.104	0.168	0.234	0.304	0.377	0.451	0.684	0.846	1.013	1.184
8	0.025	0.074	0.166	0.267	0.373	0.484	0.599	0.717	1.088	1.346	1.611	1.883
9	0.001	0.003	0.006	0.010	0.014	0.018	0.022	0.026	0.040	0.049	0.059	0.069
10	0.001	0.003	0.006	0.009	0.013	0.017	0.021	0.025	0.037	0.046	0.055	0.065
11	0.001	0.002	0.006	0.009	0.013	0.016	0.020	0.024	0.037	0.045	0.054	0.064
12	0.000	0.000	0.001	0.001	0.002	0.003	0.003	0.004	0.006	0.008	0.009	0.011
13	0.001	0.002	0.005	0.008	0.011	0.014	0.018	0.021	0.032	0.040	0.048	0.056
14	0.001	0.002	0.004	0.006	0.008	0.011	0.013	0.016	0.024	0.030	0.036	0.042
15	0.002	0.006	0.013	0.020	0.028	0.037	0.045	0.054	0.082	0.102	0.122	0.143
16	0.001	0.003	0.006	0.009	0.013	0.017	0.021	0.025	0.038	0.047	0.056	0.066
17	0.001	0.002	0.004	0.006	0.008	0.011	0.013	0.016	0.024	0.030	0.036	0.042
Total	0.058	0.170	0.382	0.613	0.858	1.114	1.378	1.650	2.503	3.097	3.708	4.334
C.R.	0.05	0.15	0.33	0.53	0.75	0.97	1.20	1.68	2.18	2.70	3.23	3.78
N.R.	0.01	0.02	0.04	0.06	0.09	0.12	0.14	0.20	0.26	0.32	0.38	0.45

Recoverable Cadmium, Estimated Mean Concentration, ug/L

Shed		*Rainfall, inches*										
	0.1	*0.25*	*0.5*	*0.75*	*1*	*1.25*	*1.5*	*2*	*2.5*	*3*	*3.5*	*4*
1	2.24	2.74	3.20	3.51	3.74	3.93	4.09	4.36	4.59	4.78	4.94	5.09
2	2.07	2.53	2.96	3.24	3.45	3.63	3.78	4.03	4.23	4.41	4.56	4.70
3	1.32	1.62	1.89	2.06	2.20	2.31	2.41	2.57	2.70	2.81	2.91	3.00
4	1.20	1.47	1.72	1.88	2.00	2.11	2.19	2.34	2.46	2.56	2.65	2.73
5	1.36	1.67	1.95	2.14	2.28	2.40	2.49	2.66	2.80	2.91	3.01	3.10
6	1.93	2.37	2.76	3.03	3.23	3.39	3.53	3.77	3.96	4.12	4.27	4.40
7	2.69	3.29	3.84	4.21	4.49	4.72	4.91	5.24	5.51	5.73	5.93	6.11
8	2.88	3.53	4.12	4.51	4.81	5.06	5.27	5.61	5.90	6.15	6.36	6.55
9	1.76	2.15	2.51	2.75	2.93	3.08	3.21	3.42	3.60	3.75	3.88	4.00
10	1.74	2.13	2.49	2.73	2.91	3.05	3.18	3.39	3.56	3.71	3.84	3.96
11	1.73	2.13	2.48	2.72	2.90	3.05	3.17	3.38	3.56	3.70	3.83	3.95
12	1.33	1.63	1.90	2.08	2.22	2.33	2.43	2.59	2.72	2.83	2.93	3.02
13	1.70	2.09	2.44	2.67	2.85	2.99	3.12	3.32	3.49	3.64	3.76	3.88
14	1.63	2.00	2.33	2.55	2.72	2.86	2.98	3.18	3.34	3.48	3.60	3.71
15	1.96	2.40	2.80	3.07	3.27	3.44	3.58	3.82	4.01	4.18	4.33	4.46
16	1.74	2.14	2.50	2.73	2.91	3.06	3.19	3.40	3.58	3.72	3.85	3.97
17	1.63	2.00	2.34	2.56	2.73	2.87	2.98	3.18	3.34	3.48	3.61	3.71
mean	1.82	2.23	2.60	2.85	3.04	3.19	3.32	3.55	3.73	3.88	4.02	4.14

Copper, Estimated Total Storm Load, kg

Shed	*Rainfall, inches*										
	0.1	*0.25*	*0.5*	*0.75*	*1*	*1.25*	*1.5*	*2*	*2.5*	*3*	*3.5* · *4*
1	0.054	0.086	0.121	0.149	0.172	0.192	0.211	0.244	0.273	0.299	0.323 0.346
2	0.076	0.120	0.170	0.209	0.241	0.270	0.296	0.342	0.383	0.420	0.454 0.485
3	0.007	0.011	0.016	0.020	0.023	0.025	0.028	0.032	0.036	0.039	0.042 0.045
4	0.013	0.021	0.030	0.037	0.043	0.048	0.053	0.061	0.068	0.075	0.081 0.086
5	0.023	0.037	0.052	0.064	0.074	0.083	0.090	0.105	0.117	0.128	0.139 0.148
6	0.058	0.092	0.131	0.160	0.185	0.207	0.227	0.262	0.294	0.322	0.348 0.372
7	0.152	0.242	0.343	0.421	0.486	0.544	0.597	0.690	0.772	0.846	0.915 0.978
8	0.069	0.110	0.156	0.191	0.221	0.247	0.271	0.313	0.350	0.384	0.415 0.444
9	0.014	0.022	0.031	0.038	0.045	0.050	0.055	0.063	0.071	0.077	0.084 0.089
10	0.032	0.050	0.071	0.087	0.101	0.113	0.124	0.143	0.160	0.175	0.189 0.203
11	0.028	0.044	0.063	0.077	0.089	0.099	0.109	0.126	0.141	0.154	0.167 0.178
12	0.017	0.027	0.038	0.047	0.055	0.061	0.067	0.077	0.087	0.095	0.103 0.110
13	0.031	0.050	0.070	0.086	0.100	0.112	0.122	0.141	0.158	0.173	0.187 0.201
14	0.036	0.057	0.081	0.099	0.115	0.129	0.141	0.163	0.182	0.200	0.216 0.231
15	0.055	0.088	0.124	0.152	0.176	0.197	0.216	0.250	0.279	0.306	0.331 0.354
16	0.038	0.060	0.085	0.104	0.120	0.134	0.147	0.170	0.190	0.209	0.225 0.241
17	0.025	0.040	0.056	0.069	0.080	0.090	0.098	0.113	0.127	0.139	0.150 0.161
Total	0.73	1.16	1.64	2.01	2.32	2.6	2.85	3.3	3.69	4.04	4.37 4.67
C.R.	0.45	0.72	1.02	1.25	1.44	1.62	1.77	2.05	2.29	2.51	2.72 2.91
N.R.	0.21	0.34	0.48	0.59	0.68	0.76	0.83	0.96	1.08	1.18	1.28 1.37

Copper, Estimated Mean Concentration, ug/L

Shed	*Rainfall, inches*											
	0.1	*0.25*	*0.5*	*0.75*	*1*	*1.25*	*1.5*	*2*	*2.5*	*3*	*3.5*	*4*
1	47	36	29	26	24	22	21	19	18	17	16	16
2	57	43	35	31	29	27	25	23	22	21	20	19
3	67	51	42	37	34	32	30	28	26	24	23	22
4	87	66	54	48	44	41	39	35	33	31	30	29
5	80	61	50	44	40	38	36	33	31	29	28	27
6	59	45	37	32	30	28	26	24	23	21	20	20
7	45	34	28	25	23	21	20	18	17	16	16	15
8	35	27	22	19	18	17	16	14	13	13	12	12
9	51	39	32	28	26	24	23	21	20	19	18	17
10	61	46	38	33	31	29	27	25	23	22	21	20
11	60	45	37	33	30	28	27	24	23	22	21	20
12	79	60	49	43	40	37	35	32	30	29	27	26
13	62	48	39	34	31	29	28	26	24	23	22	21
14	68	52	42	37	34	32	30	28	26	25	24	23
15	57	44	36	31	29	27	26	24	22	21	20	19
16	63	48	39	34	32	30	28	26	24	23	22	21
17	64	48	39	35	32	30	28	26	24	23	22	21
mean	61	47	38	34	31	29	27	25	23	22	21	20

Lead, Estimated Total Storm Load, kg

Shed	*Rainfall, inches*											
	0.1	*0.25*	*0.5*	*0.75*	*1*	*1.25*	*1.5*	*2*	*2.5*	*3*	*3.5*	*4*
1	0.05	0.11	0.20	0.28	0.36	0.44	0.51	0.64	0.77	0.90	1.03	1.15
2	0.09	0.20	0.36	0.50	0.64	0.77	0.89	1.13	1.36	1.59	1.81	2.02
3	0.02	0.05	0.08	0.12	0.15	0.18	0.21	0.26	0.32	0.37	0.42	0.47
4	0.03	0.06	0.10	0.14	0.18	0.22	0.26	0.33	0.39	0.46	0.52	0.58
5	0.04	0.09	0.16	0.23	0.29	0.34	0.40	0.51	0.61	0.72	0.81	0.91
6	0.07	0.15	0.28	0.39	0.49	0.59	0.69	0.87	1.05	1.23	1.39	1.56
7	0.13	0.29	0.51	0.72	0.91	1.09	1.27	1.62	1.95	2.27	2.58	2.88
8	0.07	0.16	0.28	0.40	0.51	0.61	0.71	0.90	1.09	1.27	1.44	1.61
9	0.02	0.05	0.09	0.13	0.16	0.19	0.22	0.28	0.34	0.40	0.45	0.51
10	0.03	0.06	0.11	0.15	0.19	0.23	0.27	0.34	0.41	0.48	0.54	0.61
11	0.03	0.06	0.11	0.15	0.19	0.23	0.27	0.34	0.41	0.48	0.55	0.61
12	0.02	0.04	0.08	0.11	0.13	0.16	0.19	0.24	0.29	0.34	0.38	0.43
13	0.04	0.09	0.17	0.23	0.30	0.36	0.41	0.53	0.63	0.74	0.84	0.94
14	0.06	0.12	0.21	0.30	0.38	0.46	0.53	0.68	0.81	0.95	1.08	1.20
15	0.07	0.15	0.28	0.39	0.49	0.59	0.69	0.88	1.05	1.23	1.40	1.56
16	0.05	0.10	0.18	0.25	0.32	0.38	0.45	0.57	0.68	0.79	0.90	1.01
17	0.04	0.09	0.16	0.22	0.28	0.34	0.39	0.50	0.60	0.70	0.79	0.89
Total	0.88	1.88	3.35	4.69	5.96	7.18	8.36	10.63	12.80	14.89	16.94	18.93
C.R.	0.5	1.1	2.0	2.8	3.5	4.2	4.9	6.3	7.6	8.8	10.0	11.2
N.R.	0.3	0.6	1.0	1.5	1.8	2.2	2.6	3.3	4.0	4.6	5.2	5.9

Lead, Estimated Mean Concentration, ug/L

Shed	*Rainfall, inches*											
	0.1	*0.25*	*0.5*	*0.75*	*1*	*1.25*	*1.5*	*2*	*2.5*	*3*	*3.5*	*4*
1	96	74	61	54	50	47	44	41	38	36	35	33
2	152	117	96	85	79	74	70	64	60	57	55	53
3	231	178	146	130	120	112	106	98	92	87	84	80
4	407	313	257	229	211	198	188	173	162	154	147	142
5	337	259	213	189	174	164	155	143	134	127	122	117
6	165	127	104	93	85	80	76	70	66	62	60	57
7	85	65	54	48	44	41	39	36	34	32	31	30
8	45	34	28	25	23	22	21	19	18	17	16	16
9	128	98	81	72	66	62	59	54	51	48	46	45
10	144	110	91	81	74	70	66	61	57	54	52	50
11	154	119	97	87	80	75	71	66	61	58	56	54
12	280	216	177	158	145	136	129	119	112	106	101	98
13	196	151	124	110	101	95	90	83	78	74	71	68
14	237	182	150	133	123	115	109	101	94	90	86	83
15	158	121	99	89	82	77	73	67	63	60	57	55
16	182	140	115	102	94	89	84	77	73	69	66	63
17	212	163	134	119	110	103	98	90	85	80	77	74
mean	189	145	119	106	98	92	87	80	75	71	68	66

Zinc, Estimated Total Storm Load, kg

Shed	*Rainfall, inches*											
	0.1	*0.25*	*0.5*	*0.75*	*1*	*1.25*	*1.5*	*2*	*2.5*	*3*	*3.5*	*4*
1	0.30	0.62	1.08	1.49	1.87	2.23	2.58	2.92	3.88	4.48	5.07	5.64
2	0.47	0.97	1.68	2.31	2.91	3.48	4.02	4.54	6.04	6.98	7.89	8.77
3	0.03	0.06	0.10	0.14	0.18	0.21	0.25	0.28	0.37	0.43	0.48	0.54
4	0.06	0.13	0.23	0.32	0.40	0.48	0.56	0.63	0.84	0.97	1.10	1.22
5	0.12	0.25	0.44	0.61	0.76	0.91	1.05	1.19	1.58	1.82	2.06	2.29
6	0.34	0.71	1.23	1.70	2.14	2.55	2.95	3.34	4.44	5.13	5.80	6.45
7	1.02	2.12	3.69	5.09	6.40	7.65	8.84	10.00	13.28	15.35	17.36	19.30
8	0.38	0.78	1.36	1.88	2.36	2.82	3.26	3.68	4.89	5.66	6.40	7.12
9	0.06	0.13	0.22	0.30	0.38	0.45	0.52	0.59	0.78	0.91	1.02	1.14
10	0.17	0.35	0.60	0.83	1.04	1.24	1.44	1.62	2.16	2.49	2.82	3.14
11	0.14	0.30	0.51	0.71	0.89	1.06	1.23	1.39	1.84	2.13	2.41	2.68
12	0.08	0.18	0.30	0.42	0.53	0.63	0.73	0.82	1.09	1.27	1.43	1.59
13	0.17	0.34	0.60	0.82	1.03	1.23	1.43	1.61	2.14	2.48	2.80	3.12
14	0.20	0.41	0.72	0.99	1.25	1.49	1.72	1.95	2.59	2.99	3.38	3.76
15	0.32	0.66	1.15	1.59	2.00	2.39	2.76	3.13	4.15	4.80	5.43	6.03
16	0.21	0.43	0.74	1.02	1.29	1.54	1.78	2.01	2.67	3.09	3.49	3.88
17	0.13	0.26	0.46	0.63	0.80	0.95	1.10	1.24	1.65	1.91	2.16	2.40
Total	4.2	8.7	15.1	20.9	26.2	31.3	36.2	41.0	54.4	62.9	71.1	79.1
C.R.	2.7	5.6	9.8	13.5	17.0	20.3	23.5	26.6	35.3	40.8	46.2	51.3
N.R.	1.1	2.4	4.1	5.7	7.1	8.5	9.8	11.1	14.8	17.1	19.3	21.5

Zinc, Estimated Mean Concentration, ug/L

Shed	*Rainfall, inches*											
	0.1	*0.25*	*0.5*	*0.75*	*1*	*1.25*	*1.5*	*2*	*2.5*	*3*	*3.5*	*4*
1	372	299	253	230	215	204	195	188	173	165	159	154
2	494	397	337	306	286	271	259	250	230	220	212	205
3	571	459	389	353	330	313	300	289	265	254	245	237
4	867	697	591	537	501	475	455	439	403	386	372	360
5	794	639	542	492	459	436	417	402	369	354	341	330
6	520	419	355	322	301	285	273	263	242	232	223	216
7	360	289	245	223	208	197	189	182	167	160	154	149
8	237	191	162	147	137	130	125	120	110	106	102	99
9	392	315	267	243	226	215	206	198	182	174	168	163
10	528	425	360	327	305	289	277	267	245	235	227	219
11	508	409	346	315	294	279	267	257	236	226	218	211
12	759	611	518	470	439	416	399	384	353	338	326	316
13	550	442	375	340	318	301	289	278	256	245	236	229
14	634	510	432	392	366	347	333	321	295	282	272	263
15	497	400	339	308	287	272	261	251	231	221	213	207
16	556	447	379	345	322	305	292	282	259	248	239	231
17	559	449	381	346	323	306	293	283	260	249	240	232
mean	541	435	369	335	313	297	284	274	252	241	232	225

Estimated Total Storm Runoff, cubic meters

Shed	*Rainfall, inches*											
	0.1	*0.25*	*0.5*	*0.75*	*1*	*1.25*	*1.5*	*2*	*2.5*	*3*	*3.5*	*4*
1	1189	3340	7295	11520	15932	20488	25161	34796	44746	54953	65379	75997
2	1228	3450	7535	11899	16456	21161	25988	35940	46217	56759	67528	78495
3	96	270	589	930	1286	1653	2030	2808	3611	4435	5276	6133
4	117	327	715	1129	1562	2008	2466	3411	4386	5387	6409	7449
5	222	622	1359	2146	2968	3817	4687	6482	8336	10237	12179	14157
6	888	2494	5446	8601	11895	15296	18785	25979	33407	41027	48812	56739
7	3520	9885	21590	34096	47154	60636	74468	102985	132432	162641	193499	224924
8	2490	6993	15273	24119	33356	42893	52678	72851	93681	115051	136879	159109
9	287	805	1758	2777	3840	4938	6065	8387	10785	13246	15759	18318
10	473	1329	2902	4583	6338	8151	10010	13843	17802	21862	26010	30235
11	434	1218	2660	4201	5809	7470	9174	12687	16315	20037	23838	27710
12	171	482	1052	1661	2297	2954	3627	5016	6451	7922	9425	10956
13	448	1258	2747	4338	6000	7715	9475	13103	16850	20694	24620	28619
14	443	1244	2718	4292	5936	7633	9375	12965	16672	20474	24359	28315
15	888	2493	5444	8598	11890	15290	18777	25968	33393	41010	48791	56715
16	532	1495	3266	5158	7133	9173	11265	15579	20034	24603	29271	34025
17	353	990	2162	3415	4723	6073	7458	10314	13264	16289	19380	22527
Total	13777	38694	84510	133464	184574	237349	291491	403117	518380	636628	757417	880424
C.R.	9749	27381	59801	94442	130608	167953	206264	285253	366815	450490	535962	623004
N.R.	3143	8828	19281	30450	42110	54151	66503	91971	118268	145246	172803	200867

Appendix E: Modeled Concentrations of Pollutants in Rivers

COD, mg/L

River	*I.C.*	*Q*	*Rainfall, Inches*									
			0.1	*0.25*	*0.5*	*0.75*	*1*	*1.25*	*1.5*	*2*	*2.5*	*3*
C.R.	100	43	146	129	112	102	95	91	87	80.9	77	73
C.R.	100	250	118	116	108	101	96	93	89	84	80	77
C.R.	100	882	106	107	104	101	98	95	93	89.7	87	85
C.R.	100	1880	103	104	102	101	99	97	96	93	91	90
N.R.	100	10	139	119	102	93	87	82	78	73	69	67
N.R.	100	64	116	111	101	94	89	85	82	77	73	71
N.R.	100	328	104	104	101	97	95	92	90	87	84	82
N.R.	100	868	102	102	100	99	97	96	95	93	91	90
C.R.	600	43	558	505	443	406	381	362	347	324	307	294
C.R.	600	250	400	414	397	378	362	349	338	320	306	295
C.R.	600	882	335	348	349	343	336	330	324	313	304	297
C.R.	600	1880	317	325	327	325	322	318	315	308	303	298
N.R.	300	10	189	142	115	102	95	89	85	79	74	71
N.R.	300	64	254	206	168	148	136	127	120	111	105	100
N.R.	300	328	288	269	245	228	217	208	201	191	183	177
N.R.	300	868	295	287	275	266	259	253	248	241	236	231

Total Dissolved Solids, mg/L

River	*I.C.*	*Q*	*Rainfall, Inches*									
			0.1	*0.25*	*0.5*	*0.75*	*1*	*1.25*	*1.5*	*2*	*2.5*	*3*
C.R.	614	43	682	634	587	559	540	525	513	495	481	471
C.R.	614	250	640	625	596	574	557	544	533	516	503	492
C.R.	614	882	623	619	605	592	581	571	563	550	540	531
C.R.	614	1880	619	616	609	601	594	588	582	573	565	559
N.R.	329	10	331	299	275	261	251	244	239	230	224	218
N.R.	329	64	330	311	290	276	267	260	254	245	238	233
N.R.	329	328	329	323	313	304	298	292	287	280	274	270
N.R.	329	868	329	327	322	317	313	310	307	303	299	296
C.R.	488	43	641	613	574	549	532	518	507	489	476	466
C.R.	488	250	547	557	546	533	522	512	503	489	478	469
C.R.	488	882	508	517	517	513	508	502	497	489	481	475
C.R.	488	1880	498	503	504	503	500	497	494	489	484	479
N.R.	248	10	310	289	269	256	248	241	236	227	221	216
N.R.	248	64	273	273	263	254	248	242	238	230	225	220
N.R.	248	328	255	256	254	251	248	245	242	238	234	231
N.R.	248	868	251	251	251	249	248	246	245	243	240	238

Total Nitrogen, mg/L

River	*I.C.*	*Q*				*Rainfall, Inches*						
			0.1	*0.25*	*0.5*	*0.75*	*1*	*1.25*	*1.5*	*2*	*2.5*	*3*
C.R.	0	43	5.84	6.10	5.77	5.48	5.25	5.07	4.92	4.69	4.51	4.37
C.R.	0	250	2.28	3.40	3.92	4.03	4.04	4.01	3.97	3.87	3.79	3.71
C.R.	0	882	0.82	1.46	1.99	2.24	2.38	2.46	2.50	2.54	2.55	2.54
C.R.	0	1880	0.42	0.79	1.13	1.33	1.45	1.53	1.59	1.65	1.69	1.70
N.R.	0.032	10	5.21	5.17	4.80	4.53	4.33	4.17	4.04	3.84	3.69	3.57
N.R.	0.032	64	2.17	3.09	3.45	3.49	3.47	3.42	3.37	3.28	3.19	3.12
N.R.	0.032	328	0.58	1.06	1.46	1.66	1.77	1.84	1.88	1.92	1.93	1.93
N.R.	0.032	868	0.25	0.47	0.68	0.81	0.90	0.95	0.99	1.04	1.07	1.09
C.R.	0.056	43	5.85	6.10	5.77	5.48	5.25	5.07	4.92	4.69	4.51	4.37
C.R.	0.056	250	2.29	3.41	3.92	4.04	4.04	4.01	3.97	3.88	3.79	3.71
C.R.	0.056	882	0.83	1.48	2.00	2.25	2.39	2.46	2.51	2.55	2.55	2.55
C.R.	0.056	1880	0.44	0.80	1.15	1.34	1.46	1.54	1.60	1.66	1.70	1.71
N.R.	0.05	10	5.21	5.18	4.8	4.53	4.33	4.17	4.04	3.84	3.69	3.57
N.R.	0.05	64	2.18	3.10	3.45	3.50	3.47	3.43	3.38	3.28	3.20	3.12
N.R.	0.05	328	0.60	1.07	1.47	1.67	1.78	1.85	1.89	1.92	1.94	1.94
N.R.	0.05	868	0.27	0.48	0.70	0.83	0.91	0.97	1.01	1.06	1.09	1.10

Total Kjeldahl Nitrogen, mg/L

River	*I.C.*	*Q*				*Rainfall, Inches*						
			0.1	*0.25*	*0.5*	*0.75*	*1*	*1.25*	*1.5*	*2*	*2.5*	*3*
C.R.	0	43	3.76	3.82	3.55	3.33	3.16	3.04	2.93	2.77	2.65	2.55
C.R.	0	250	1.45	2.12	2.40	2.44	2.43	2.40	2.36	2.28	2.22	2.16
C.R.	0	882	0.50	0.90	1.21	1.35	1.42	1.46	1.48	1.49	1.48	1.47
C.R.	0	1880	0.25	0.47	0.68	0.79	0.86	0.90	0.93	0.96	0.97	0.98
N.R.	0	10	4.45	4.31	3.92	3.66	3.46	3.32	3.20	3.02	2.88	2.77
N.R.	0	64	1.84	2.56	2.81	2.82	2.77	2.72	2.67	2.57	2.49	2.42
N.R.	0	328	0.48	0.86	1.18	1.32	1.40	1.45	1.47	1.49	1.49	1.48
N.R.	0	868	0.19	0.36	0.54	0.64	0.70	0.74	0.77	0.80	0.82	0.83
C.R.	0.07	43	3.78	3.83	3.55	3.33	3.17	3.04	2.94	2.77	2.65	2.55
C.R.	0.07	250	1.50	2.16	2.43	2.47	2.45	2.41	2.38	2.30	2.23	2.17
C.R.	0.07	882	0.57	0.95	1.26	1.39	1.46	1.50	1.51	1.52	1.52	1.50
C.R.	0.07	1880	0.32	0.53	0.74	0.85	0.91	0.95	0.98	1.01	1.02	1.02
N.R.	0.07	10	4.47	4.32	3.93	3.66	3.47	3.32	3.20	3.02	2.88	2.77
N.R.	0.07	64	1.89	2.60	2.83	2.83	2.79	2.73	2.68	2.58	2.50	2.43
N.R.	0.07	328	0.54	0.92	1.23	1.37	1.45	1.49	1.51	1.53	1.53	1.52
N.R.	0.07	868	0.26	0.43	0.60	0.69	0.75	0.79	0.82	0.85	0.87	0.88

Total Phosphorus, mg/L

River	I.C.	Q	Rainfall, Inches									
			0.1	0.25	0.5	0.75	1	1.25	1.5	2	2.5	3
C.R.	10	43	3.78	2.18	1.49	1.24	1.10	1.02	0.96	0.88	0.83	0.79
C.R.	10	250	7.60	5.66	4.24	3.57	3.17	2.91	2.73	2.48	2.31	2.2
C.R.	10	882	9.17	8.16	7.10	6.45	6.01	5.69	5.44	5.10	4.86	4.68
C.R.	10	1880	9.59	9.04	8.37	7.92	7.59	7.33	7.13	6.84	6.62	6.46
N.R.	10	10	3.30	1.96	1.41	1.20	1.09	1.02	0.97	0.90	0.86	0.82
N.R.	10	64	7.23	5.22	3.85	3.23	2.87	2.64	2.47	2.25	2.10	2.00
N.R.	10	328	9.28	8.40	7.43	6.81	6.39	6.08	5.85	5.50	5.27	5.09
N.R.	10	868	9.72	9.32	8.82	8.47	8.20	8.00	7.83	7.58	7.40	7.25
C.R.	0	43	0.47	0.51	0.50	0.49	0.48	0.46	0.45	0.44	0.43	0.42
C.R.	0	250	0.18	0.29	0.34	0.36	0.36	0.37	0.37	0.36	0.36	0.35
C.R.	0	882	0.06	0.12	0.17	0.20	0.21	0.22	0.23	0.24	0.24	0.24
C.R.	0	1880	0.03	0.06	0.10	0.12	0.13	0.14	0.14	0.15	0.16	0.16
N.R.	0	10	0.67	0.70	0.67	0.65	0.63	0.61	0.60	0.58	0.56	0.55
N.R.	0	64	0.28	0.42	0.48	0.50	0.50	0.50	0.50	0.49	0.49	0.48
N.R.	0	328	0.07	0.14	0.20	0.24	0.25	0.27	0.28	0.29	0.29	0.29
N.R.	0	868	0.03	0.06	0.09	0.11	0.13	0.14	0.14	0.15	0.16	0.16

Total Dissolved Phosphorus, mg/L

River	I.C.	Q	Rainfall, Inches									
			0.1	0.25	0.5	0.75	1	1.25	1.5	2	2.5	3
C.R.	0.0034	43	0.093	0.094	0.088	0.083	0.079	0.076	0.073	0.069	0.066	0.064
C.R.	0.0034	250	0.038	0.054	0.061	0.062	0.061	0.060	0.059	0.058	0.056	0.055
C.R.	0.0034	882	0.015	0.025	0.032	0.036	0.037	0.038	0.039	0.039	0.039	0.038
C.R.	0.0034	1880	0.009	0.015	0.020	0.022	0.024	0.025	0.025	0.026	0.027	0.027
N.R.	0.0027	10	0.123	0.120	0.110	0.102	0.097	0.093	0.090	0.085	0.081	0.078
N.R.	0.0027	64	0.053	0.072	0.079	0.079	0.078	0.077	0.076	0.073	0.071	0.069
N.R.	0.0027	328	0.016	0.026	0.035	0.039	0.041	0.042	0.043	0.043	0.043	0.043
N.R.	0.0027	868	0.008	0.013	0.017	0.020	0.022	0.023	0.024	0.025	0.025	0.025
C.R.	0.0063	43	0.094	0.095	0.088	0.083	0.079	0.076	0.073	0.069	0.066	0.064
C.R.	0.0063	250	0.040	0.055	0.062	0.062	0.062	0.061	0.060	0.058	0.057	0.055
C.R.	0.0063	882	0.018	0.027	0.034	0.037	0.039	0.040	0.040	0.040	0.040	0.040
C.R.	0.0063	1880	0.012	0.017	0.022	0.024	0.026	0.027	0.028	0.028	0.028	0.028
N.R.	0.0053	10	0.124	0.12	0.110	0.103	0.097	0.093	0.090	0.085	0.081	0.079
N.R.	0.0053	64	0.054	0.074	0.080	0.080	0.079	0.078	0.076	0.073	0.071	0.069
N.R.	0.0053	328	0.018	0.028	0.037	0.041	0.043	0.044	0.044	0.045	0.045	0.044
N.R.	0.0053	868	0.010	0.015	0.020	0.022	0.024	0.025	0.026	0.027	0.027	0.027

Recoverable Cadmium, mg/L

River	*I.C.*	*Q*	*Rainfall, Inches*									
			0.1	*0.25*	*0.5*	*0.75*	*1*	*1.25*	*1.5*	*2*	*2.5*	*3*
C.R.	0.000	43	0.0066	0.0086	0.0095	0.0099	0.0102	0.0104	0.0105	0.0107	0.0108	0.0110
C.R.	0.000	250	0.0026	0.0048	0.0065	0.0073	0.0078	0.0082	0.0085	0.0088	0.0091	0.0093
C.R.	0.000	882	0.0009	0.0020	0.0032	0.0040	0.0046	0.0050	0.0053	0.0058	0.0061	0.0063
C.R.	0.000	1880	0.0004	0.0011	0.0018	0.0024	0.0028	0.0031	0.0033	0.0037	0.0040	0.0042
N.R.	0.000	10	0.0027	0.0033	0.0036	0.0037	0.0038	0.0039	0.0039	0.0040	0.0040	0.0041
N.R.	0.000	64	0.0011	0.0020	0.0026	0.0029	0.0031	0.0032	0.0033	0.0034	0.0035	0.0036
N.R.	0.000	328	0.0003	0.0007	0.0011	0.0014	0.0015	0.0017	0.0018	0.0020	0.0021	0.0022
N.R.	0.000	868	0.0001	0.0003	0.0005	0.0007	0.0008	0.0009	0.0009	0.0011	0.0011	0.0012
C.R.	0.016	43	0.0119	0.0112	0.0111	0.0112	0.0112	0.0113	0.0113	0.0114	0.0115	0.0116
C.R.	0.016	250	0.0144	0.0134	0.0127	0.0124	0.0123	0.0123	0.0122	0.0122	0.0122	0.0122
C.R.	0.016	882	0.0155	0.0149	0.0143	0.0140	0.0138	0.0137	0.0136	0.0135	0.0135	0.0134
C.R.	0.016	1880	0.0157	0.0154	0.0151	0.0148	0.0147	0.0146	0.0145	0.0144	0.0143	0.0143
N.R.	0.005	10	0.0040	0.0039	0.0040	0.0040	0.0040	0.0041	0.0041	0.0041	0.0042	0.0042
N.R.	0.005	64	0.0046	0.0044	0.0043	0.0042	0.0042	0.0042	0.0043	0.0043	0.0043	0.0043
N.R.	0.005	328	0.0049	0.0048	0.0047	0.0046	0.0046	0.0046	0.0046	0.0046	0.0046	0.0046
N.R.	0.005	868	0.0050	0.0049	0.0049	0.0048	0.0048	0.0048	0.0048	0.0048	0.0048	0.0048

Copper, mg/L

River	*I.C.*	*Q*	*Rainfall, Inches*									
			0.1	*0.25*	*0.5*	*0.75*	*1*	*1.25*	*1.5*	*2*	*2.5*	*3*
C.R.	0	43	0.059	0.042	0.029	0.023	0.020	0.017	0.016	0.013	0.011	0.010
C.R.	0	250	0.023	0.023	0.020	0.017	0.015	0.014	0.012	0.011	0.010	0.009
C.R.	0	882	0.008	0.010	0.010	0.009	0.009	0.008	0.008	0.007	0.006	0.006
C.R.	0	1880	0.004	0.005	0.006	0.006	0.005	0.005	0.005	0.005	0.004	0.004
N.R.	0	10	0.095	0.064	0.044	0.035	0.029	0.026	0.023	0.019	0.017	0.015
N.R.	0	64	0.039	0.038	0.031	0.027	0.023	0.021	0.019	0.016	0.015	0.013
N.R.	0	328	0.010	0.013	0.013	0.013	0.012	0.011	0.011	0.010	0.009	0.008
N.R.	0	868	0.004	0.005	0.006	0.006	0.006	0.006	0.006	0.005	0.005	0.004
C.R.	0.06	43	0.079	0.052	0.035	0.028	0.023	0.021	0.019	0.016	0.014	0.012
C.R.	0.06	250	0.067	0.055	0.043	0.036	0.032	0.029	0.027	0.023	0.021	0.020
C.R.	0.06	882	0.063	0.058	0.052	0.047	0.044	0.041	0.039	0.036	0.034	0.033
C.R.	0.06	1880	0.061	0.059	0.055	0.052	0.050	0.048	0.047	0.045	0.043	0.042
N.R.	0.021	10	0.100	0.066	0.045	0.036	0.030	0.026	0.024	0.020	0.017	0.016
N.R.	0.021	64	0.054	0.048	0.038	0.032	0.028	0.025	0.023	0.020	0.018	0.016
N.R.	0.021	328	0.029	0.030	0.028	0.026	0.025	0.023	0.022	0.020	0.019	0.018
N.R.	0.021	868	0.024	0.025	0.024	0.024	0.023	0.022	0.022	0.021	0.020	0.019

Lead, mg/L

River	*I.C.*	*Q*	*Rainfall, Inches* 0.1	0.25	0.5	0.75	1	1.25	1.5	2	2.5	3
C.R.	0	43	0.0675	0.0642	0.0566	0.0516	0.0480	0.0453	0.0432	0.0400	0.0376	0.0357
C.R.	0	250	0.0260	0.0356	0.0383	0.0379	0.0369	0.0358	0.0347	0.0330	0.0315	0.0303
C.R.	0	882	0.0090	0.0151	0.0193	0.0209	0.0216	0.0218	0.0218	0.0215	0.0211	0.0206
C.R.	0	1880	0.0045	0.0079	0.0108	0.0123	0.0130	0.0135	0.0137	0.0139	0.0138	0.0137
N.R.	0	10	0.1207	0.1093	0.0946	0.0856	0.0794	0.0748	0.0712	0.0657	0.0617	0.0586
N.R.	0	64	0.0499	0.0650	0.0677	0.0659	0.0636	0.0613	0.0593	0.0560	0.0533	0.0511
N.R.	0	328	0.0129	0.0218	0.0283	0.0310	0.0322	0.0326	0.0327	0.0325	0.0320	0.0314
N.R.	0	868	0.0051	0.0092	0.0129	0.0149	0.0160	0.0167	0.0171	0.0175	0.0176	0.0175
C.R.	0.061	43	0.1778	0.1601	0.1383	0.1251	0.1160	0.1093	0.1040	0.0960	0.0902	0.0857
C.R.	0.061	250	0.1060	0.1160	0.1133	0.1081	0.1032	0.0991	0.0956	0.0899	0.0855	0.0819
C.R.	0.061	882	0.0767	0.0843	0.0873	0.0870	0.0857	0.0842	0.0827	0.0798	0.0774	0.0753
C.R.	0.061	1880	0.0687	0.0732	0.0758	0.0762	0.0759	0.0753	0.0746	0.0731	0.0718	0.0705
N.R.	0.021	10	0.1246	0.1105	0.0948	0.0856	0.0793	0.0746	0.0710	0.0655	0.0615	0.0584
N.R.	0.021	64	0.0638	0.0742	0.0738	0.0707	0.0676	0.0650	0.0627	0.0589	0.0560	0.0536
N.R.	0.021	328	0.0321	0.0389	0.0431	0.0444	0.0446	0.0444	0.0440	0.0430	0.0420	0.0410
N.R.	0.021	868	0.0254	0.0286	0.0311	0.0322	0.0327	0.0330	0.0330	0.0328	0.0325	0.0322

Zinc, mg/L

River	*I.C.*	*Q*	*Rainfall, Inches* 0.1	0.25	0.5	0.75	1	1.25	1.5	2	2.5	3
C.R.	0	43	0.3551	0.3266	0.2807	0.2520	0.2321	0.2173	0.2057	0.1882	0.1755	0.1657
C.R.	0	250	0.1369	0.1811	0.1901	0.1850	0.1782	0.1715	0.1655	0.1553	0.1471	0.1404
C.R.	0	882	0.0476	0.0768	0.0957	0.1022	0.1042	0.1043	0.1036	0.1012	0.0984	0.0957
C.R.	0	1880	0.0235	0.0402	0.0536	0.0599	0.0629	0.0645	0.0652	0.0653	0.0647	0.0637
N.R.	0	10	0.5073	0.4441	0.3744	0.3338	0.3064	0.2862	0.2705	0.2471	0.2302	0.2172
N.R.	0	64	0.2096	0.2642	0.2680	0.2570	0.2452	0.2347	0.2255	0.2105	0.1988	0.1893
N.R.	0	328	0.0542	0.0886	0.1122	0.1209	0.1241	0.1249	0.1244	0.1221	0.1192	0.1162
N.R.	0	868	0.0215	0.0376	0.0512	0.0581	0.0617	0.0638	0.0649	0.0657	0.0655	0.0650
C.R.	0.356	43	0.4729	0.3859	0.3160	0.2787	0.2545	0.2370	0.2236	0.2039	0.1898	0.1791
C.R.	0.356	250	0.4011	0.3726	0.3289	0.2992	0.2781	0.2621	0.2495	0.2305	0.2168	0.2061
C.R.	0.356	882	0.3717	0.3630	0.3424	0.3247	0.3104	0.2989	0.2893	0.2742	0.2628	0.2538
C.R.	0.356	1880	0.3637	0.3597	0.3483	0.3376	0.3285	0.3207	0.3140	0.3032	0.2948	0.2880
N.R.	0.14	10	0.5441	0.4618	0.3846	0.3415	0.3128	0.2919	0.2757	0.2516	0.2343	0.2210
N.R.	0.14	64	0.3070	0.3314	0.3151	0.2951	0.2783	0.2646	0.2531	0.2351	0.2215	0.2106
N.R.	0.14	328	0.1832	0.2042	0.2133	0.2130	0.2100	0.2063	0.2024	0.1952	0.1888	0.1834
N.R.	0.14	868	0.1572	0.1672	0.1735	0.1750	0.1748	0.1739	0.1726	0.1697	0.1669	0.1642

I, Karl W. Forge, hereby submit this thesis to Emporia State University as partial fulfillment of the requirements for an advanced degree. I agree that the Library of the University may make it available to use in accordance with its regulations governing materials of this type. I further agree that quoting, photocopying, or other reproduction of this document is allowed for private study, scholarship (including teaching) and research purposes of a nonprofit nature. No copying which involves potential financial gain will be allowed without written permission of the author.

Karl W. Forge
Signature of Author

April 13, 1998
Date

Analysis and Estimation of Urban Runoff Constituent Concentrations as Functions of Land Use Characteristics of Watersheds at Emporia, Kansas
Title of Thesis

Doug Cooper
Signature of Graduate Office Staff

April 13, 1998
Date Received