NUTRIENT LOADS IN AN URBAN OZARK WATERSHED: JORDAN, FASSNIGHT AND UPPER WILSON CREEKS, SPRINGFIELD, MISSOURI

A Thesis
Presented to
The Graduate College of
Missouri State University

In Partial Fulfillment
Of the Requirements for the Degree
Master of Science, Geospatial Sciences

By
Ronald B. Miller
May 2006

NUTRIENT LOADS IN AN URBAN OZARK WATERSHED:

JORDAN, FASSNIGHT AND UPPER WILSON CREEKS,

SPRINGFIELD, MISSOURI

Department of Geography, Geology and Planning

Missouri State University, May 2006

Master of Science

Ronald B. Miller

ABSTRACT:

The study watershed includes Jordan Creek, the primary stream draining the central downtown area of Springfield, Missouri, and also Fassnight and upper Wilson Creeks. Ten sample sites were established within the watershed and water samples and were collected during baseflow and storm runoff events between August 1, 2004 and July 31, 2005. Samples were tested for total nitrogen (TN), total phosphorus (TP) and selected heavy metals (zinc, arsenic, lead, copper and cadmium) and the parameters pH, specific conductance, turbidity, temperature and dissolved oxygen. Rating curves were used to correlate discharge and water quality variables. Separate rating curves were developed for baseflow and storm runoff conditions. A significant negative correlation between baseflow TN and water temperature indicated that variation in TN could be due to seasonal trends in plant activity. A negative correlation between TP and specific conductivity is probably due to increased TP with storm runoff. Concentrations of TP and TN at the study watershed outlet were found to be below proposed MoDNR TMDL limits for 86 % and 55 % of the study period respectively. Nutrient levels in Jordan Creek are similar to those of Ozark watersheds not influenced by waste-water treatment plants. Annual loads from the study watershed based on daily average flow are estimated to be 26.8 and 2.2 metric tons/year for TN and TP respectively. Concentrations of TN are relatively similar among sample sites at storm runoff, and baseflow variations appear to be related to karst spring discharge. Concentrations of TP are also similar among sites at baseflow but storm levels can be affected by land use and channel condition.

KEYWORDS: Springfield, MO; Jordan Creek; Fassnight Creek; Wilson Creek; Nutrients; Total phosphorus; Total nitrogen; Metals; Water quality; Annual load; Concentration; Discharge; Land use; Karst; Flow exceedance

This abstract is approved as to form and content

Dr. Robert T. Pavlowsky
Chairperson, Advisory Committee
Missouri State University

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CHAPTER 1

INTRODUCTION

Human interactions with the landscape, including construction and use of urban areas are the leading national causes of degraded quality in streams, lakes and coastal waters (USEPA, 1983, 1993 [1], 2002; Novotny, 1994). Degradation of these streams has mainly resulted from increased loads of sediment, nutrients, bacteria, toxic metals and chemicals as well as storm water discharges (USEPA, 1996, 2002; Novotny, 1994). A significant distinction can be made between "point" and "nonpoint" pollution sources. Point pollution sources are those that originate from discrete, definable sources such as sewage treatment outfalls, or industrial waste pipes. These sources are relatively easily identified and generally are subject to discharge regulations such as the National Pollution Discharge Elimination System (NPDES) (USEPA, 1992). Nonpoint sources are diffuse or dispersed across the land surface, such as agricultural fields, urban streets, parking lots and septic tanks, and may introduce pollution into the stream only when storm runoff enters a stream. Thus, it is commonly seen that point pollution is diluted and nonpoint pollution is increased by storm runoff (Novotny, 1994; Schueler and Holland, 2000).

Nonpoint sources, though they may be dispersed and individually of little consequence compared to an industrial outfall, are nonetheless believed to be a significant cause of stream impairment and are responsible for 40% to 60% of impaired river miles nationally (USEPA, 1996; 2000). Sources of nonpoint pollution are difficult to pinpoint, largely because streams function as "integrators" of inputs from the surrounding landscape. While urban areas constitute only 2.6% of the nation's total area, a small proportion of landuse (O'Toole, 2003) they are considered one of the leading sources of water quality problems (Table 1.1) (USEPA, 2002). Since urban areas are concentrated in coastal areas it is not surprising that urban runoff is also the primary stressor for coastal estuaries and bays (USEPA 2002).

Urbanization is the process of clearing and developing natural or agricultural landscapes for human habitation, transportation or economic activities (Paul and Meyer, 2001). The development process creates temporary areas of disturbed and erodible land and ultimately a landscape dominated by impervious surfaces (Schueler and Holland, 2000).

Precipitation on an urban area falls on a landscape highly changed from its original state since the impervious surfaces and modified storm drainages reduce infiltration rates and increase runoff percentage and velocities (USEPA, 1983; Novotny, 1994). These changes in runoff produce a "typical" urban hydrograph that features reduced baseflows and very high and short runoff peaks (Schueler and Holland, 2000;

Table 1.1: Leading Human-induced causes of water quality imaipairment[1]

Rivers and Streams	**Lakes, Ponds and Reservoirs**	**Estuaries**
Agriculture (48%)	Agriculture (41%)	Municipal Point Sources (37%)
Hydrologic Modifications (20%)	Hydrologic Modifications (18%)	Urban runoff/storm sewers (32%)
Habitat Modifications (14%)	Urban runoff/storm sewers (18%)	Industrial discharges (26%)
Urban runoff/storm sewer (13%)	Misc. nonpoint source pollution (14%)	Atmospheric deposition (24%)

[1]from USEPA, 2005
Nonpoint sources in shaded boxes

USEPA, 1993 [2]; 1997). Open construction sites can increase the sediment load in that runoff tremendously to more than 100 times previous levels (Knighton, 1998; Leopold, 1972: Wolman and Schick, 1967). The typical urban hydrograph, sometimes in combination with increased urban sediment loads, can create morphological changes in urban streams that include wider and/or deeper channels with steeper, less stable banks (Wolman and Schick, 1967; Leopold, 1972; USEPA, 1997). In addition the stream itself is often perceived by residents as more of a problem than a benefit because of increased flooding, reduced habitat for aquatic species, and reduced overall water quality (Schueler and Holland, 2000; USEPA, 1997). Covering land with as little as 10 % impervious surface has been identified as sufficient to induce negative changes in streams and stream water quality (Schueler and Holland, 2000).

Typical pollutants found in urban storm water include suspended sediment, nutrients bacteria, heavy metals, and oil and grease (USEPA, 2005, 1993: Novotny, 1994). These are produced and distributed on the urban landscape as a result of activities such as erodible soil at construction sites, parts wear and fluids from automobile use, overspray from lawn fertilization and poor pet sanitation practices (Paul and Meyer, 2001; Novotny, 1994). The impervious surfaces typical of the urban environment collect and store these pollutants during dry periods so that they are available for transport into streams with surface runoff during storm events (Paul and Meyer, 2001; Schueler and Holland, 2000; Waschbusch et al, 1999; Novotny, 1994). In addition, urban areas produce large amounts of waste water that is typically transported to collection sites for treatment before being released into streams. The concentrations of nutrients in waste water effluent have typically been very high (USEPA, 2002). Surface runoff into urban streams typically produces higher concentrations of suspended sediment and metals than other streams, and waste treatment plants in urban areas can produce nutrient concentrations even exceeding those in agricultural streams (USEPA, 2002; Paul and Meyer, 2001).

There are qualitative differences between point sources, such as waste water treatment plants (WWTPs) or industrial waste outfalls, and nonpoint sources such as street dust (Table 1.2). Nonpoint sources are diffused across the landscape and the pollution signal from a point on the landscape, because the sources of nonpoint pollution are related to natural processes (such as soil erosion) or to human urban activities, can vary in intensity over time. Nonpoint sources are a pollution problem because they are the sum of a very large number of very small sources and thus are difficult to identify. In contrast, point sources are relatively easily identified and are regulated by the U. S. EPA's NPDES, which issues discharge permits and has controlled discharges from point sources since 1972 (USEPA, 1992:2006). The NPDES program, and point source controls in general, has greatly improved the quality of the Nation's waterways with the

Table 1.2: Comparison between urban point and nonpoint sources of pollution

Point	**Nonpoint**
End of pipe, easier to identify source	Ill defined, diffuse source
Pollutants may be products of manufacturing	Pollutants usually natural (e. g. sediment)
Loads far in excess of natural loads	Loads relatively low from any single source
Stationary sources, easier to set up representative monitoring sites	Management can move across the landscape, impacts can diminish [or increase] over time, difficult to establish representative monitoring sites
Pollution discharge may be less tied to weather and hydrology	Pollution discharge strongly influenced by weather and hydrology
Pollution controlled by using process controls or effluent treatment under NPDES permit	Pollution controlled with Best Management Practices (BMPs) through voluntary, incentive or regulatory source control programs

from Ice, 2004

result that nonpoint sources have become relatively more important as agents degrading water quality (USEPA, 1983; Laenen and Dunnette, 1996).

Missouri has several state-wide water quality concerns including eutrophication of reservoirs, mercury contamination of fish, toxic drainage from abandoned lead and zinc mines and disruption of stream habitat through channelization and suburban development (MoDNR, 2001[1]). The growing urban areas in Missouri have an increasing impact on streams through increased impervious surface area and modification of riparian corridors by clearing, straightening and installation of road culverts (USDA, 2005).

These statewide issues are reflected in Springfield and its urban streams as well (Figs. 1.1 and 1.2). Jordan Creek drains the central urban core of Springfield and has felt the effects of the last 150 years growth. Once a perennial, spring-fed headwater stream draining the oak savannah of the Springfield Plateau, the stream is now mostly unseen, having been channelized and encased to reduce the impact of storm-induced flooding (Bullard, 2000). Jordan Creek is a major tributary to Wilson Creek which flows into the James River and both of these rivers are currently on the Missouri Department of Natural Resources (MoDNR) 2002 303(d) list of impaired waterways (MoDNR, 2002). The James River is listed as impaired by nutrients and the state and U.S. Environmental Protection Agency (USEPA) approved water quality report on Total Maximum Daily Load (TMDL) notes that sources of nutrients include urban point and non-point sources (MoDNR, 2001[2]). Nutrients and other pollutants from Springfield's Jordan Creek will have an effect on the concentrations and loads both downstream water bodies.

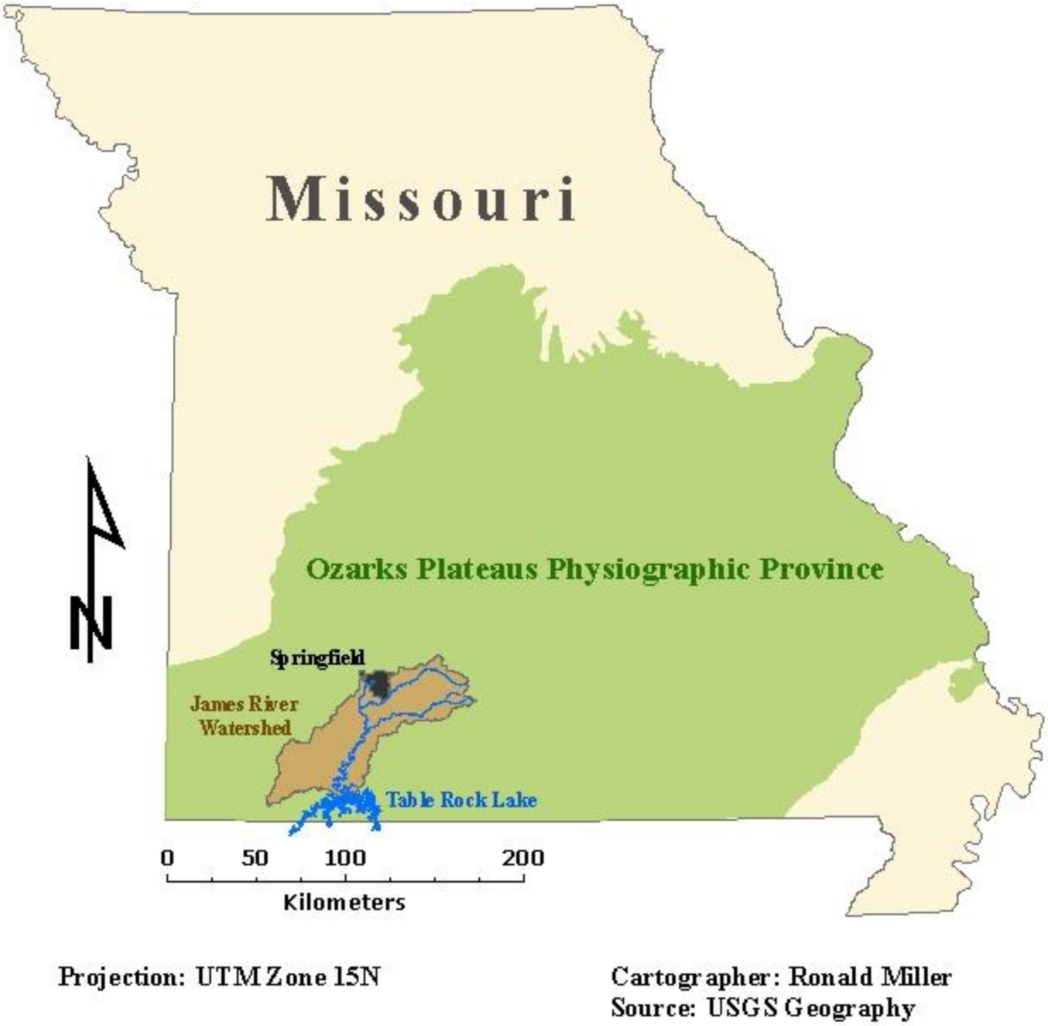

Missouri
Ozarks Plateaus Physiographic Province
Springfield
James River Watershed
Table Rock Lake
0
50
100
200
Kilometers
N
Projection: UTM Zone 15N
Cartographer: Ronald Miller
Source: USGS Geography

Figure 1.1: Regional map showing locations of City of Springfield, the James River and its major tributaries and watershed area, and the Ozark Plateaus Physiographic Province, a region of uplifted carbonate rocks featuring high, level upland areas dissected by deep river valleys and also many karst features such as caves, springs and sinkholes.

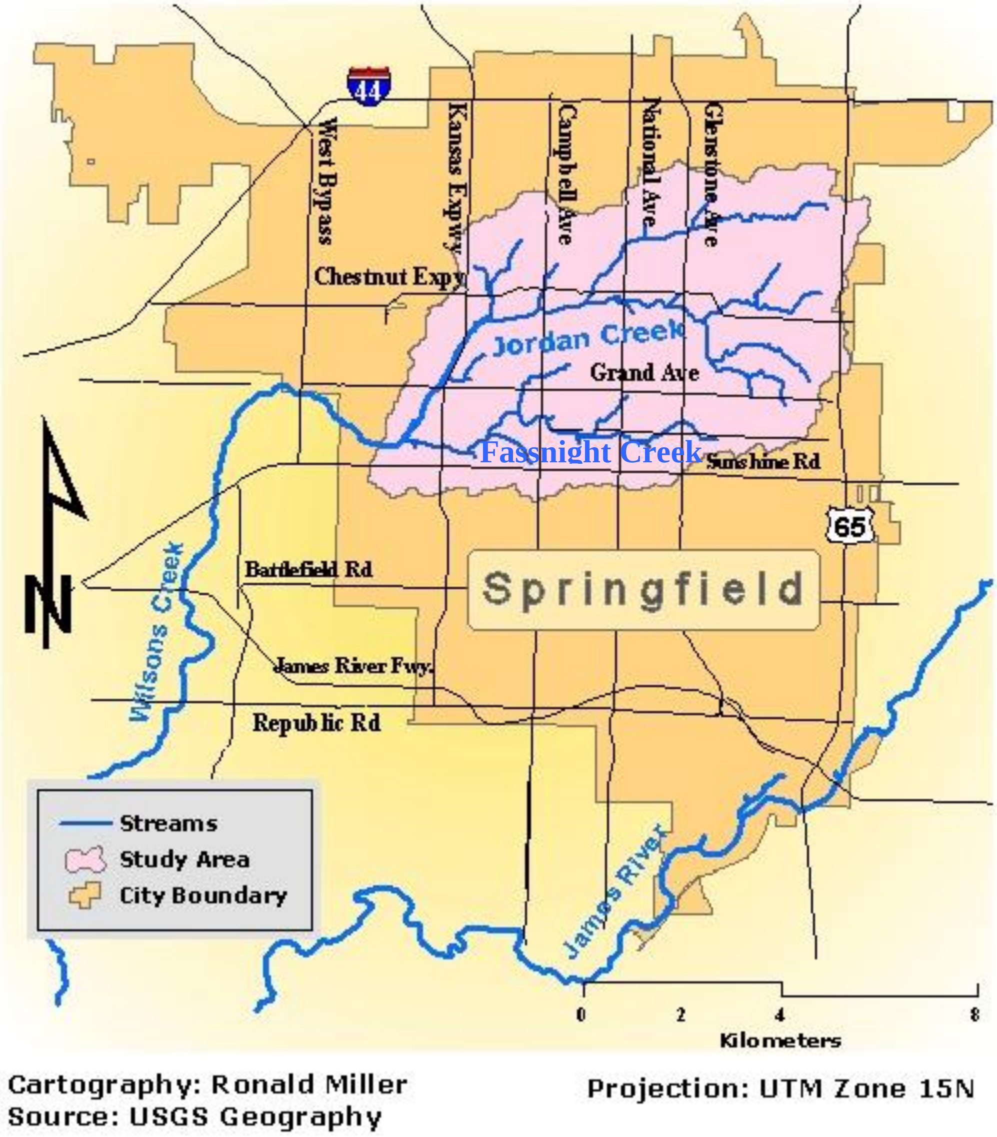

44
West Bypass
Kansas Expwy
Campbell Ave
National Ave
Glenstone Ave
Chestnut Expy
Jordan Creek
Grand Ave
Fassnight Creek
Sunshine Rd
65
Battlefield Rd
Springfield
Wilsons Creek
James River Fwy.
Republic Rd
N
Streams
Study Area
City Boundary
James River
0
2
4
8
Kilometers
Cartography: Ronald Miller
Source: USGS Geography
Projection: UTM Zone 15N

Figure 1.2: Study area location within the City of Springfield showing location of Jordan, Fassnight and Wilson Creeks and James River.

Purpose and Objectives

The City of Springfield is currently working with the U.S. Army Corps of Engineers (USACE) on a project to re-engineer the flood control features of Jordan Creek (USACE, 2004). The main purpose of the USACE project is to reduce flood potential along the watercourse and its secondary purposes are to release the creek from its underground enclosure, to create a more geomorphically sound stream profile, and to improve water quality and aquatic habitat. In order to fully evaluate how the project improves the creek it is necessary to assess the existing water quality. The purpose of the research involved with this thesis is to support the USACE project by describing the baseline concentrations and annual loads of nutrients in Jordan Creek.

Water quality in Jordan Creek is primarily controlled by urban non-point source pollutants such as nutrients and urban-derived metal particulates. Assessing water quality in the creek therefore involves studying the quality of the water, but also studying the spatial distribution of water quality and the source factors within the environment that may influence that quality. Four main objectives will help the project attain this purpose:

1. Water Quality Monitoring. Water samples will be taken from 10 sample sites distributed through the Jordan Creek study watershed. Samples will be tested for ambient water chemistry and concentrations of the nutrients total nitrogen and total phosphorus as well as the common urban metals arsenic, copper, lead, cadmium and zinc.
2. Staff Gages and Discharge Measurement. Staff gages will be set and stream discharge (Q) measurements will be taken from each site as each sample is taken. This will allow concentrations within each sample to be converted to a mass of pollutant

transported over time since load is calculated as the product of concentration and discharge.

3. Range of Conditions for Sampling. The sample collection will continue for a year and samples will be collected over a variety of runoff and seasonal conditions in order to best understand the range of water quality conditions and best identify the factors that affect those conditions.

4. Evaluation of Pollution Source Areas. Available information about watershed landuse will be used to assess source factors for pollutants in the stream. A Geographic Information System (GIS) will be used to identify the watershed area as a whole and the contributing sub-area of each sample site.

5. Comparison to Concentrations in Other Streams in the Region. Nutrient concentration results from the Jordan Creek study will be compared to other studies of nutrient concentrations in the Springfield region from recent years. This will help to assess the affect the Springfield urban area has on water quality.

The study area includes Jordan Creek, Fassnight Creek and the upper Wilson Creek. Jordan Creek flows generally westward across the northern third of Springfield from its headwaters in the lightly developed lands east of Highway 65, through the commercial heart of the downtown area and then continues west into the lightly developed lands near the study area boundary at Scenic Ave. Eight sample sites located upstream of, within and below the downtown area will thus allow an assessment of the influence of the downtown area on the overall water quality of Jordan Creek. Fassnight Creek is located immediately south of Jordan Creek and flows westward through residential and commercial areas to a confluence with Jordan Creek near the western edge of the study area. Wilson Creek is formed by the confluence of Jordan and Fassnight Creeks and the final sample site is located where Scenic Ave crosses Wilson Creek. The U. S. Geological Survey (USGS) Real-time stream gage “Wilson Creek at Scenic Ave” (07052000), located at this final sample site, provides access to highly detailed discharge data, including storm hydrographs, daily averages and exceedence probabilities, that will improve the accuracy of pollutant loads calculated for the study.

This study will measure in-stream water chemistry parameters including pH, dissolved oxygen (DO), specific conductance (SC), turbidity (TURB) and temperature (TEMP) at the time each sample is collected. These measurements are helpful for describing and identifying the conditions within the stream that affect the concentration of contaminants. Contaminants measured for the study include the nutrients total phosphorus (TP), total nitrogen (TN) and the metals arsenic (As), copper (Cu), lead (Pb), zinc (Zn) and cadmium (Cd). Measuring the nutrients is important because elevated concentrations of these nutrients can affect the degree of eutrophication and habitat quality in Jordan Creek as well as nutrient concentration in the 303-D listed receiving waters of the James River and Table Rock Lake (Petersen et al, 1998). The metals to be tested for are typical urban pollutants and are listed as “Priority Toxic Pollutants” by the EPA (USEPA, 2004). Concentrations of those contaminants, along with measured discharge at those sites, will be used to calculate total loads and unit area yields from the watershed. Differences among calculated yields among sites may also be used to assess source differences with the watershed.

Benefits of the Study

The concentration, load estimates produced by this study will meet the project goal of producing a baseline for water quality to match against measurements made in Jordan Creek after channel improvements have been made. Beyond the main project goal, the project will provide insight into the contribution of Springfield to the nutrient loads in the 303(d) listed Wilson Creek and James River (MoDNR, 2002). Also, those estimates will provide a basis for evaluating sources of non-point pollution in the watershed, and for comparing water quality in Jordan Creek to that in other streams within the region. Since Springfield is the sole major urban area in the Ozarks, the results of this project will allow urban water quality to be compared to national data to assess any differences produced by this unique physiographic region.

CHAPTER 2

REVIEW OF LITERATURE

To adequately understand urban water quality and nonpoint source pollution it is important to understand the nitrogen, phosphorus and heavy metal sources in the environment and how those pollutants are transported into urban streams. Additionally, to evaluate the results of the study it is also important to compare the findings to nutrient concentrations and loads in urban and in undeveloped watersheds in other areas of the Ozarks. This chapter will review the published literature concerning sources, concentrations and loads of nutrient pollution in the urban environment as well as any reports concerning the Ozark region or Springfield. Additionally, this chapter will include an overview of existing literature that considers the value or effectiveness of the various methods employed in the study.

Nutrient Runoff Patterns

Nitrogen (N) and phosphorus (P) are both important nutrients for aquatic plants and thus concentrations of these nutrients can determine the degree of eutrophication of a water body. Eutrophication is a process in which excess nutrients entering a water body cause an increase in algal plant growth. This excess plant growth can reduce dissolved oxygen concentrations in the water body as the plants die and begin to decay and those low oxygen concentrations can be harmful or fatal to other aquatic life (USGS, 2005; USEPA, 1999) Eutrophication in freshwaters streams and lakes is most often limited by the availability of P and thus most often urban stream research focuses on that nutrient, although N remains an important factor in aquatic ecosystems.

Nitrogen. Nitrogen has a complex chemistry involving organic and inorganic, dissolved and particulate forms and is further complicated by the fact that some aquatic plants can fix nitrogen from the atmosphere (Taylor et al, 2005). Measurement of N in water samples can occur as discrete measurements of different common species (nitrate (NO_3^-), nitrite (NO_2^-) or ammonium (NH_4^+)) or by converting all species to nitrate and measuring that “total nitrogen” (TN) concentration.

It is important to note that most nitrogen in streams is found in the dissolved phase and is the result of soil-ground interactions (Taylor et al, 2005). Baseflow concentrations of nitrogen are therefore generally higher than storm event concentrations, although the storm loads of nitrogen which are scaled to discharge are higher than baseflow loads. Novotny and Olem (1994) compiled a range of typical concentrations for both TN and TP in streams dominated by various land uses (Table 2.1). Those values show a very wide range of TN concentrations with human-influenced areas having much higher TN concentrations than background.

In a more detailed background study, Clark et al (2000) identified a subset of undeveloped watersheds from various national water quality databases and then published nitrogen and phosphorus concentrations and yields for those watersheds in an effort to create a baseline for water quality. Total nitrogen concentrations ranged from 0.10 to 2.6 mg/L with the median 0.26 mg/L. The highest concentrations appeared in basins located in the eastern US and those concentrations appeared to be related to the higher rates of atmospheric deposition of nitrates in that region.

Table 2.1: Typical TN and TP concentrations for various land uses (Novotny and Olem, 1994, from various studies)

		Total Nitrogen (mg/L)	**Total Phosphorus (mg/L)**
Rural[1]	Background	0.05 - 0.5	0.01 - 0.2
	Cropland[3]	9	1.2
	Grazed pasture[3]	4.5	7
	Feedlots	920 - 2,100	290 - 380
Urban[1]	Stormwater	3 - 10	0.2 - 1.7
	WWTP[3]	30	10
Undisturbed[2]	Range	0.10 - 2.6	<0.01 - 0.20
	Median	0.26	0.02

[1] from Novotny and Olem (1994)
[2] from Clark et al (2000)
[3] mean value

The delivery of nitrogen to streams is a complex phenomenon, related to through-flow of soil water and the activities of plants within and outside the stream. Zhang and Schilling (2005) found that nitrate concentrations in the Raccoon River, Iowa varied seasonally. The Raccoon River drains an agricultural area and has nitrate concentration records for the last 30 years. Analysis of the record showed a strong correlation between nitrate concentration and season, with high concentrations in spring and fall apparently due to the corresponding seasonal application of nitrate fertilizers and aquatic plant activity. Vanderbilt et al, (2003) found a seasonal trend for nitrate concentration in a mountainous, non-agricultural watershed that featured a fall-winter maxima and spring-summer minima. The winter maximum was attributed to the seasonal occurrence of plant dormancy that increased availability of nitrogen in the soil and the presence of soil temperatures generally above 0º C that allowed dissolved forms of nitrogen to flow through the soil and into the streams.

In both of the cases above, seasonally high soil nitrogen concentrations corresponded to high in-stream nitrogen concentrations. The difference in seasonal trend between the studies is due to the local differences in source for the high soil nitrogen concentration: seasonal fertilizer input in Zhang and Schilling (2005) and seasonal plant dormancy in Vanderbilt et al (2003).

Total nitrogen concentration does not appear to be controlled or influenced by the presence of karst drainage features. Karst drainage features such as caves, sinkholes, springs, and gaining or losing streams occur in carbonate bedrock areas. Those structures are produced by the gradual dissolution of the carbonate rock by slightly acidic groundwater and produce channels for groundwater flow that are both relatively independent of surface topography and conduits for rapid movement of water and pollutants from the surface into the groundwater system. Ozark studies of groundwater quality have found that karst groundwaters are naturally oligotrophic or nutrient-poor, and that elevated nutrient levels can generally be traced to agricultural or human waste disposal sources (Graening et al, 2003; Adamski et al, 1995). Nitrogen found in the water of Jordan Creek is thus unlikely to be due merely to the fact that it may have traveled through a karst drainage structure to reach the stream.

Phosphorus. All phosphorus naturally in the environment results from the weathering of fluorapatite-bearing igneous rocks, sedimentary phosphorites and rare guano deposits (Holtan et al, 1988; Ahl, 1988). However, human activities have dramatically increased the supply, transport and cycling rates of phosphorus through the environment. These activities include the mining of phosphates for fertilizers and other uses, the application of phosphorus in fertilizers, human-induced increases in rates of soil erosion, and discharging of waste waters rich in phosphorus from detergents and human or animal wastes (Novotny, 1994). Because phosphorus does not occur in the atmosphere except as suspended particles it is usually easier to calculate potential atmospheric yields for phosphorus than for nitrogen. Atmospheric yields of P are related to wind traveling over dust source areas with oceanic winds being lowest and desert winds or winds traveling over mining or agricultural regions being very high (Ahl, 1988).

While nitrogen is generally found as nitrate which is dissolved in the water column, phosphorus is generally bound to small mineral and organic particles and is suspended in the water column (Holtan et al, 1988, Ahl 1988). These two nutrients thus may be found to behave differently in a stream and they tend to show different concentration trends over discharges. In general, P concentrations in streams are expected to follow the suspended sediment trends. Pionke et al (1996) found that phosphorus export from an agricultural catchment was dominated by storm flows while nitrate export was dominated by base flows.

Phosphorus concentrations in streams can vary widely based on land use and activities that increase sediment loads or that artificially enriches natural phosphorus levels generally have the highest concentrations. Total phosphorus (TP) is a measure of all phosphorus species present in the water. TP concentrations in undeveloped watersheds range from < 0.01 to 0.20 mg/L with median concentration 0.022 mg/L (Clark et al, 2000).

First Flush. It has frequently, although not universally, been observed that suspended sediment and hence TP concentrations are higher on the rising limb of the storm hydrograph than on the falling limb (Novotny and Olem, 1994, Bowes et al, 2005).

This has become known as the “first flush” of a storm since it often contains a disproportionate mass of pollutants. For example, in a 1983 study of the Mad River of Northern California during a month that included 6 storms, 95 % of the suspended sediment budget was transported during only 5% of the total time (Thomas, 1988). For this reason, discharge may not be a good predictor of sediment concentration or TP because the pollutant supply peak can enter the channel ahead of the storm discharge.

Schueler and Holland (2000) reviewed a study from Austin, Texas that evaluated the first flush “rule of thumb” that the first half inch of runoff contains 90 % of the pollutants. The study found that the pollutants in the first half inch of runoff were within 90 % of the total pollutant load only for watersheds with low impervious area. Watersheds with 50 % impervious area and above might reasonably be considered urban. The first half inch of runoff from those watersheds contained percentages of pollutants that were high but consistently less than 90 % of the total runoff load. For the purposes of this study therefore, “first flush” will refer to significantly greater pollutant concentrations within the rising hydrograph as compared to the recession but will not imply any set percentage of total load.

Hysteresis describes a constituent concentration curve that is offset from its corresponding hydrograph. Bowes et al (2005) studied phosphorus-discharge hysteresis loops during storm flows and found that the magnitude and direction of the loops was related to sediment supply both in the channel and on the watershed surface. Extreme runoff events, those capable of moving material into the channel from the watershed surface and suspending channel sediment, created extreme clockwise hysteresis loops in which sediment and TP concentrations increased rapidly in relation to discharge as the runoff event began. Counterclockwise loops occurred when short intervals between events were insufficient to recharge in-channel particulates or dislodge surface sediment. These loops showed increased sediment and TP concentrations only well into the event, perhaps as a result of wetted stream bank collapse.

Urban Water Quality. Urban lands and agricultural lands, while seemingly very different in terms of land use, are alike in that they are both drastically altered from their natural state by human activities. It is not surprising then that each show much higher constituent concentrations and unit area yields than their natural counterparts (Characklis, 1997; Booth et al, 2004; Coulter et al, 2004). Novotny and Olem (1994) show that both urban and rural landuses have much higher concentrations of TP and TN than the background levels detected in unaltered watersheds. The urban environment can also be an important source for metals since Novotny and Olem (1994) report “General Urban” areas as yielding 0.14 – 0.5 kg/ha-yr Pb, and 0.02 – 0.21 kg/ha-yr Cu.

In a qualitative study of the effect of urbanization type on water quality, Carle et al, (2005) used a GIS model to determine the urban watershed characteristics that best explained the concentrations of various constituents in the streams of Durham, NC. While each model picked household density as the primary explanatory variable in the equation, the second third and fourth variable changed as different constituents were evaluated. The total Kjeldahl nitrogen model included household age and recent rainfall, while the TP model included median impervious patch size, and the Total Suspended Solids model included percent connected impervious surface and stormwater outfall density. These differences point to a complex pattern of pollutant loading in the urban landscape and somewhat different source mechanisms for each constituent and the manner in which each variable was sampled and quantified.

Land use composition generally controls variation in TP and TN in an urban watershed (Walsh et al, 2001). Waschbusch et al (1999) studied sources of TP in runoff from various typical urban sources including streets, driveways, parking lots, roofs and lawns in a study of two small urban watersheds in Madison, WI. By comparing the concentrations from each of these sources to composite samples gathered at a common collection site (a storm sewer) he was able to determine that urban lawns and roadways contributed the most to TP concentrations in waterways. Appel and Hudak (1999) found concentrations of TP to be associated with soils, lawns and building material uses in four watersheds that he sampled.

In general, landuse composition of the watershed is used to model or predict the rates of nutrient transport in streams. These models vary from simple models based on landuse and precipitation to complex models that involve the above as well as soils and infiltration rates, the hydraulic characteristics of streams, and values for pollutant accumulation over time. In a comparison between simple and complex pollutant load models, it was shown that the simple model is adequate when the watershed area is small, landuse is fairly uniform, and only a runoff load estimate is required (not time history of concentrations) (Schueler and Holland, 2000). Some “very simple” models omit the precipitation and rely only on landuse area to estimate loading (USEPA, 1999). These models permit a general estimate but cannot adjust for abnormal precipitation patterns.

Rating Curves. Rating curves for streams are a method that uses a regression equation to relate an easily measured stream variable, such as stream depth, to estimate a more difficult parameter such as discharge (Fig. 2.1). Concentration rating curves are a popular method for estimating pollutant concentration in a stream because they do not require constant water quality sampling to derive the estimate (Ferguson, 1987; Thomas, 1989). A concentration rating curve relates discharge, a relatively easily measured stream parameter, to pollutant concentration, which is more difficult and expensive to measure, with an equation based on an empirical distribution or logarithmic relationship. Generally, increasing the number of concentration and discharge samples improves the fit of the rating curve to the actual data but at increasing expense (Robertson, 2003). However, factors other than stream discharge, such as the seasonal application of fertilizer or between-storm accumulation of road dust, may influence concentration and thus reduce the quality of the fit between the rating curve and actual concentration (Ferguson, 1987; Butcher, 2003; Zhang and Schilling, 2005).

In the case of TP, such factors include the first flush phenomenon in which rising

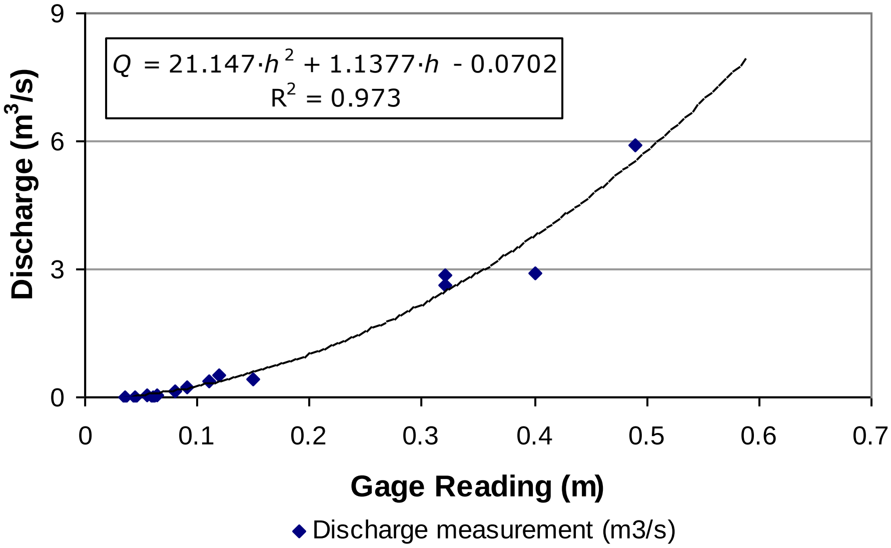


Figure 2.1: Sample discharge rating curve from Site NB2 showing equation used to estimate discharge (Q) from gage reading (h), based on sampled Q and h pairs.

limb concentrations are higher than falling limb concentrations for a given discharge, sporadic source events such a bank sloughing that occasionally deliver large amounts of sediment and P to the stream, and the timing of storms in relation to the buildup of street dust. Factors affecting TN concentration include seasonal changes in soil TN due to plant nitrogen uptake activity inside and outside of the stream, seasonal variation in fertilizer application and TN delivery to the stream due to seasonal precipitation changes and the presence or absence of drainage modifications (Zhang and Schilling, 2005).

In a study dealing with prediction of sediment load in a system with pronounced sediment-discharge hysteresis, Thomas (1988) found that even including all samples from a nearly continuous set of suspended sediment and discharge measurements created a rating curve that under-predicted actual sediment concentration. Discharge by itself did not contain enough information to describe the concentration of sediment. The resulting poor fit of rating curves can sometimes be corrected by using multiple factors in the curve (Cohn et al, 1992) or by using multiple curves dividing the data by season or event to improve the fit of concentration to discharge (Ferguson, 1987).

Sampling Frequency and Pattern. How does a researcher ensure that samples taken from a stream will provide an accurate representation of the loads of constituents in the stream? Intuitively it seems obvious that continuous sampling of water quality and discharge would produce the most accurate estimate albeit at great expense (McBride et al, 1997). Alternatively, a single water quality sample that happens to constitute the exact average annual concentration of constituents will reduce sampling expense tremendously but leave the problem of when to sample. The compromise solution is a program that takes samples over a period of time and/or a range of flows. Ferguson (1987) proposed that a sampling program must have a sampling interval smaller than the interval of concentration change in the stream in order to accurately model concentration. In a small stream the interval of change is likely to be very small which requires frequent sampling to achieve ideal accuracy.

In several papers involving re-sampling of nearly continuous concentration and discharge data from Bower Creek in Wisconsin, Robertson and others (1999, 2003) compared the accuracy of various common water sampling schemes at predicting different types of Total Suspended Sediment (TSS) and TP loads. Common load estimations include mean daily, median daily and total annual loads. Common sampling schemes include constant-interval schemes, such as bi-weekly, monthly or semi-monthly, and also constant-interval schemes enhanced with storm event sampling, commonly known as “storm chasing”. By selecting regular subsets of the Bowers Creek dataset, Robertson et al recreated these common sampling strategies and then tested their load predictions against the “true” load estimated by the entire dataset.

Robertson et al calculated the simulated loads for the various sampling strategies by creating a regression equation of measured load (concentration multiplied by discharge) and average daily discharge and annual loads were calculated from the regression by summing the loads for each average daily discharge for the year. The “true” load for the year was calculated using integration of the instantaneous load record from the year where load equals instantaneous concentration times instantaneous discharge. Robertson et al, noted that constant interval schemes tend to miss the storm-related concentrations unless the total period of sampling is greater than three years, in which case a sampling of storm events occurs through random chance. However, studies focused on mean and median daily loads, corresponding the average or usual conditions facing aquatic life, do not require input from extreme events and thus he found that the most effective sampling for accurately estimating those loads to be the various fixed interval schemes, and that the addition of storm-chasing created a positive bias. However, suspended sediment and TP are disproportionally transported in storm events and thus an annual total load estimate that cannot account for storm concentrations will likely under-predict the annual load. Robertson found that studies including storm-chasing with regular intervals had the least bias in predicting total annual load.

The method used to obtain the sample can affect results as well. Common methods include "grab-samples" which are generally obtained by "grabbing" a sample from a single point in a stream, and horizontally (or vertically) integrated samples, which are obtained by collecting a regular amount of sample at regular intervals horizontally across or down in a stream. In a paired-sample test, Martin et al (1992) studied the concentrations of various constituents that resulted from single grab-samples and regular-interval horizontally-integrated samples. The study found that the grab samples estimated the same concentrations of dissolved constituents as the horizontally-integrated samples, including nitrate and nitrite, but generally underestimated particulate constituents such as suspended sediment.

Studies within the Ozark Region.

Berkas (1987). In an early work focused on the effects of the Southwest WWTP on Wilson Creek and the James River, Berkas (1987) studied nutrients concentrations (including TP and Nitrate plus Nitrite), discharge and travel time (through dye tracing) in Wilson Creek below the WWTP and in the James River above and below the confluence with Wilson Creek Because this report does not address the water quality of Wilson Creek above the WWTP it is not directly comparable to the current study, however Berkas' sites on the James River above the confluence (sites 1 and 4) may be comparable since they, like the current study, have concentration values from sites that lack effluent from waste water plants. Unlike the current study, the Berkas' James River sites contain a large proportion of flows with non-urban sources which may reduce their value as a direct comparison. Berkas' sites 1 and 4 showed very low TP concentrations (< 0.05 – 0.21 mg/L) and Nitrate plus Nitrite (0.43 – 0.90 mg/L), which stand in contrast to the much higher concentrations in sites influenced by the WWTP.

USGS Water Quality Studies in the Ozarks. A general survey of the Ozark Plateaus physiographic unit over the period 1992-1995 studied land use-based variations in the water quality of Ozark streams and published the results in several documents (Davis and Bell, 1998; Petersen et al, 1998). The studies did not directly address urban water quality because no sites included solely urban-sourced water; however the urban water quality was sampled indirectly at Center Creek near Smithfield, MO (Site 27). The watershed for the Center Creek site is only about 7% urban with most of the area agricultural. Most of the study's inferences about urban water quality are based on this site. These studies are most valuable in providing a non-urban reference with which to compare the urban water sampled in the current study. The studies found that nitrates are highest in basins with high percentage of agricultural use and lowest in mostly forested basins with urban basins equivalent to the high range of agricultural basins. Phosphorus concentrations are highest in urban-agricultural and agricultural basins and lowest in forested basins with predominantly urban basins within the range of the high concentrations (Petersen et al, 1998). It is not clear from the site descriptions how the authors were able to identify strictly urban influences from among the sampling sites in the study which listed only two sites with urban land-use mixed with agriculture (James River at Boaz) and agriculture and mining (Center Creek at Smithfield).

Fredrick (2001) Masters Thesis. The Masters thesis presented by Brian S. Frederick (2001) studied the distribution of phosphorus bound to bed sediments in the James River Basin. He also evaluated TP concentrations in the water column from data collected by the USGS and the City of Springfield, at various sites throughout the basin in order to estimate the relationship between bed P and water column P. Several of the sites used by Frederick can be used to compare to results from this study in that they are receive runoff from the Springfield urban area but not effluent from the SWWWTP. Mean TP concentrations listed in the study were 0.49 mg/L at “Wilson Creek-Above Plant” and 0.40 mg/L at “James River-Nelson Mill”.

Wilson and Pearson Creek Study (2002). Richards and Johnson (2002) studied Wilson and Pearson Creeks to assess the aquatic life toxicity. They sampled six sites including the USGS Gage at Scenic Avenue (07052000) that is included in the present study. The study took 2 baseflow and 4 storm runoff water samples between August 1999 and July 2000 at the Scenic. Samples were analyzed for many constituents including nitrate plus nitrite and total phosphorus and loads were calculated using hydrologic data from the Scenic gage. Generalizing data from all sites, the study found “(t)he nitrogen species median concentrations generally were greater than the median concentrations of the base-flow samples, and the median concentrations of the phosphorus species generally were less than the median concentrations of the base-flow samples (p. 16)." Results from this study are directly comparable to the current study because the sample site at the Scenic Gage is the same as site WC1 in the current study. The actual concentration values per site are not listed in the report although they are available online as part of the USGS Gage (07052000) database. Event Mean Concentrations (EMC) for storm samples and baseflow concentrations listed TP concentrations ranging from 0.05 to 2.03 mg/L and Nitrate plus Nitrite from 0.786 to 8.29 mg/L. The study reported event mean load estimates (pounds per day) for each site in chart form for each sampling event (Fig.2.2). The EMC sample was composited from a number of samples with sampling initiated after a preset rise in stage. Four more samples were taken at various intervals afterwards (4 to 7 minutes) and mixed together to produce the EMC. Because these samples are concentrated on the rising limb, it is expected that they will show higher concentrations than the falling limb samples collected during this study.

City of Springfield NPDES Stormwater Report (2004).   This report includes ambient and storm runoff concentrations from samples taken during the reporting period (July 2003-June 2004). The sample sites do not correspond exactly to the sites from this study but they do represent samples from the same urban core area (Table 2.2). Site "JC" is Jordan Creek at Bennett Street, which is located upstream of site JC1 from the present study, and site "WC" is Wilson Creek at Farm Road 146, downstream from site WC1 from the present study and upstream from the Southwest WWTP.

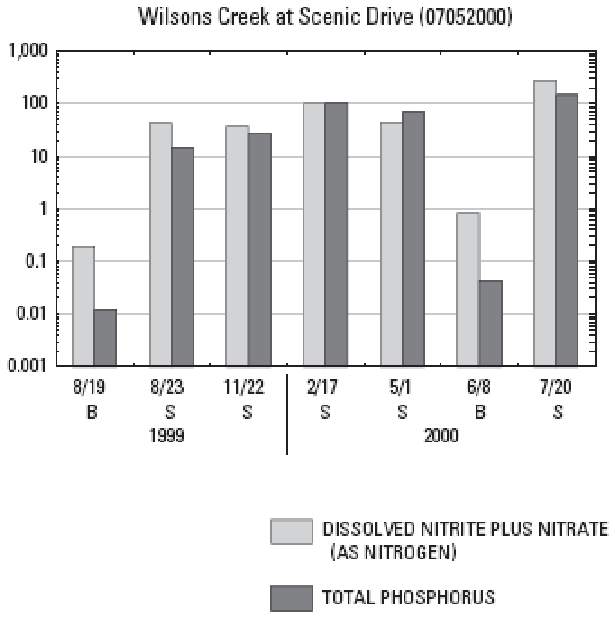


Figure 2.2: Calculated event loads (pounds per day on vertical axis)) from Richards and Johnson (2002). B = baseflow S = storm event

Table 2.2: Data from City of Springfield NPDES 2004 report. JC is Jordan Creek at Bennett Street; WC is Wilson Creek at Farm Road 146. All are ambient (baseflow) samples except 3/25. Samples taken July 2003-June 2004.

Site	Date (d/m)	pH	Ammonia/ nitrogen (NH3-N) (mg/L)	Nitrate + Nitrite (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Dissolved Phosphorus (mg/L)	Total Phosphorus (mg/L)
JC	11/10	7.35	0.29	4.94	N/A	0.02	0.74
	3/9	7.74	0.1	3.02	0.64	0.09	0.49
	3/25	7.1	0.1	1.57	0.76	0.01	0.34
	5/10	7.21	0.12	2.18	1.3	0.03	0.07
WC	11/10	7.67	0.1	2.27	N/A	0.03	0.82
	3/9	7.83	0.1	3.12	0.58	0.13	0.49
	3/25	7.84	0.1	2.05	0.56	0.01	0.34
	5/10	7.5	0.1	2.12	1.09	0.01	0.07

CHAPTER 3

STUDY AREA

Location

The study area for the Jordan Creek Baseline Water Quality Study is the upper reach of Wilson Creek and its tributaries Jordan and Fassnight Creeks. The study watershed is located entirely within the City of Springfield, the largest city in southwestern Missouri, and Jordan Creek has the most urbanized watershed in the city. The study area comprises a headwater tributary of the James River which drains south from Springfield into Table Rock Lake, a US Army Corps of Engineers reservoir on the state boundary with Arkansas (Fig. 1.1).

The study area consists of the entire Jordan Creek and Fassnight Creek watersheds and part of the upper Wilson Creek watershed (Fig. 1.2). The study streams flow generally east to west across the northern third of the City of Springfield. Stream gradients are low, and flow can be low or intermittent, especially in dry late-summer months. The watersheds are heavily urbanized, and the stream channels, especially Jordan Creek through downtown have been modified to better conduct storm runoff (Bullard, 2000; City of Springfield, 2001).

Geology and Soils

Ozark Plateaus. Southwestern Missouri is part of the Ozark Plateaus Physiographic Province, an uplifted block of carbonate rock with unique hydrologic and topographic characteristics. The Ozarks Plateaus province is characterized by flat central plateaus dissected at the edges by steep-sided stream valleys. Rocks within the region are mainly limestones and dolostones of Mississippian age, composed nearly entirely of the calcareous body parts of benthic sea creatures, with varying percentages of secondary chert. The bedrock erodes quickly when exposed and is very poorly represented in coarse alluvial sediment, which is nearly all residual chert (Adamski et al, 1995). The carbonate nature of the bedrock produces many karst features in the area such as caves, sinkholes and springs. These features complicate surface drainage by producing “losing” and gaining” sections of streams as water enters the stream from springs and leaves the stream at karst fissures or swallow holes.

Caves, sinkholes, springs and gaining or losing stream reaches, often referred to as “karst” features, are common around the Ozarks and within the study area. These features are common in the Ozark Plateaus because of the carbonate nature of the bedrock, which is chemically eroded over time by slightly acidic groundwater (Adamski et al, 1995). Karst-affected drainages, including the study area, often have very complex hydrologies where the surface topography only partially determines the source and fate of water within the drainage.

Soils. Factors controlling soil development include parent material, cover vegetation and topography (Hughes, 1982). Topography is a primary control on the distribution of soils: low-lying areas are likely to be inundated in floods and thus develop deep alluvial soils while upland areas are dependent on parent material for soil formation. The parent material for most soils in the study area is the red clay residuum that results from the weathering of the underlying limestone bedrock, although some glacial loess does occur as a parent material in some upland area soils, although the study area is south of the primary area of loess deposition (GSA, 1949; Hughes, 1982). Different vegetation coverage produces different soils as well, and the soils within the study area reflect its oak savannah prehistory with some originating under prairie grasses and others under deciduous forest.

The relative abundance of soils (Table 3.1, Fig. 3.1) also shows the predominance of upland soil types within the study area. Soils within the study area belong to one of three soil associations. All are formed on the clay-chert residuum from the weathered bedrock and may contain some loess. The *Pembroke-Eldon-Creldon* association generally occupies the level or slightly sloping upland areas at the eastern, headwater area of the study watershed and developed under prairie grasses. These soils may contain some loess and are also associated with sinkholes. The *Goss-Wilderness-Peridge* association occurs in riparian areas and the slopes along the upper stream corridor and developed under deciduous forests. The *Viraton-Wilderness* association occurs on the

Table 3.1: Relative abundance and some characteristics of soil types in study area (Hughes, 1982).

Soil Symbol	**Soil Name**	**Percent Area**	**Slope %**	**Landform**	**Parent Material**	**Infiltration rate (in/hr)**	**Depth to impervious layer (in)**
6B	Creldon silt loam	31.4	1 to 3	uplands	loess/residuum	0.6-2	24
81B	Viraton silt loam	19.1	2 to 5	upland/terrace	loess/residuum	0.6-2	22
2B	Pembroke silt loam	12.9	1 to 5	upland/terrace	loess/residuum	0.6-2	72+
5C	Wilderness cherty silt loam	6.9	2 to 9	uplands	residuum	2.0-6	10
33B	Keeno and Eldon cherty silt loams	5.1	2 to 14	uplands	residuum	2.0-6	19-28
21B	Peridge silt loam	3.8	2 to 5	upland/terrace	loess/residuum	0.6-2	72+
1B	Newtonia silt loam	3.8	1 to 3	uplands	loess/residuum	0.6-2	72+
43D	Goss cherty silt loam	3.4	2 to 20	uplands	residuum	2.0-6	20
76	Hepler silt loam	2.9	0 to 2	stream terrace	alluvium	0.6-2	30
54	Lanton silt loam	2.7	0 to 2	flood plain	alluvium	0.6-2	10
53B	Wilderness & Goss cherty silt loam	2.6	2 to 9	uplands	residuum	2.0-6	24
11B	Sampsel silty clay loam	2.3	1 to 5	uplands	residuum	0.6-2	13
Trace	< 2.3 % Area	3.1					

[1] Ten soils with 2.3% area or less have been aggregated into a single group.

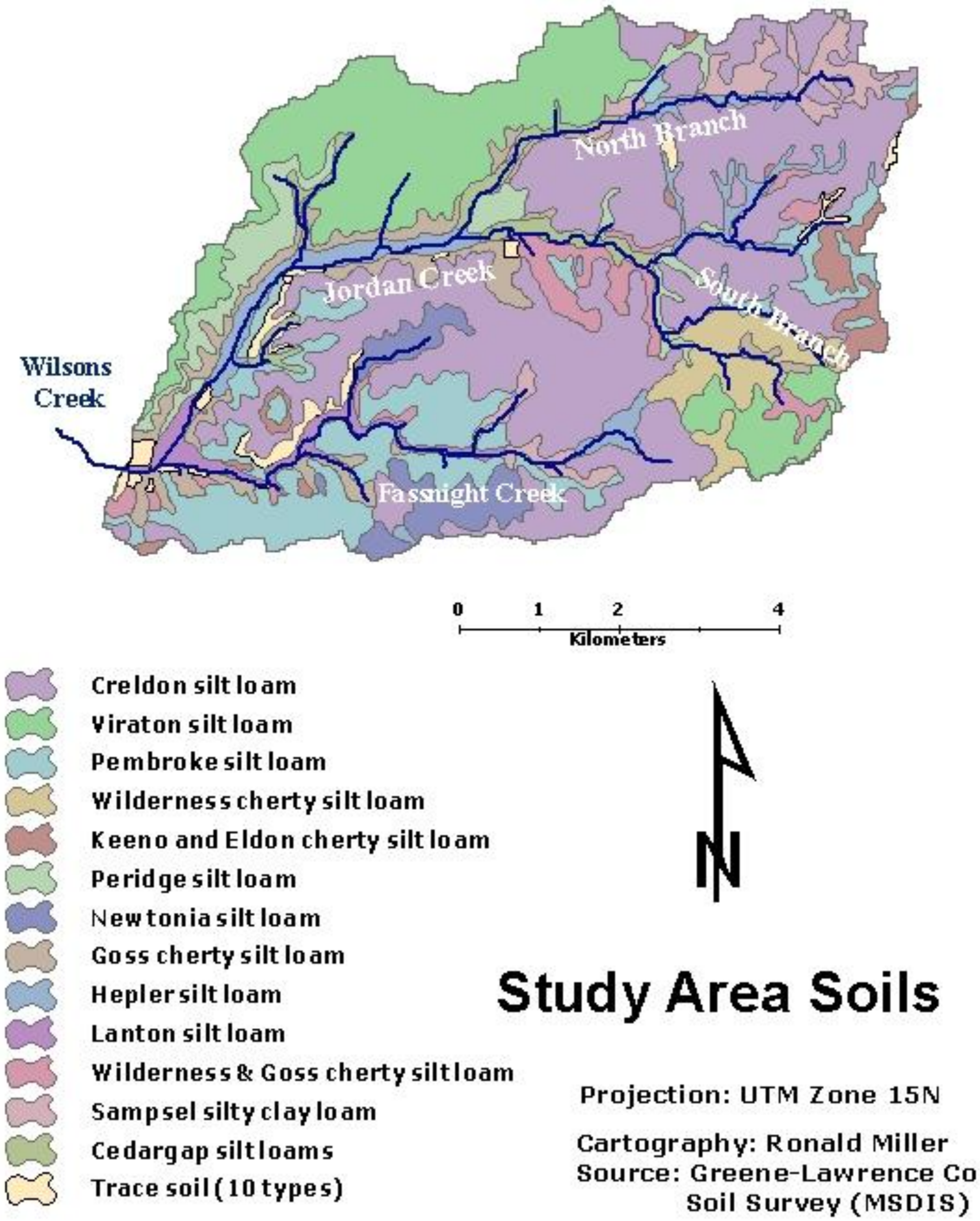

North Branch
Jordan Creek
South Branch
Wilsons Creek
Fassnight Creek
0
1
2
4
Kilometers
Creldon silt loam
Viraton silt loam
Pembroke silt loam
Wilderness cherty silt loam
Keeno and Eldon cherty silt loam
Peridge silt loam
Newtonia silt loam
Goss cherty silt loam
Hepler silt loam
Lanton silt loam
Wilderness & Goss cherty silt loam
Sampsel silty clay loam
Cedargap silt loams
Trace soil (10 types)
N
Study Area Soils
Projection: UTM Zone 15N
Cartography: Ronald Miller
Source: Greene-Lawrence Co Soil Survey (MSDIS)

Figure 3.1: Distribution of soil types in the Jordan Creek Study area.

tops and slopes of uplands and terraces in the southeast and northwest edges of the study area and also developed under deciduous forests (Hughes, 1982).

Climate

The Springfield area is humid temperate, averaging 114 cm total precipitation per year as measured at the Springfield Airport gage and compiled in the NOAA 30 year average and available from the National Climate Data Center (NCDC) (Fig.3.2). Cold winter temperatures allow some precipitation in the form of snow, but it is rare for snow to accumulate in large quantities or to persist on the ground. Precipitation is distributed fairly evenly throughout the year with the greatest amount coming in the spring and early summer with a minor peak in the fall. Extreme rainfall events can occur at any time of the year, however. Air temperatures vary greatly over the course of a year with the lowest temperatures occurring in January and the highest in July.

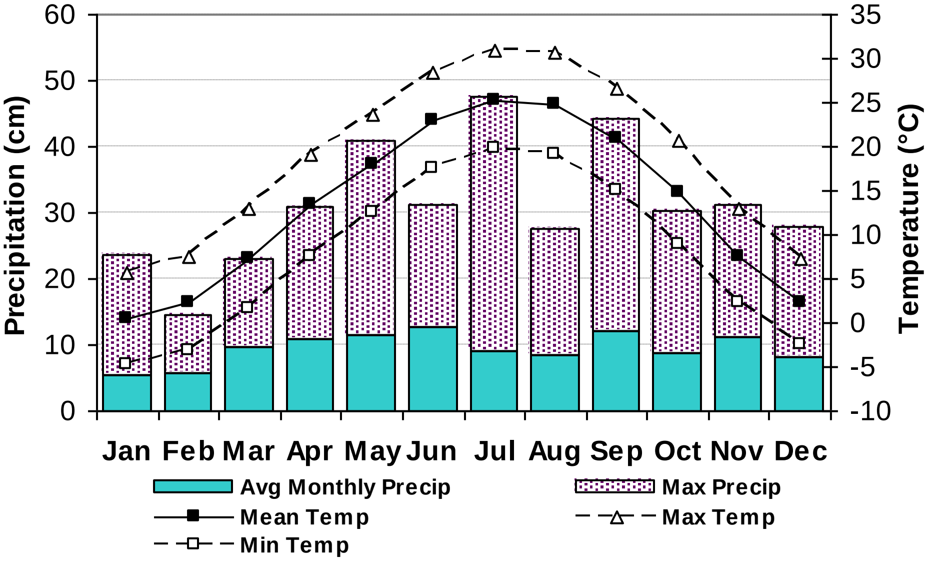


Figure 3.2: Springfield 30-year monthly average monthly rainfall totals 1971-2000, daily maximum rainfall per month and Average monthly temperature and range (from NCDC)

Karst Hydrology

Springs and Sinkholes. According to maps produced by the Missouri Department of Natural Resources Geologic Survey and Resource assessment Division the study area features 10 named and 2 un-named springs as well as 138 mapped sinkholes (MoDNR GSRAD, 2002 and 2004). The highest concentration of sinkholes is in the eastern portion of the study area and several of these have been linked to discharge areas in a separate drainage farther to the east (Fig. 3.3)

Losing or Gaining Streams. Several reaches of Jordan Creek within the study area appear to have anomalously low discharges compared to reaches immediately upstream or downstream and conversely, other reaches appear to have much better flow than others nearby. Karst drainage can produce these and similar phenomena by capturing stream flow at “swallow holes” or by springs discharging into the stream (Fig. 3.5). For this reason the hydrology and water quality of the study area may not be as dependent on watershed area and surface characteristics as would be the case in a non-karst area.

James River Watershed. The study watershed constitutes a headwater source area of Wilson Creek, a major tributary of the James River. Both Wilson Creek (below the Southwest Waste Water Treatment Plant) and the James River are on the EPA’s 303D list for impaired waterways due to nutrient concentrations as is the local base level Table Rock Lake (MoDNR, 2002). Understanding the nutrient contribution of Jordan Creek, and indirectly of the Springfield urban area, is important for managing nutrient concentrations in those streams.

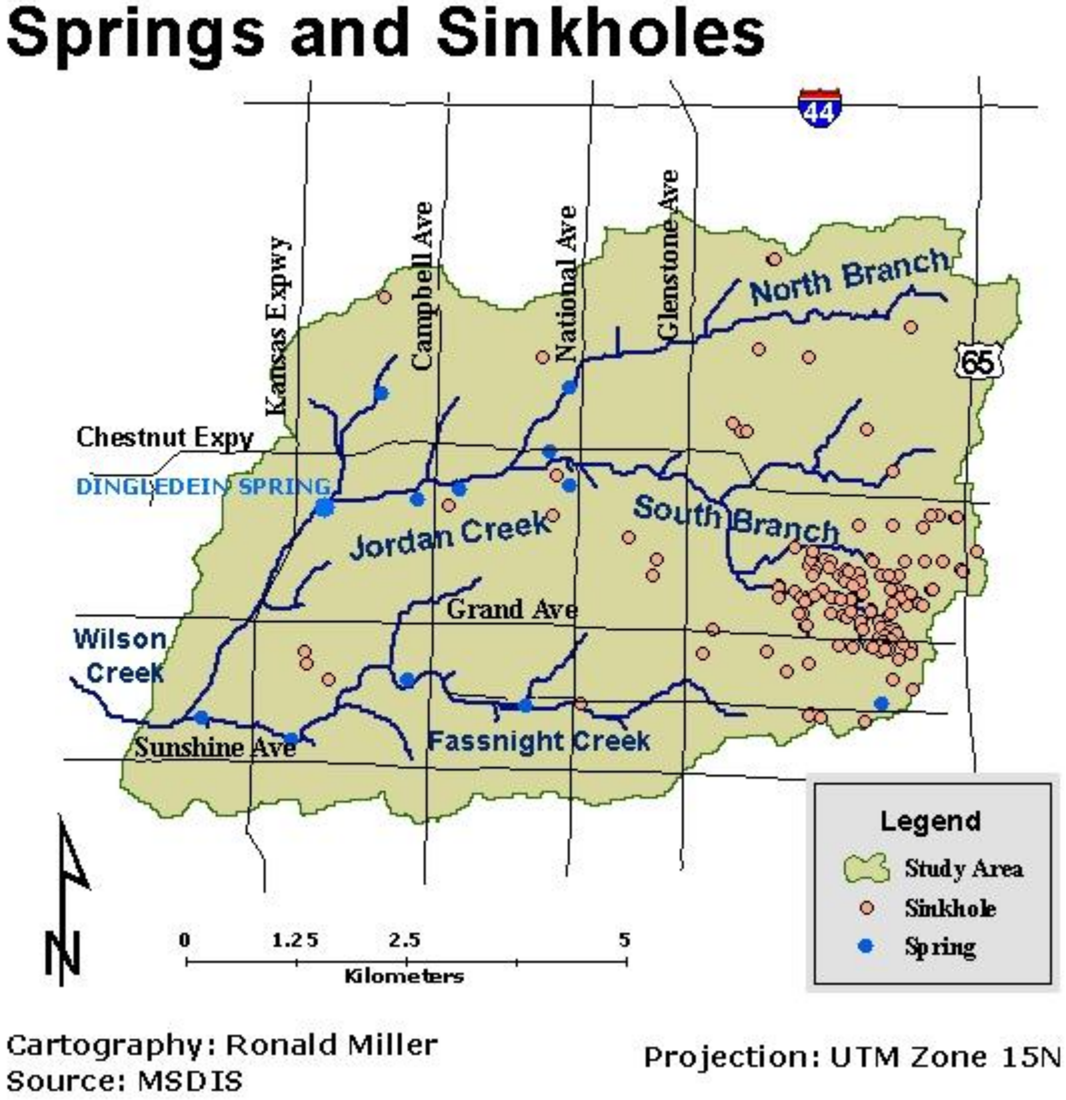

Springs and Sinkholes
44
65
Kansas Expwy
Campbell Ave
National Ave
Glenstone Ave
North Branch
Chestnut Expy
DINGLEDEIN SPRING
Jordan Creek
South Branch
Grand Ave
Wilson Creek
Sunshine Ave
Fassnight Creek
Legend
Study Area
Sinkhole
Spring
N
0
1.25
2.5
5
Kilometers
Cartography: Ronald Miller
Source: MSDIS
Projection: UTM Zone 15N

Figure 3.3: Spring and sinkhole locations within the study area.

Land Use

Springfield Population and History of Urban Area. Springfield is the largest urban area in the Ozark region and the third-largest city in Missouri. The population is 151,580 within the city limits and 229,738 in the urban area (US Census, 2002). The urban area is a regional medical and educational center with two large medical groups offering hospital and medical specialty services (13 % employed) and more than three universities (9.2 % employed). Manufacturing has a small presence in Springfield with about 11 % employed based on the 2000 census. A landuse map prepared by the City of Springfield based on interpretation of 2001 air-photos shows the urban nature of the study watershed (Fig. 4.5) (City of Springfield, 2001). The Jordan Creek watercourse hosts the most concentrated commercial zone in the city, a fact that is likely to affect water quality in the stream itself.

History of Urban Growth. The town that was to become Springfield was established in 1829 alongside a perennial stream known as “Campbell’s Creek” as Jordan Creek was originally known (Bullard, 2000). According to Bullard, the town began to grow in the 1850’s when the Butterfield Overland Mail used the town as a stop on its route from Tipton, Missouri to San Francisco. As the town grew along the banks of the Jordan the occasional flooding became more and more disruptive for business and destructive for property. The flood of 1909 inspired thoughts of engineering the creek to control floodwaters, and in 1933-35 thoughts turned to action. Jordan Creek was channelized through downtown, from Main Street to Washington (3,520 feet), with two parallel boxes eleven feet wide and ten feet tall and a concrete “lid”. Many people cross over Jordan Creek in this area and never know it is there. The urbanization of the stream also included box sections without “lids” for sections on the north and south branches, rip-rapped banks on other sections, and throughout the watershed, encased springs outflows and street runoff directed into storm drains discharging into the creek.

The creek is currently subject of study by the USACE and the City of Springfield for feasibility for re-engineering directed at better handling of stormwater and improving stream aesthetics. The research for this thesis is intended to help support this study by providing water quality and spatial analysis for the current state of Jordan Creek.

Study Area Hydrology

The USGS Gage 07052000, located on the Scenic Ave bridge over Wilson Creek, has flow records for the study area (USGS [1]). The gage was in operation from 1933 to 1939 and then from 1999 to the present. The supervising USGS hydrologist for the gage provided flow statistics even though this period of record contains less than the 30 years of flow data necessary to create a statistically valid flow duration table (Wilson, 2005). The records provided contain the total number of average daily flows for each year of record for 35 flow intervals from 0.81 to 2060 cubic feet per second (cfs) and were used to prepare a flow duration graph (Fig. 3.4). The entire table is included in Appendix G. The flow duration graph shows the estimated percentage of total time per year that a particular discharge will be exceeded, with the smallest flows having the largest and the largest flows having the lowest “exceedance” values. The probable median flow is 0.25 m^3/s (8.8 cfs), meaning that half of the time this flow will be exceeded.

As noted above, the duration graph for USGS Gage 07052000 is a compilation of the number of days per year with average discharge within each of a continuous set of

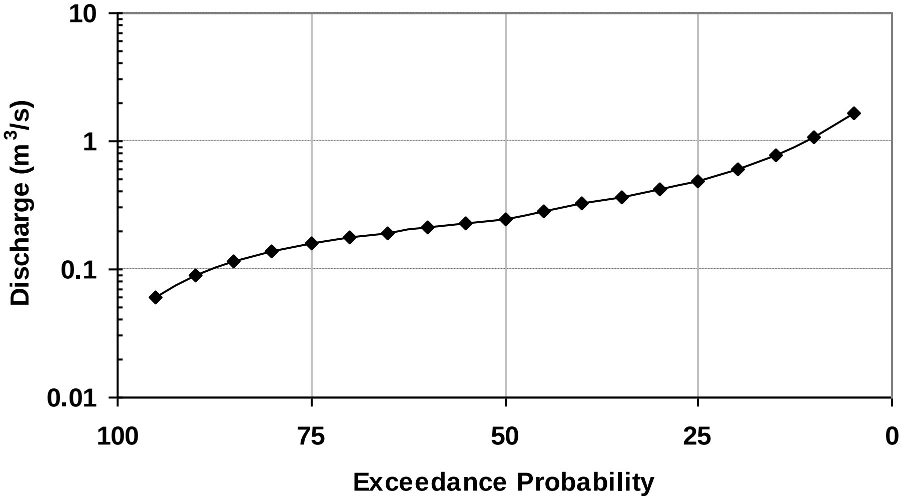


Figure 3.4: Daily average flow exceedance for USGS Gage 07052000 “Wilson Creek at Scenic.” Based on 13 years of average daily discharge records.

ranges. The gage record happens to be discontinuous with one set of values from the 1930’s and the other from 1999 – 2004 (App. G).

The two subsets of records appear to be quite different, with the 1930’s having more flows near the median and fewer extremely low and extremely high flows. It is common in streams that have undergone urbanization to see changes in flow regime including more extremely high flows as precipitation runs quickly off of impervious surfaces and more extremely low flows as less water infiltrates into the ground to enter the stream slowly as groundwater (Hollis, 1988; Schueler and Holland, 2000). Flow duration graphs for each subset were prepared and the difference in between the curves could be a sign that this process has occurred in Jordan Creek (Fig. 3.5). The duration curve for the 1999 – 2004 period contains most of the very high flows as well as most of the very low flows. The median daily discharge for the entire record is 0.25 m^3/s and the mean is 0.47 m^3/s, for the 1934 - 1939 the median discharge is 0.31 m^3/s and the mean 0.49 m^3/s and for 1999 – 2004 the median is 0.17 m^3/s and the mean 0.42 m^3/s. The annual precipitation average for the 1930's period of record is 96 cm and for the 1999 – 2004 period is 104 cm (NCDC). The monthly distributions of precipitation for the two periods are similar enough that the duration curve difference does not appear to be due to differences in precipitation over those periods (Fig. 3.6).

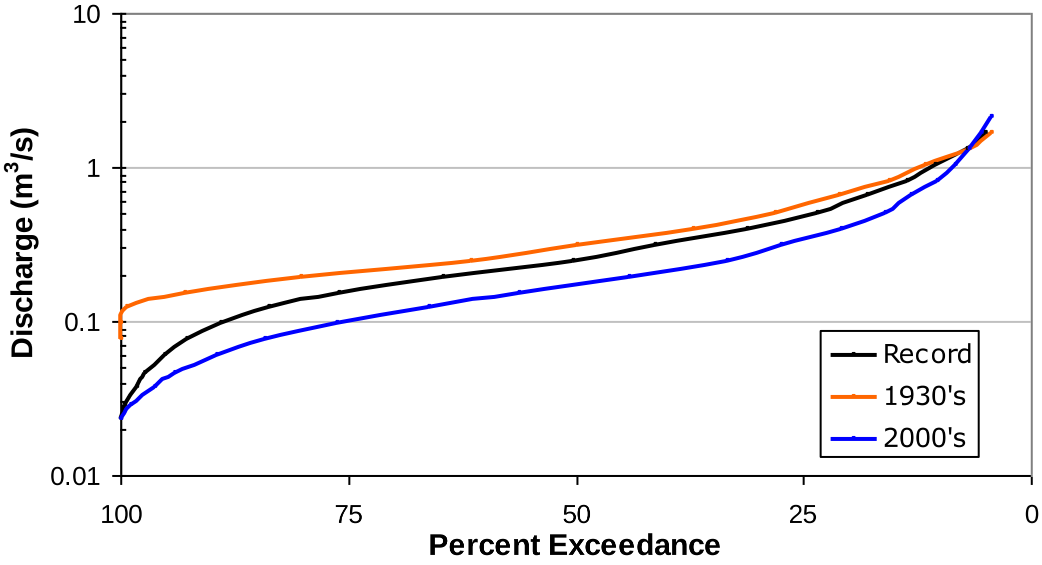


Figure 3.5: Comparison of flow duration graph for USGS Gage 07052000 to subsets of flows from 1930's and 2000's (Wilson, 2005).

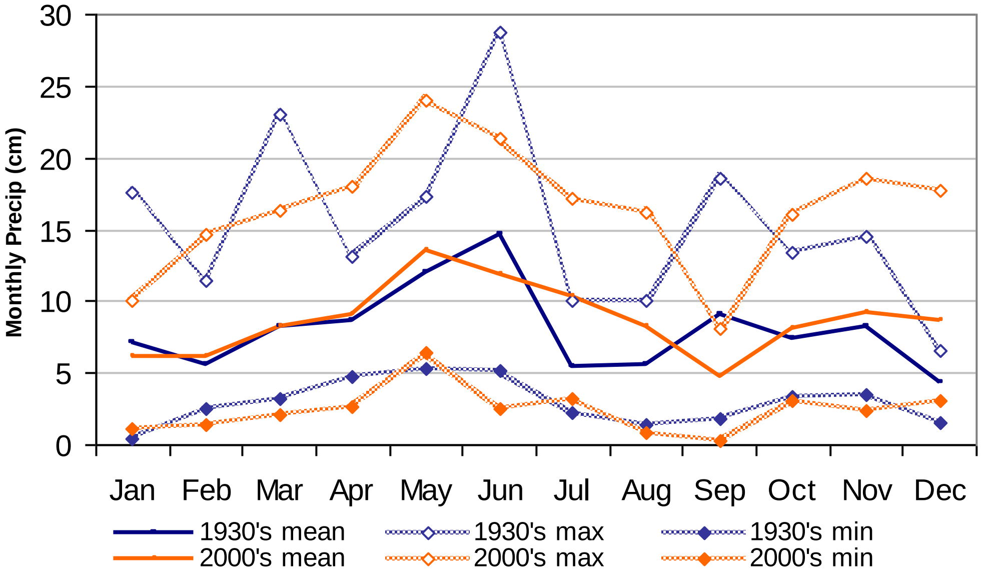


Figure 3.6: Maximum, minimum and mean monthly rainfall totals for 1934 – 1939 and 1999 – 2004 (NCDC).

CHAPTER 4

METHODS

Sampling Design

The study area consists of the Jordan Creek and Fassnight Creek watersheds and the upper portion of the Wilson Creek watershed. The study is intended to calculate annual loads of TP, TN and selected metals from the study area, and in addition, it will attempt to quantify the discharge concentration relationships and identify spatial patterns of concentration and load, and identify sources within the study area. Instantaneous estimates will be made by measuring concentrations of these pollutants in grab samples and simultaneously measuring discharge. These instantaneous estimates will be compiled into rating curves that correlate of concentration and load with discharge. The concentrations of these pollutants may possibly vary seasonally and with discharge and therefore sampling will occur over the period of a year and will attempt to collect approximately equal numbers of both storm and base samples with at least two samples collected each month.

Sample Site Distribution. Ten sample sites were established within the study area. These sites were placed to sample water quality within the downtown core area and also sites upstream and downstream of the downtown area and allow comparisons to be made between the sites and their watershed source areas (Fig. 4.1). Each sample site is located at a bridge over-crossing and sites are labeled according to stream segment and (if necessary) numbered by series in upstream to downstream order. WC1 is the site farthest

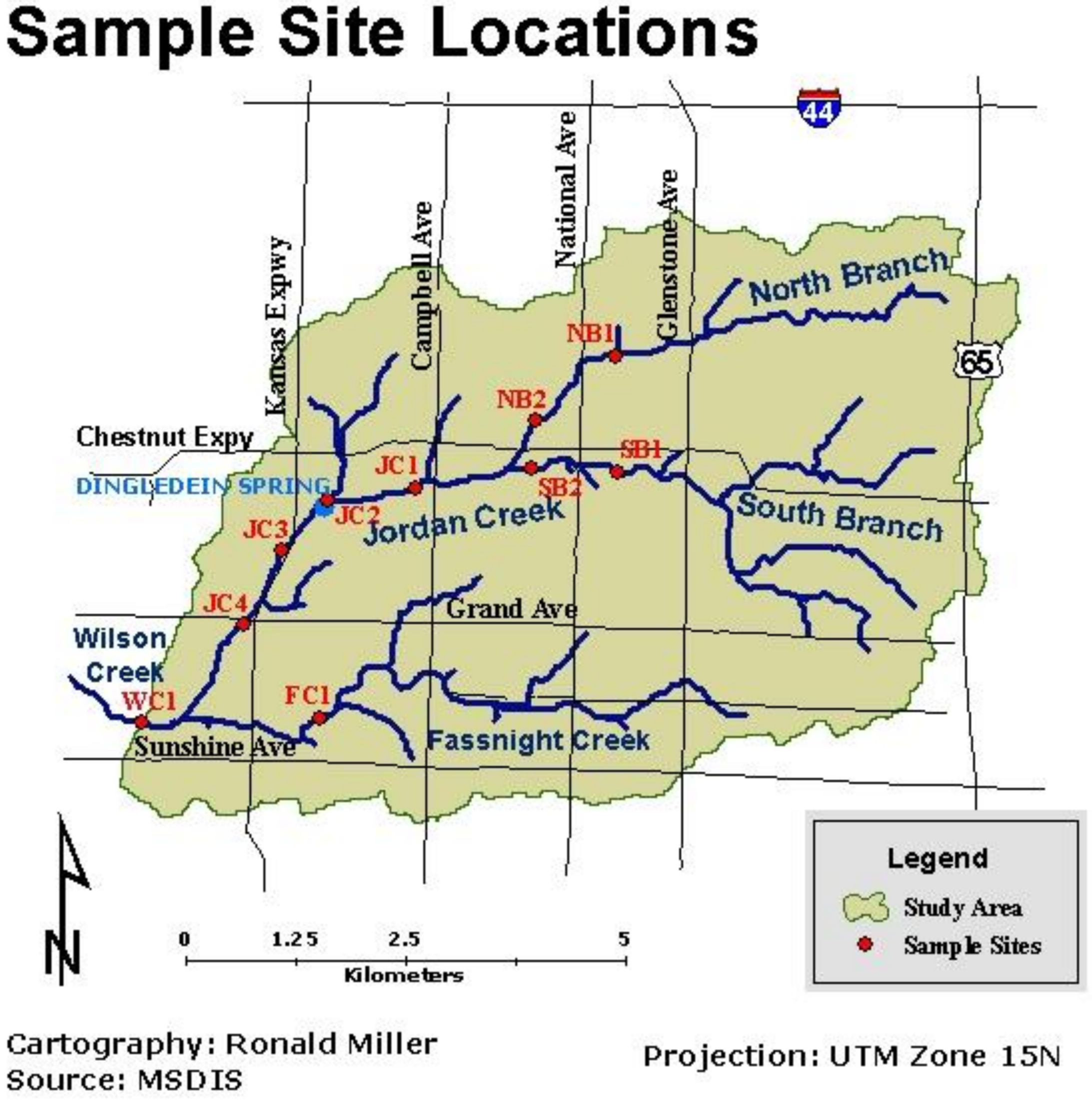

Sample Site Locations
44
National Ave
Glenstone Ave
Campbell Ave
Kansas Expwy
North Branch
65
NB1
NB2
Chestnut Expy
JC1
SB1
SB2
DINGLEDEIN SPRING
JC2
Jordan Creek
South Branch
JC3
JC4
Grand Ave
Wilson Creek
WC1
FC1
Sunshine Ave
Fassnight Creek
Legend
Study Area
Sample Sites
0
1.25
2.5
5
Kilometers
N
Cartography: Ronald Miller
Source: MSDIS
Projection: UTM Zone 15N

Figure 4.1: Distribution of sample site locations throughout study watershed

Table 4.1: Sample site descriptions and river distances between sites

	Name	Description	Lat	Lon
Jordan Creek	NB1	North Branch at Smith Park	37.224925	-93.270428
	NB2	North Branch at OTC	37.218053	-93.281162
	SB1	South Branch at Fremont Ave	37.212507	-93.270761
	SB2	South Branch at Harry Cooper Supply	37.212641	-93.281854
	JC1	Main Ave bridge	37.210801	-93.296660
	JC2	Fort Ave bridge	37.209551	-93.307813
	JC3	Mt. Vernon bridge near Kansas Expwy	37.204535	-93.314170
	JC4	Grand Ave bridge near Kansas Expwy	37.197052	-93.318874
Other	FC1	Fassnight Creek at Fort Ave	37.187358	-93.308655
	WC1	Wilson Creek at Scenic (USGS gage)	37.186875	-93.331491

Segment	River Distance (km)[1]	Slope[1]
JC4 - WC1	1.8	0.003
JC3 - JC4	1.0	0.003
JC2 - JC3	0.8	0.005
JC1 - JC2	1.0	0.004
SB2 - JC1	1.4	0.003
SB1 - SB2	1.1	0.005
NB2 - JC1	1.8	0.004
NB1 - NB2	1.3	0.004
FC1 - WC1	2.3	0.004
North/South Confluence - WC1	5.8	
South Headwater - WC1	8.1	
North Headwater - WC1	11.7	
Fassnight Headwater - WC1	12.0	

[1] Distances and slopes measured using Arc Map

downstream and is also co-located with USGS Gage 07052000. The USGS offers instantaneous and historical discharge data from this site which allows better control of discharges and thus better load and yield estimates than will be produced from the other sites (USGS [1]). The sample site on Fassnight Creek (FC1) provides concentration and load estimates for the other watersheds contributing to WC1 and is an urban watershed that is independent of the dense downtown commercial district. The watershed study area extends about 12 km from the North Branch headwaters and 11.7 km from the South Branch headwaters to the WC1 sample site (Table 2). The Fassnight Creek extends 8.1

km from headwaters to WC1. Maps of the watershed area and pictures of each sample site are included in Appendix A.

Sample Site Mapping. Each sample site was spatially located by collecting a Global Positioning System (GPS) point using a *Garmin Etrex Legend*®. The latitude and longitude (in decimal degrees) was down-loaded as a text file, projected into UTM Zone 15N, NAD 87, and added to the study area map (Table 4.1). These locations were used when placing the sample sites in a Geographic Information System (GIS).

Site Surveys. Each sample site was surveyed using an auto-level. The surveys included a cross-section extending through the staff gage and a longitudinal profile of the stream thalweg from the upstream riffle crest through the sample site cross-section to the downstream riffle crest. The sample sites were placed at bridges over the channel and thus generally did not feature natural stream characteristics such as bankfull or low- or high terraces. Instead the cross-sections generally measured box height and central pier width and the stream bed geometry in between. The cross-sectional surveys also established the staff-gage position in relation to these measurements. The cross-section was most useful for determining the wetted area for a given staff-gage reading. Water levels on the staff gages were recorded at each time a sample was taken. At some sites (JC1, SB2, FC1) the staff gages were normally dry during low flows. For these sites, low flow gaging was measured at a prescribed location marking the deepest part of the channel and that reading and sample location was recorded at the sampling time. Care was taken to include the elevation of that alternate gage site in the cross-sectional survey.

Cross-Section Area Calculations. Data from site surveys were entered into Excel® and projected as a scatterplot with elevation (in meters) on the Y axis and cross-section distance (in meters) on the X axis. The location and elevation of the base of the staff gage and any other alternate gaging locations were noted on the diagram. The diagrams were used to calculate cross-sectional area for recorded staff gage readings in the following manner:

1. A horizontal line was plotted on the diagram at the elevation of the given staff gage reading

2. The length of the horizontal line was measured with a ruler and converted to meters by using a proportion of a measurement of 1 meter measures on the same axis

$$\frac{x}{a} = \frac{c}{b} \tag{1}$$

Where:

x = water width in meters
a = water width in cm
c = 1 meter on parallel axis
b = 1 meter on axis measured in cm

3. The line length was divided by 9 to create 10 measurement increments (including line origin)

4. Water depth at each increment calculated above was measured with a ruler and converted to meters by using a proportion as above

5. All ten depth measurements were averaged to determine average depth of cross-section.

6. Cross-sectional area was calculated by multiplying water width by average depth.

$$A_c = w \times \bar{d}$$

Where:

A_c = Cross-sectional area (m^2) (2)

w = water width (m)

$\bar{d}$ = average water depth (m)

Watershed Mapping. To determine yields it was important to determine the watershed area contributing to each sample site. This was achieved by processing a 30-m Digital Elevation Model (DEM) clipped from the National Elevation Dataset (NED) using the ArcHydro extension of ArcGIS 9 (Copyright 1999-2004 ESRI, Inc.). All DEMS and other datasets used in mapping were re-projected (if necessary) into UTM Zone 15 (NAD 83). ArcHydro uses automated routines to condition the DEM raster so that it can be used to determine stream locations and watershed boundaries (Maidment, 2002). After the DEM has been conditioned, the ArcHydro tool “Point Delineation” was used to determine the area of the subwatershed contributing to each sample point. The sample point “WC1” is located at the USGS Gage 07052000 and thus the area reported for the gage in the published site description could be used as a validation for the mapping process. The watershed area produced by ArcHydro for this study is 50.2 km^2 (19.4 mi^2) and is within 10% of the 46.1 km^2 (17.8 mi^2) area published in the gage website for the watershed (USGS[1]). However, a recent USGS Water Investigations Report reported the watershed area for USGS Gage 07052000 Wilson Creek at Springfield as 19.4 mi^2, so it is possible the reported area for the official USGS gage website is outdated (Richards and Johnson, 2002).

Discharge

Flow Velocity Gaging with Velocity Meter. Discharge was generally gaged with a *Global Water FP 201* velocity meter set in velocity-averaging mode. Sample sites are located at bridge crossings of Jordan, Fassnight or Wilson Creeks and during event flows, the velocity was measured from the bridges, while at baseflow, velocity was measured from within the stream. Velocities from the *Global Water* meter are reported in *ft/sec* to the nearest 0.01 (Global Water, 1997 [1]). After setting the readout to zero, the meter was moved from bank to bank at a steady rate at approximately 0.6 of water depth and the resulting average velocity value recorded in the field book. Measurements were repeated three or four times and each value recorded for later averaging. Measurements were converted to *m/sec* using the formula:

$$V_{m/s} = \left(\sum V_{f/s} \big/ n \right) * c \tag{3}$$

Where:

$V_{m/s}$ = Velocity in meters per second
$V_{f/s}$ = Velocity in feet per second
n = number of velocity measurements
c = conversion feet to meters (0.3048)

Alternate Site Flow Velocity Gaging. During baseflow periods, the stream velocity at the sample site was often too low (due to wide cross-section) to measure and thus an alternate site was used. The alternate sites were selected using the following criteria: proximity to actual sample site, converging flow, and lack of obstacles protruding through the water. Each time a velocity measurement was taken from an alternate site, width and average depth were measured for that location in addition to the normal staff gage readings from the sample site. In that way that low flow discharges could be calculated and correlated with the site staff gage readings. Alternate sites were not surveyed as described above for staff – gaged sites.

Flow Velocity Gaging with Float. Some low flows were insufficient to measure with the *Global Water* meter, usually because the propeller could not be completely immersed. In these cases estimates were made using a timed float test along a measured length (usually 1-2 m) of straight channel length. The float method is modified from the USGS method for high flows, which is assumed to be accurate to within 10% of actual average velocity (Rantz, 1982). For the study, a straight reach was marked and measured (usually 1-2 meters) and the passage time for three or four “floats” (usually consisting of native objects were recorded along with the average depth and width of the channel (meters) at that point. Care was taken to assure that the “float” was timed while in the thalweg or zone of fastest flow.

$$V_{m/s} = \left(\frac{\sum \frac{d}{t}}{n} \right) * c \tag{4}$$

Where:

$V_{m/s}$ = Velocity (m/s)
d = float distance (m)
t = float time (sec)
n = number of tests
c = average velocity constant (0.8)

The times were later averaged and divided as a ratio (if necessary) into float distance to produce velocity in meters per second and this result was then multiplied by a factor of 0.8 to account for reduced flow velocities at the channel perimeter and produce average velocity. The 0.85 factor from Rantz (1982) was reduced to account for the greater influence of surface roughness at low discharges. That final value was multiplied by the measured cross-sectional area to produce the discharge at time of sample.

USGS Real-Time Discharge Data. Site WC1 is located at USGS Gage 07052000 “Wilson Creek at Springfield” which is equipped with real-time telemetry for discharge data with data delivered every 15 minutes (USGS [1]). Discharge gaging at this site consisted of downloading the real-time flow data and selecting the discharge most closely matching the sample time. Data from this gage also provided information about precipitation, antecedent conditions, daily-average and flow-frequency for the study area.

Discharge Calculations. For each remaining sample time and site, cross-sectional area was multiplied times flow velocity to calculate discharge. Each calculated discharge was classified as either a baseflow or storm sample depending on the conditions at the time of sampling.

$$Q = V_{m/s} * A_c \tag{5}$$

Where:

Q = discharge (m^3/sec)
$V_{m/s}$ = flow velocity (m/s)
A_s = cross-sectional area (m^2)

Discharge Rating Curves. Data from velocity measurements and stage readings were combined to create a rating curve for each site in the following way. For each sample date, stage (in meters from staff-gage reading) was plotted against discharge to produce a discharge rating curve. A second-order curve was fitted to the resulting distribution with correlation coefficients (R^2) ranging from 0.997 (NB1) to 0.936 (JC4). The curve formulae were then used to estimate discharge from stage measurements alone. The flows sampled during the study were clustered at either the low or the high end of the range leaving a range of discharge values unsampled. However, since the flows sampled seemed to fit well onto the calculated curves this did not appear to be a severe defect.

Water Sampling

Water Chemistry. Water chemistry parameters were collected at each sample time with a *Horiba U-22XD Multi-parameter* water quality meter (Horiba, 2001). Parameters measured include pH, Specific Conductance (mS/cm), Turbidity (NTU), Temperature (˚C), Dissolved Oxygen (mg/L) and sample time and day (Table 4.2). The

Table 4.2: Horiba U-22XD parameter measurement range and accuracy[1]

Parameter	Range	Accuracy	Method
pH	0-14	± 0.1	Glass Electrode
DO	0-19.99 mg/L	± 0.2 mg/L	Diaphragm Galvanic Battery
SC	0-9990 mS/cm	± 3 %	4 AC Electrode
TURB	0-800 NTU	± 5 %	Penetration and Scattering
TEMP	0-55 ˚C	± 1.0 ˚C	Thermistor

[1](Horiba, 2001)

procedure entailed placing the sensor into the stream at the sample site taking care to ensure that free-flowing water from the stream was able to move freely over the sensor. The sensor readings were allowed to stabilize before collecting the reading (usually 3-5 minutes). After sampling, readings were downloading into a spreadsheet and Site and Stage information added. Instrument accuracy was maintained by using the auto-calibration procedure before each sample run and by re-conditioning and manually calibrating each sensor every few months.

Grab Samples. Water samples were collected at each site at each sample time in 500 ml polyethylene bottles using one of two methods. In addition, each sample run was classified as either "baseflow" or "storm" depending on the general runoff conditions (i.e. the continuing presence of rain during the sample period). Baseflow samples or any samples collected when the stream could be safely entered on foot, consisted of grab samples: bottles and lids were rinsed three times in free-flowing stream water and then a sample was collected by inverting the bottle to approximately 0.6 of depth and then turning up the opening to allow water to enter while sweeping the bottle across the stream width to achieve an integrated flow sample. Care was taken to insure that bottom sediment was not disturbed by sampling activity: the bottle was not allowed to contact the bottom, and sampling occurred upstream of the technician and upstream of or previous to other data-gathering activities.

Integrated Depth Sampler. A DH-48 hand-held depth-integrated sampler was used when entering the stream was unsafe. The DH-48 is designed to collect suspended sediment samples in a controlled and repeatable manner from a depth-wise cross-section of a stream. Filling time of the sample bottle is directly related to stream velocity and an artificially concentrated suspended sediment sample can be created if the bottle is overfilled and water allow to cycle through the container (FISP). This unit, with handle extensions, was deployed from bridges in the following way: a bottle was attached to the sampler and immersed in the water (to as close to 0.6 of depth as possible) and swept across the stream width to collect a cross-sectionally integrated flow sample. Care was taken to avoid disturbing bottom sediment with the sampler and to avoid overfilling the sample bottle. The shallow water predominant in Jordan Creek generally does not permit use of the DH-48 at base-flow conditions.

Quality Control. To help evaluate data quality, a field duplicate sample and a field blank were collected at each sample time. The duplicate sample was assigned randomly to a sample site. Blanks consisted of de-ionized (DI) water collected in a 500 ml sample bottle. Once prepared, all QC samples were treated and processed in the same manner and at the same time as actual field samples. All samples, including blanks and duplicates, were acidified with H_2SO_4 in the field to less than pH 2 to stop all biological processes and preserve metal and nutrient concentrations, and then stored on ice in a cooler while in the field. In the lab all samples were stored in a refrigerator at 20° C until analyzed.

Laboratory Analyses

Water samples were analyzed in the MSU laboratory for concentrations of TP, TN and the metals arsenic, copper, lead, zinc and cadmium. The analytical methods for this project were developed and adapted by Mary Krause and they are described in detail in her thesis (Krause, 2005). Method descriptions below are from that thesis.

Total Phosphorus. The method used to measure total phosphorus is based on converting all forms of phosphorus to orthophosphate by an acid-persulfate digestion process described in EPA method 365.2 (JC-V1, 2004). The detection limit is 0.01 mg TP/L, and the applicable range is 0.01 mg TP/L to 0.5 mg TP/L. The EPA states that changes may be made to their methods as long as results are demonstrated to be the same. Variations from EPA Method 365.2 include reducing the sample size from 50 milliliters to 10 milliliters and reducing the volume of reagents accordingly.

A “combined reagent”, containing ammonium molybdate and antimony potassium tartrate in ascetic acid is added to the digested sample which produces a deep blue antimony-phospho-molybdate complex. The concentration of phosphorus is proportional to the intensity of the blue and is measured by plotting the spectrographic absorbance of each sample at 880 nm on a curve made up of known concentrations and measured absorbances (Krause, 2005).

Total Nitrogen. The method used to measure total nitrogen is based on the oxidation of all nitrogen-containing compounds to nitrate followed by second derivative spectrophotometric analysis as described in Crumpton et. al. (1992). The EPA states that methods may be adjusted as long as results are the same, so some adjustments have been made to the method (TN-JC-1, 2004). Variations from the method include using a 1 cm cell instead of a 5 cm cell. The desired sensitivity is still achieved, and the process is streamlined. Four reagent blanks are used instead of one, which improves the calibration at low concentrations. In addition, urea is used instead of glutamic acid for the source of organic nitrogen. Concentration in samples are made on a UV/Visible spectrometer by measuring the transmittance at 220, 225 and 230 nm and comparing that value to a second order calibration plot created by known standards. Second order calibration is used rather than a linear plot since the transmittance values over the range of 0 to 5.0 mg/L is slightly curved (Krause, 2005). The detection limit for the method is 0.1 mg TN/L, and the applicable range is from 0.1 mg TN/L to 5 mg TN/L.

Metals. Inductively coupled plasma-atomic emission spectroscopy (ICP-AES) was the method used to analyze for arsenic, cadmium, zinc, copper, and lead. Samples were prepared by microwave – assisted acid digestion to ensure that all adsorbed metals were dissolved before analysis (USEPA, 1998). One standard of 1.25 mg/L arsenic, 1.25 mg/L copper, 1.25 mg/L cadmium, 1.25 mg/L lead, and 5.00 mg/L zinc was prepared in nitric acid, which provided the same matrix as the samples. A blank was also acidified, and a control check of 0.625 mg/L arsenic, 0.625 mg/L cadmium, 0.625 mg/L copper, 0.625 mg/L lead, and 2.25 mg/L zinc was prepared to verify the accuracy of the ICP-AES internal calibration plot. A Varian Liberty 150 AX Turbo ICP Emission Spectrometer was used for analysis of all samples. The ICP-AES was calibrated by running the standard and blank. After running the standard and blank, the blank was run as a sample and the control check was run to verify accurate calibration. The samples were then analyzed, running both the blank and the control check after every five samples to avoid any drift that may occur. More information about this method can be found in Krause

(2005). Detection limits for each metal were calculated by determining the standard deviation of several blank readings and multiplying this value by three (Table 4.3). The ICP-AES will report concentrations below the element detection limit, but those values have too much variance to be
accepted as valid concentrations. Several sample runs were tested for Arsenic using Hydride Generation Atomic Absorption Spectroscopy method which has a much lower detection limit (~0.005 mg/L) (Krause, 2005).

Load and Yield Calculations

The load of a particular constituent is based on its concentration and estimated volume of discharge and is reported as mass over time. The yield of a constituent is its load normalized by watershed area at the sampling point. The period of interest here is the year-long period of the study and thus annual loads are to be calculated. Because concentration is found to vary with discharge, to accurately model load one must be able to determine the frequency of flows over the desired period. For this study, the flows at the site at USGS Gage 07052000 have the most complete record and thus the most accurate load/yield calculations are for this site. Three different

Table 4.3: Calculated ICP-AES detection limit and EPA MCL for drinking water (EPA, 2004).

Element	Detection Limit (mg/L)	EPA MCL (mg/L)
Arsenic[1]	0.32	0.01
Arsenic[2]	~0.005	
Copper	0.041	1.3
Zinc	0.01	5.0
Lead[1]	0.016	0.015
Cadmium	0.0018	0.005

[1] Detection Limit above EPA MCL

[2] Hydride Generation Atomic Absorption Spectroscopy

load/yield calculations were made for this site. Estimates of median, 10% exceedence and 1-yr flood flows were created for the other sites based on flow and watershed modeling and used for intra-site comparisons.

Daily Load Calculation. Sample concentrations for each nutrient (TN and TP) were used with the corresponding sample discharge to create a daily loading curve.

$$L_d = C * Q * c_t \tag{6}$$

Where:

L_d = Daily load (kg/day)
C = concentration (mg/L)
Q = discharge (m^3/sec)
C_t= mass/time/volume conversion constant (86.4)

The resulting daily loads were log-plotted against discharge to create a load rating curve with the form:

$$L_d = b_0 * Q^{b_1} \tag{7}$$

Where:

L_d = Daily Load (kg/day)
Q = Discharge (m^3/sec)

Curves were created for each sample site and these daily load curve equations were used to estimate constituent load in several different ways. The baseflow and storm event curves generally seemed to have different slopes and intercepts and thus a separate load curve was developed for baseflow and storm flow at each site and for each nutrient. Base and storm flows were originally designated in the field by antecedent conditions and then confirmed by examining the discharge record at the USGS Gage at Scenic Ave. Seasonal flow variations and the sample timing effect on the storm hydrograph create a situation where some measured baseflow discharges may be higher than some storm discharges at some sites.

Flow Frequency-based Annual Load Calculation. The WC1 sample site is located at USGS Gage 07052000. The gage is maintained by the USGS hydrology office in Rolla, Missouri with financial support from the City of Springfield, Missouri. Data available from the gage include real-time gage height, discharge and precipitation, daily average discharge and gage height, and yearly peak flows. Historical records for the gage exist for the years 1933-1939 and 1999-present. Based on this historical data the USGS provided a flow-frequency analysis for the gage, with the caveat that the values may not be statistically significant since there are less than 30 years of record (Wilson, 2005). The flow-frequency chart (Fig. 4.2) consisted of the log of discharge (in cfs) and the percent of time that flow is exceeded. The nineteen flow exceedance values were converted to the endpoints of 20 probability bins by re-graphing the flow exceedance graph with percent exceedance as the predictor variable and then fitting a third-order curve to the data points. The curve formula was then used to estimate the log of

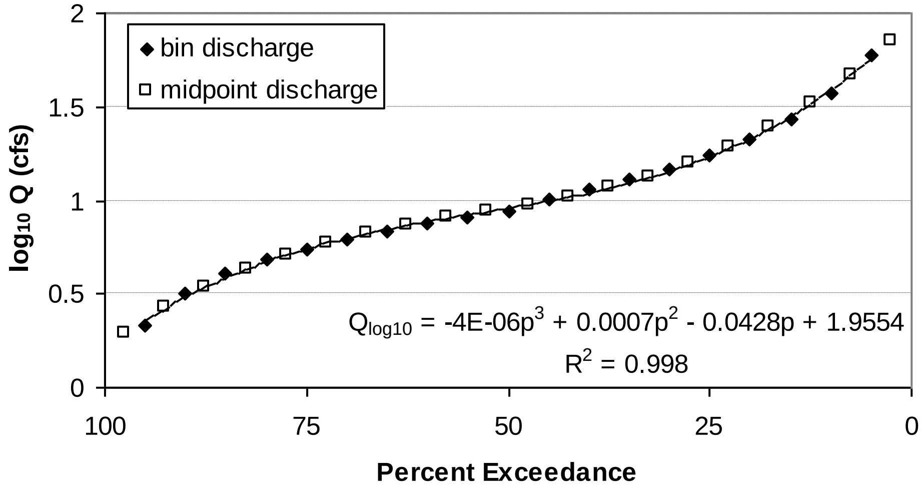


Figure 4.2: Percent exceedance of logged discharges at USGS Gage 07052000 “Wilson Creek at Scenic”, projected midpoint values and curve equation (Wilson, 2005).

discharge for each of the twenty bin midpoints. The midpoint log discharges were converted to actual discharge (m^3/sec), and those discharge values were used in the daily load formula for each nutrient and then divided by the probability of that discharge range occurring (1/20). The load proportions were summed to produce a probable daily load. When multiplied by 365, the estimate created by this method serves as a probable average annual load from the study area.

Convert to midpoint discharge:

$$Q_{mp} = 10^{\log_{10} Q_{cfs}} * c$$

Where:

Q_{mp} = midpoint discharge (m^3/sec) (8)

c = conversion constant ft^3 to m^3 (0.0283)

Calculate bin load:

$$L_b = \left| \begin{array}{l} Q_{mp} \leq t : b_0 Q_{base}^{b_1} \\ Q_{mp} > t : b_0 Q_{storm}^{b_1} \end{array} \right.$$

Where:

L_b = load for each bin discharge (kg/day) (9)

t = threshold discharge between baseflow and storm discharges

Base = formula for baseflow loads

Storm = formula for storm loads

Calculate probable annual load:

$$L_{pa} = \left(\sum_{i=1}^{1-20} L_i \big/ 20 \right) 365$$

Where:

L_{pa} = probable annual load (kg/y) (10)

L_i = bin load L_b (kg/day)

Average Daily Flow-based Load. An estimate of the load from the watershed for the period of the study was created using average daily flow data from the USGS Gage 07052000 (Wilson, 2005). The study period was 8/1/2004 to 8/1/2005, but average daily flow values were not available for the entire period because the gage was temporarily removed in order to allow construction of a bicycle path. The gage was out of service between 6/28/2005 and 7/6/2005, resumed collecting data until 7/15/2005 then again went offline until mid-September. To create a continuous string of average daily discharge values covering a time period as similar as possible to the actual study period I chose to work with the period 7/16/2004 to 7/15/2005 and to extrapolate values for the missing days in June and July. This was justified because the flows in question were mostly base flows. One day of rainfall did occur during this missing data period, according to the records from Springfield Regional Airport (SGF) (NCDC, 2005). The SGF rain gage is about 8 miles from the USGS gage at Scenic Ave and the storm-cell-dominated rainfall patterns during the summer season can create rainfall at one gage that is not detected at the other. My field records indicate that rainfall did occur within the watershed on about July 1, 2005 when a fairly significant rain event was recorded at SGF (17.8 mm).

A plot was created to relate rainfall at SGF to discharge at the Scenic gage and a curve fitted to the data (Fig. 4.3). The recorded rainfall at SGF for 7/1/2005 was used to estimate storm event discharge at the Scenic gage using the fitted curve. The other missing flows were assumed to be base flows and those values were estimated by fitting a curve to the daily average baseflow values before and after the missing interval excluding event flows (Table 4.4). The curve equation is:

$$\overline{Q} = 1.9886 \times 10^{-4} x^2 - 15.328x + 295374.6 \tag{11}$$

Where:

$\overline{Q}$ = Average daily discharge (m^3/sec)

x = *Excel*® numeric date code (between 38518 and 38550)

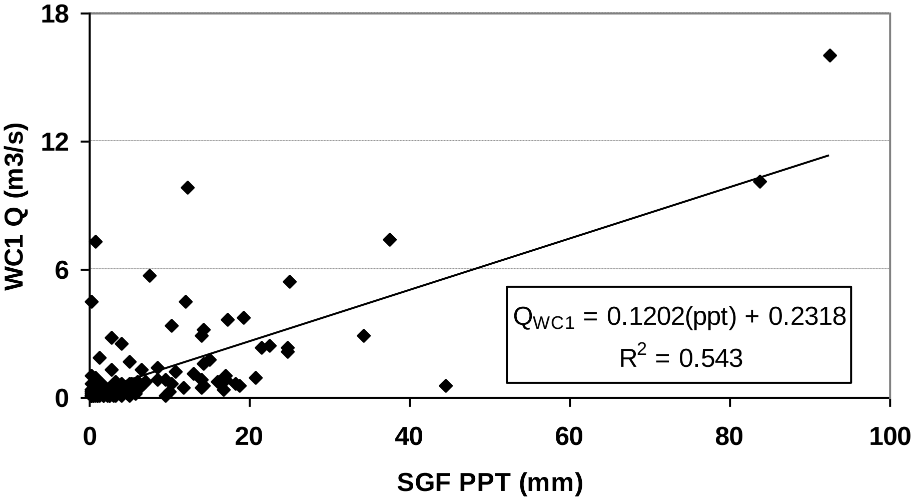


Figure 4.3: Data plot and curve for estimating average daily discharge for storm events at Site WC1 using rainfall events recorded at Springfield Airport (SGF).

Table 4.4: Estimated values for missing flow records

Date	Q (m^3/s)	Event
6/29/2005	0.06	Base
6/30/2005	0.06	Base
7/1/2005	2.37	Storm
7/2/2005	0.05	Base
7/3/2005	0.05	Base
7/4/2005	0.05	Base
7/5/2005	0.05	Base
7/6/2005	0.05	Base

The daily average discharges from the gage record and from the calculations above were used to calculate an estimation of the annual load for the study period.

$$L_{\overline{Q}} = \sum_{Q=i}^{1-365} \left(\begin{array}{l} Q_i \leq t : b_{0base} Q_i^{b_{base1}} \\ Qi > t : b_{0event} Q_i^{b_{1event}} \end{array} \right)$$

Where:

$L_{\overline{Q}}$ = Daily Average Discharge -based annual load (kg/y) (12)
Q_i = Daily average discharge (m^3/sec)
t = Threshold for dividing baseflow and storm discharges
b_0 and b_1 = Factors in load power equation for base or storm event flow

Due to removal and subsequent recalibration of the gage in June and July of 2005, the period 7/16/2004 to 7/15/2005 was the continuous period of record (including reconstructed discharges outlined above) from USGS gage 07052000 closest to the study period to the study period. This period was used to calculate average daily flow-based discharges.

Peak Daily Discharge-Based Annual Load. Another estimate of annual load, assumed to be a maximum estimate, was based on peak discharge data from the USGS gage. Real-time discharge records for the gage include discharge and gage height values taken every 15 minutes. The average daily record was analyzed and all days with average daily discharges greater than 0.75 m^3/sec were flagged and real-time data was acquired for these days (Wilson, 2005). There were 47 such days and the peak discharge from each of these days was recorded and used to replace the average daily value in the Average Daily Discharge record. The new daily discharge data was used as above to create an annual load estimate based on peak discharge values.

Inter-site Comparisons

Site WC1, located at the USGS Gage 07052000, had unique access to recorded real-time and historic discharges. The remaining sites had recorded discharges for each sample but no continuous record for the study period. These values served to create a load rating curve for each site but could not be used to create annual load or yield estimates. Furthermore, due to the nature of sampling during event flows, it was never known if the samples at all sites corresponded to the same point on the flood peak. This limited direct comparison of loads between sites. To compare loads and yields between sites using rating curves it was necessary to use modeled discharges for each site.

City of Springfield Flood Modeling. The City of Springfield Stormwater Services Department provided, for each sample site except WC1, modeled discharge values (ft^3/sec) for the 0.5, 1, 1.5, 2, 3 and 5-year rainfall events given 2, 3, 6, 12, 18 and 24 hour periods of accumulation (the exception being values for the WC1 2 hr accumulation) (Kemper, 2005) (App. D). The modeled discharge values were converted to m^3/sec by multiplying by 0.0283. The WC1 site 12 hr, 1-year event discharges were needed for comparison with the other sites, so the discharges were estimated by plotting the differences between the 2 hr and 12 hr discharges for each site against the drainage area for the site and fitting a curve to the data (Fig. 4.4). The WC1 1-year event discharges were then estimated by putting the WC1 drainage area (in hectares) into the curve equation and then adding the estimated negative discharge difference to the 2 hr, 1-year discharge value.

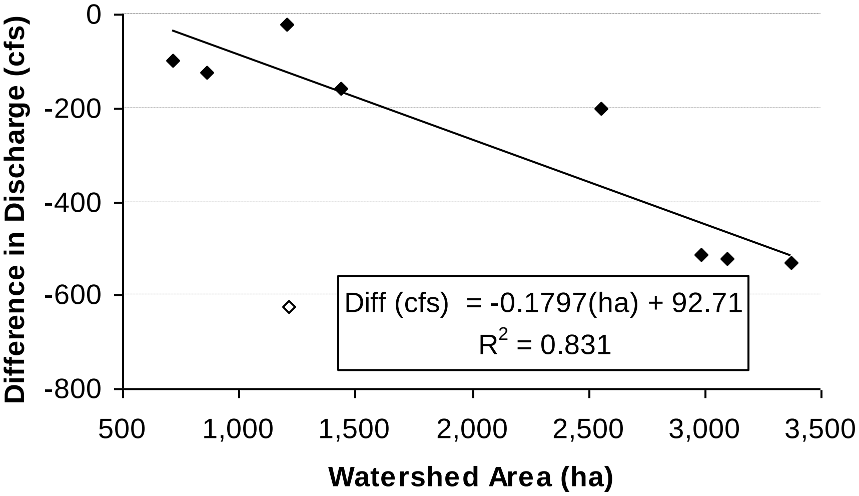


Figure 4.4: Curve and equation for estimating difference between 2 hr and 12 hr accumulations of 1 – year discharges by watershed area. Open diamond signifies data point (FC1) eliminated from analysis.

Land Use-based Load Estimate. In the Protocol for Developing Nutrient TMDLs (USEPA, 1999) the EPA recommends unit-loading rate "simple methods" calculations to estimate loads and yields to a receiving body of water, and offer loading ranges to use (Table 4.5). The study watershed was divided into sub-watersheds whose areas contributed to each sample site by using the Arc Hydro extension to Arc Map. A land use database provided by the City of Springfield (City of Springfield, 2001) was clipped using those sub-watersheds which gave a land use profile for each sub-watershed. The land use classification, based on interpretation of 2001 air photos, classifies areas to the level of the parcel. The City of Springfield classification includes 20 landuse category codes; however the EPA landuse-based yield has only eight categories. A matrix (Table 4.6) was devised to merge the city classification into the EPA classification. In its classification the City of Springfield left actual roadways (and only roadways) un-classified, so the difference between the watershed area and the clipped landuse classification area was assumed to be roadway area and was added to the EPA "Roadway" classification (Fig. 14). ArcMap was used to calculate the area of each landuse classification within each clipped polygon and these values were used with the load range values from Table 8 to produce percent area for each watershed (Table 4.7).

Table 4.5: EPA simple method for estimating typical Phosphorus and Nitrogen loading ranges for various land uses (USEPA, 1999). (After Horner *et al*, 1994)

	Total Phosphorus (kg/ha-y)			**Total Nitrogen (kg/ha-y)**		
Land Use	**Minimum**	**Median**	**Maximum**	**Minimum**	**Median**	**Maximum**
Roadway	0.59	1.10	1.50	1.3	2.4	3.5
Commercial	0.69	0.80	0.91	1.6	5.2	8.8
SF Low-Density	0.46	0.55	0.64	3.3	4.0	4.7
SF High-Density	0.54	0.65	0.76	4.0	5.8	5.6
Multi-family Res	0.59	0.70	0.81	4.7	5.6	6.6
Forest	0.1	0.11	0.13	1.1	2.0	2.8
Grass	0.01	0.13	0.25	1.2	4.2	7.1
Pasture	0.01	0.13	0.25	1.2	4.2	7.1

Table 4.6: 2001 Springfield Land-use to EPA simple method conversion matrix (City of Springfield, 2001).

City Land Use (LU_Code)	City Land Use Label	EPA Label
ROW	Right of Way	Roadway[1]
TCU	Transport, Communication	
ED	Education and Cultural	Commercial
GQ	Group Quarters	
HC	Heavy Commercial	
LC	Light Commercial	
MG	Manufacturing	
O	Office	
P	Public Building	
QP	Quasi-public (Church)	
WH	Warehouse and Storage	
H	Hospital	
X	Quarry and Mining	
1F	Single Family Residential	SF Low Density
MHP	Mobile-home Park	
2F	Duplex	SF High Density
MF	Multi-family	Multi-family Res.
V	Vacant and Forest	Forest
R	Parks and Recreation	Grass
A	Agriculture and Grazing	Pasture

[1] Also included as “Roadway” is the difference between classified area and watershed area.

Table 4.7: Percent land-use for sample site watersheds (from City of Springfield, 2001)

	NB1 %	**NB2 %**	**SB1 %**	**SB2 %**	**JC1 %**	**JC2 %**	**JC3 %**	**JC4 %**	**FC1 %**	**WC1 %**
Roadway	12.4	14.9	15.5	16.7	17.0	18.6	18.9	19.0	18.0	14.4
Commercial	41.5	37.1	33.6	34.3	37.5	36.3	36.6	34.5	25.8	37.1
SF Low-Density	22.2	25.4	29.3	28.6	25.3	26.3	26.2	27.7	43.7	30.8
SF High-Density	1.0	1.3	1.2	1.4	1.5	1.5	1.5	1.8	1.5	1.3
Multi-family Res	0.1	0.8	1.8	2.7	2.1	2.1	2.0	2.6	4.4	2.9
Forest	15.0	12.9	10.9	9.7	10.1	9.4	9.2	9.0	3.6	8.5
Grass	1.9	2.7	7.6	6.5	4.8	4.4	4.2	4.2	2.5	3.9
Pasture	5.9	4.9	0.1	0.1	1.7	1.4	1.4	1.3	0.5	1.2
Sum	100	100	100	100	100	100	100	100	100	100

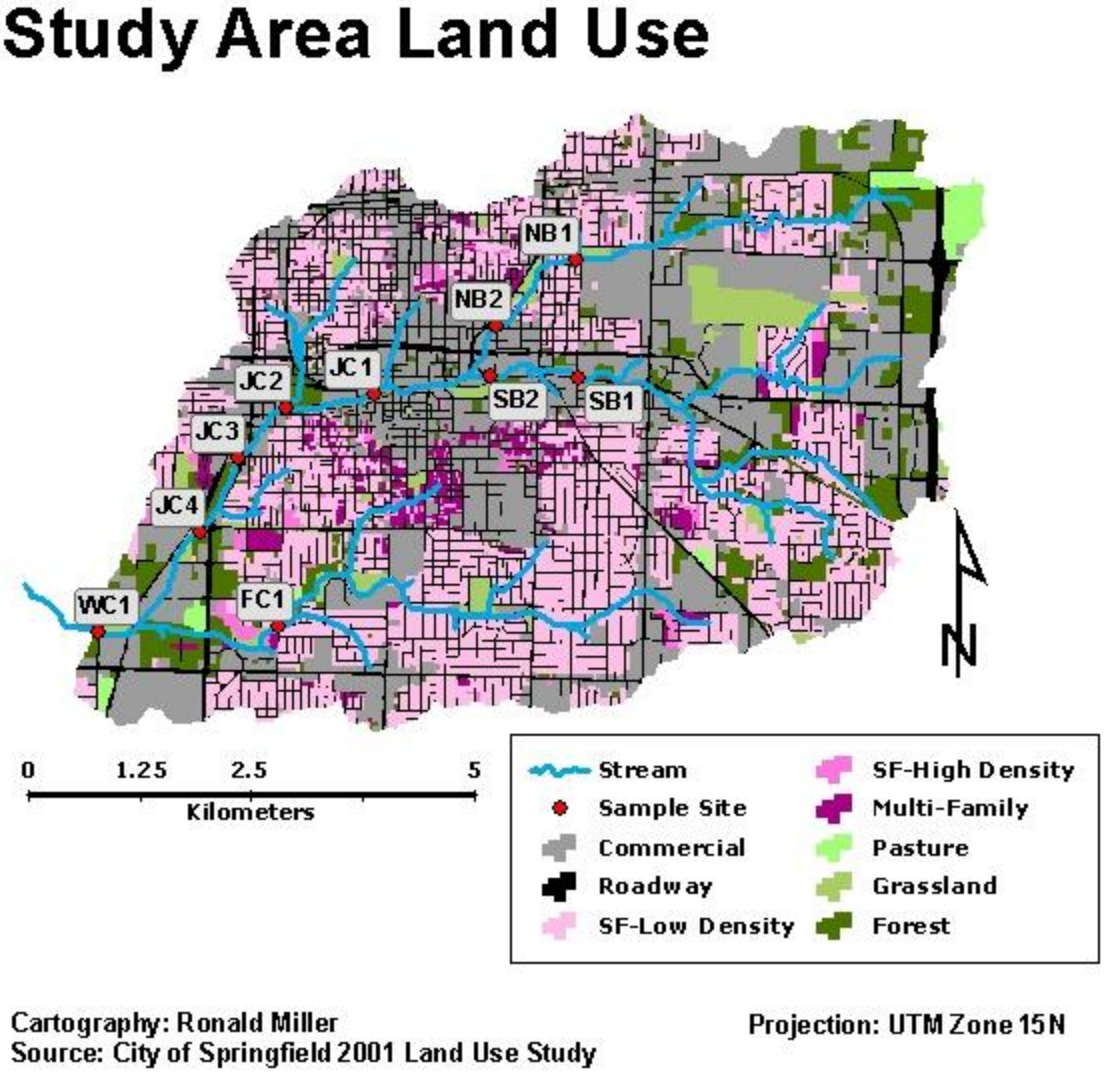

Study Area Land Use
NB1
NB2
JC1
JC2
JC3
JC4
SB2
SB1
WC1
FC1
N
0
1.25
2.5
5
Kilometers
Stream
Sample Site
Commercial
Roadway
SF-Low Density
SF-High Density
Multi-Family
Pasture
Grassland
Forest
Cartography: Ronald Miller
Source: City of Springfield 2001 Land Use Study
Projection: UTM Zone 15N

Figure 4.5: Map of land-use classifications within study area.

CHAPTER 5

RESULTS

Sample Characteristics

Twenty seven grab samples and discharge measurements for each site were collected over the study period from August 2004 to July 2005 including 17 baseflow and 10 storm events (Table 5.1). Baseflow was defined during the study as flows with at least 24 hours between sample time and any antecedent precipitation. The intention of the study was to collect each storm event sample during a rainfall event and to end up with a set of samples distributed over the storm hydrograph as recorded at the USGS gage located at site WC1. This particular effort was not entirely successful as all storm samples except one were found to be on the falling limb of the hydrograph, one small event was sampled on the rising limb and none at peak discharge. Individual storm event hydrographs, as recorded at USGS Gage 0705200, are collected in Appendix D.

Hydrology

Site Discharge Rating Curves. Measured discharges were plotted against their corresponding stage measurements to create a rating curve for each site (Table 5.2). The rating curves were created using measured baseflow and storm event discharges, the entire range of measured and curve-estimated discharges for each site is listed in Table 5.3. A discharge rating curve allows estimation of discharge with only a stage measurement. Discharge rating curves for each site, along with site surveys and photos are included in Appendix A. Sites SB2 and JC2 required curve equation with the Y intercept set at zero to avoid predicting negative discharges at the lowest stages. Both of

Table 5.1: Sample event descriptions and positions on Site WC1 hydrograph.

			Base			Storm		
Event	**DATE (m/d/y)**	**TIME (hr:min)**	**Sample Q (m^3/s)**	**Prev peak (days)**	**Prev peak Q (m^3/s)**	**Event peak Q (m^3/s)**	**Time to storm peak (hrs)**	**Event Duration (hrs)**
Base	9/7/2004	13:04	0.17	1.8	3.57			
Base	9/24/2004	14:52	0.16	18.9	3.57			
Base	11/23/2004	14:48	0.68	0.6	1.50			
Base	12/14/2004	12:48	0.34	7.5	2.41			
Base	12/21/2004	12:53	0.40	14.5	2.41			
Base	1/21/2005	13:18	0.74	7.6	55.22			
Base	2/10/2005	13:20	0.48	1.5	1.84			
Base	2/24/2005	11:12	0.51	1.0	2.12			
Base	3/15/2005	11:46	0.28	6.1	1.39			
Base	4/22/2005	11:08	0.31	10.1	8.29			
Base	4/30/2005	8:33	0.28	1.9	1.42			
Base	5/18/2005	12:27	0.20	4.4	18.93			
Base	5/30/2005	11:32	0.20	16.3	18.93			
Base	6/30/2005	12:31	0.09	16.6	11.24			
Base	7/8/2005	10:20	0.05	24.5	11.24			
Base	3/24/2005	15:23	0.37	1.8	14.97			
Base	6/16/2005	10:19	0.17	1.5	11.24			
Storm-falling	8/28/2004	16:40	2.58			11.21	2.25	3
Storm-falling	9/5/2004	18:15	1.39			3.57	1.25	5.5
Storm-falling	10/8/2004	10:25	0.85			8.07	6.25	5
Storm-falling	10/11/2004	13:56	15.11			24.31	1.75	13
Storm-falling	10/14/2004	12:27	2.18			2.36	0.50	6
Storm-falling	10/26/2004	12:19	6.40			10.58	0.75	14.5
Storm-falling	11/29/2004	14:03	4.67			16.98	5.75	10
Storm-falling	1/4/2005	14:00	17.32			19.75	1.75	7
Storm-falling	1/5/2005	12:30	16.10			39.90	5.00	16.5
Storm-rising	6/11/2005	13:27	3.57			6.40	-0.25	8.25

Table 5.2: Discharge rating curve equations and coefficients of determination

Site	a	b	c	R^2
NB1	23.701	-0.4061	0.033	0.997
NB2	21.147	1.1377	-0.0702	0.973
SB1	8.3886	-4.1802	0.5584	0.996
SB2[1]	5.8552	0.6048		0.992
JC1	14.75	2.8242	0.6023	0.951
JC2[1]	21.587	2.0606		0.962
JC3	14.791	0.2547	-0.1199	0.944
JC4	3.1269	14.205	-1.1915	0.936
FC1	8.4407	-1.9238	0.1187	0.984

[1] Equation forced through zero to avoid predicting negative discharges

Equation form: $Q = a(stage)^2 + b(stage) + c$

Where: Q = m^3/s
Stage = gage reading in meters

Table 5.3: Range of discharges (m^3/s) for each sample site.

	BASE		STORM	
	Min	Max	Min	Max
NB1	0	0.04	0.04	3.61
NB2	0.01	0.09	0.01	3.54
SB1	0	0.13	0.09	5.89
SB2	0.01	0.51	0.10	2.41
JC1[1]	0.02	1.58	0.39	8.15
JC2	0.02	0.30	0.56	12.05
JC3	0.02	0.71	0.50	15.07
JC4[2]	0.03	0.28	0.59	8.90
FC1	0.01	0.17	0.12	3.38
WC1	0.05	0.74	0.85	17.32

these sites were gaged at slow-moving pools which may have affected the precision of low-flow velocity estimates.

Water Quality Measurements

Measurements of water quality parameters pH, SC, Turbidity, DO and Temperature were taken simultaneously with each sample. These parameters showed remarkable consistency between sites with a few exceptions described below (Fig. 5.1). Baseflow values indicate the mean of seventeen samples and storm values the mean of ten samples. Water quality parameters were also measured twice at Dingledein Spring, which discharges into Jordan Creek just above Site JC2 (Figure 5.2). The water quality parameters of Dingledein Spring water were very different than Jordan Creek water, and in some cases appeared to change the Jordan Creek parameters in a measurable way as noted below.

pH. Mean baseflow pH measurements for all sites are typically within the range 7.5 – 8.0, which is within the normal carbonate-buffered range of 5.5 – 8.3 for water in areas with limestone bedrock (Drever, 1997). Exceptions are found at Site JC2 which has a lower mean baseflow pH of 7.3, and sites JC1 and FC1 which each have mean baseflow pH values of 8.1 (Fig. 5.1a). Site JC1 is located at the end of the "underground" section of Jordan Creek where the stream is encased in a concrete channel. Prolonged contact with concrete probably serves to increase the pH at this site, although high-pH point-source discharge into Jordan Creek at a point below Sites NB2 and SB2 cannot be ruled out. Site FC1, on Fassnight Creek is in a separate sub-watershed from the sites on Jordan Creek. High pH values at this site cannot be attributed to contact with concrete because the stream does not flow in a concrete channel near the site but Fassnight Creek has very low baseflow discharge and slow velocities, and thus the prolonged contact with the carbonate rocks in the streambed may elevate the pH relative to most of Jordan Creek in the same manner. A very low pH baseflow mean value occurs at Site JC 2, which receives significant flow from Dingledein Spring, located about 50 m upstream from the sample site (Fig. 4.1). Dingledein Spring has water quality parameters which are very different than the stream (Fig 5.2), namely very low pH and DO levels which indicate it is almost

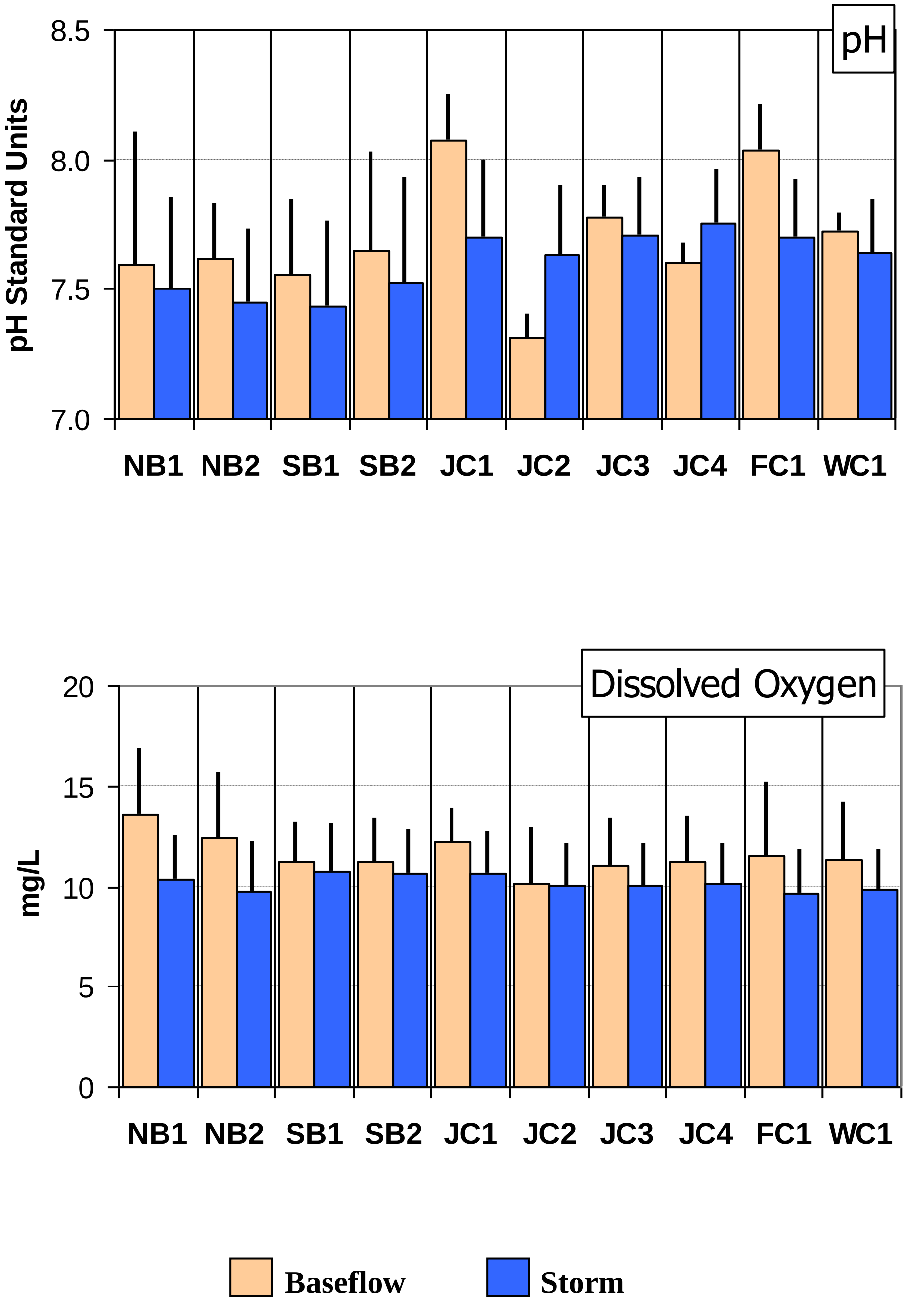


Figure 5.1: Mean and plus 1 Standard Deviation of measured pH and Dissolved Oxygen at each sample site

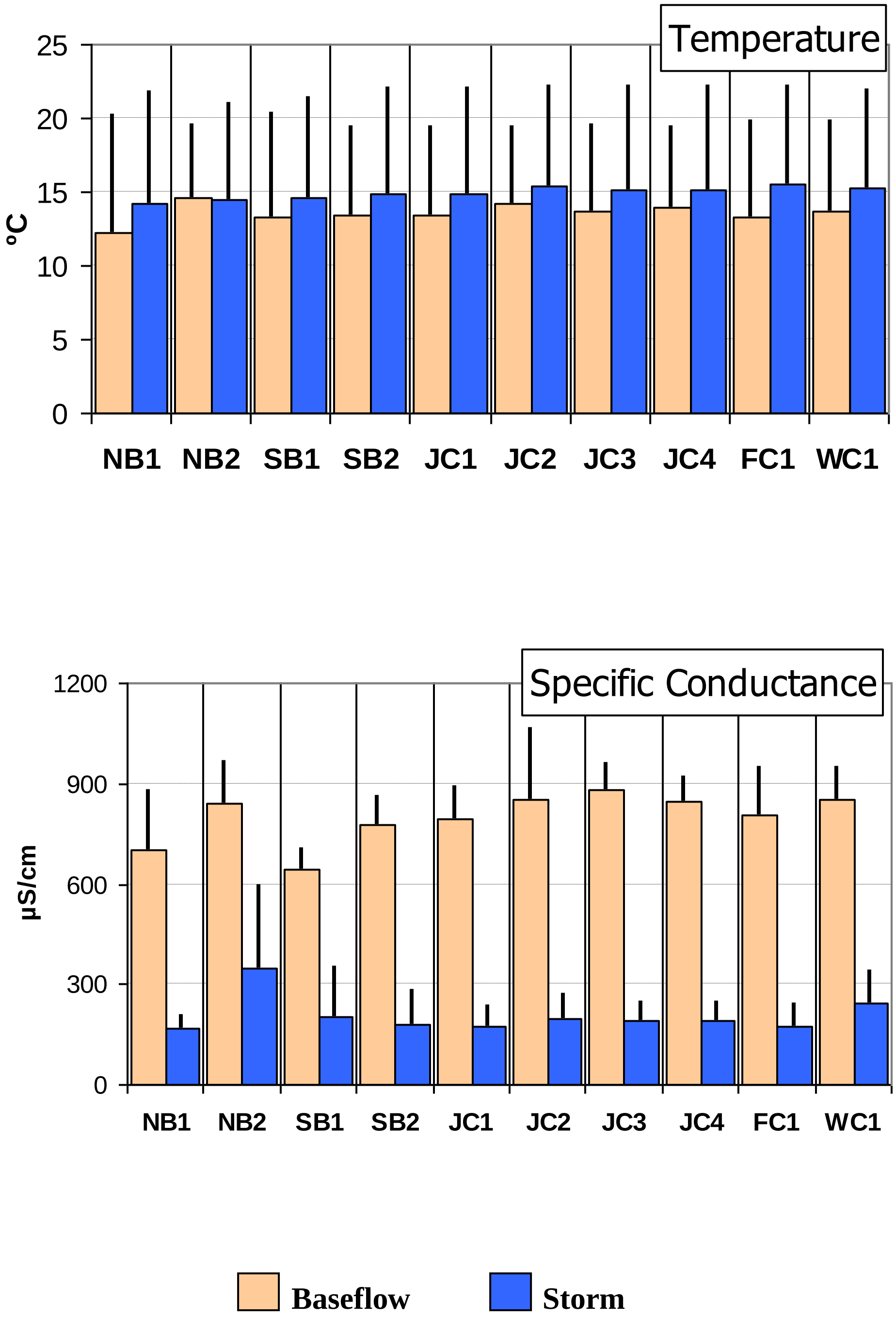


Figure 5.1(cont'd): Mean and plus 1 Standard Deviation of Temperature and Specific Conductance at each sample site.

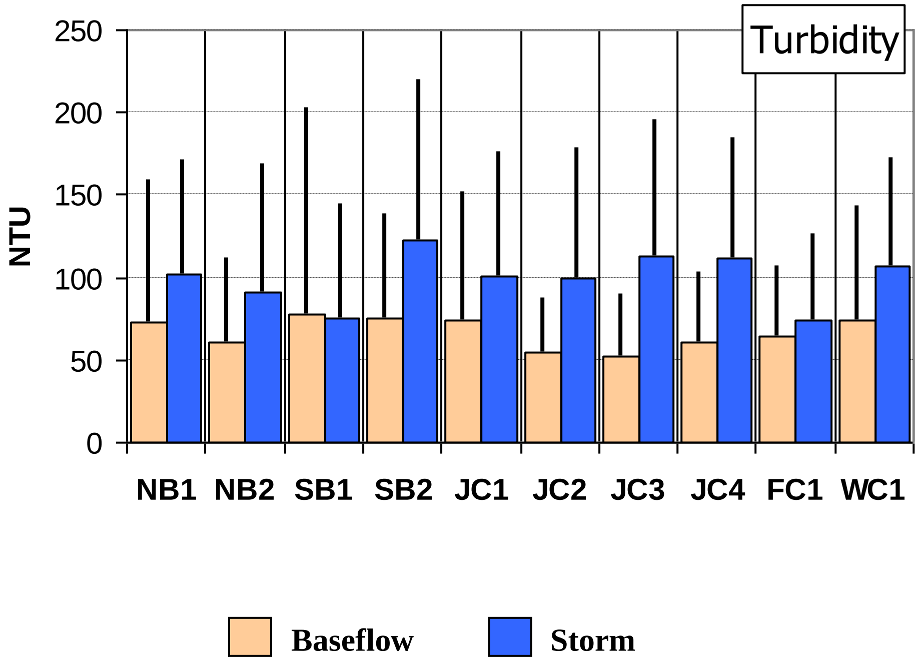


Figure 5.1 (cont'd): Mean and plus 1 Standard Deviation of Turbidity at each sample site.

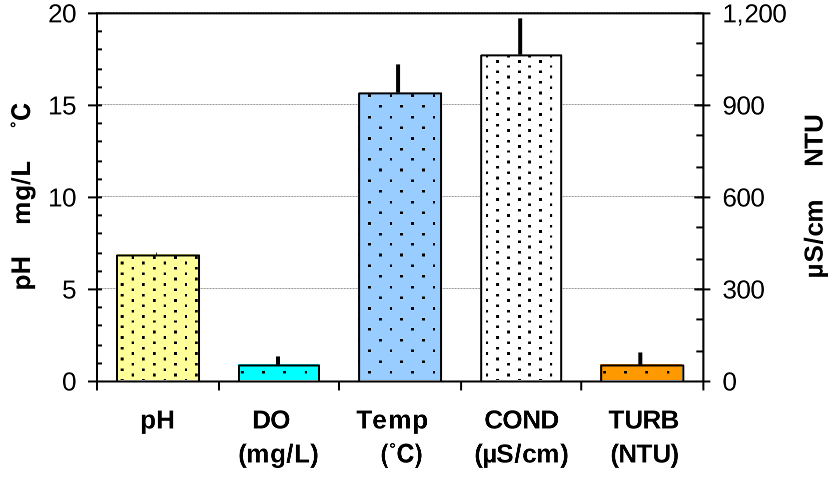


Figure 5.2: Dingledein Spring water quality parameters (Mean plus Standard Deviation). Sampled 9/24/04, 1/21, 2/10 and 4/22/05.

anoxic. Mixing of these waters at site JC 2 probably explains the lower baseflow pH readings.

Storm event pH values show lower overall mean values than baseflow but more consistency between sites. This pattern is reasonable given that the pH of precipitation is usually 5.6 (USEPA, 1994) and thus would be expected to lower the pH of the stream since the high volumes of runoff would tend to overwhelm the effects of point sources or local effects that create the inter-site variation seen at baseflow. Sites JC2 and JC4 depart from the general pattern which is higher baseflow than storm runoff pH. The difference at Site JC2 is explained by the quality of water discharging from Dingledein Spring. Dingledein Spring does not seem to influence the unusual pattern at Site JC4, since pH levels for Site JC3 appear to follow "normal" patterns. No low – pH sources were noted near Site JC4 during the study that could explain the unusual pH pattern at that site.

Dissolved Oxygen. Dissolved oxygen (DO) concentration is an important measure of aquatic habitat quality. The State of Missouri has established a 5 mg/L minimum DO concentration for all waters and all except one baseflow sample at Site WC1 were above this limit (MoDNR, 2005) (Table 5.4). Mean DO values are generally very consistent between sites with baseflow means slightly higher than storm mean values (Fig. 5.1 b). Site JC2 stands out with a low DO baseflow mean, probably because of the nearly anoxic inflow from Dingledein Spring (Fig. 5.2). Baseflow DO may be

Table 5.4: Minimum measured DO concentrations per site.

			Minimum DO Concentrations (mg/L)							
	NB1	**NB2**	**SB1**	**SB2**	**JC1**	**JC2**	**JC3**	**JC4**	**FC1**	**WC1**
Base	7.65	7.01	7.41	7.91	9.44	6.12	6.79	7.69	5.04	4.88
Storm	7.68	6.53	7.31	8.15	8.10	7.25	7.41	7.68	6.44	7.54

greater than storm DO because the relative contribution of aquatic plant oxygen may be greater than the turbulent integration of oxygen during storm flows, although this was not tested during the study.

Temperature. Water temperatures were very similar between sites during baseflows and storm events as evidenced by the similar mean values and standard deviations (Fig. 5.1 c). Higher storm mean temperatures probably are due the timing of events and the normal seasonal variation temperature since storm sampling in fall and spring probably skew the stream water results to a warmer mean temperature. Dingledein Spring shows less variability than Jordan Creek, in general spring water temperatures are less affected by air temperature and thus have less variation (Fig. 5.2).

Specific Conductance. Specific Conductance (SC) varies dramatically and consistently between baseflow and storm mean values but is very consistent between sites (Fig. 5.2 d). SC is a measure of dissolved ions in the water column and the mean value for baseflow is high because the stream water at baseflow has had a lot of time to interact with and dissolve ions from bedrock and soil. The difference between baseflow and storm means is probably due to the dilution effect of storm runoff in which solute-poor storm water mixes with the baseflow water. The SC of precipitation can be an order of magnitude less than stream water: mean values reported for a nationwide network of recording stations between 1981 and 1983 ranged from 10 to 59 microSiemens per centimeter (µS/cm) whereas Jordan Creek baseflow mean values ranged from 640 to 880 µS/cm (Schroder and Brennan, 1985). Dingledein Spring SC mean was 1060 µS/cm.

Turbidity. The mean values show that generally storm’s Turbidity (TURB) means are higher than baseflow means, but the relationship is neither as strong nor as consistent as the SC difference (Fig 5.2 e). Site SB 2 has a baseflow TURB mean higher than the storm TURB mean. This site is located at a concrete channel section of the South Branch of Jordan Creek. Some large-scale construction activities were going on in the area, including the construction of Hammons Field and there is also a cement-truck washing station located upstream from the site. The concrete particles entering the stream may have affected TURB in the baseflow samples. The surfaces typical of a built-up urban environment, paved and concrete streets, managed lawns and roof areas, contribute little to soil erosion and sediment loads and thus lower turbidity measurements may be expected compared to the disturbed surfaces typical of cultivated regions (Wolman, 2002).

Pollutant Concentrations

Nutrients. Total phosphorous and total nitrogen concentrations were measured in each sample taken during the study (Table 5.5). Complete tables of concentrations per sample are included in Appendix B. The general pattern for TP is higher concentrations in storm event flows and lower concentrations in base flows while TN shows the opposite trend. These results are consistent with TP being a primarily particulate-bound constituent washed into the stream from the watershed surface and thus more likely to be suspended in the water column during elevated discharge. The TN trend is explained as being primarily a dissolved constituent whose concentration is controlled by contact time with soil and bedrock and thus is generally highest in baseflow dominated by ground-water and spring supply and is diluted by storm runoff.

Table 5.5: Mean, geometric mean, standard deviation and sample sizes for TP and TN concentrations by site.

	NB1	NB2	SB1	SB2	JC1	JC2	JC3	JC4	FC1	WC1
Total Phosphorus (µg/L)										
All Mean	175	86	101	196	145	107	100	107	89	86
All Std Dev	229	83	75	251	194	78	84	102	87	77
Base Mean	101	38	47	176	92	52	36	30	36	28
Base Std Dev	233	63	12	315	224	24	14	12	30	11
Storm Mean	286	157	184	200	220	196	200	227	172	177
Storm Std Dev	171	55	55	43	76	51	43	59	84	45
All Geo Mean	85	47	77	108	70	79	65	61	50	53
Base Geo Mean	40	23	45	70	37	48	34	28	26	26
Storm Geo Mean	256	145	175	196	208	190	196	220	157	171
Total Nitrogen (mg/L)										
All Mean	1.59	1.84	0.83	1.42	1.78	1.61	1.74	1.80	2.53	2.00
All Std Dev	1.16	0.80	0.50	0.63	0.80	0.79	1.14	0.95	1.67	1.15
Base Mean	1.87	2.12	0.77	1.63	2.09	1.83	1.88	2.03	2.98	2.28
Base Std Dev	1.30	0.78	0.58	0.63	0.74	0.83	1.34	1.02	1.71	1.23
Storm Mean	1.17	1.23	0.89	0.99	1.16	1.11	1.29	1.21	1.35	1.25
Storm Std Dev	0.70	0.46	0.31	0.37	0.52	0.45	0.52	0.49	0.97	0.61
All Geo Mean	1.29	1.67	0.69	1.28	1.58	1.42	1.45	1.58	2.02	1.71
Base Geo Mean	1.53	1.99	0.60	1.53	1.96	1.67	1.52	1.81	2.44	1.94
Storm Geo Mean	1.00	1.14	0.83	0.91	1.04	1.01	1.16	1.11	1.12	1.12

Sample size (n): All = 27, Base = 17, Storm = 10.

Metals. Each sample was analyzed for concentrations of five metals: As, Cu, Zn, Pb and Cd. As and Cu were detected in no or very few samples respectively, Pb and Cd were detected in many samples and Zn was detected in nearly every sample (Table 5.6). The concentrations were also compared to the EPA Maximum contamination Level (MCL) for drinking water (Table 5.6) (USEPA, 2004). Only Pb appeared to be significant in this comparison. In all samples analyzed, the As concentrations were similar to the blanks. Therefore it was assumed that As concentrations were below the EPA MCL. The Pb detection limit was very close to the EPA MCL and were assumed to be the same for this study. Complete metal concentration data for each sample are included in Appendix B.

Table 5.6: Percent of samples with metal concentrations above Detection Limit and above EPA MCL

Metal		NB1	NB2	SB1	SB2	JC1	JC2	JC3	JC4	FC1	WC1
				Percent above detection							
As (0.005)[2]	**Total[1]**	0	0	0	0	0	0	0	0	0	0
	Base	0	0	0	0	0	0	0	0	0	0
	Storm	0	0	0	0	0	0	0	0	0	0
Cu (0.041)[3]	**Total**	15	7	15	7	15	11	19	19	15	15
	Base	18	6	6	6	12	6	12	18	18	18
	Storm	10	10	30	10	20	20	30	20	10	10
Zn (0.01)[3]	**Total**	93	100	100	96	100	100	100	100	100	96
	Base	88	100	100	94	100	100	100	100	100	100
	Storm	100	100	100	100	100	100	100	100	100	90
Pb (0.016)[3]	**Total**	30	37	37	33	37	41	44	44	22	37
	Base	35	41	41	24	24	29	35	35	29	29
	Storm	20	30	30	50	60	60	60	60	10	50
Cd (0.0018)[3]	**Total**	41	44	30	41	44	41	41	41	37	44
	Base	53	53	41	53	59	53	53	53	41	65
	Storm	20	30	10	20	20	20	20	20	30	10
				Percent above MCL							
As (0.01)[4]	**Total**	0	0	0	0	0	0	0	0	0	0
	Base	0	0	0	0	0	0	0	0	0	0
	Storm	0	0	0	0	0	0	0	0	0	0
Cu (1.3)[4]	**Total**	0	0	0	0	0	0	0	0	0	0
	Base	0	0	0	0	0	0	0	0	0	0
	Storm	0	0	0	0	0	0	0	0	0	0
Zn (5.0)[4]	**Total**	0	0	0	0	0	0	0	0	4	0
	Base	0	0	0	0	0	0	0	0	6	0
	Storm	0	0	0	0	0	0	0	0	0	0
Pb (0.015)[4]	**Total**	33	37	37	37	37	41	41	41	19	33
	Base	18	41	24	24	41	35	35	41	6	35
	Storm	60	30	60	60	30	50	50	40	40	30
Cd (0.005)[4]	**Total**	19	15	22	11	11	19	19	15	11	15
	Base	24	18	29	12	12	24	24	18	12	18
	Storm	10	10	10	10	10	10	10	10	10	10

[1] Sample size (n): Total = 27, Base = 17, Storm = 10.
[2] Hydride Generation Atomic Absorption method detection limit (mg/L).
[3] ICP – AES method detection limit (mg/L).
[4] EPA MCL (mg/L).

Pearson Correlation Analysis (r)

Pearson's Product Moment Correlation Coefficient (r) measures the linear relationship between two variables. The nature of the relationship is denoted by the sign of the coefficient, with a positive coefficient indicating that both variables increase simultaneously and a negative coefficient indicating that one variable decreased as the other increases. The strength of the relationship is indicated by the value of the coefficient with higher values indicating a stronger linear relationship between the variables. The statistical significance of the Pearson correlation is related to sample size and the standard deviation of the sample distributions. Statistical significance can be quickly determined by referring to a table of critical values based on the degrees of freedom allowed by the sample size (n – 2). Three Pearson Correlation matrices were prepared for Site WC1, one with the sample population as a whole and also one each with the samples divided into Base and Storm subsets (Table 5.7 a - c). Each table includes the critical value for statistical significance at the 95% and 99 % confidence level.

Metal Correlations. The following discussion will concern all tested metals except As, whose tested values were consistently below the detection limit of both ICP-AES (0.01 mg/L) and Metal Hydride Plasma Induction (0.001 mg/L) methods and thus considered to be negligible. The metal concentrations seem to have no significant correlations with discharge or any of the water quality parameters measured although they are generally very highly correlated with each other, especially when all samples are aggregated and at base flow. When all samples are aggregated the metals show a weak negative correlation with pH (with the exception of Zn) and a weak negative correlation with TURB and Q (except Zn and As). The strong internal correlations point to a common source mechanism for the metals.

The metals examined in this study are highly adsorbed at the range of pH encountered in this study (7.3 – 8.1) and thus could be expected to behave as suspended particles (Forstner and Wittmann, 1981; Drever, 1997). Suspended particles are commonly found in highest concentration on the rising limb of the storm hydrograph as accumulated street dust and loose sediments are washed into streams. This phenomenon is not reflected in the relationship between Zn, the most common metal found in this study, and discharge (Fig. 5.3). With the exception of a single outlier, all Zn concentrations are within the range of 0.28 – 3.01 mg/L and concentration neither increases nor decreases with discharge. This general lack of relationship between storm runoff and concentration may indicate that “first flush” samples are needed to accurately detect trends in metal concentration, or that there is no increase in Zn with storm runoff.

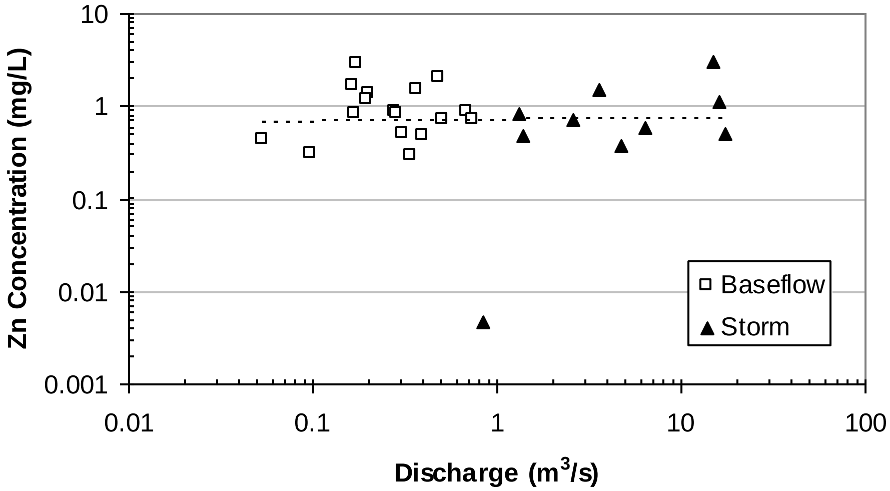


Figure 5.3: Zn concentration rating curve from Site WC1, illustrating lack of clear concentration – discharge relationship.

Table 5.7 a: Pearson correlation matrix for all samples at Site WC1. Significance at 95 % is indicated by **bold**, significance at 99 % is indicated by **bold**.

	pH	SC	TURB	DO	Temp	TP	TN	As	Cu	Zn	Pb	Cd
SC	0.206											
TURB	-0.064	-0.164										
DO	0.200	0.235	0.161									
Temp	-0.057	-0.042	-0.096	***-0.768***								
TP	***-0.404***	***-0.886***	0.223	-0.302	0.145							
TN	-0.128	***0.498***	-0.245	***0.558***	***-0.522***	***-0.386***						
As	-0.044	-0.235	0.025	-0.365	0.278	0.232	-0.170					
Cu	-0.070	0.114	-0.226	-0.247	0.185	-0.018	0.189	***0.821***				
Zn	0.309	-0.015	-0.021	0.084	0.013	-0.010	-0.016	***0.439***	***0.467***			
Pb	-0.057	0.023	-0.138	-0.368	***0.399***	0.072	-0.093	***0.813***	***0.876***	***0.570***		
Cd	-0.111	0.144	-0.243	-0.177	0.192	-0.066	0.130	***0.697***	***0.856***	***0.440***	***0.891***	
Q	-0.034	0.144	0.319	0.119	-0.279	***0.637***	-0.259	0.115	-0.115	0.190	-0.079	-0.160

Sample size (n) = 27

Significance: 95 % = ± 0.381   99 % = ± 0.487

Table 5.7 b: Pearson correlation matrix for baseflow samples at Site WC1. Significance at 95 % is indicated by **bold**, significance at 99 % is indicated by **bold**.

	pH	SC	TURB	DO	Temp	TP	TN	As	Cu	Zn	Pb	Cd
SC	***0.555***											
TURB	0.423	0.347										
DO	0.135	0.064	0.128									
Temp	0.090	0.128	0.155	***-0.721***								
TP	-0.410	***-0.542***	-0.208	***-0.542***	***0.563***							
TN	-0.125	0.204	-0.217	***0.614***	***-0.731***	***-0.535***						
As	-0.027	-0.211	-0.112	-0.351	0.364	0.264	-0.078					
Cu	0.068	-0.083	-0.275	-0.247	0.146	-0.019	0.127	***0.889***				
Zn	-0.098	-0.360	0.032	-0.008	0.109	0.208	-0.078	***0.616***	***0.584***			
Pb	0.078	-0.239	-0.097	-0.403	0.422	0.289	-0.247	***0.933***	***0.848***	***0.737***		
Cd	-0.083	-0.235	-0.214	-0.179	0.128	0.043	-0.009	***0.824***	***0.821***	***0.583***	***0.847***	
Q	-0.388	-0.191	-0.142	***0.640***	***-0.666***	-0.087	***0.719***	-0.211	-0.168	-0.084	-0.373	-0.131

Sample size (n) = 17

Significance: 95 % = ± 0.482   99 % = ± 0.606

Table 5.7 c: Pearson correlation matrix for storm samples at Site WC1. Significance at 95 % is indicated by **bold**, significance at 99 % is indicated by **bold**.

	pH	SC	TURB	DO	Temp	TP	TN	As	Cu	Zn	Pb	Cd
SC	***-0.747***											
TURB	-0.261	-0.084										
DO	0.192	-0.378	0.540									
Temp	-0.091	0.322	-0.601	***-0.933***								
TP	-0.369	0.152	0.117	0.001	-0.039							
TN	***-0.759***	***0.761***	0.017	0.019	-0.031	0.581						
As	0.061	0.100	0.170	-0.257	0.074	0.057	-0.149					
Cu	-0.246	0.519	-0.079	-0.375	0.293	0.311	0.369	***0.790***				
Zn	0.530	-0.158	-0.058	0.220	-0.088	0.176	-0.001	0.235	0.287			
Pb	-0.168	0.520	-0.223	-0.354	0.376	0.275	0.375	0.621	***0.944***	0.337		
Cd	-0.231	0.570	-0.235	-0.331	0.333	0.226	0.411	0.604	***0.936***	0.239	***0.988***	
Q	0.236	-0.475	0.400	***0.784***	***-0.683***	0.154	-0.007	-0.039	-0.140	0.459	-0.137	-0.158

Sample size (n) = 10

Significance: 95 % = ± 0.632   99 % = ± 0.765

Nutrient Correlations. There are significant correlations, when all samples are considered, between TP and the parameters SC and Q, and significant correlations between TN and SC (Table 5.7 a). Furthermore there are significant correlations between TN and DO and TEMP, DO and TEMP. There is also a negative correlation between DO and TEMP. At baseflow TP has a significant correlation between SC, DO and TEMP and TN has significant correlations with DO TEMP, TP and Q (Table 5.7 b). Discharge is correlated with TEMP and DO. For storm event flows TN is correlated with pH and SC and DO is correlated with TEMP and Q. There are no significant correlations with TP for storm events (Table 5.7 c, 5.8).

The correlation between DO and TEMP is due to a known physical relationship that controls the solubility of oxygen in water and is consistently negative at all sites (Drever, 1997). The correlations between TN and Temp could be related to seasonal changes in plant growth and their impact on soil nitrogen. The winter seasonal water temperatures are lower and coincide with the seasonal dormant period for many plants. Nitrogen is primarily present in streams in dissolved form and appears in streams as a result of groundwater interaction with soils (Novotny, 1994; Drever, 1997). Dormant

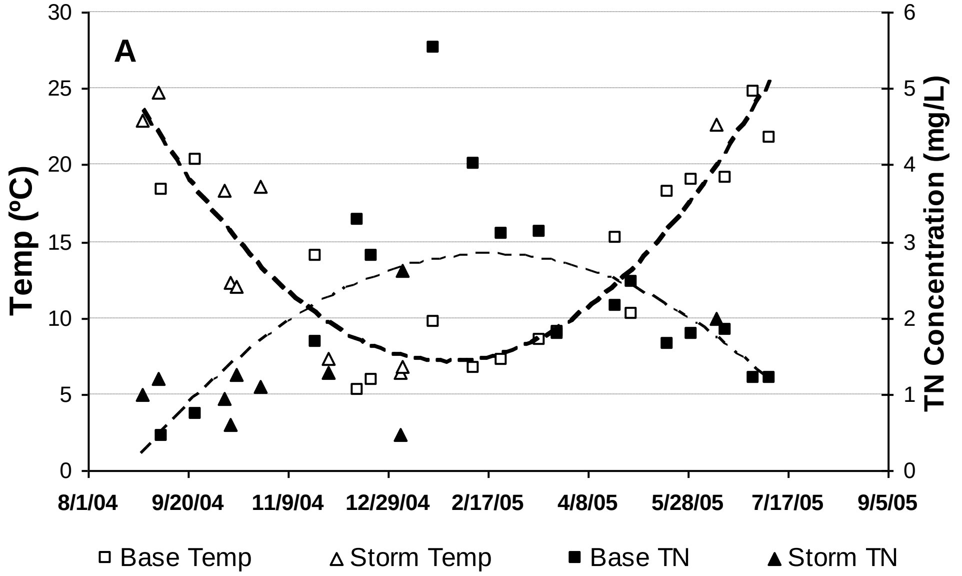
Table 5.8: Pearson Correlations for TN and TP at Site WC1

		pH	SC	TURB	DO	Temp	TP	TN	Q
TN	**All**	-0.128	***0.498***	-0.245	***0.558***	***-0.522***	***-0.386***	***1.000***	-0.259
	Base	-0.125	0.204	-0.217	***0.614***	***-0.731***	***-0.535***	***1.000***	***0.719***
	Storm	***-0.759***	***0.761***	0.017	0.019	-0.031	0.581	***1.000***	-0.007
TP	**All**	***-0.404***	***-0.886***	0.223	-0.302	0.145	***1.000***	***-0.386***	***0.637***
	Base	-0.410	***-0.542***	-0.208	***-0.542***	***0.563***	***1.000***	***-0.535***	-0.087
	Storm	-0.369	0.152	0.117	0.001	-0.039	***1.000***	0.581	0.154

	Significance	
	95%	**99%**
All	***±0.381***	***±0.487***
Base	***±0.482***	***±0.606***
Storm	***±0.632***	***±0.765***

plants draw fewer nutrients from soil water and thus more is transported with groundwater flow into streams (Fig. 5.4 a). TN concentration in streams has been similarly found to vary with season by Vanderbilt et al (2003) and Zhang and Schilling (2005). The observed variation does not appear to be due to seasonally biased sampling of storms and baseflows since storm samples consistently contain low TN throughout the study due to dilution by surface runoff. In contrast, baseflow samples are either low or high depending on the season during which they were collected. Phosphorus concentrations are more likely to be bound to suspended particles rather than dissolved in the water column, and thus TP concentration would be expected to be more closely related to discharge than to season and to be consistently low in baseflow samples due to the lack of stream energy required to suspend sediments. The seasonal distribution shows that high TP concentrations are associated with storm events, and that there is relatively little variation in TP concentration at baseflow (Fig. 5.4 b).

There is a baseflow-only significant positive correlation between TP and Temp (r = 0.563) (Table 5.8) that may indicates a seasonal variation opposite that of TN. Mulholland (2003), in a study of nutrient concentration trends in a stream in Tennessee, found a similar seasonal concentration trend for dissolved P that features low winter and high summer concentrations. The method used to analyze TP in the present study did not distinguish between dissolved and particulate-bound P, therefore it cannot be stated that the same trend exists in Jordan Creek, but it is a possible cause of the pattern seen at baseflow, a time when particulate-bound P would be unlikely to dominate the TP measurement as seen by the relatively low TURB measurements at baseflow (Fig 5.1).



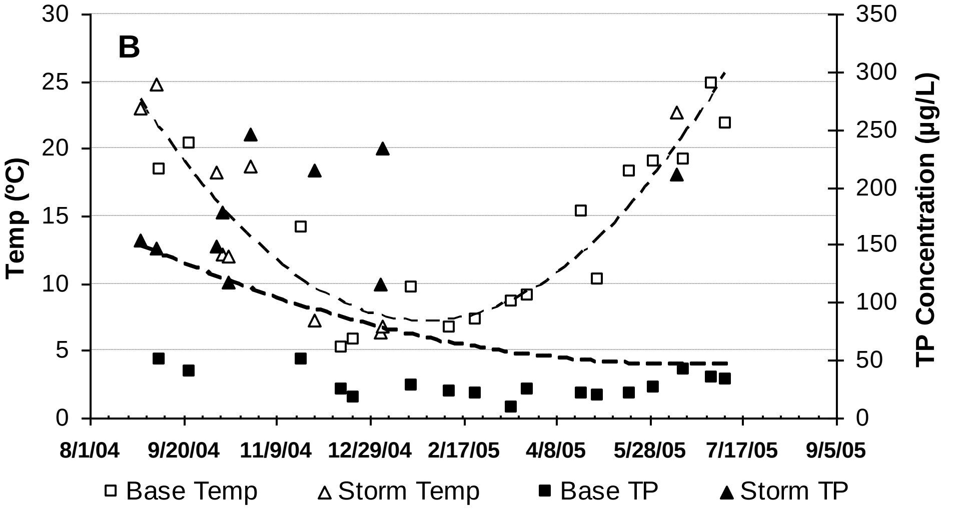
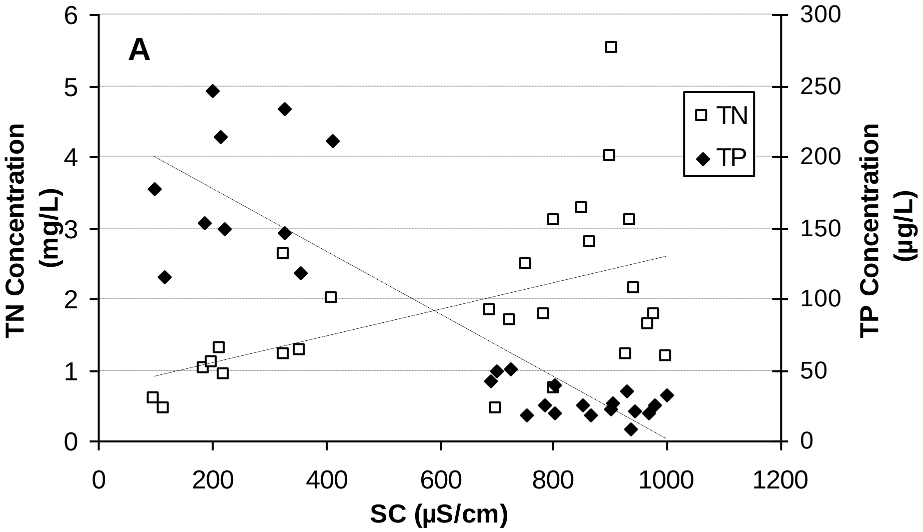


Figure 5.4: Seasonal distributions of (a) TN concentrations and TEMP and (b) TEMP and TP. Second – order trend lines are fitted to show change over time.

The correlation between TP, TN and SC most likely has to do with the source mechanisms for TN and TP and the dilution effects of stormwater on SC. TN is predominantly a dissolved constituent and the major source to the stream is water flowing through soil (Novotny and Olem, 1994). TP is predominantly a particle-bound constituent that primarily reaches the stream as suspended sediment in storm runoff. SC is a measure of dissolved ions in the water and is expected to be highest at baseflow when soil/water contact time is highest and lowest during storm events when large amounts of surface runoff enters the stream quickly. The TN/Q relationship is thus expected to be similar to the SC/Q relationship and the inverse of the relationship between discharge and TP. The plot of TN and TP versus SC confirms that they have the expected inverse relationships (Fig. 5.5 a).

One would hypothesize that TP and TURB would be positively correlated because turbidity is a measure of suspended sediment and TP is primarily a suspended pollutant especially during storm events. The correlation between Storm TP and TURB was found to be positive but not significant (r = 0.117) (Fig. 5.5 b). Lack of significant correlation of TP and Q with TURB could be due to problems with the measurement stability, the fact that most storm measurements missed the sediment-rich first flush or because the urban surfaces present in the watershed may not yield great quantities of sediment during runoff compared to an agricultural landscape. Visually, the TP – TURB data does seem to segregate into three general groups: low TP and TURB less than 50 NTU, a transitional range between 50 and 130 NTU, and a high TP and TURB range above 130. The low range may measure algae or other suspended particles that register as turbidity but contain little TP and the high range may be a measure of sediment



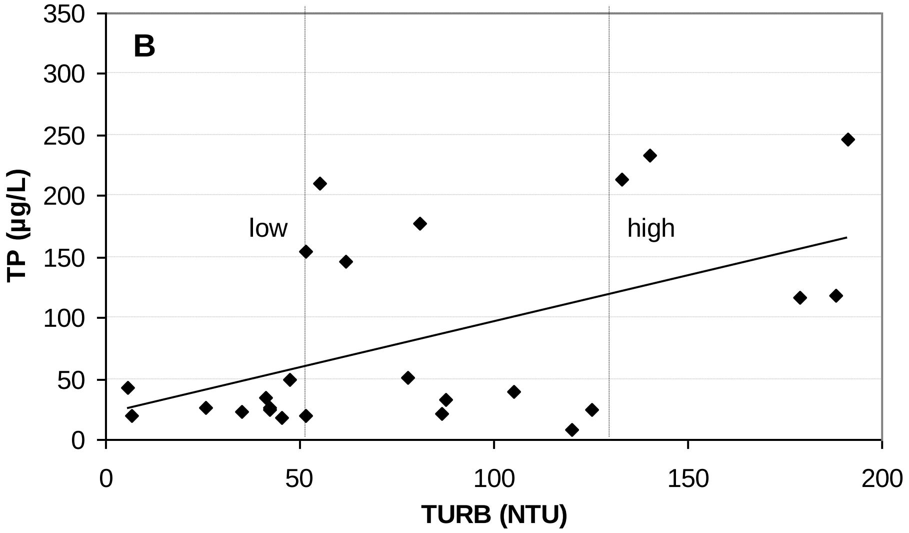


Figure 5.5: Water quality parameter relationships to TN and TP concentrations at Site WC1. (a) SC relationships with TP and TN concentration showing negative and positive correlations respectively. (b) Relationship between TP concentration and TURB with (-10 and 999 values removed) showing positive, but poor correlation. TURB – TP data divided into low transitional and high ranges.

particles high in bound TP.

Nutrient Load Rating Curves

To calculate loads in Jordan Creek and yields per watershed area it was necessary to create load rating curves that relate discharge to mass transport in kg/day of nutrients. Load is the product of discharge (m^3/s) and concentration (mg or µg/L) scaled to the appropriate time period (day or year) (see Methods: Daily Load Calculation). The load rating equations slopes (b_1) are very similar for both TN and TP, with the exception of Site NB1 (Table 5.9). Because discharge is rarely the sole factor controlling concentration in streams, McBride and Smith (1997) suggest various methods, including

Table 5.9: Rating equations and equation form to calculate nutrient load (kg/d) per site.

$$L_i = b_0 * Q_i^{b_1} * c$$

Where: L_i = Load (kg/d)
Q_i = Discharge (m^3/s)
c = conversion constant

						Total Phosphorus					
		NB1	**NB2**	**SB1**	**SB2**	**JC1**	**JC2**	**JC3**	**JC4**	**FC1**	**WC1**
Storm	**b_0**	7.3789	13.244	15.92	16.406	18.197	17.129	15.914	16.295	13.572	13.067
	b_1	-0.2501	1.1652	1.1017	0.9603	0.9787	0.9584	1.0477	1.1598	1.0036	1.0849
	R^2	0.070	0.952	0.950	0.986	0.919	0.941	0.974	0.968	0.858	0.957
Base	**b_0**	14.812	2.5028	4.0213	22.471	3.6302	2.6057	2.8553	1.6184	1.611	1.8385
	b_1	1.4383	1.0761	1.0095	1.3975	1.117	0.8012	0.9891	0.823	0.9024	0.0439
	R^2	0.811	0.635	0.951	0.346	0.638	0.701	0.890	0.659	0.395	0.651
						Total Nitrogen					
		NB1	**NB2**	**SB1**	**SB2**	**JC1**	**JC2**	**JC3**	**JC4**	**FC1**	**WC1**
Storm	**b_0**	69.838	92.056	71.712	71.457	103.73	109.63	106.81	109.1	93.688	108.24
	b_1	0.7914	0.7985	0.9926	0.8704	0.7738	0.778	0.9528	0.8647	0.9183	0.9198
	R^2	0.902	0.943	0.898	0.955	0.834	0.789	0.824	0.755	0.725	0.805
Base	**b_0**	131.22	353.78	39.514	316.36	180.33	380.73	145.4	293.12	720.32	372.65
	b_1	1.0431	1.2368	0.8968	1.2635	1.0564	1.467	1.0466	1.2659	1.3756	1.0009
	R^2	0.305	0.957	0.655	0.842	0.928	0.951	0.731	0.723	0.725	0.843
Threshold Q^1 (m^3/s)		0.04	0.11	0.15	0.09	0.47	0.3	0.71	0.28	0.17	0.8

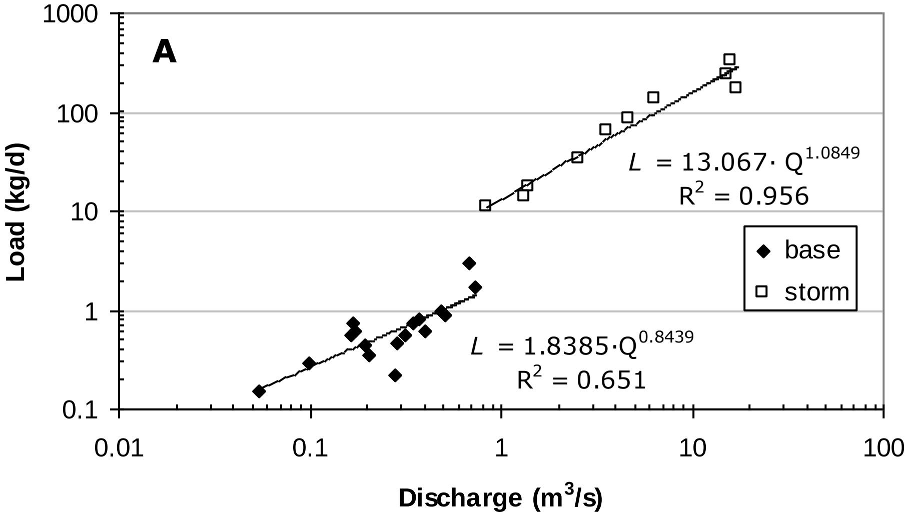
[1] Discharge (Q) threshold distinguishing baseflow from storm flow.

using multiple rating curves, to help to more accurately estimate concentration. One such factor is the difference in how source water enters the stream between baseflow, which enters the stream as groundwater and storm water which runs off the watershed surface before entering the stream. Following this, the curves were separated into baseflow and storm components because there appeared to be better fit to the data (Fig.5.6 a). The TN and TP loadrating curves for Site WC1 will be used to create annual estimates for mass transport out of the study area, because it is co-located with USGS Gage 07052000. Graphs of load ratings for all sites appear in Appendix C.

The TP mean storm response for NB1 is very different than the other sites (Fig. 5.7). The storm load curve has a negative slope, probably because of the very high TP concentrations that occur at this site at lower storm discharges. This site is also unique because it was often dry at baseflow. Perhaps sediment-bound P loads built up in the channel during those dry periods and were suspended during runoff thereby increasing the relative TP loads of those events. Other sites that are wet at baseflow would not show this effect because the sediment particles would have been borne away and not accumulated to be sampled during event flows. To avoid the prospect of predicting smaller TP loads for larger storm discharges, the mean TP response value (24.7 kg/day) was used in load modeling for Site NB1.

Flow-Probability Annual Load

Since the USGS Gage 07052000 is located at Site WC1, the outlet of the study watershed, real-time and historical discharge data is available to create a flow duration table. The gage record used for the flow exceedance calculation consists of the number



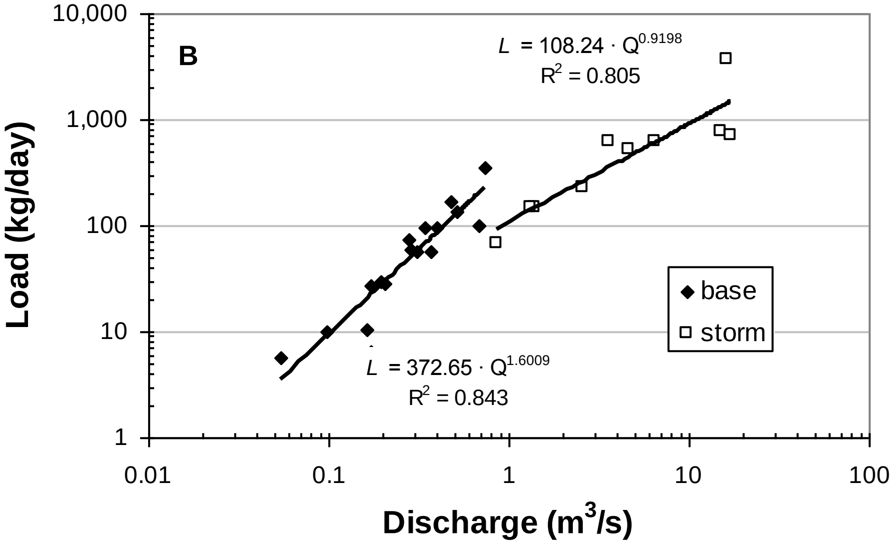


Figure 5.6: Load rating curves for Sites WC1 (A) TP and (B) TN.

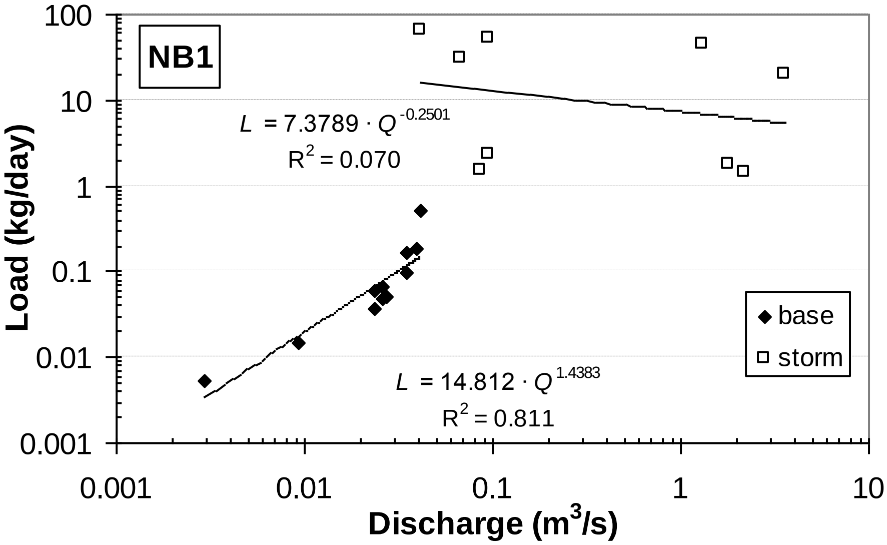


Figure 5.7: TP load rating curve for Site NB1 showing negative storm slope. Event mean (24.7 kg/d) instead of curve was used to calculate NB1 storm loads

of days per year that recorded average daily discharge falls within one of 35 discharge intervals, also referred to as "bins". The gage record includes 13 years; 1933 –39 and 1999 – 2004. The flow duration table was used to create a probability-based annual load for the study area (Table 5.10). The TN and TP load rating curves for site WC1 were used with flow exceedance discharges to calculate daily and annual loads based on probability. Because the record does not encompass 30 years of data (not necessarily consecutive), the agreed standard used by the USGS to conform to World Meteorological Organization methods, the results do not meet USGS standards for statistical validity; however they do provide the best available estimate of flow probability (Searcy, 1959). The estimates created from this record should be evaluated as "percent of flows during a 13-year period likely to be exceeded by a particular flow" rather than percent of a particular year's flows that will be exceeded (Searcy, 1959).

Table 5.10: Flow Exceedance Probability Load Proportions for TN and TP

					Nitrogen		**Phosphorus**	
Exceedance Range (avg daily Q)	**Midpoint %**	**$\log_{10}$ Q (cfs)**	**Actual Q (cfs)**	**Actual Q (m^3/s)**	**N Load (kg/day)**	**Load Proportion (load/20)**	**P load (kg/day)**	**Load Proportion (load/20)**
95 to 100	97.5	0.28	1.93	0.05	3.54	0.18	0.16	0.01
90 to 95	92.5	0.42	2.65	0.08	5.90	0.30	0.21	0.01
85 to 90	87.5	0.54	3.46	0.10	9.03	0.45	0.26	0.01
80 to 85	82.5	0.63	4.30	0.12	12.79	0.64	0.31	0.02
75 to 80	77.5	0.71	5.13	0.15	17.00	0.85	0.36	0.02
70 to 75	72.5	0.77	5.93	0.17	21.42	1.07	0.41	0.02
65 to 70	67.5	0.82	6.68	0.19	25.89	1.29	0.45	0.02
60 to 65	62.5	0.87	7.37	0.21	30.35	1.52	0.49	0.02
55 to 60	57.5	0.91	8.04	0.23	34.89	1.74	0.53	0.03
50 to 55	52.5	0.94	8.73	0.25	39.79	1.99	0.57	0.03
45 to 50	47.5	0.98	9.50	0.27	45.54	2.28	0.61	0.03
40 to 45	42.5	1.02	10.43	0.30	52.87	2.64	0.66	0.03
35 to 40	37.5	1.07	11.63	0.33	63.00	3.15	0.72	0.04
30 to 35	32.5	1.12	13.28	0.38	77.90	3.89	0.81	0.04
25 to 30	27.5	1.19	15.63	0.44	101.10	5.06	0.92	0.05
20 to 25	22.5	1.28	19.10	0.54	139.29	6.96	1.09	0.05
15 to 20	17.5	1.39	24.38	0.69	206.00	10.30	1.35	0.07
10 to 15	12.5	1.52	32.78	0.93	101.08	5.05	12.05	0.60
5 to 10	7.5	1.67	46.71	1.32	140.02	7.00	17.70	0.89
0 to 5	2.5	1.85	71.08	2.01	205.99	10.30	27.91	1.40
			Probable daily load (kg/d)			66.7		3.4
			Probable annual load (kg/y)			24,334		1,233
			Probable yield (kg/y - km^2)			484.7		24.6

Two Models for Daily Flow – Based Load Estimates

Two methods were devised to estimate actual annual loads and yields of TP and TN from the study watershed during the study period using discharge records from USGS Gage 07052000. The first method used averaged daily discharges. The data needed for this method is created by the USGS by calculating the mean of real-time discharge data for each day and is available at the gage website (USGS [1]). Because of the rapid rise and recession of storm hydrographs at this site, the high discharges that occur for only short periods of time but that feature high concentrations of nutrients, especially TP, are likely to be under-represented. Load estimates from this method may be low. To offset this, a second method was devised that utilized the maximum discharge for each day during the study period. For days without precipitation the maximum and mean discharges are the same but for storm events the difference is dramatic. This method is very likely to overestimate the nutrient loads because the peak discharge for the day is treated as an entire day of discharge in the model, and thus this estimate will be treated as an upper limit for loads and yields. Values for average and peak daily discharges are included in Appendix D.

Average Daily Discharge – Based Load Estimate. Flow records at this site include average daily discharge values. After estimating values to fill in a gap in data during the study period (Methods: Average Daily Flows), the average daily loads were compiled inserting discharge into the WC1 load rating equation for each nutrient constituent (Table 5.9).

Peak Daily Discharge – Based Load Estimate. The peak daily record was created by selecting the peak flows recorded for all days with average flows greater than 0.75 m^3/s (Table 5.11). The selected peak values were retrieved from archived real-time discharge data provided by the USGS. It was assumed that flows below this threshold were baseflows, and that peak flows for baseflows would not differ significantly from average flows. Because instantaneous peak flows from the gage record were used to calculate a daily load, a process that extended the duration of a peak flow to the period of an entire day, the estimates from this method were expected to be much higher than the others.

Watershed Land Use-based Load Estimate

The EPA TMDL handbook outlines a “simple method” for estimating load based on total area and percent of landuse type within the watershed (US EPA, 1999) (Table 5.12, Fig 5.7). The method outlined produces minimum, median and maximum expected loads of TP and TN based on expected yields from typical urban surfaces. A graphic comparison of simple method loads and the flow based loads shows that average daily flow – based and flow exceedance – based estimates were similar to EPA simple method estimates for TN and low for TP and that in both cases the peak daily flow – based estimate was very much greater (Fig. 5.7).

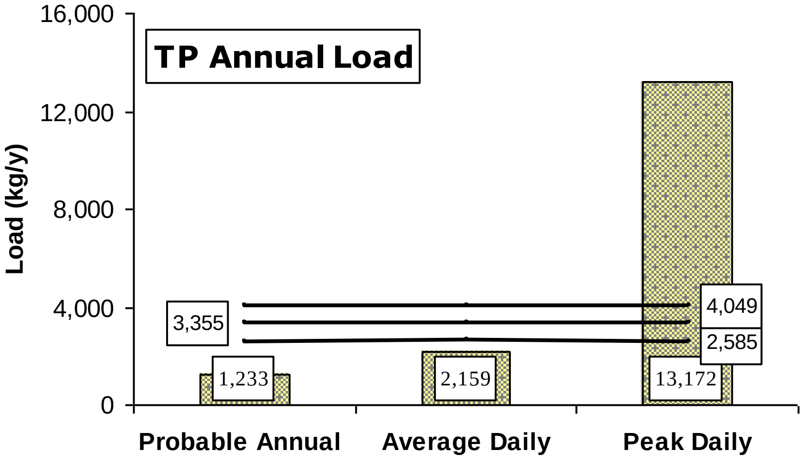
Simple Method Subwatershed Load and Yield. This method can also be applied to each subwatershed because it is not dependent on continuous discharge records (Fig. 5.8 and 5.9). The percent area of each land use type does not vary much between

Table 5.11: Annual load and yield estimates at Site WC1 based on different methods for study period August 2004 to July 2005.

Method		**Load (kg/y)**		**Yield[1] (kg/y-km^2)**		**Yield[2] (kg/y-ha)**	
		TN	**TP**	**TN**	**TP**	**TN**	**TP**
Daily Flow	Average	26,818	2,159	535	43	5.35	0.43
	Peak	76,616	13,172	1,527	263	15.27	2.63
EPA	Min	10,728	2,585	214	51.5	2.14	0.51
	Median	20,693	3,355	412	66.8	4.12	0.67
	Max	30,471	4,049	607	80.7	6.07	0.81
Probable Annual		24,334	1,233	484.7	24.6	4.85	0.25

[1] Based on watershed area of 50.2 km^2

[2] Based on watershed area of 5016 ha



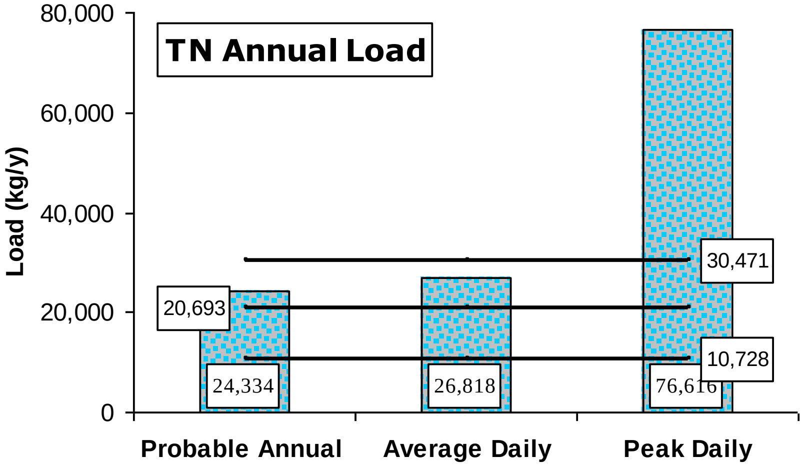


Figure 5.8: Comparison of probable TP and TN annual load estimates for Site WC1. EPA land use-based maximum, median and minimum estimates shown as lines.

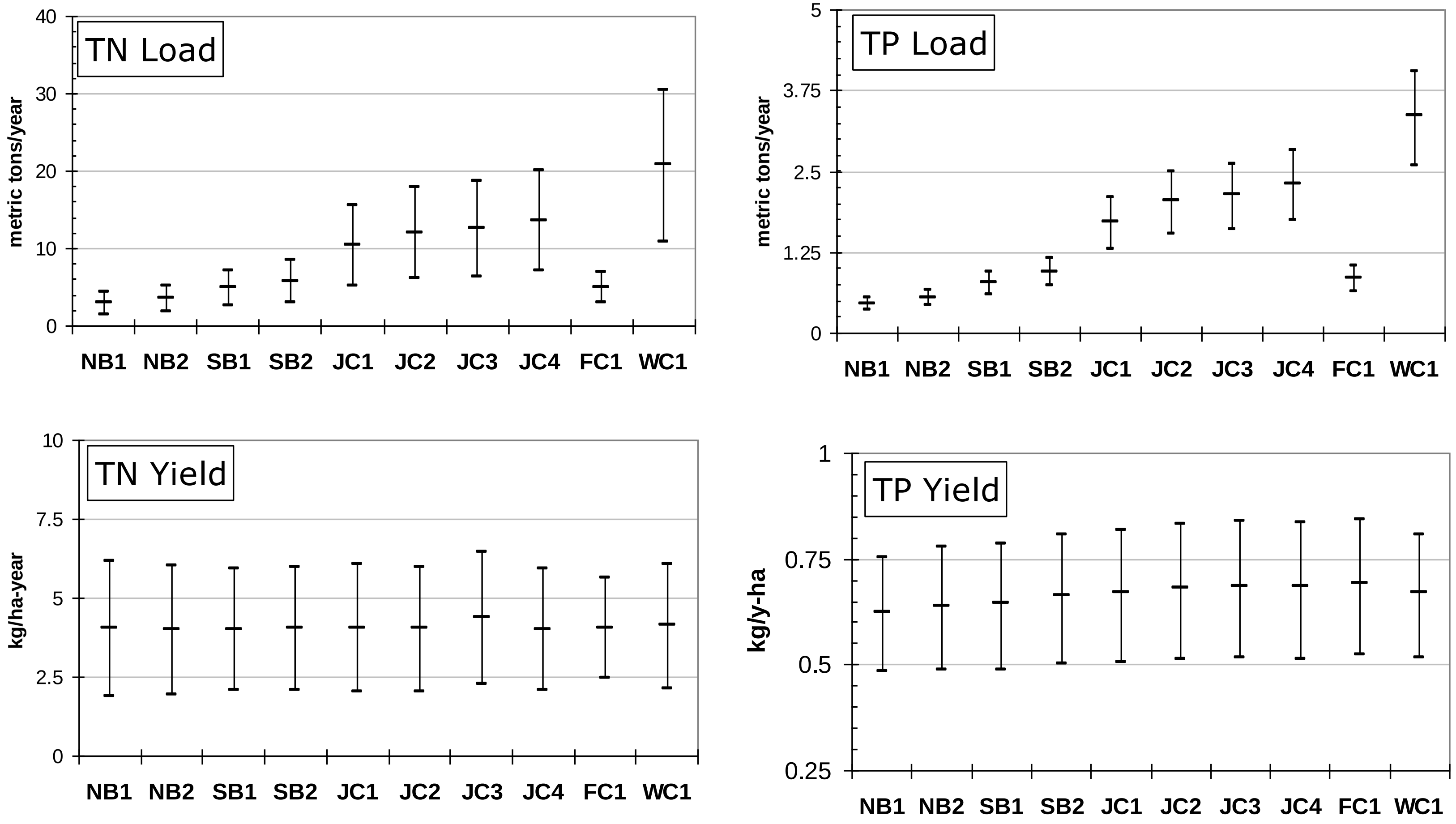


Figure 5.9: Loads and yields based on land-use loading rates showing max, median and minimum values (USEPA, 1999).

Table 5.12: EPA “simple method” loads and yields for each site

	NB1	NB2	SB1	SB2	JC1	JC2	JC3	JC4	FC1	WC1
					TP Load (kg/y)					
Min	346	417	586	718	1,294	1,526	1,594	1,726	636	2,585
Max	539	666	942	1,157	2,085	2,484	2,597	2,819	1,026	4,049
Median	447	548	774	950	1,712	2,034	2,126	2,306	843	3,355
					TP Yield (kg/y-km^2)					
Min	48.34	48.60	48.69	49.98	50.63	51.14	51.43	51.16	52.26	51.54
Max	75.34	77.59	78.33	80.58	81.55	83.24	83.77	83.54	84.28	80.73
Median	62.45	63.85	64.31	66.15	66.98	68.16	68.59	68.35	69.24	66.88
					TN Load (kg/y)					
Min	1,329	1,671	2,467	2,978	5,122	6,035	6,263	6,984	2,957	10,728
Max	4,409	5,159	7,113	8,516	15,465	17,838	18,552	19,940	6,864	30,471
Median	2,884	3,434	4,815	5,776	10,349	12,002	12,474	13,543	4,930	20,693
					TN Yield (kg/y-km^2)					
Min	185.86	194.53	205.12	207.80	200.36	202.20	225.32	206.97	242.97	213.88
Max	616.54	600.76	591.33	594.31	604.98	597.71	643.27	590.91	564.07	607.50
Median	403.30	399.89	400.29	403.11	404.87	402.15	436.90	401.33	405.11	412.54
Area (km^2)	7.2	8.6	12.0	14.3	25.6	29.8	31.0	33.7	12.2	50.2

watersheds which is likely why the TN and TP yields for each subwatershed are very similar. Variation in the loads per watershed produced by this method is thus probably due mostly in this case to the differences in watershed area. Tables of land-use areas for each watershed are included in Appendix E.

Flow Modeling-based Site Comparisons

The sampling methodology used during the study did not lend itself easily to comparing loads from one site to another because there was no guarantee that samples were taken from the same point on the hydrograph at each site during a sample run. Also, because only Site WC1 had continuous discharge records, annual load estimates could not be prepared for the subwatersheds using load rating curves. To permit better intra-site comparisons city flood-discharge modeling data was used to create a set of common discharges that could be used in each site's load equation (Table 5.13, Fig. 5.10) (Kemper, 2005). The modeled discharge represents the 1 – year recurrence precipitation event with a 12 – hour accumulation period (1 – year flood). This common magnitude of discharge approximates sampling from a common point on the hydrograph. Because of the negative slope for storm TP load at Site NB1 and the unlikelihood of lower TP loads for higher discharges, the city - modeled load was calculated using the storm load sample mean for TP rather than the curve-predicted value. Loads are presented in kilograms per day (kg/d) and represent the load predicted by the TN or TP load rating curve if the modeled flood discharge persisted for an entire day. This is not necessarily a realistic situation, but it does allow for inter – site comparison based on a common discharge level.

According to the 1-year flood modeling, the distribution of TP and TN loads within the watershed are different. The small sub-watersheds located in the headwaters of the watershed (NB1, NB2, SB1 and SB2) and Site FC1 have the lowest TP loads, with the smallest load of TP occurring at Site NB1. The main stem sites JC1-4 have larger TP loads that the headwater sites with a trend that increases downstream. The peak TP load within the study area occurs at site JC4. Site WC1, located at the outlet for the study watershed, has the second largest predicted load of TP (Fig. 5.9).

Loads of TN are lowest at the headwaters sites (NB1, NB2, SB1 and SB2), with the North Branch sites (NB1 and NB2) having an increasing load trend downstream and the South Branch sites (SB1 and SB2) showing a decreasing trend downstream. The main stem sites JC1-4 have greater loads with the trend increasing from JC1 to JC3 and then decreasing JC3 to JC4. Site FC1 has a smaller load than the main stem but greater than the headwater sites. Site WC1, having the largest area, also has the greatest load.

Yields signify load per unit of watershed area, and yield comparisons can be made without the distortion of differing size. The largest TP yield in the study watershed occurs at Site JC4 and the second largest at site NB2. The smallest yield occurs at site NB1. The upper watersheds show an increasing downstream trend for the North Branch sites (NB1 and NB2) and a decreasing downstream trend for the South Branch watersheds (SB1 and SB2). The main stem sites (JC1 to JC4) show an increasing downstream trend. Yield for Site FC1 is approximately equal to the yield for Site SB1. The yield at Site WC1, the study area outlet is less than the maximum yield seen at Site JC4.

The maximum TN yield occurs at Site JC3, with Sites FC1 and WC1 closely grouped with the second largest yield. The North Branch watersheds show increasing downstream while the South Branch watersheds show decreasing downstream trends. As with TN loads, the main stem yields increase downstream to Site JC3 and then decrease to Site JC4.

Table 5.13: City of Springfield modeled 1 – year flood (12 – hour accumulation)

					Discharge (m^3/s)					
	NB1	**NB2**	**SB1**	**SB2**	**JC1**	**JC2**	**JC3**	**JC4**	**FC1**	**WC1**
Q	10.6	12.6	11.6	15.1	31.0	42.2	43.1	47.5	16.9	67.2
					Load (kg/d)					
TP	25	253	237	223	525	619	820	1,433	232	1,256
TN	451	695	816	760	1,480	2,017	3,852	3,072	1,257	5,193
					Yield (kg/d-km2)					
TP	3.5	29.5	19.7	15.5	20.5	20.7	26.5	42.5	19.0	25.0
TN	63.1	80.9	67.8	53.0	57.9	67.6	124.3	91.0	103.3	103.5

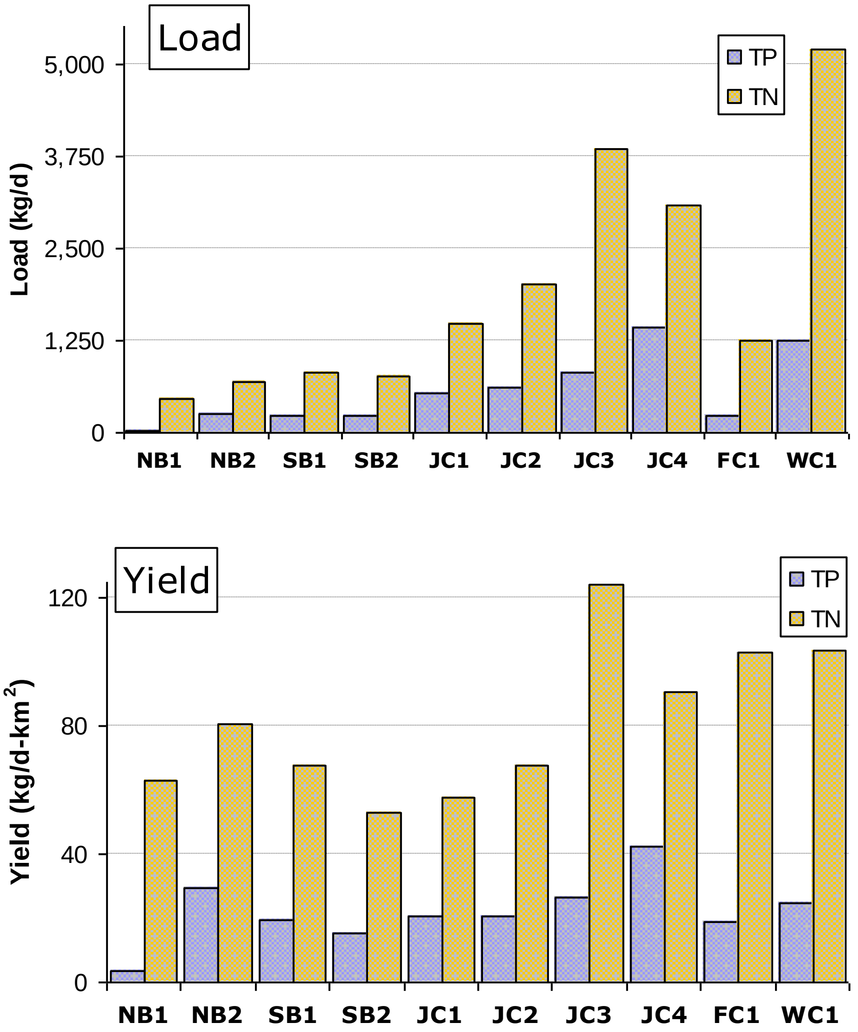


Figure 5.10: City modeled 1-year flood loads and yields.

CHAPTER 6

DISCUSSION

This chapter presents a discussion of the results of the study. The first section addresses the sample concentration, load and water chemistry results, the Temp and SC water chemistry trends and their associations with TN and TP, and general watershed trends. The second section examines sources of error in the study, including sampling, analysis and calculations. The final section compares results of the study to other local and regional studies.

General Trends for Concentrations, Loads, Water Chemistry

Baseflow and Storm Separation. The decision during the study, to separate samples into baseflow and storm subsets for purposes of creating rating curves for concentration and load, was based on two factors. First, that the study area streams, Jordan Creek, Fassnight Creek and upper Wilson Creek, are relatively small with a very fast discharge response to precipitation. The event hydrographs recorded at USGS Gage 07052000 transition in a matter of hours from baseflow to peak discharge and back again (Table 5.1). This seems to describe a stream system affected by two flow modes (base and storm) with no intermediate or transitional mode. The second factor was the difference in nutrient concentration trends between the two flow modes (Fig. 6.1). The sample concentrations, when considered together, produced a very different trend than when split into baseflow or storm subsets. Use of the larger trend would mask important underlying trends such as

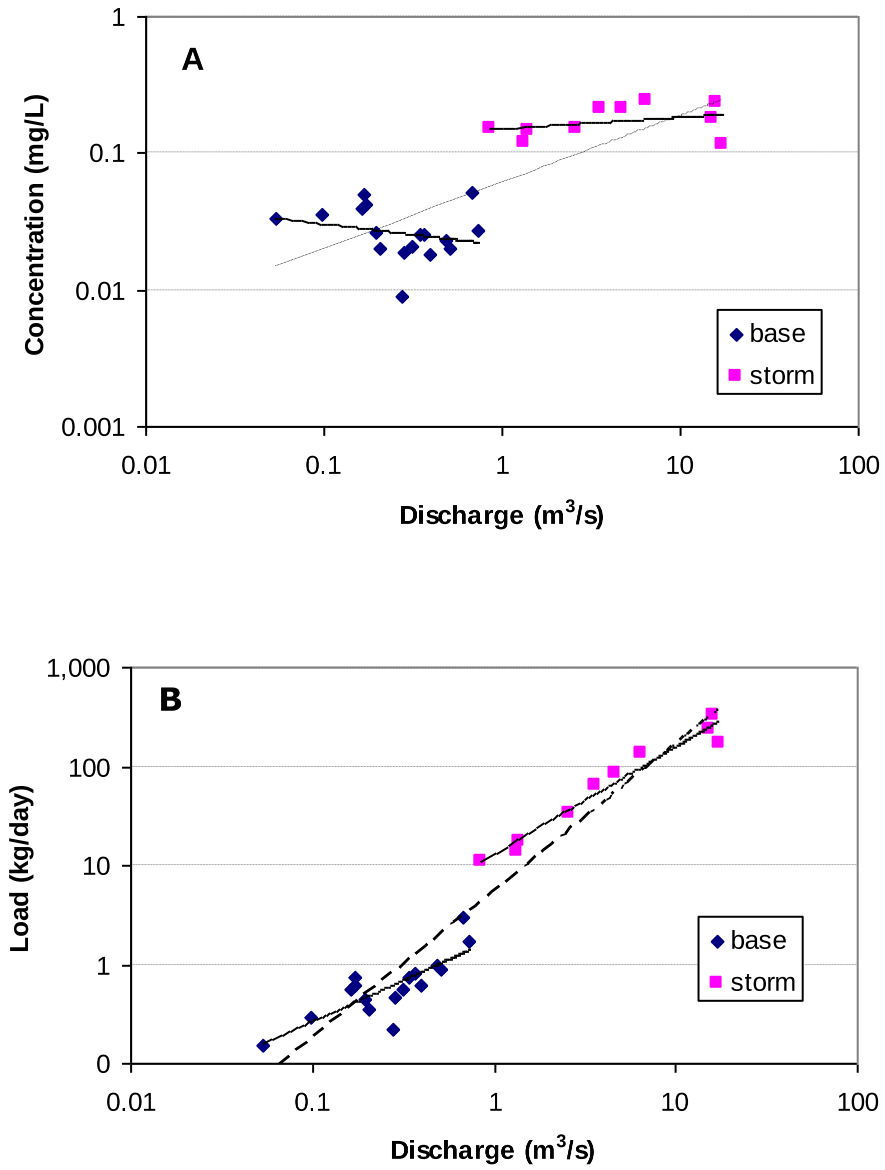


Figure 6.1: Comparison of Site WC1 TP rating curve slopes including baseflow, storm and universal curves for (a) concentration and (b) load.

the decreasing concentration of TP with increasing baseflow discharge at Site WC1. To test for the consistency of the difference between separated and universal rating curve slopes the 95 % confidence interval for the linear regression of discharge and TN and TP was calculated (Table 6.1). In 9 out of 10 cases for TP the 95 % confidence interval for

Table 6.1: Table of linear regression slope coefficients and 95 % confidence ranges for TP and TN concentration ratings. “TRUE” or “FALSE” in the **Incl. Zero** field indicates whether the 95 % confidence range includes a slope of 0.

	Base TP				**Storm TP**				**All TP**			
		95 % Confidence				**95 % Confidence**				**95 % Confidence**		
	Slope	**Lower**	**Upper**	**Incl. Zero**	**Slope**	**Lower**	**Upper**	**Incl. Zero**	**Slope**	**Lower**	**Upper**	**Incl. Zero**
NB1	-4341.47	-13246.48	4563.54	TRUE	-52.88	-166.31	60.55	TRUE	19.99	-92.98	132.96	TRUE
NB2	527.12	-210.07	1264.31	TRUE	7.59	-16.07	31.25	TRUE	29.51	6.95	52.06	FALSE
SB1	5.64	-74.96	86.23	TRUE	13.84	-32.75	60.44	TRUE	64.67	32.29	97.05	FALSE
SB2	3820.52	-4667.17	12308.22	TRUE	-13.67	-37.10	9.76	TRUE	-0.80	-102.03	100.43	TRUE
JC1	258.23	33.17	483.28	FALSE	-4.13	-25.25	16.99	TRUE	20.79	-14.26	55.84	TRUE
JC2	-42.34	-218.62	133.94	TRUE	-2.27	-12.53	8.00	TRUE	12.85	4.09	21.61	FALSE
JC3	3.61	-37.41	44.62	TRUE	1.34	-6.03	8.72	TRUE	14.46	8.08	20.85	FALSE
JC4	-48.69	-139.32	41.94	TRUE	13.79	0.16	27.43	FALSE	34.95	25.15	44.76	FALSE
FC1	189.67	-171.44	550.77	TRUE	2.83	-57.18	62.84	TRUE	47.94	12.18	83.69	FALSE
WC1	-5.29	-38.49	27.91	TRUE	1.10	-4.64	6.84	TRUE	9.85	4.94	14.77	FALSE
	Base TN				**Storm TN**				**All TN**			
NB1	-12.09	-63.49	39.31	TRUE	-0.25	-0.70	0.20	TRUE	-0.39	-0.94	0.15	TRUE
NB2	8.95	0.52	17.38	FALSE	-0.10	-0.29	0.09	TRUE	-0.24	-0.47	-0.02	FALSE
SB1	-0.50	-4.35	3.34	TRUE	0.04	-0.23	0.30	TRUE	0.07	-0.21	0.35	TRUE
SB2	13.22	-2.82	29.26	TRUE	-0.15	-0.34	0.03	TRUE	-0.28	-0.51	-0.05	FALSE
JC1	0.35	-0.50	1.20	TRUE	-0.07	-0.20	0.07	TRUE	-0.15	-0.29	-0.02	FALSE
JC2	7.45	3.30	11.61	FALSE	-0.04	-0.13	0.04	TRUE	-0.10	-0.19	0.00	FALSE
JC3	-0.24	-4.27	3.80	TRUE	0.01	-0.08	0.10	TRUE	-0.05	-0.16	0.07	TRUE
JC4	5.61	-1.72	12.94	TRUE	-0.01	-0.15	0.14	TRUE	-0.12	-0.27	0.04	TRUE
FC1	8.41	-12.48	29.30	TRUE	0.03	-0.66	0.72	TRUE	-0.51	-1.27	0.25	TRUE
WC1	4.73	2.22	7.24	FALSE	0.00	-0.08	0.08	TRUE	-0.06	-0.15	0.03	TRUE

baseflow and storm included zero, but this was true for only 2 out 10 for the universal rating curves. This fact points to a qualitative difference between the subsets and the universal curves: that the subset sample mean TP concentrations could be substituted for either baseflow or storm curve-predicted values but the mean of all TP concentrations cannot substitute for curve-predicted universal values. The TN slope data does not show this pattern as strongly, but the WC1 baseflow – storm slope difference seen in Fig. 6.1 indicates that, as with TP, it is better to predict baseflow behavior with baseflow samples and storm behavior with storm samples.

Study Period Flow Duration. A ranked distribution of the average daily flow record was used to create a flow exceedance graph for the study period. The graph is a graphic representation of the probability during the study period that a certain level of discharge was exceeded (Fig. 6.2). The median Q (0.20 m^3/s) has 1/2 of flows smaller and 1/2 larger and is found on the graph above 50 % exceedance. The mean Q (0.57 m^3/s) is the arithmatic average of daily discharges from the study period, its position on the curve indicates that it was exceeded by 40 % of daily discharges during the study period. The baseflow-storm flow threshold used in the study (0.8 m^3/s) was exceeded by about 12 % of daily discharges.

A ranked distribution of concentrations of TP and TN, calculated from the average daily flow and concentration ratings for Site WC1, was used to create a concentration exceedance graph (Fig. 6.3). This graph denotes the amount of time that a particular

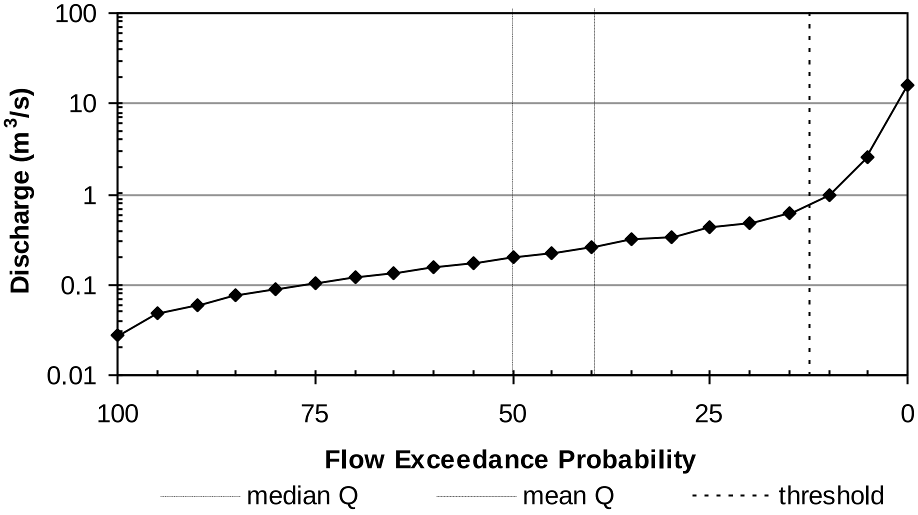


Figure 6.2: Average daily discharge duration graph for study period. Horizontal dashed line indicates baseflow-storm threshold for the study (0.8 m^3/s). The vertical dashed lines indicate the probability that the median (0.20 m^3/s), mean annual (0.57 m^3/s) and storm threshold (0.8 m^3/s) flows will be exceeded.

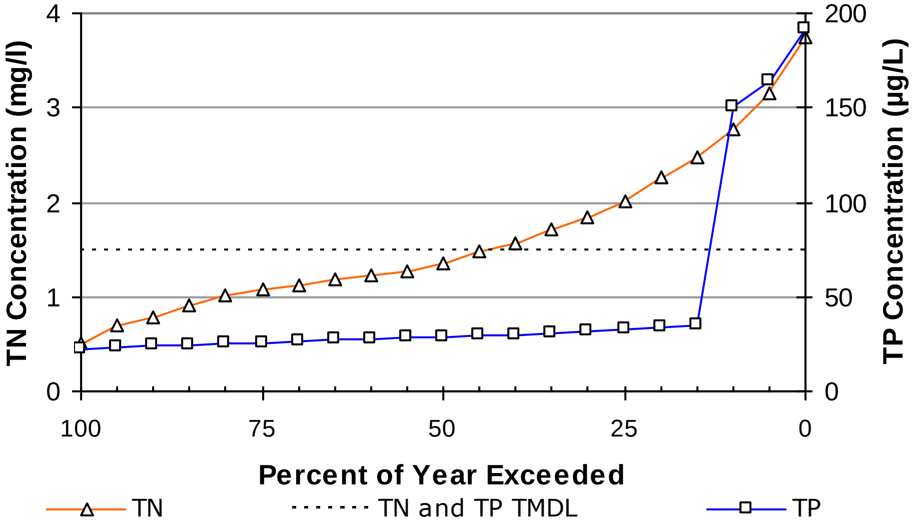


Figure 6.3: Daily concentration exceedance curves for the study period. Position on curve indicates the percent of the study period that a particular concentration was exceeded. Horizontal dashed line represents James River TMDL concentrations for TN (1.5 mg/L) and TP (75 µg/L) (MoDNR (2001)[2]).

concentration of TP or TN was exceeded during the study period. Critical concentrations for the study are the James River TMDL nutrient target recommendations (75 µg/L TP and 1.5 mg/L TN). The concentration exceedance graph for the study period indicates that the recommended concentration for TN was exceeded during 45 % and TP was exceeded during 14 % of the study period.

A similar graph, based on ranked loads of TN and TP, shows the cumulative percent of load transported during the study period (Fig. 6.4). The horizontal scale represents percent of time (the study period) and the vertical scale represents the percent of load transported. The vertical scale does not originate at zero because there were no loads of zero during the study, and a log scale is used to increase separation between the curves. The graph shows that half of the time transports only 5 % of the total TN and 1 % of the total TP. Half of the total TN load is transported in 93 % of the total time and

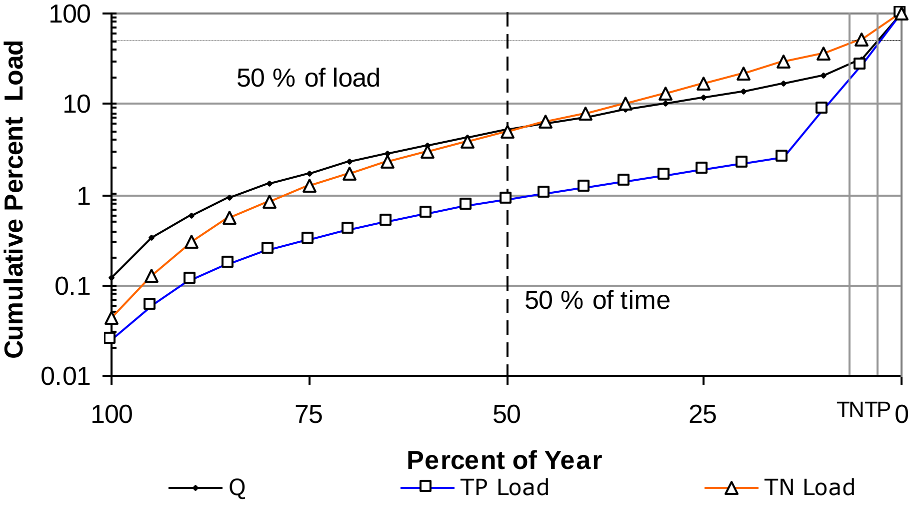


Figure 6.4: Cumulative load duration graph for study period. Vertical dashed line indicates loads transported in 50 % of the study period. The horizontal dashed line divides the total load into halves and illustrates that 50 % of the load is transported in a small percentage of the time (7 % TN and 3 % TP).

half of the total TP load in 97 % of the total time. This illustrates that a few very large events are responsible for much of the load transport.

Seasonal TN - Temperature Relationship. A seasonal TN concentration trend was detected at Site WC1 (Fig. 5.4). The WC1 trend is negative, showing the highest TN concentrations at the lowest water temperatures and the lowest TN concentrations at the highest water temperatures. This trend could indicate a seasonal change in soil TN concentrations similar to trends found by Zhang and Schilling (2005) in Iowa and Vanderbilt et al (2003) in Oregon.

Examination of the Pearson correlation coefficients for TN and stream temperature shows that a negative trend appears at all Sites except NB1 and is strongest for baseflow conditions (Table 6.2, Figure 6.5). Site NB1 was unique among sites in having long periods with no measurable discharge. Water samples were taken and water quality parameters measured at a karst related seep that fed a pool of water at the site but often introduced no flow to the channel. This unique circumstance may be responsible for the positive trend at Site NB1. Therefore, with the exception of Site NB1, it appears that the seasonal trend for baseflow TN concentration is consistent throughout the watershed.

Table 6.2: Pearson correlation coefficients showing negative relationship for temperature and TN concentration at baseflow for each site except NB1.

				TN and Temp						
	NB1	**NB2**	**SB1**	**SB2**	**JC1**	**JC2**	**JC3**	**JC4**	**FC1**	**WC1**
All	0.252	-0.193	-0.362	-0.286	-0.341	-0.279	**-0.441**	-0.437	**-0.516**	**-0.522**
Base	0.150	**-0.652**	**-0.489**	**-0.594**	**-0.774**	**-0.627**	**-0.703**	**-0.734**	**-0.682**	**-0.731**
Storm	**0.792**	0.622	-0.060	0.479	0.515	0.519	0.354	0.251	-0.028	-0.031

Bold = significant at 95 % **Bold** = significant at 99 %.

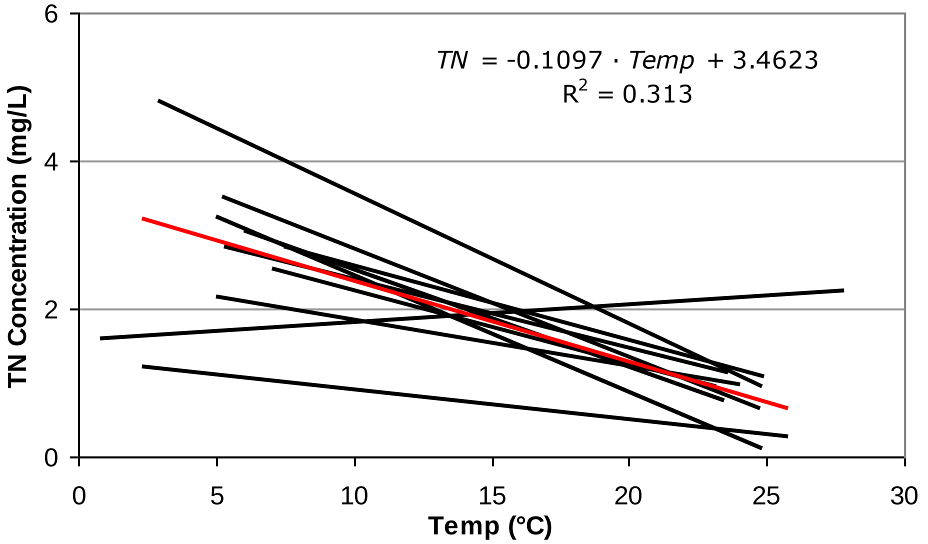


Figure 6.5: Trendlines for TN – TEMP relationship at baseflow for all sample sites. The positive trendline occurs for Site NB1, which differed from most sites in having no flow at times during the study period. Shown in red, with equation and R^2, is the trendline for all sites together.

Specific Conductance – TP Relationship. A very significant (99 %) negative correlation appeared at Site WC1 between SC and TP (-0.886) when all samples were included,. This implies that TP concentrations are greater when the concentrations of dissolved electrolytes decreases, such as when SC – poor storm runoff enters the stream. The strength of the correlation is reduced considerably when baseflow and storm samples were considered separately however. This pattern is consistent throughout the study sites when all samples are included, with all sites having a negative correlation between SC and TP and most being significant at 99 % confidence except Sites SB2 and JC1 (Table 6.3). When baseflow and storm samples are considered separately the pattern of reducing strength of negative correlation generally continues, although Site SB2 and NB2 are exceptions, showing positive correlations. Storm TP and SC correlations seem to have no consistent pattern since four sites show positive and six sites negative correlations

Table 6.3: Pearson correlation coefficients for SC and TP.

				SC and TP						
	NB1	**NB2**	**SB1**	**SB2**	**JC1**	**JC2**	**JC3**	**JC4**	**FC1**	**WC1**
All	**-0.551**	**-0.689**	**-0.858**	-0.020	-0.330	**-0.818**	**-0.929**	**-0.934**	**-0.685**	***-0.886***
Base	**-0.548**	0.087	-0.379	0.106	-0.079	-0.465	-0.268	**-0.633**	**-0.508**	***-0.542***
Storm	-0.196	**-0.771**	-0.320	0.027	-0.231	0.164	-0.123	-0.397	**0.875**	0.152

Bold = significant at 95 %   **Bold** = significant at 99 %.

with one each being significant at 99 % confidence. The change in correlation between including all samples and including only baseflow or storm samples implies that the strength of the relationship comes from the difference between storm TP and SC values and their baseflow values and not from any consistent relationship between TP and SC, therefore despite the strong correlation SC probably cannot be used to predict TP concentration.

Discharge is one of the important parameters measured in the study. Changes in discharge are the stream response to changes in precipitation and help divide the sample set into baseflow and storm subsets, and discharge is used as the control variable in concentration and load rating curves for TN and TP. It is important therefore to try to understand how discharge relates to other important water quality parameters measured in the study such as pH, specific conductance and turbidity. The Pearson correlation coefficients for all samples indicate a negative relationship between pH and discharge for all sites except JC4 with sites NB2, SB2 and JC2 having significant negative correlations (Table 6.4). This means that for most sites the storm pH samples are lower than the baseflow pH samples. This is the pattern one would expect since runoff water which falls as mildly acidic precipitation, would reduce the pH of the buffered stream water (Schroder and Brennan, 1985; Drever, 1997). The Pearson correlation coefficients for

Table 6.4: Pearson correlations with discharge for pH, specific conductance and turbidity.

Discharge Correlations

	NB1	**NB2**	**SB1**	**SB2**	**JC1**	**JC2**	**JC3**	**JC4**	**FC1**	**WC1**
pH										
All	-0.022	**-0.534**	-0.251	**-0.398**	-0.676	**-0.676**	**-0.447**	0.147	-0.333	-0.034
Base	**0.787**	-0.294	0.163	0.094	**-0.565**	**-0.565**	-0.203	-0.068	-0.195	-0.388
Storm	0.062	-0.631	-0.284	-0.611	-0.547	-0.547	-0.520	-0.337	0.130	0.236
SC										
All	**-0.491**	0.223	0.288	0.163	0.015	0.015	0.135	0.203	-0.039	0.144
Base	-0.303	-0.323	0.220	-0.182	0.054	0.054	-0.123	0.016	-0.403	-0.191
Storm	-0.119	-0.507	-0.519	-0.530	-0.412	-0.412	-0.016	-0.093	-0.076	-0.475
TURB										
All	0.244	**0.502**	0.169	0.194	0.291	0.291	**0.700**	**0.481**	0.250	0.319
Base	0.382	0.402	0.037	-0.297	0.326	0.326	-0.387	0.054	0.205	-0.142
Storm	0.340	0.597	0.576	0.036	0.328	0.328	**0.705**	0.361	0.337	0.400

Bold = significant at 95 % **Bold** = significant at 99 %.

pH and discharge in baseflow and storm sample sets are generally negative, indicating that generally within each sample set pH decreases as discharge increases.

Specific conductance correlation with discharge shows a lot of variation both when all samples are included and when baseflow only are considered, but are uniformly negative for storm samples (Table 6.4). Specific conductance in rainwater is very low and storm runoff has little time to dissolve material as it travels across the urban surface and into the stream. Therefore, it is expected that large storm discharges would have low SC, so it is surprising that the trend does not appear with all samples included (Schroder and Brennan, 1985).

Turbidity is an optical measurement related to the suspended sediment concentration in a water sample. It would be expected that TURB would increase as discharge increases since large discharges and flow velocities have greater ability to pick up and carry sediment. This is shown with the positive correlation between TURB and discharge for all sites both when all samples and when only storm samples are included

(Table 6.4). At baseflow are there some negative correlations between TURB and discharge. These may be due to site conditions that stirred up bottom sediment in slow-flowing water.

Comparison of Inter-site Loads and Yields. Two techniques were used to create estimates of loads and yields for each sub-watershed: the EPA ”simple method” based on watershed area and percent land use and the common discharge method based on City of Springfield discharge modeling and site load rating curves. The two methods are not equivalent; the EPA method produces an annual estimate while the common discharge method produces a daily estimate, but the relative difference of loads and yields between sites should provide a basis for comparison between the two methods.

A line graph comparison shows that the two estimates have the same general pattern (Fig. 6.6). Very low loads occur at the upstream north branch sites (NB1 and NB2), larger loads on South Branch sites (SB1 and SB2) then an increasing trend through

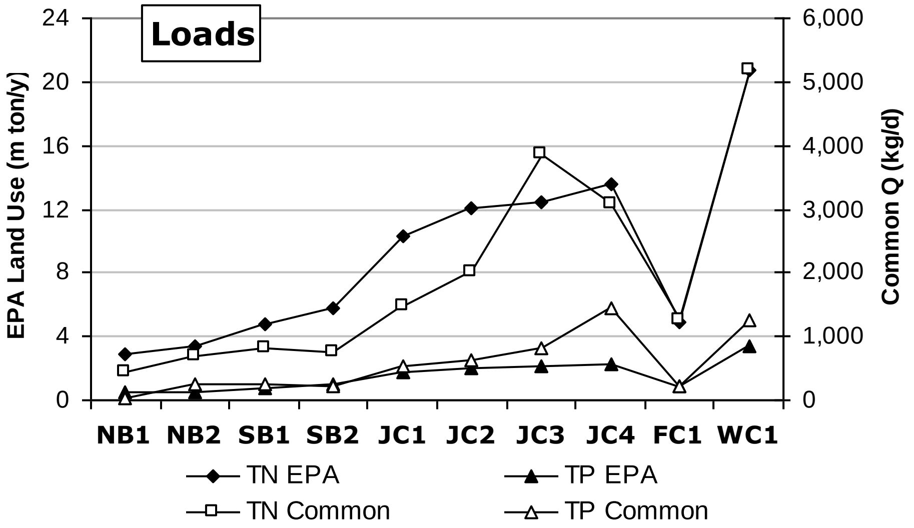


Figure 6.6: Line graph of loads estimated by EPA land use and common discharge methods.

the main branch sites the EPA estimate peaks at site JC3 while the common discharge estimate peaks at site JC4. The distributions appear much different when plotted by drainage area (A_d). The slopes of regression lines for the two load estimates are very similar but the EPA loads have a very linear distribution whereas the common discharge loads are scattered around their trend line as is reflected in their respective correlation coefficients (Fig. 6.7). Drainage area explains nearly 100 % of the EPA method loads of TP and TN but 88 % of TN and 82 % of TP loads for the common discharge method. Because this method incorporates data collected independently from each watershed it is likely that the remainder of variation is due to source differences between sites.

The differences become more evident when loads are divided by watershed area to produce yields. The EPA method yields, because they are heavily based on watershed area, are nearly linear but the common discharge method again shows more widely distributed data and when the yield estimates are plotted by drainage area the difference in patterns becomes more distinct (Fig. 6.8). The EPA method produces a distribution with a slope that is very nearly zero while the common discharge method has a distinct positive slope. The slope is probably due more to the distribution of yields caused by the common discharge method than to the effects of watershed size. The distribution of points seems to be influenced by some very low values for small watershed areas that give the distribution an artificial positive slope. Because the land use is relatively uniform over the watershed it is likely that the true slope would, like the EPA estimate, be zero.

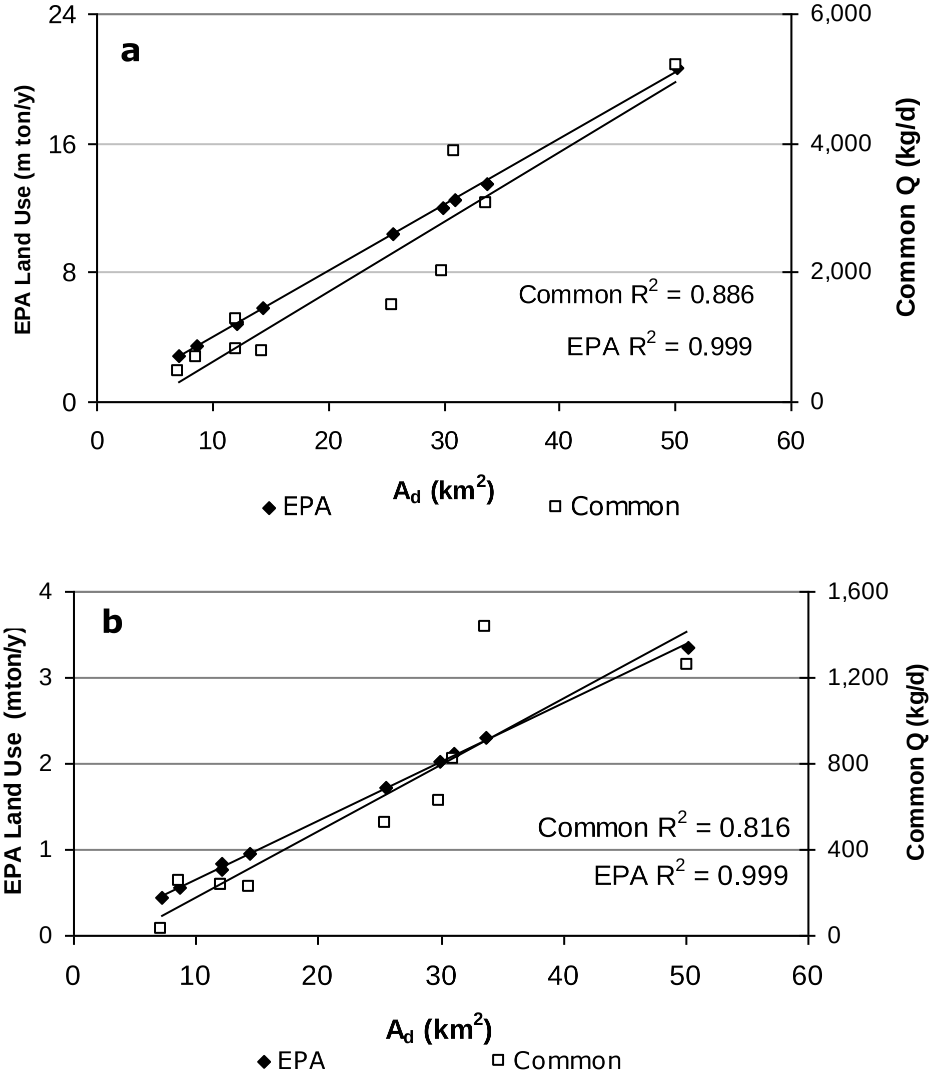
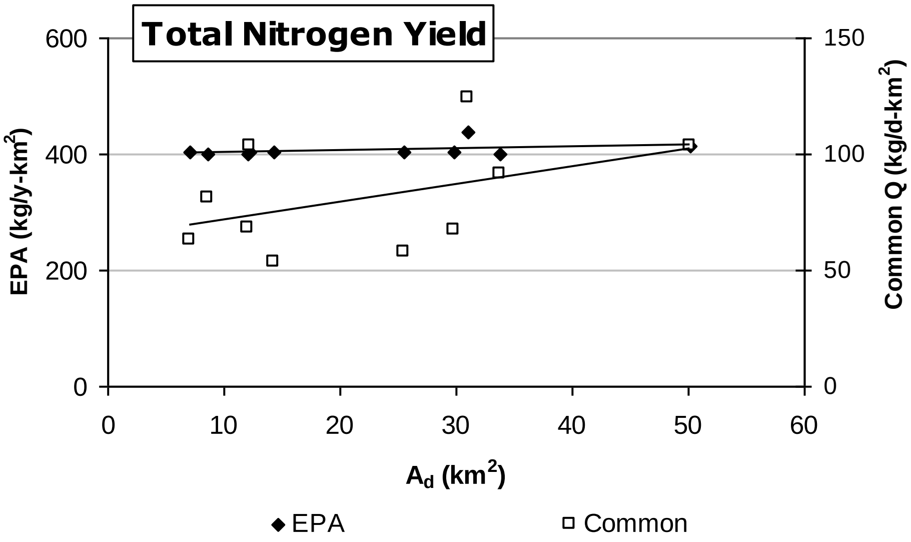


Figure 6.7: Comparison of loads estimated by EPA land use and common discharge methods.(a) TN and (b) TP. A_d = drainage area.

Sources of Error in Load Estimates

Error in load estimates can come from several sources including sampling, discharge measurement and laboratory analysis. These errors can further be classified as random errors, those that vary randomly above or below the true value and have a mean of zero and systematic errors, those that are biased above or below the true value and thus



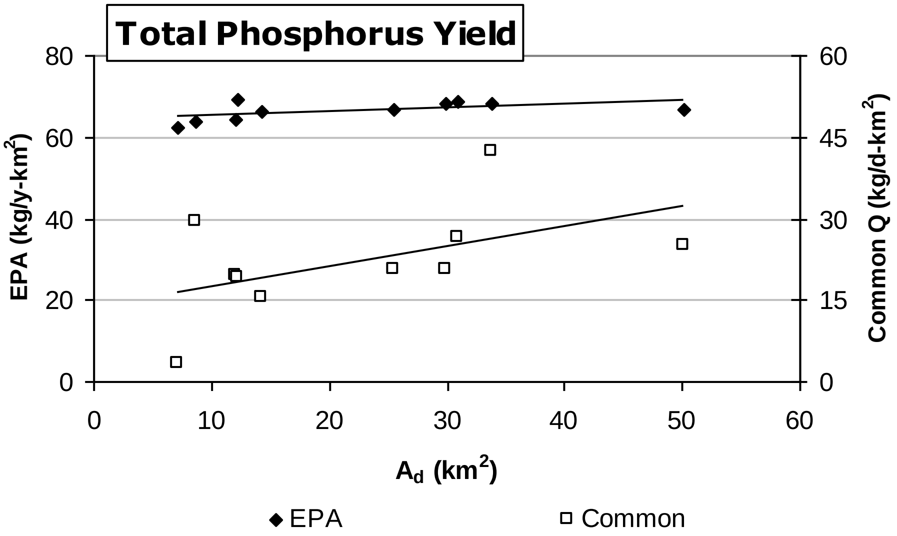


Figure 6.8: Comparison of TN and TP yields for EPA and common discharge methods.

have a mean that is not zero. Random errors can effectively be ignored, especially if the sample size is large, but systematic errors must be resolved if possible. Errors should be evaluated for their potential impact on the quality of the load estimate (Haan et al, 1994). Potential sources of error in this study are: water sampling methodology, water sample analysis, stream velocity measurement, and discharge estimation.

Sampling Error. Sampling error includes error associated with both the sampling of water and errors estimating flow. The present study used a grab-sampling method to collect an instantaneous sample of concentration and discharge at a site. This method assumes that concentrations are uniform across the stream and also that they are not changing dramatically from one moment to the next around the sample time. An attempt was made to control for cross-channel variations by sweeping the sample bottle across the thalweg to collect a "cross-sectional" grab sample. No tests were conducted on the actual cross-sectional variation of concentration since the study stream is narrow and relatively well mixed. Variation of concentration through time was addressed through the collection of field duplicate samples, in which a second sample was taken from a randomly-selected selected site during a sample period, usually within 1 minute. If the field duplicate concentrations fall outside the expected range (± 20%) of the original sample concentrations then the source of the error, including in-stream variation, should be explored. The mean 20 % range for TP samples was 14.5 µg/L for baseflow and 81.2 µg/L for storm samples, for TN the range was 0.86 mg/L baseflow and 0.42 mg/L storm. The mean percent difference for original and field duplicate samples for TP was 10.3 % for baseflow and 4.4 % for storm events, which may be attributable to the low values approaching the detection limit. For TN the mean percent difference was 5.9

% baseflow and 8.6 % for storm event samples. Both TN and TP field duplicates fall within this acceptable range and thus the assumption of uniform concentration per discharge can be accepted (Fig 6.9).

Temporal Variations Due to First Flush. An exception to this assumption involves the asymmetry or hysteresis of pollutant concentrations within the storm hydrograph. This is the “first flush” phenomenon in which the rising limb of the

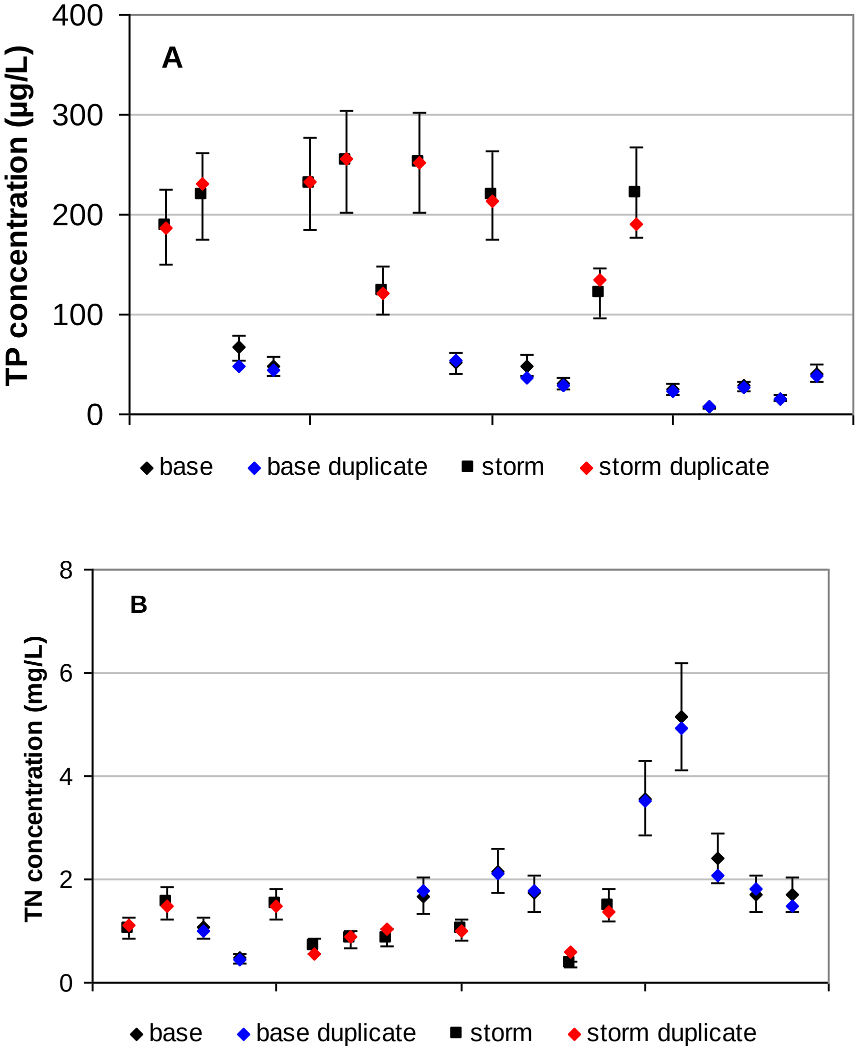


Figure 6.9: Field duplicate acceptance range ± 20% of original sample for (a) TP and (b) TN for storm and baseflow samples.

hydrograph is found to contain higher concentrations of some pollutants than the falling limb. Pollutants most likely to be present in a first flush are either suspended sediment and any pollutants associated with sediment such as phosphorus or metals, extremely soluble pollutants such as road salt or floatable pollutants such as oil and grease. Continuous sampling throughout a storm event can detect and correct for this but a single sample cannot. The present study sampled consistently on the falling limb of the hydrograph (as measured at USGS Gage 07052000) and thus is very likely to have missed the highest concentrations of TP and metals in storm events. The under-representation of TP in storm samples is supported by the consistent difference between the Richards-Johnson flow-composite TP concentrations and the TP concentrations from the present study (Fig. 6.17) although, if it exists, the magnitude of the error is unknown and cannot be estimated.

Discharge Calculation Error. Discharge was measured for each sample by measuring stream velocity with a velocity meter or float test and then multiplying that velocity by an estimate of cross-sectional area. Direct measurements as above were included in a discharge rating curve that was used to estimate discharge from stage measurements alone. Errors in discharge measurement can lead to errors in load estimates. Stream velocities measured with the flow meter have a potential error of 0.03 m/sec (± 0.1 fps) (Global Water, 1997 [1] and [2]).

The site surveys used to calculate discharge are a source of error although for most sites this is probably minimal since most sites featured engineered channels that were very regular in shape and easy to survey and measure. Sites JC3, JC4 and FC1 were the exceptions since they had more natural cross-sections. Applying velocity meter and area estimated errors to discharge calculations for Site JC3 showed that the error range increased with large discharge (Fig. 6.10). Because the small discharges had a relatively small range of errors compared to larger discharges, it is probably simplest and best to assign separate baseflow and storm event error ranges. To avoid calculating error for each event I used the JC3 discharge sample set since it was the largest and chose the median error for baseflow and storm events. Baseflow discharge error is thus approximately ± 0.01 m^3/sec and storm event discharge error is ± 0.60 m^3/sec for all sites.

Sample Analysis Error. The methods used for analyzing TN, TP and metal concentrations in the samples have acceptance criteria designed to evaluate the quality of the analyses and ensure that the results are within the method limits (JC-V1, 2004; TN-JC-1, 2004). These include recovery percentages for samples spiked with known quantities of sample, limits on the variability of laboratory duplicates and ideal ranges for detection of analytes in blanks. Laboratory duplicate analyses demonstrate the repeatability of the process and they are acceptable if the laboratory duplicate

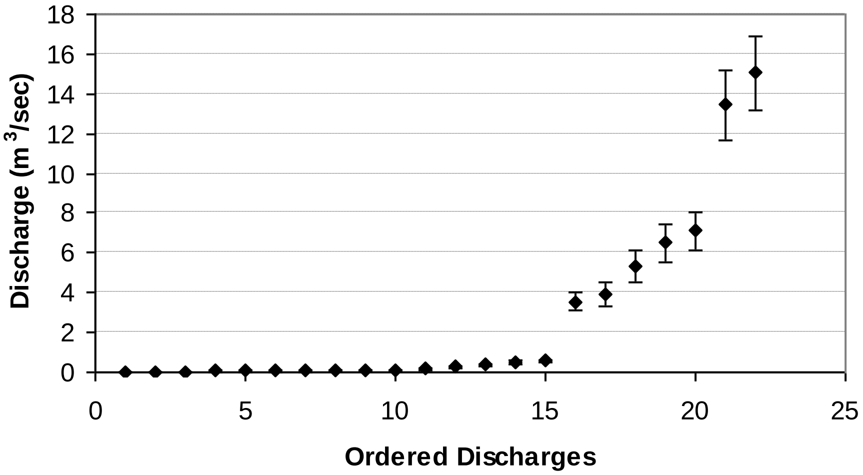


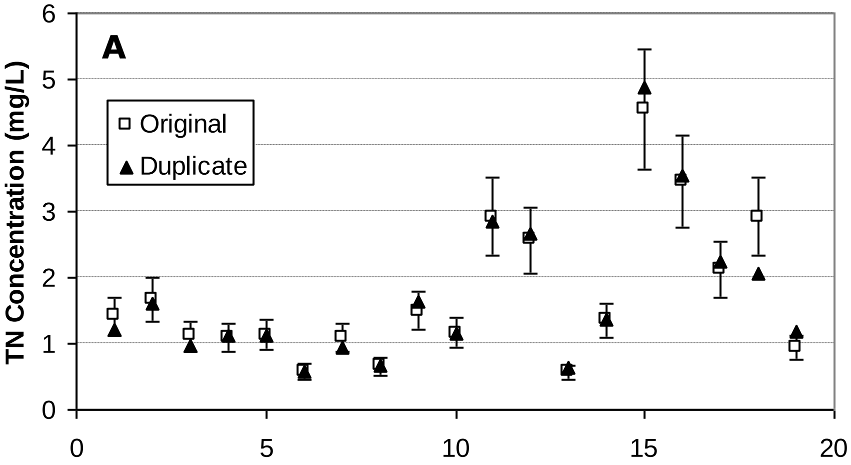
Figure 6.10: Measured discharges and calculated errors for Site JC3.

concentrations are within 20% of the original (Fig. 6.11). The laboratory duplicates all fall within the acceptable range with the exception of one TP and one TN duplicate. In each of these cases the duplicate sample concentration falls below the original concentration.

Laboratory Control Checks (LCC) are designed to check the stability of the process through the batch and LCC concentrations are acceptable if they fall within 10% of the assumed concentration (Fig. 6.12). All of the TP LCCs and all but one of the TN LCCs fall with the acceptable range. The analysis process thus is acceptably stable.

Matrix spike recovery tests for sample solution interference with the accuracy of the analysis and matrix spikes are deemed acceptable if recovered concentrations are within 10% of the spike (Fig. 6.13). All but one of the TP matrix spikes were recovered within acceptable limits although only 66 % of the TN matrix spikes were within the acceptable recovery limits. The TN procedure is vulnerable to interference from turbidity within the sample although the outlying matrix recovery concentrations are not consistently from storm samples that might be expected to have greater sediment concentrations.

Reagent blanks (RBL) and field blanks (FB) are designed to test for contamination of laboratory and field equipment as well as to set the detection baseline for each sample batch (Table 6.6). These concentrations are acceptable if they are at or below the detection limit for the procedures: 0.1 mg/L for TN and 0.001 mg/L for TP (Fig. 6.14). Negative values in these cases are considered to be below the detection limits of the instrument and sampling procedure. Total nitrogen RBLs were very consistently below the ideal limit although 58% of Field Blanks were above that limit. For TP 52 %



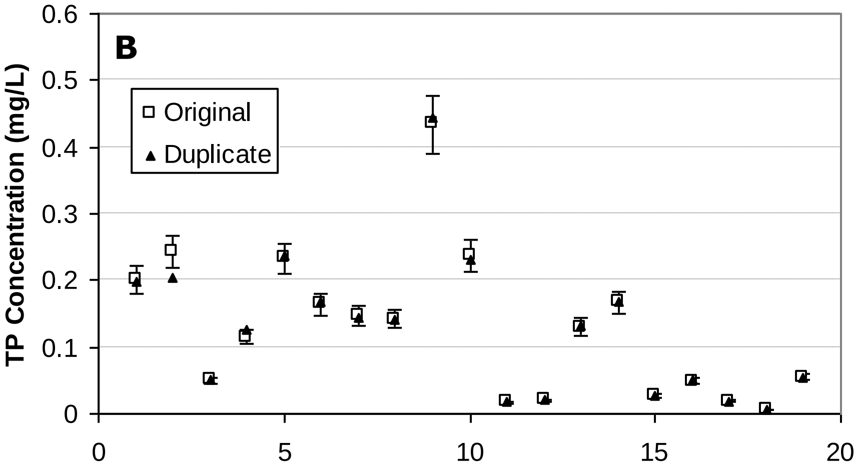


Figure 6.11: Laboratory duplicate acceptance limits (± 20%) for (a) TN and (b) TP.

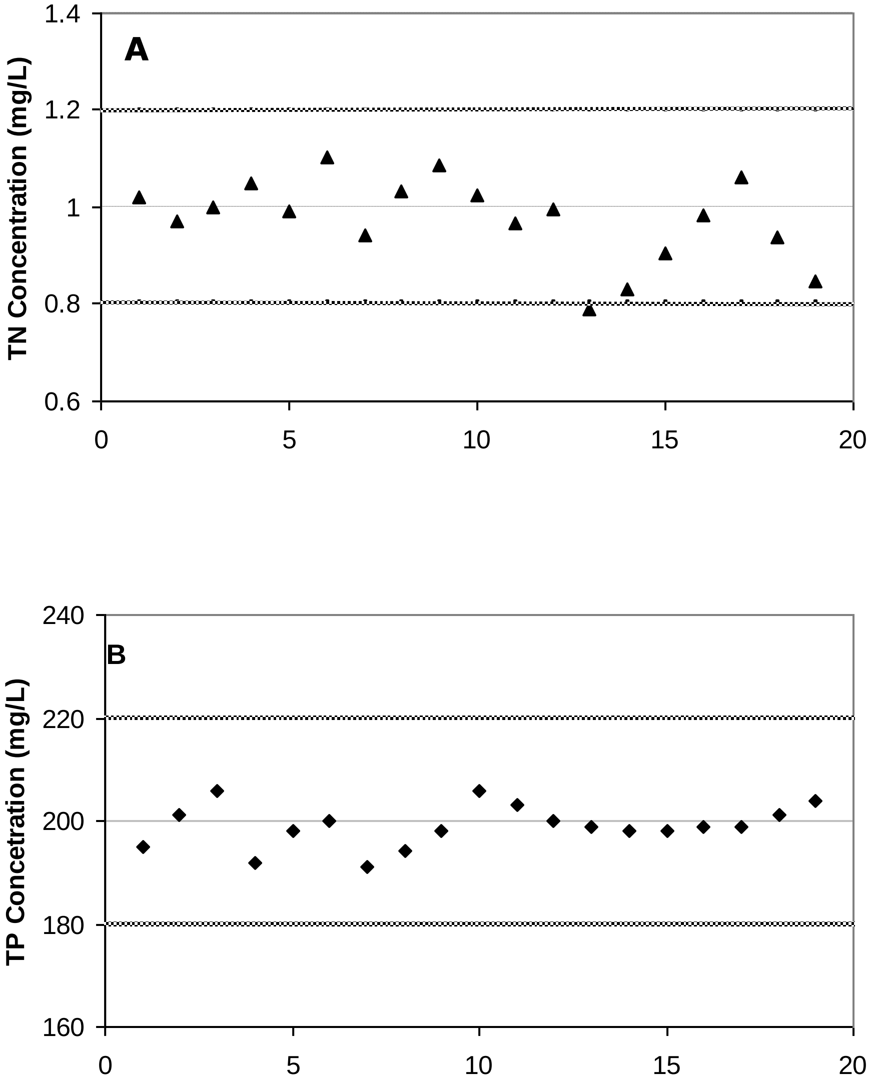


Figure 6.12: Laboratory control check acceptance for (a) TN and (b) TP. TN acceptance range 0.8 – 1.2 mg/L. TP acceptance range 180 – 220 µg/L.

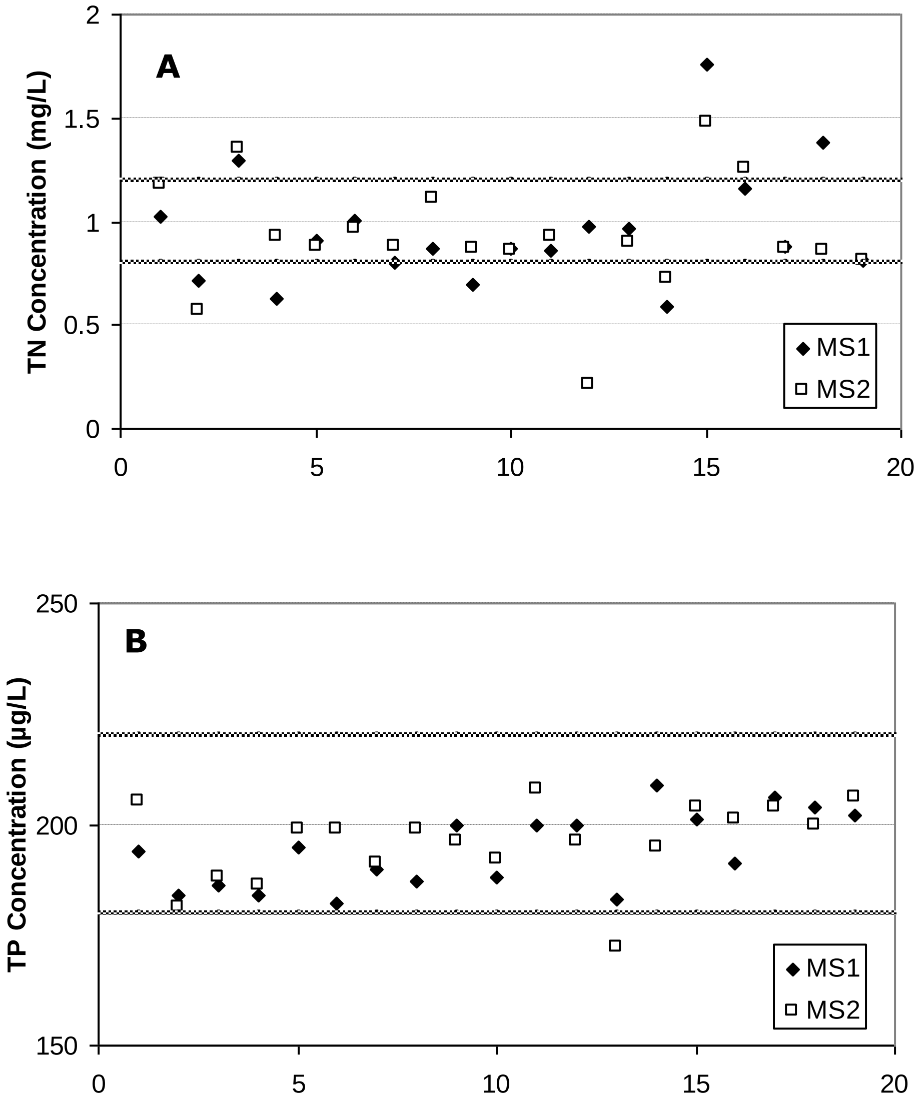


Figure 6.13: Matrix spike recovery acceptance for (a) TN and (b) TP.

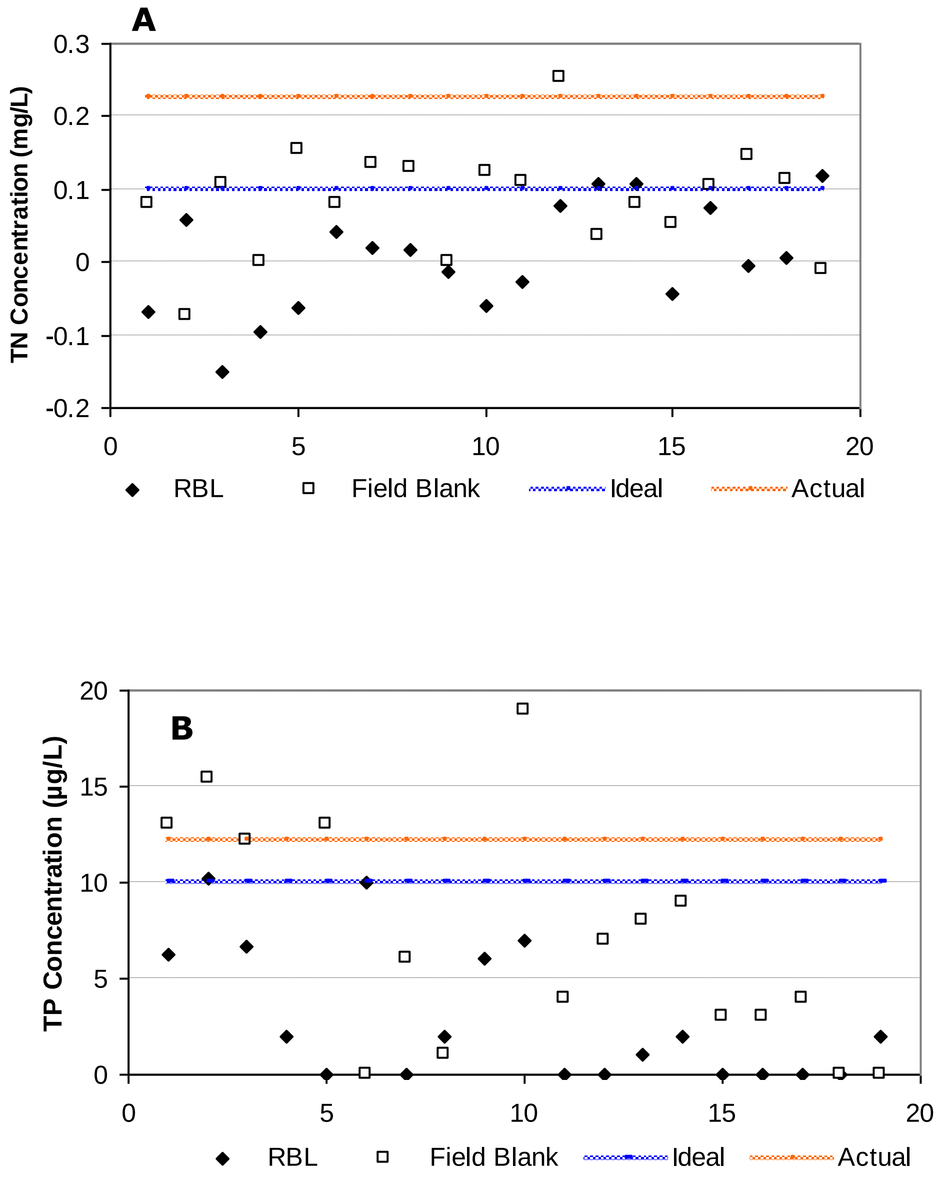


Figure 6.14: RBL and field blank concentrations, ideal limits and method detection limits for (a) TN and (b) TP. Negative values are plotted as zero.

of RBLs and 76 % of FBs were above the ideal limits. These results indicate that there may be some contamination of field equipment with TN and TP and laboratory equipment with TP. Dr. Richard Biagioni has explored the possibility that double de-ionized water used in the laboratory procedures was contaminated by suspended particles from one of the in-line filters. These could be the source of TP contamination and a final filter has been installed to correct the laboratory TP problem. Also, a possible source of TN cross-contamination exists with the pH electrode used during adjustment of sample pH to neutral (Biagioni, 2005). This leaves the possibility that field equipment has been contaminated by TN and TP. The source could be the DI water used as FB (general supply piped to laboratories in Temple Hall) or cleanliness of field equipment. This would therefore be a systematic positive error and leads to the possibility that the true concentrations are less than the analysis results. The mean of TN and TP for FBs are 0.01 and 0.07 mg/L respectively and these values can be used in calculating potential experimental error.

Calculated Detection Limit. Actual detection limits for TN and TP are calculated by multiplying the standard deviation for RBL concentrations by 3 (JC-V1, 2004; TN-JC-1, 2004) (Table 6.5). These actual detection limits are somewhat larger than the published method limits of 0.1 mg/L TN and 10 µg/L TP (0.01 mg/L). Seven TP concentrations, all from baseflow samples, and no TN concentrations were below the method limit.

Comparisons to Ozark Area Studies

Wilson and Pearson Creek (Richards and Johnson, 2002). This study is significant because the Wilson Creek sample site from the study is the same as site WC1

Table 6.5: Calculated detection limits for TN and TP laboratory analysis. Detection limit equals 3 times standard deviation.

	Calculated Detection Limit	
	TN (mg/L)	**TP (μg/L)**
Standard deviation	0.075	4.047
Detection limit	0.225	12

in the present study. The Wilson-Pearson (W-P) study examined water quality in the two streams that drain much of downtown Springfield to assess the toxicity of the water for aquatic life. Mean baseflow concentration and storm EMC are critical for measuring this and the study did not assess annual loads. The concentration data is available at the USGS Gage 07052000 website under "Water Quality: Discrete Samples", and includes concentrations of TN (nitrate plus nitrite) and TP as well as many others including Specific Conductance (SC) measurements from the field and the laboratory. Unfortunately, the data does not include discharge values. To estimate discharge for the W-P concentrations it seemed best to exploit the dilution relationship between SC and discharge. Data from the present study included Conductivity measured in the field with the Horiba U-22 multi-parameter meter which was assumed to be comparable to the field SC measurement from W-P. That data is missing a value, so the missing value was estimated from the lab SC measurements (Fig. 6.15). The estimated field SC value was entered into an equation generated by the relationship between SC and Q from the present study (Fig. 6.16). The presence of a relationship demonstrates the dilution of dissolved ions by stormwater and is used in this instance to predict discharges based on measured SC.

With these estimated discharges, the W-P concentrations can be compared to concentrations from this study (Fig. 6.17). The W-P TP concentrations plot higher than the WC1 baseflow and storm TP data, probably due to sampling differences: the W-P samples were composites collected both on the rising limb and falling of each storm hydrograph and then averaged while the present study managed to collect primarily falling limb samples. Sediment (and thus sediment-bound phosphorus) tends to be concentrated in the rising limb and depleted in the falling limb, the W-P samples include the rising limb which could account for the difference between the studies.

The WC1 TN data shows remarkably different trends for baseflow and storm runoff. Baseflow TN concentrations are much higher with a steep positive slope while the storm concentrations are lower and have a slightly negative slope (Appendix C). All of the W-P TN concentrations fit within the WC1 data, probably because TN concentration is dominated by baseflow and is less sensitive to storm discharge.

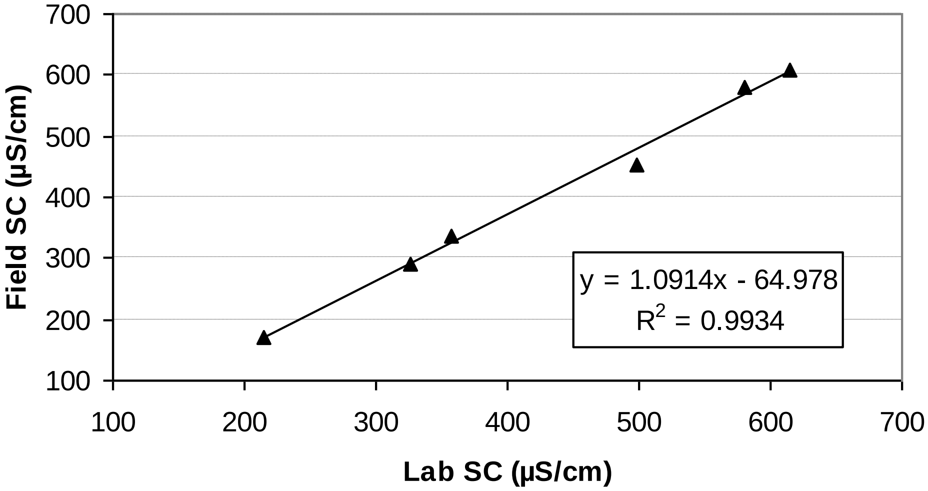


Figure 6.15: Lab and Field SC relationship from Wilson-Pearson study (Richards and Johnson, 2002).

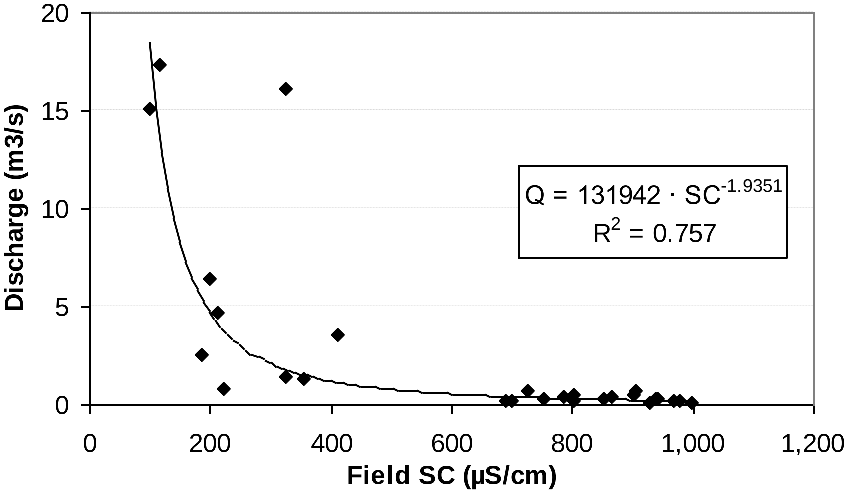


Figure 6.16: Field measured SC and discharge at Site WC1 from present study.

James River TMDL. The TMDL study from 2001 is an important comparison for the present study because it includes long-term water quality data from streams in the immediate vicinity of Springfield (MoDNR, 2001). Samples were collected during base flows over the summer months of 2001-03, and included TN and TP. The TMDL sample sites affected by discharge from waste water treatment plants were removed from comparison leaving 7 sites that have land-uses ranging from mixed urban-rural to mixed agricultural-forest (Table 6.6). Because the TMDL samples were taken exclusively during summer baseflow conditions, and because the TMDL sites do not correspond exactly with the sites from the present study, the best comparison is the mean and standard deviation of TN and TP (Figure 6.18).

The mean baseflow TP and TN concentrations found in this study fit well within

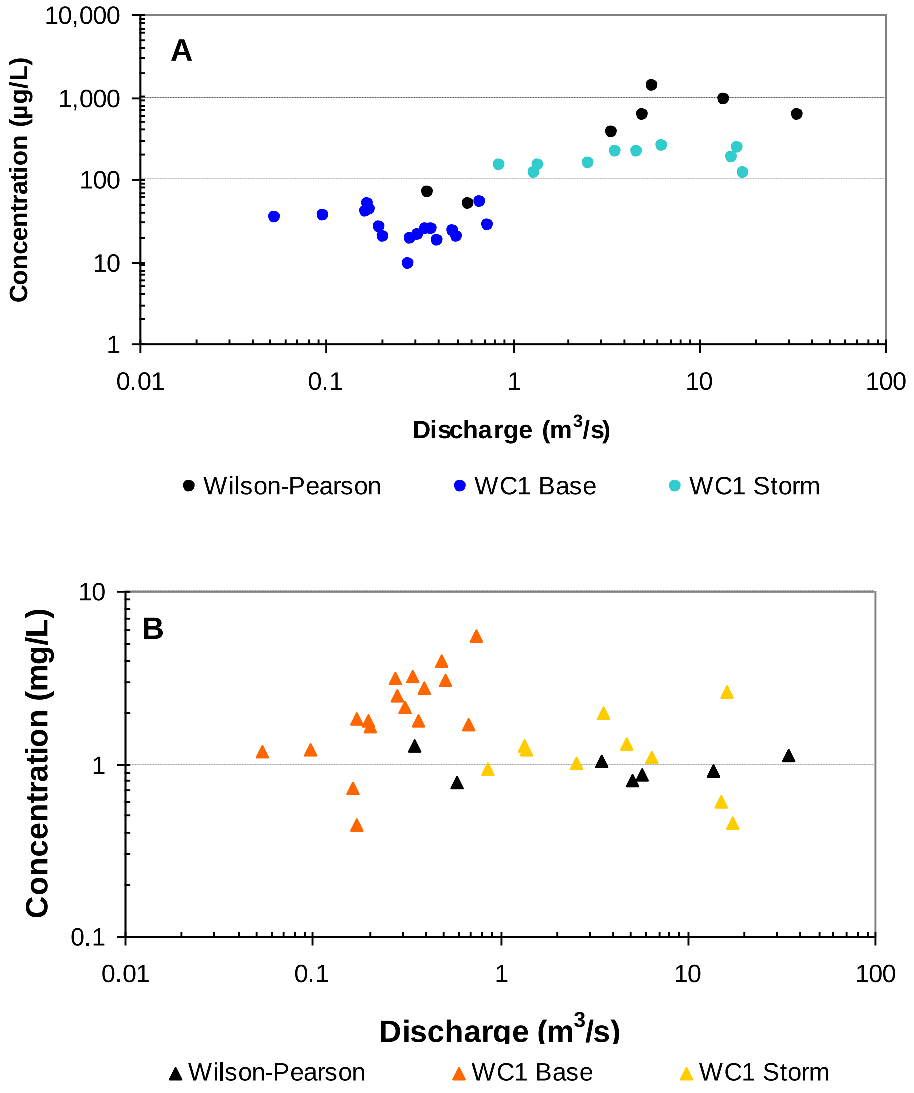


Figure 6.17: Comparison of Wilson-Pearson and WC1 Nutrient Concentrations and Discharges for (a) TP and (b) TN (Richards and Johnson, 2002).

Table 6.6: James River TMDL Sample Site Descriptions

Watershed		**Drainage Area (mi^2)**	**Land Use (%)**			**Obvious WWTP Influence**
Site #	**Location**		**Urban**	**Forest**	**Ag**	
TMDL-2	James at Galena	987	6	30	64	(yes) SWWWTP
TMDL-3	Crane Cr	153	1	20	79	
TMDL-8	Finley Cr. at Green Bridge	178	1	60	39	
TMDL-9	James at Kinser	251	2	38	60	
TMDL-10	Pearson Cr	20	1	25	74	
TMDL-11	Panther Cr	36	1	43	56	
TMDL-12	James off B Hwy	92	1	42	57	

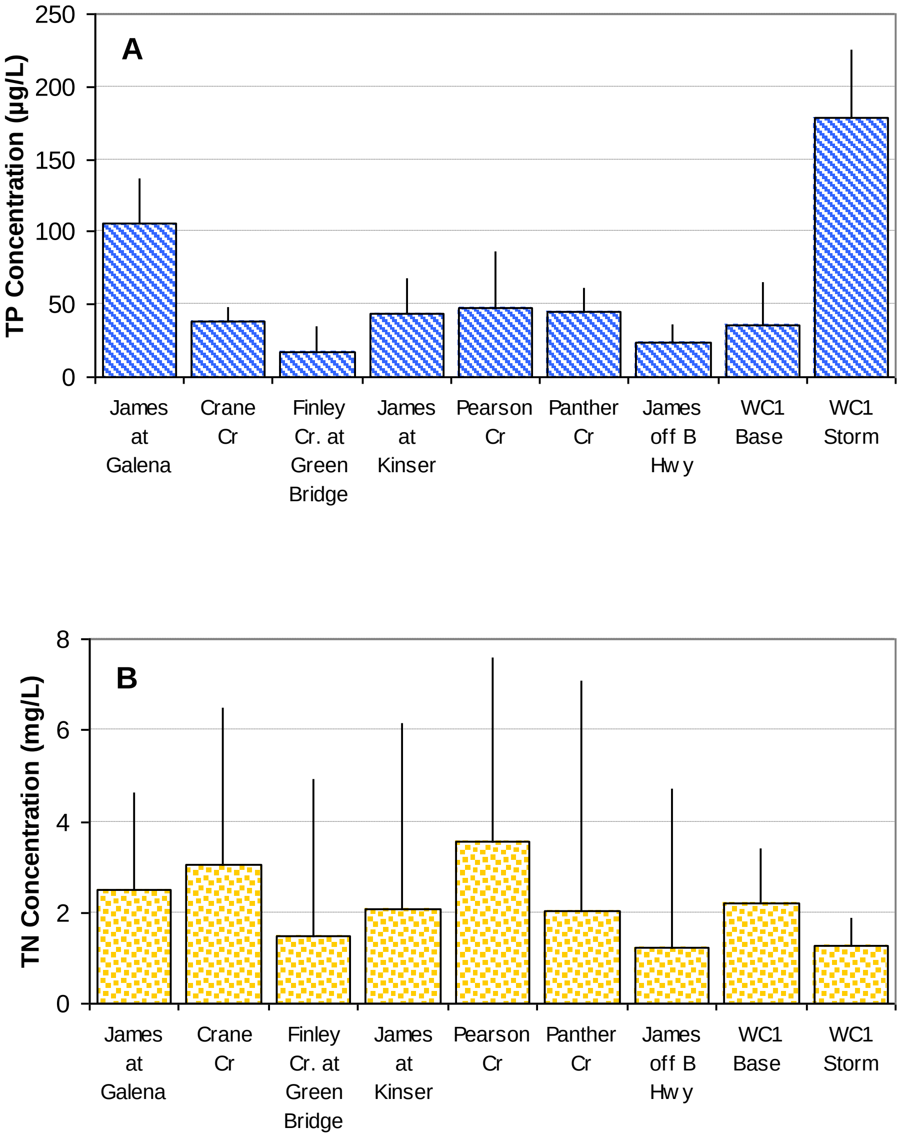
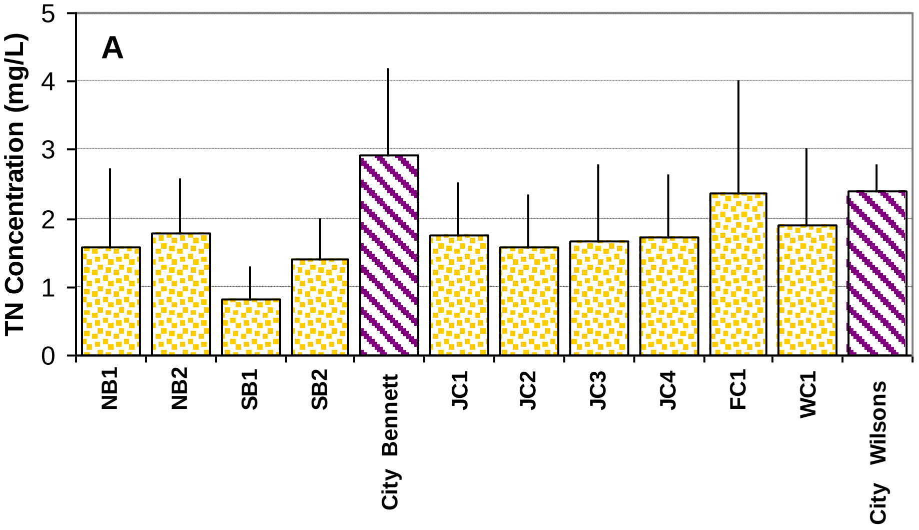


Figure 6.18: Comparison of concentration means and standard deviations between Site WC1 and selected TMDL sites (a) TP and (b) TN

the range of mean TN and TP for good quality streams from the TMDL study. Mean storm TN fits into this range as well although mean storm TP falls above the range of TMDL baseflow TP means. This is evidence that Jordan Creek has similar nutrient content to other local streams at baseflow.

City of Springfield NPDES Permit. In 2003-04 the City of Springfield sampled water quality in Jordan Creek at Bennett Avenue and Wilson Creek at Farm Road 146 as part of their NPDES permit program (City of Springfield, 2004). The sample sites do not coincide with sample sites from this study, but constituent means and standard deviations are compared (Figure 6.19). The City water samples were analyzed at the City of Springfield Wastewater Laboratory and data set includes four dates all of which occur before sampling for the current project began (Table 2.2). City of Springfield sample values for pH fall within the range of values for the present study. City TN values compare well with baseflow means for the present study but are higher than storm means. The City TP values are much higher than baseflow TP means from the present study with the exception of the SB2 site which had several very high TP concentrations. The storm TP means approach the City TP mean and there is overlap of the ranges of values, but the City TP values still appear much higher than the storm TP values from the present study. Information was not given on the City's sampling procedure, and the possibility that they captured rising limb samples could account for TP concentration differences.

Mark Bowen (2004) Masters Thesis. Mark Bowen (2004) studied the quality of water flowing into and out of Valley Water Mill Reservoir in 2002 and 2003 using the same equipment and methods (including both baseflow and storm runoff samples) used in the current study. The Valley Water Mill discharges into the South Dry Sac River and its watershed area includes a portion of northeast Springfield. Land uses within the watershed include industrial, residential and grazing as well as a golf course. The hydrology of the area is complicated by karst because most of the reservoir inflow is discharge from Sanders Spring which has an undetermined source area. Sites from the



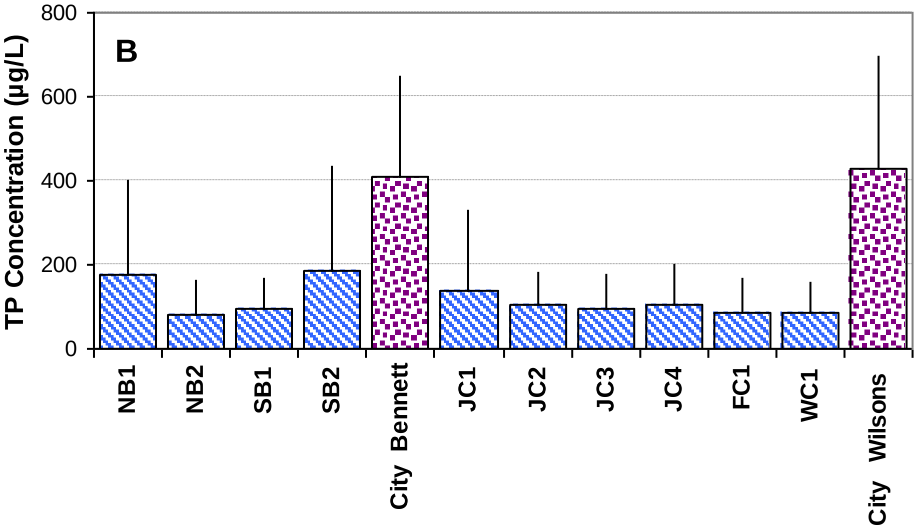


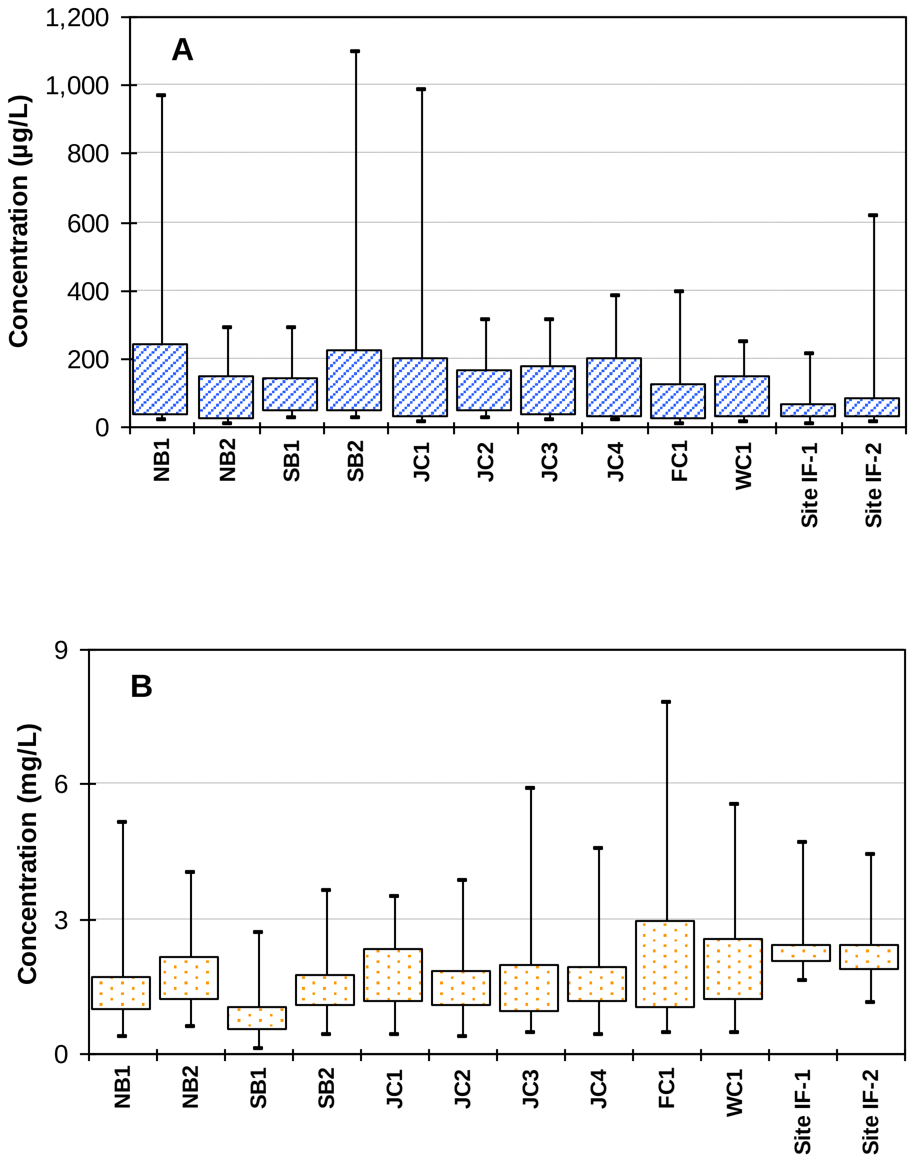
Figure 6.19: Comparison of study sample means with City NPDES Water Samples from Bennett Ave and Wilson Creek at FR 146 (a) TN and (b) TP. City sites are placed in geographic context.

Bowen study used for comparison with Jordan Creek data have TN and TP data from Sanders Spring (IF-1) as it enters the Valley Water Mill Tributary (VWM Trib) and the VWM Trib (IF-2) as it enters the reservoir about 0.5 km downstream.

Bowen's TN and TP data fall within the range of data from Jordan Creek although the distribution of the data is somewhat different with the inter-quartile range more compact. TN data from Bowen has fewer low values, indicating consistently higher concentrations although the 75th percentile and high TN values are similar to Jordan Creek values (Fig. 6.20). Nearly the opposite situation occurs in TP concentrations: Bowen's low and 25th percentile and max measurements are very similar to Jordan Creek concentrations but his 75th percentile measurements are consistently much lower than Jordan Creek 75th percentile concentrations. This indicates consistently lower TP concentrations in VWM water.

Brian Frederick (2001) Masters Thesis. Brian Frederick (2001) collected water column TP concentration data from the USGS and the City of Springfield to use as a comparison to sediment P concentration as he researched the distribution of phosphorus in river sediment within the James River basin. The data can be compared to TP concentrations from the present study (Fig. 6.21, Table 6.7) although the conditions under which the samples were collected were not specified.

The concentrations from the present study fall with the range of variation of Frederick's data but the means are much lower. The Frederick values are more in line with City of Springfield stormwater sampling (Fig. 6.19), although more information is needed about both the method used for Frederick's samples and the sample times to draw conclusions.



Data Order (top to bottom): Max, 75th percentile, 25th percentile, Min

Figure 6.20: Bowen (2004) data distribution and comparison to study data for (a) TP and (b) TN, (n = 12).

Ozarks Plateaus Water Quality Assessment (1993-95) (Davis and Bell, 1998). This report is the most current regional assessment of water quality. A large number of streams were systematically sampled and the general watershed characteristics recorded (Table 6.8). Samples were collected monthly during the sampling period and thus probably included both base and storm-influenced flows. Neither Jordan Creek nor any

Table 6.7: Frederick thesis TP concentration values (Frederick, 2001).

Station	n	Mean TP (mg/L)	Std Dev
Wilson Creek above SWWWTP[1]	11	0.49	0.46
James River-Nelson Mill[1]	36	0.40	0.49

[1] Samples Taken by Southwest WWTP

Table 6.8: Percent land use for Ozark Region sample sites (Davis – Bell, 1998).

Site	Location	Area (mi^2)	% Landuse			
			Forest	Agriculture	Urban	Other
19	Elk R. near Tiff City, MO	872	50.8	46.7	-	-
27	Center Creek near Smithfield, MO	294	17.4	76.8	3.4	3.4
30	Black R. near Annapolis, MO	495	93.2	6.2	-	-
38	Niangua R near Windyville, MO	338	42.2	56.3	1.4	-

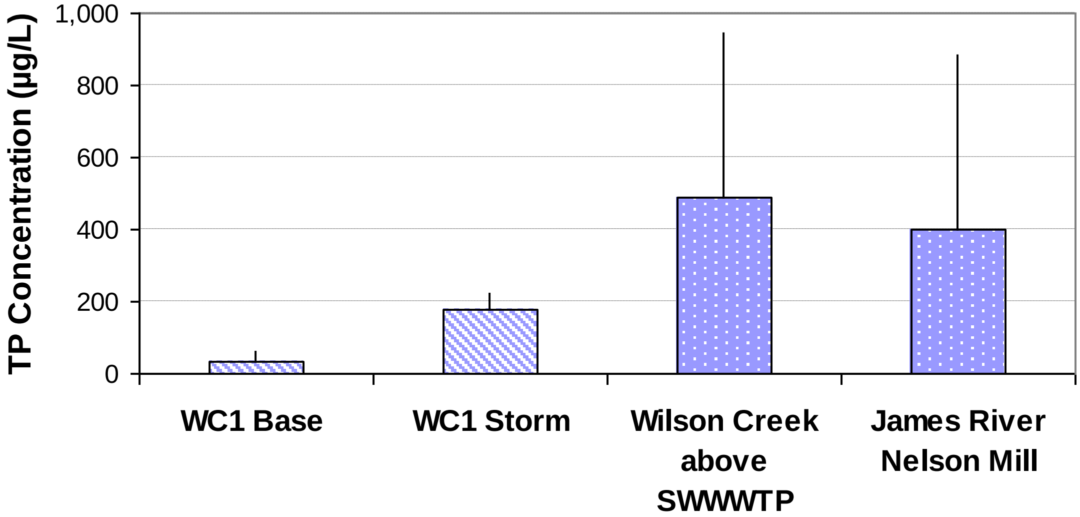
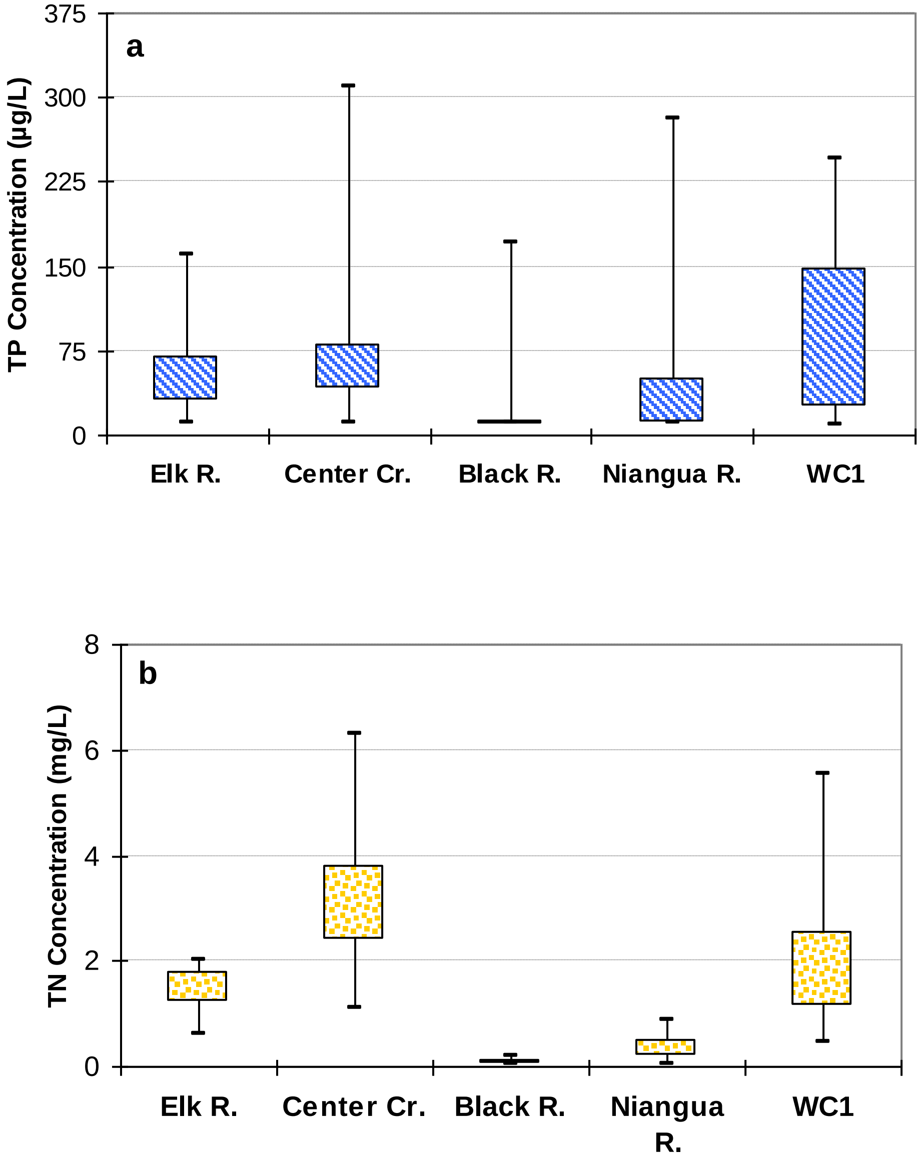


Figure 6.21: Frederick (2001) TP concentration comparison with baseflow and storm means from Site WC1. Shown are mean concentrations and standard deviation.

streams in the immediate Springfield area were sampled. The Davis-Bell paper reports TN and TP values as medians and percentiles so for comparison purposes the WC1 site data was analyzed in this manner (Fig. 6.22). The watershed areas for each sample site for the Davis-Bell study are much larger and land uses skewed very much toward agricultural and forest (Table 6.9). The Davis-Bell site 27 is the most urban, although its urban percentage is much lower than the Jordan Creek study area. The TP sample concentration distributions from the present study fit into the Davis-Bell distributions, although the range between the 25th and 75th percentiles is much larger. The Davis-Bell site 30 is notable for its extremely small range with a single high value. The TN sample concentration range from the present study appears to be the most similar to Davis-Bell site 27 (the most urban), the other sites have much lower max concentrations, especially the forested site 30. The nutrient concentrations of water samples from the present study appear to be very similar to the general water quality of the Ozark region excepting "pristine" watersheds: those with primarily forest cover.

Fort Leavenworth, KS Loads and Yields (Rasmussen, 1998). Rasmussen's study measured loads and yields for several small watersheds on the Fort Leavenworth Army reservation. The watersheds vary from undeveloped to primarily urban, and are very small compared to the watersheds in the present study (Table 6.9). Loads and yields were calculated for each watershed. Yields are the most appropriate comparison with the present study because the extreme difference in watershed size will distort the comparison of loads. The TN yields of the present study fall with the range presented by the Fort Leavenworth watersheds but the TP yields fall below the corresponding Fort



Values top to bottom: Max, 75th percentile, 25th percentile, Min

Figure 6.22: Comparison with Davis-Bell Regional Data (a) TP and (b) TN.

Leavenworth range (Fig. 6.23). The TP yield differences may be attributed to sampling differences since the Fort Leavenworth storms were sampled with an auto-sampler programmed to collect when flow increased by a set amount, which is qualitatively different than the grab-sampling employed in the present study. Flow-weighted sampling insures an integrated event sample that includes the rising-limb. Evidence presented earlier supports the importance of sampling the rising limb for accurate estimations of TP concentrations in storm runoff; the present study missed these rising limb samples and the estimated TP loads and yields may be lower than the Fort Leavenworth estimates for that reason.

Table 6.9: Fort Leavenworth study watershed areas and % land use. (Rasmussen, 1998)

		Land use type						
Watershed	**Area (km^2)**	**% Imperv**	**Non-urban**	**Urban open**	**Residential**	**Commercial**	**Industrial**	**Water**
Quarry Creek	3.77	10	70	14	1	15	0	1
Un-named Trib	1.74	54	2	58	13	24	1	2
Corral Creek	4.96	13	45	23	20	11	1	1

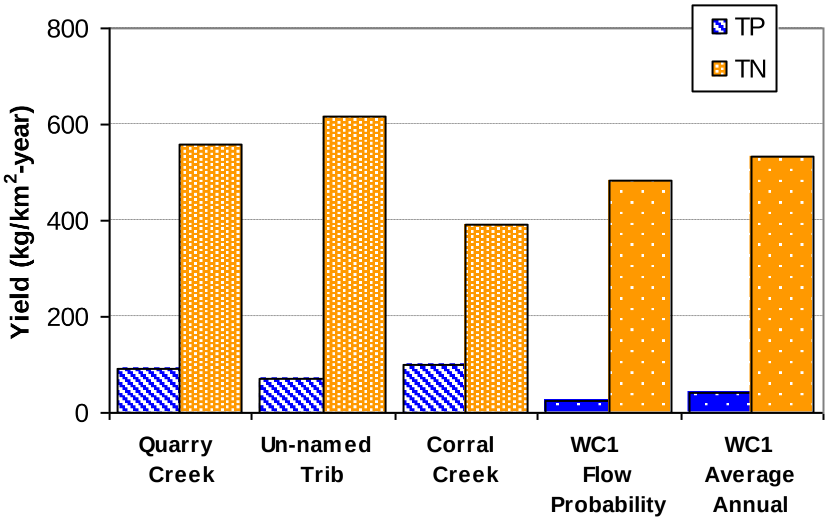


Figure 6.23: Comparison of Fort Leavenworth yields with Site WC1 yield estimates.

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Comparisons with Undisturbed Watersheds. We've seen that the nutrient levels in Jordan Creek are similar to Ozark streams that are unaffected by wastewater treatment plants, but these streams generally drain watersheds that have human-influenced uses. How does the Jordan Creek data compare to undisturbed streams? Clark et al (2000) compiled data from several nationwide databases with the intention to create a "baseline" dataset of water quality in undisturbed watersheds. The study includes 43 basins from the Hydrologic Benchmark Network (HBN) consisting of data from wilderness area and National Forest watersheds and 22 relatively undeveloped watersheds from the USGS National Water Quality Assessment (NAWQA) program, including one watershed in Missouri. The basins include a range of sizes from 18 to 2,700 km^2 and of the two sets, the NAWQA watersheds are more likely to include human impacts such as rangeland grazing and logging.

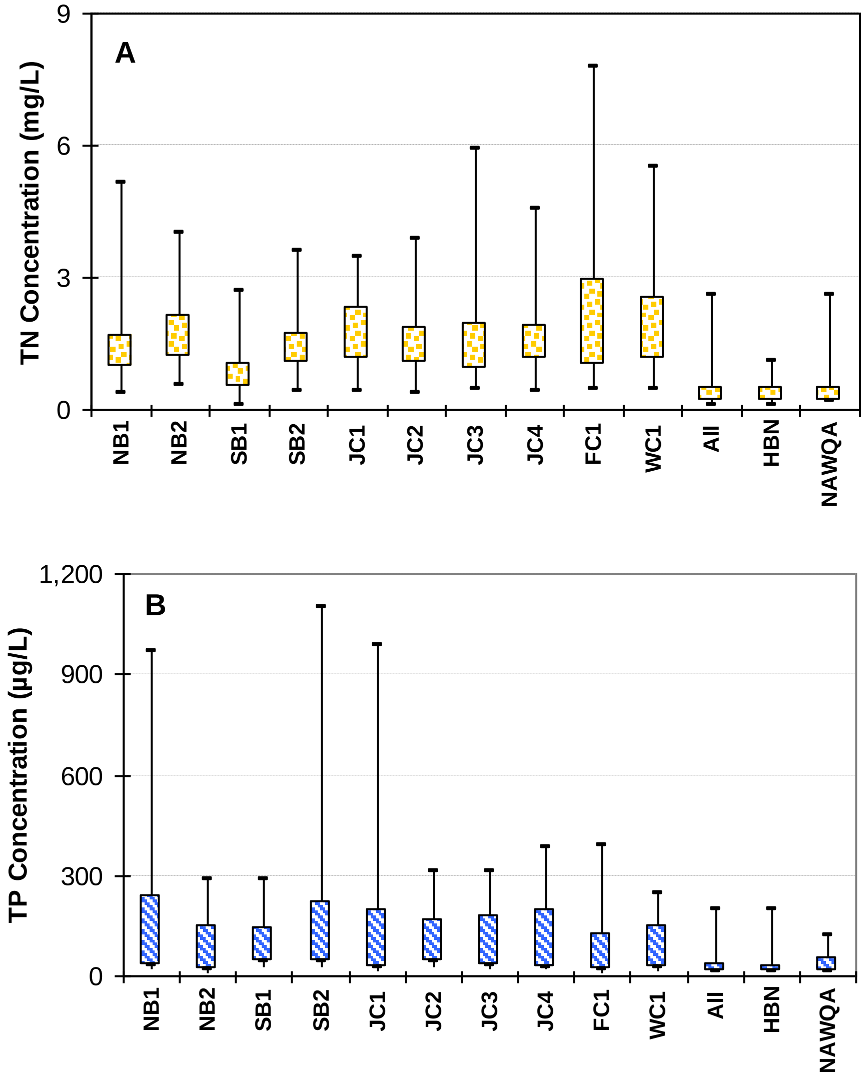
Data for the study was collected on a bi-monthly basis from water years 1982-1997 and thus is likely to include mostly baseflow with some storm samples. According to Robertson (2003) this type of strategy because it lacks storm-chasing, is likely to somewhat underestimate maximum and volumetrically-weighted TP concentrations and yields but accurately estimate mean and median TP concentrations and yields. With that in mind, the Clark et al (2000) data can be compared to data from the present study. The undeveloped watersheds feature a much smaller range of data distribution for TN and TP as well as much lower maximum values than the values found for Jordan Creek sites (Fig. 6.24). Median TN values undisturbed watersheds are much lower than Jordan

TN median values, and the relative difference is greater than the relative difference in TP values (Table 6.10).

Clark et al (2000) calculated yields of TN and TP as well, which is a very useful since it normalizes watersheds by area and allows unit area comparison. Clark used a rating curve to calculate yields for each watershed and then plotted the distribution of each yields foe each watershed. Site WC1 is the only site for which we can calculate a similar yield because of the discharge record provided by the USGS gage, so the comparison will be between the rating curve-based yield for TN and TP and the data range from Clark et al (2000) (Fig. 6.24). The ranges of yields for both TN and TP are very wide with the most extreme values for both coming from the NAWQA watersheds which are reported to have relatively more human disturbance. TP yields from Jordan Creek are within the range of undisturbed TP yields, and appear to be equivalent to both the 75th percentile of the NAWQA distribution and the Max value of the HBN distribution. TN yields from Jordan Creek are again within the range of values for undisturbed TN yields and appear to be generally equivalent to the Max value for HBN and above the 75th percentile for NAWQA watersheds. This is evidence that urban watersheds in general and Jordan Creek in particular have concentrations and yields of TN and TP that are above those of undisturbed watersheds.

Watershed Source Analysis

Median values represent the “typical” conditions within the stream at the sample site (Robertson, 2003). Thus, comparing the downstream trends of the median specific discharge and concentration values for each site can reveal source differences within the



Values in order: Max, 75th percentile, 25th percentile, Min

Figure 6.24: Data distribution comparison for concentrations in Jordan Creek and Undisturbed Watersheds (Clark et al, 2000) (a) TN and (b) TP.

Table 6.10: Median TP and TN values for Jordan Creek and undisturbed watersheds (Clark et al, 2000)

	Jordan Creek Study										**Undisturbed**		
	NB1	**NB2**	**SB1**	**SB2**	**JC1**	**JC2**	**JC3**	**JC4**	**FC1**	**WC1**	**All**	**HBN**	**NAWQA**
TN (mg/L)	1.21	1.65	0.66	1.21	1.56	1.31	1.42	1.67	2.08	1.68	0.26	0.24	0.32
TP (µg/L)	55	33	50	114	66	67	47	37	55	40	22	20	37

study watershed. Given the influence of discharge variation on water quality observed in this study, separate trends are evaluated for baseflow and storm runoff conditions. These values were compared by plotting the median values according to stream distance or "river kilometer" from the watershed outlet at Site WC1.

Discharge. Discharge for storm events is related to the surface area of the watershed: a larger surface will capture more precipitation and thus will have greater discharge than a smaller watershed. For example, the Mississippi River at St. Louis, with a watershed area in the thousands of square miles, has a much larger discharge than the James River at Boas with a watershed area in the hundreds of square miles. To compare discharges between watersheds of differing sizes, it is necessary to correct for watershed size by dividing by watershed area which creates a unit area discharge measurement known as "specific discharge". To maintain whole numbers, specific discharge is often reported in Liters per second per km^2 ($L/s – km^2$).

Typically, specific discharge will decrease as watershed area increases due to the greater opportunities in larger watersheds for runoff to be stored in temporary storage areas, such ponds, groundwater and vegetation and thus reduce the runoff peak (Chorley, 1971). Urban impervious area influences specific discharge in the same way that it influences the urban hydrograph. Increased impervious surface area reduces both stream recharge and specific discharge at baseflow, and the increased surface runoff associated with impervious area increases both the peak of the hydrograph and the specific discharge for storm flows. The study area land use is relatively uniform and therefore it was expected that the impervious urban influence would affect all sites relatively equally, and that specific discharge for all sites, based solely on surface area, would be relatively uniform.

Deviations from a predicted uniform specific discharge pattern would indicate increased or decreased flows in the stream unrelated to watershed surface area. Karst drainage features can either increase discharge in streams through springs or reduce discharge through swallow holes or “losing” stream reaches. Because these karst features are discrete rather than uniform across the study area, they would be expected to affect some stream sections more than others and thus appear in a specific discharge comparison: departures from the expected discharge trend within the watershed could be due to karst related inputs such as springs, or abstractions from the stream such as “losing” reaches. Other factors that could be responsible for an “anomalous” specific discharge pattern would include stormwater routing that concentrates or directs stormwater from one subwatershed to another, or errors in discharge monitoring.

Median specific discharges for storm flows show much more variability between sites than the City of Springfield modeled 1-year or baseflow specific discharges (Fig. 6.25). The difference between median storm and modeled 1-year specific discharges are most evident in the difference seen at Sites JC3 and FC1. The 1-year model has general linear trend of discharges broken only by low specific discharges between Sites SB1 and JC1, the storm pattern is much more complicated with no linear trend. The baseflow pattern also shows no linear trend, instead there are specific discharge peaks in the upper branches and at Site JC1 on the main stem.

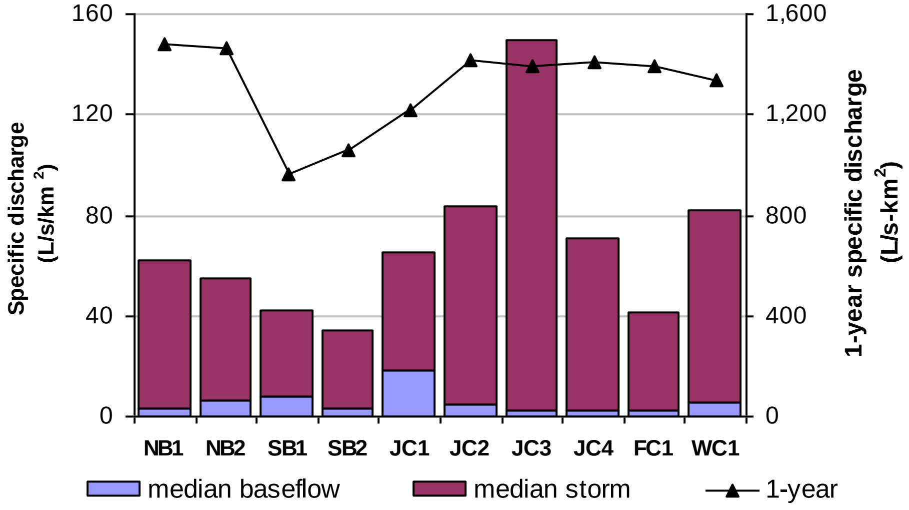


Figure 6.25: Specific discharge by study sample site.

A more spatially-linked analysis of the specific discharge data shows the sample sites as they are distributed along the main stem in kilometers from the watershed outlet at site WC1 to the North Branch sites (Fig. 6.26). The North Branch was chosen as the upstream continuation of the main stem because it demonstrates the expected uniform specific discharge pattern. The three sites that are off of the main stem and North Branch are plotted as crosses. At baseflow, median specific discharge is very similar at all sites, including sites off of the man stem, with the exception of Site JC1, which is located at the point where Jordan Creek exits the “underground” section.

The pattern of 1-year specific discharges shows a very steady trend from the upper watershed on the North Branch sites to the outlet with a low specific discharge at Site JC1. The “offline” South Branch sites have low specific discharge that may contribute to the low value at Site JC1 since it is downstream of the confluence of the two branches. The South Branch watershed has many more mapped sinkholes than any other area of the study watershed, which may explain the low specific discharge values from those sites (Fig. 3.3). Sinkholes would probably have more influence during surface runoff events than during baseflow conditions, which might explain why the South Branch sites are not dramatically different than the rest of the channel at baseflow.

The median storm exhibits a similar steady pattern to the 1-year pattern with the exception of very high specific discharge at Site JC3, and a low value at Site FC1. The South Branch median storm specific discharges are low, similar to the pattern shown in the 1-year discharges. The high value at Site JC3 may be due to stormwater channels adding flow to the stream at that site, or to measurement errors. Site JC3 has a very natural channel and storm runoff at that site was often eddied and swirled as it passed under the bridge. The velocity meter used for discharge gaging registered upstream flow as zero velocity rather than negative and thus discharge at that site may have been overestimated.

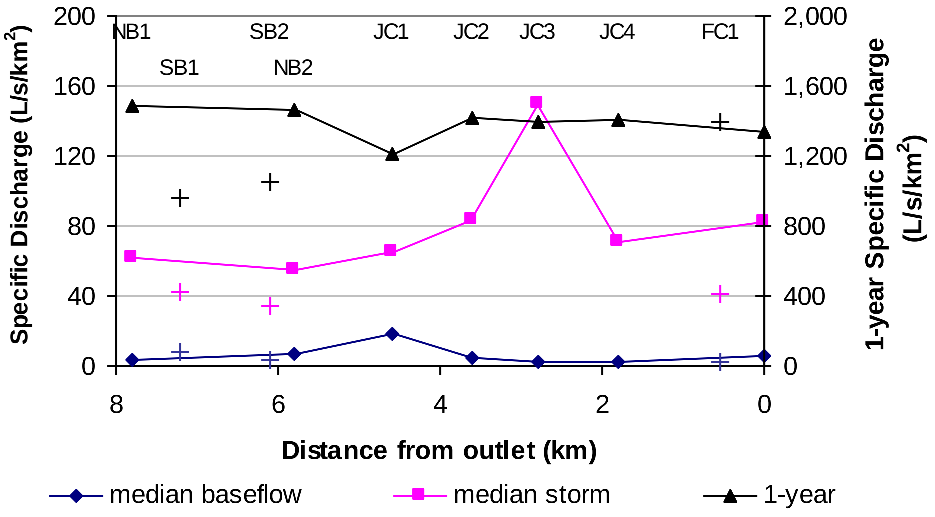


Figure 6.26: Specific discharge by distance from watershed outlet on main stem of Jordan Creek and North Branch. Sample sites off of main stem are plotted as crosses by distance from watershed outlet.

Median nutrient concentration. Median concentrations of TN and TP represent the typical nutrient conditions within the stream at baseflow and during storm runoff based on samples collected for the study. Median TP concentrations are very consistent for baseflow with values falling in range from 25 to 45 µg/L. The median storm TP concentrations are higher but consistently in the range 135 to 215 µg/L with the exceptions of Site WC1 where the concentration is lower than the general watershed trend (116 µg/L) and Site NB1 which is slightly higher than then range at 245 µg/L. When plotted by site distance from the watershed outlet, these median concentrations can help to understand nutrient pollution sources within the watershed (Fig. 6.27). Fassnight Creek joins Jordan Creek to form Wilson Creek 0.5 km from Site WC1. The low median TP storm concentration of Fassnight Creek, as represented by Site FC1 may dilute the Jordan Creek stormwater and ex[plain the low median concentration at Site WC1.

The median baseflow TN concentrations show more variation by site than the storm concentrations (Fig. 6.27 b). Baseflow median TN concentration values appear to be generally within a range of 1.3 – 2.1 mg/L with the exceptions of Site SB1 at the upper South Branch with a much lower concentration of 0.57 mg/L and Site JC1 on the main stem with a higher concentration of 2.7 mg/L while median storm TN concentrations are all within the range of 0.9 to 1.3 mg/L. At baseflow, the combination of elevated discharge and TN concentration could indicate the presence of a spring since local reports have noted that spring-related discharge in the area is relatively high in TN and low in TP as compared to surface flow (Bowen, 2004; Pavlowsky, 2006). Sites NB2, JC1 and FC1 seem to fit this pattern of high TN and low TP. Evidence for spring discharge at these

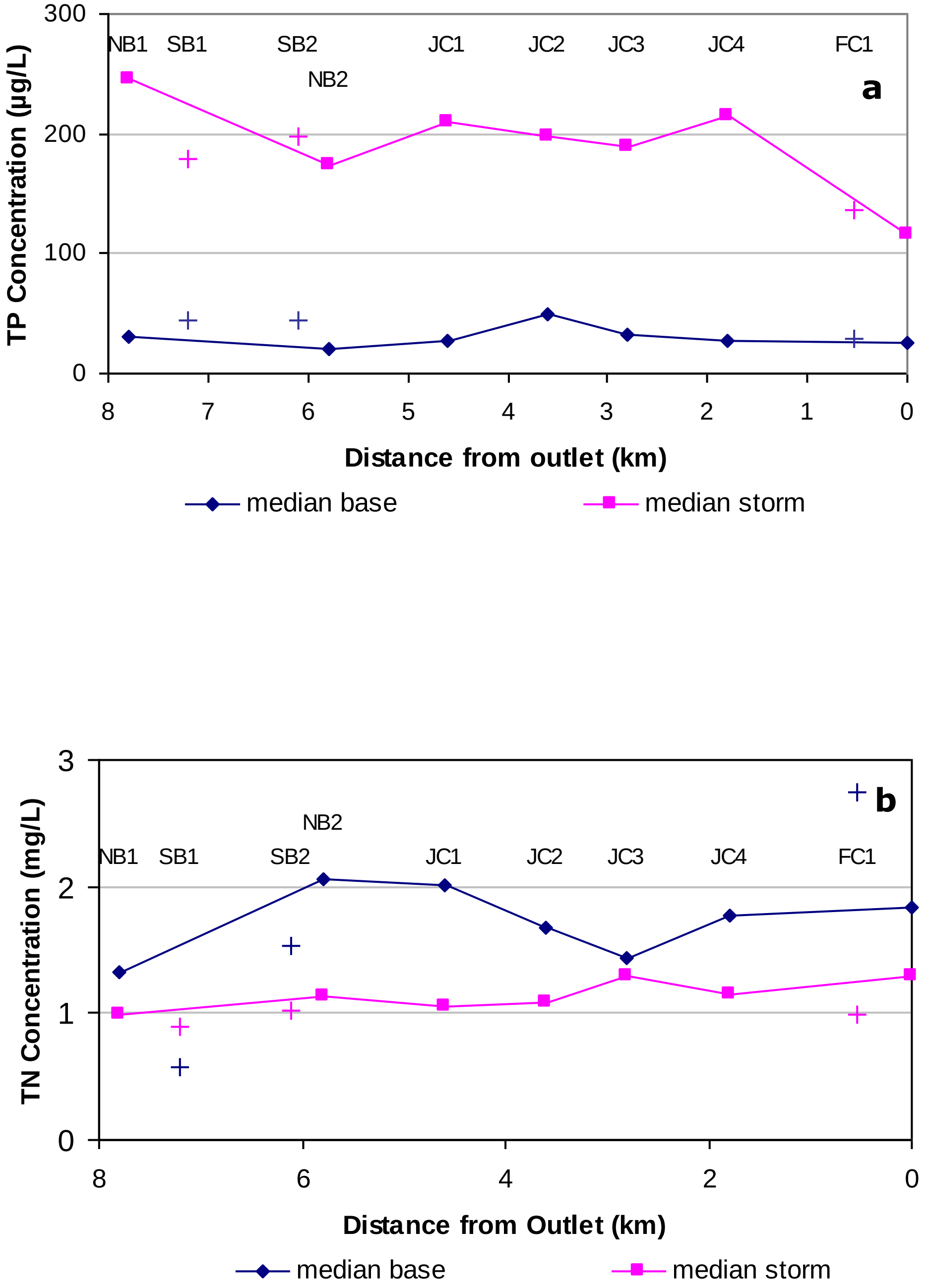
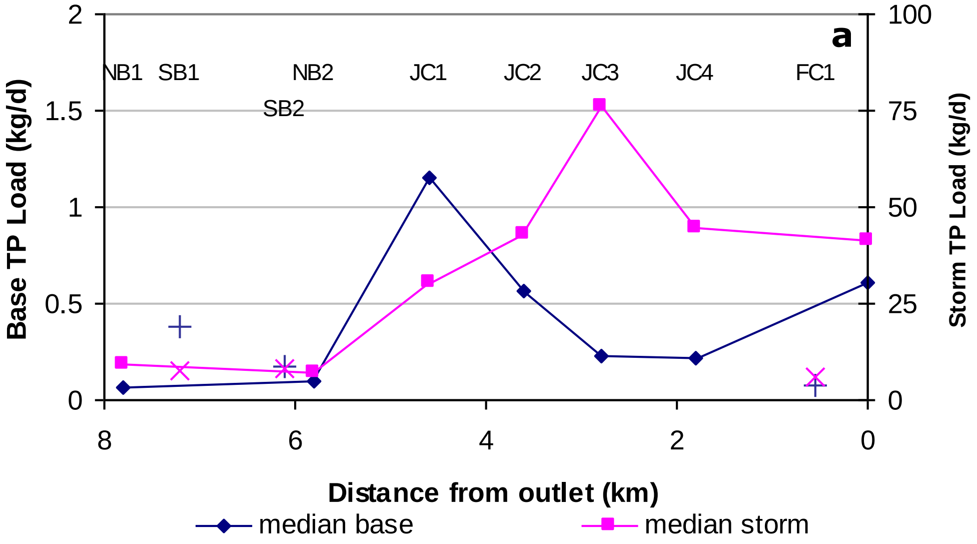


Figure 6.27: Median nutrient concentrations (a) TP and (b) TN by distance from watershed outlet at Site WC1 on main stem of Jordan Creek and North Branch. Sample sites off of main stem are plotted as crosses by distance from watershed outlet.

sites is anecdotal: Site NB2 had flow at every sample time yet is 2 km downstream from Site NB1 which often had no flow and similarly Site FC1 had flow at every sample time yet upstream in Fassnight Park the stream bed was often dry. Site JC1 is located at the end of the "underground" section of Jordan Creek and thus it is not possible to confirm the presence of a spring, although Bullard (2000) notes that the present-day traces of many historic springs in the downtown area are outflow pipes into Jordan Creek that are indistinguishable from storm culverts.

Median loads. Loads relate concentration and volume of discharge into a measure of the mass of pollutant transported in a stream in a period of time. Median daily loads were calculated by multiplying the median discharge times the median TP and TN concentrations. These values do not necessarily represent actual measured conditions, since the median baseflow may not have occurred at the same time as the median concentration, but represent a theoretical "typical" daily load (Fig. 6.28). Similarity between the TP and TN load patterns along the Jordan Creek watercourse illustrates the power of discharge in the load calculation: the high storm specific discharge at Site JC3 creates large storm TN and TP loads while the relatively high baseflow specific discharge at Site JC1 creates large baseflow TN and TP loads.

In a stream network with little storage or loss of discharge in the downstream direction, discharge and pollutants that enter the stream remain in the stream and therefore the load measured at the watershed outlet will be equal to the sum of inputs along the way. The load patterns for both TN and TP indicate that Jordan Creek is not a "conservative system" in this manner. A possible explanation involves the karst-related



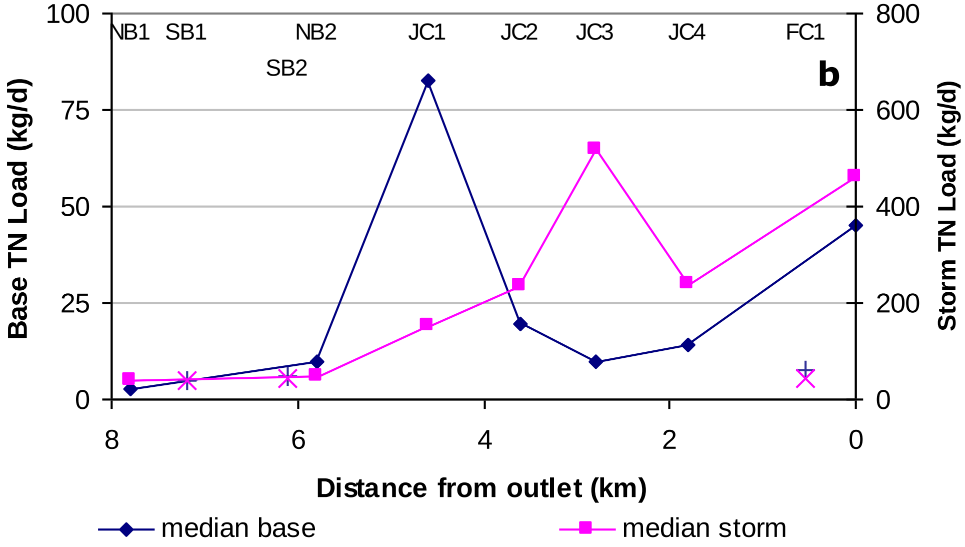


Figure 6.28: Median loads for (a) TP and (b) TN by distance from watershed outlet on main stem of Jordan Creek and North Branch. Sample sites off of main stem are plotted as crosses by distance from watershed outlet. Loads are calculated by multiplying median discharge by median concentration.

hydrology of the area which creates streams that behave much like “leaky pipes” in which water can enter and leave the stream at many points along its length. It is possible that karst conduits both draw away and add water to the stream containing varying TN and TP concentrations. This would provide a mechanism to explain how loads are not conserved within the watershed and show how greater masses could be found high in the watershed that are not represented at the watershed outlet.

Source Analysis. In the relatively uniform landuse within the study watershed one would expect to find that pollutants with primarily nonpoint sources would display relatively uniform concentrations while those with point sources within the watershed would display a non-uniform concentration pattern. Baseflow discharge sources include “nonpoint” groundwater and “point” spring discharges entering the stream, therefore median concentrations will be dominated by groundwater processes and by point sources. Spring discharge is likely to behave much like point sources in that they affect the stream only downstream of their point of discharge and their discharge and concentration contributions may be overwhelmed by storm runoff. Storm discharge is dominated by runoff from the watershed surface and therefore median storm concentrations will probably be dominated by landuse-influenced nonpoint sources.

The median concentrations seem to indicate that baseflow TP pollution is the result of nonpoint sources because the trend for is uniform throughout the study watershed (20 to 50 µg/L) (Fig. 6.27 a). The median concentration trend for storm TP is more complex, with a consistent central range of 170 to 235 µg/L that is exceeded at Site NB1 at the uppermost site (215 µg/L) and inferior values at Sites FC1 and WC1 (135 and 115 µg/L, respectively). The pattern may still indicate a nonpoint source for TP since most of the watershed is fits into a uniform range and nonpoint source mechanisms can explain the high and low values. The high value at Site NB1 could be due to the fact that the site was dry for long periods during the study which may have allowed sediment bound TP to accumulate in the channel that could be suspended with storm flows and cause higher TP concentrations. The watershed area for Site FC1 has similar land use percentages to the other sample sites, but the areal distribution is different. The land uses adjoining Fassnight Creek are primarily residential with a large percentage of grassland and forest which is in contrast to the main stem of Jordan Creek where commercial land use dominates the area next to the stream. This difference may explain the low median concentration of storm TP at Site FC1, and dilution of Jordan Creek by low-TP Fassnight Creek may explain the low median concentration at Site WC1.

The median TN baseflow concentrations show a variability that may indicate a point source influenced pattern in which the point source may be spring discharge as described above (Fig. 6.27 b). Several sites have high median TN concentrations at baseflow and these sites, as noted above, are probably influenced by spring discharge. The median storm TN concentration has pattern in which all sites fit into a narrow range between 1.3 and 2.1 mg/L. This may be a result of relatively TN-poor surface runoff diluting the baseflow point source variation.

The median baseflow and storm load graphs for the watershed can help to identify the sources for the TN and TP exported from the watershed (Fig. 6.28). The baseflow TP and TN patterns have peaks at the Site WC1 watershed outlet. Because both the TN and TP concentration patterns are relatively level, this indicates that the increase in load is driven by the increase in discharge caused by the confluence of Fassnight and Jordan

Creeks. The storm load patterns show a general “increasing downstream” trend that seems to emphasize the main stem downtown sites as adding significantly to the load of TN and TP.

Future Work

By collecting water quality and discharge data over the period of a year for a spatially distributed set of sample sites the present study has created a unique water quality data set for Springfield, MO. This data set is doubly important because Springfield is the largest urban area within the unique geologic and social region known as “the Ozarks”. The following improvements to data collection techniques or project focus could help the data to point to more conclusive results.

Better Control of Discharge at Sample Sites. The present study collected discharge data only at each sampling time. There was no ability during the study to collect samples from the same point (i.e. flood peak) of the hydrograph at each sample site. This was sufficient to create a rating curve for each site but in effect limited the study to comparisons of constituent means, rating curve slope, and concentration or load for calculated common discharges. Future work would be improved if it included a method to collect continuous discharge data at the study sample sites. This would allow future researchers to create and compare annual loads for each sample site and further to calculate and analyze the propagation of flood waves through the Jordan Creek watershed.

Improve Concentration and Load Rating Curves. The present study did not consistently sample water from the rising limb of storm hydrographs and thus consistently missed the “first flush” concentrations of pollutants if it existed.

Comparisons of results with previous data sets (City of Springfield, 2004; Richards and Johnson, 2002) indicate that higher concentrations may indeed exist in the rising limb. Future work on the study would benefit from use of automated sampling technology. The difficulties of programming the sampler and handling the volume of samples are significant, not to mention protecting the sampler from mischief, but results would help illuminate the existence and nature of the pollutant chemograph within the hydrograph and produce much more accurate rating curves for concentration and load.

CHAPTER 7

SUMMARY AND CONCLUSION

The primary goal of the present study is to estimate the loads and yields of nutrients from the watershed into Wilson Creek, and to use load and yield estimates at intermediate sample sites to identify source differences within the watershed. To create these estimates water samples and instantaneous discharges were taken under both baseflow and storm runoff conditions over the period of a year between July 2004 and July 2005. Water quality parameters were collected with each sample to explore the stream conditions that may contribute to pollutant concentrations. The watershed load was calculated by using baseflow and storm runoff water samples and instantaneous discharges to create a load rating curve for each of ten sample sites, and then calculating annual loads by using that load rating curve with average annual flows or flow frequencies. The WC1 sample site, located at the USGS Gage on Wilson Creek at Scenic Ave has the discharge records to support these load and yield estimates. The other sample sites were compared to each other by using regional runoff equations and City of Springfield flood modeling to calculate equivalent discharges for each site.

Results of the Jordan Creek baseline water quality study indicate:

1. **Concentrations of TN in Jordan Creek appear to vary with season (TEMP) and baseflow Q but TP concentrations do not.**

After the completion of data collection, a Pearson correlation matrix for TP and TN concentrations and water quality parameters was prepared. A significant correlation ($\alpha = 0.01$) appeared between both temperature (-0.714) and DO (0.614) and baseflow TN concentration at Site WC1. When these values were plotted as a time series it seemed apparent that seasonal changes in temperature and temperature-related dissolved oxygen levels were correlating with seasonal changes in TN uptake by plants from soil water. The same time series plot shows no similar seasonal variation for TP concentrations. A positive correlation between storm event concentration of TP and turbidity did appear (0.117) but it was not significant. This may be due to missing high first-flush concentrations in grab samples, to unstable turbidity measurements or it could be that the urban surfaces in the watershed do not yield enough sediment during runoff events to create a significant turbidity signal.

2. **Multiple rating curves help to more accurately describe baseflow and storm concentrations and loads.**

The present study used pollutant concentrations in samples from both baseflow and storm events and corresponding measured discharges over the course of the study period to create rating curves. The rating curves have two stages, corresponding to baseflow and storm runoff concentrations or loads. Using separate curves based on stage creates a better fit to the data since for many sites the slope of the two baseflow and storm event curves are both different from each other and from a curve fitted to the aggregated data.

Some sites exhibited overlap between the highest baseflow and the lowest storm event discharges. In these cases the midpoint of the overlap area was used to separate base and runoff load rating curves.

3. **Different methods for calculating loads and yields for study area show similar results for TN and a wide range of results for TP.**

The discharge records from the USGS gage located at Site WC1 allow calculation of annual loads of TN and TP. Four methods were employed to create these calculations with the first three methods employing the load rating curve prepared for Site WC1. (1) Daily average discharge utilized daily discharge from the gage records. (2) Maximum daily discharge used real-time discharge data to replace average daily discharge with the maximum discharge for each day during the study period with storm runoff. (3) Flow probability loads utilized flow exceedence data provided by the USGS. The load for each discharge was calculated using the load rating curve, multiplied by the probability of that flow occurring per day, then multiplied by 365 to create a probable annual load. The actual period of record for this gage is less than the 30 years considered minimum by the USGS for statistical confidence and therefore this estimate is somewhat suspect. (4) An EPA "simple method" land use load was prepared using typical land use loads multiplied by percent of watershed area derived from a City of Springfield landuse map.

The average annual load estimate for TP and TN was 2,159 and 26,818 kg/y respectively and yields were 0.4and 5.4 kg/ha-y at Site WC1. Maximum TP and TN load estimates were 13,172 and 76,616 kg/y with yields of 2.6 and 15.3 kg/ha-y. The extreme difference between the average daily annual and maximum annual yields probably is a reflection of the flashiness of the watershed reflected in the discharge records since most events peak and recede within a day and thus projecting maximum discharge over the period of a day is likely to over-predict actual discharge. The flow probability-based predicted annual loads for TP and TN were 1,233 and 24,334 kg/y and the median landuse area-based annual loads were 3,355 and 20,693 kg/y respectively.

The daily average flow estimate is assumed to be the most accurate because it is based on measured actual discharge. A range of ± 20 % from the daily average was used to create zone of acceptable estimates; values within this range were considered "similar" estimates (Fig. 22). For TN annual loads, the flow probability and land use based estimates each were within the 20% range but for TP loads those estimates were both outside the 20% range. For both TP and TN the maximum daily estimate was much higher than all other estimates.

4. Concentrations of TN and TP are similar to concentrations of nutrients in Ozark rural watersheds but higher than undisturbed watersheds.

One purpose of the study was to evaluate how water quality from the Jordan Creek study area compares with regional data. Means and distribution of concentrations data were compared to existing regional data including the James River TMDL study, masters thesis data from Mark Bowen and Brian Fredrick, USGS water resources investigations by Davis et al, and Richards and Johnson, and to a survey of undisturbed watersheds by Clark and others (Davis et al, 1998; Clark et al, 2000; Fredrick, 2001; MoDNR, 2001; Richards and Johnson, 2002; Bowen, 2004). The overall means of TN and TP concentrations (1.90 mg/L and 83 µg/L respectively) for Site WC1 are similar to or less than TN and TP values from studies within the region by Bowen, Fredrick and Davis.

The James River TMDL (MoDNR, 2001) study collected samples only at baseflow. Baseflow TN and TP means for the present study at Site WC1 are 2.28 mg/L and 28 µg/L and storm concentrations are 1.25 mg/L and 177 µg/L respectively. The baseflow TP values are similar to TMDL sites un-influenced by WWTPs and much less than those with influence from WWTPs and the mean storm event TP concentrations are higher even than sites with WWTP influence. Both baseflow and storm TN concentrations are within the range of values from the TMDL study (Fig. 25). Concentration exceedance data for the study indicates that TMDL target concentration for TN (1.5 mg/L) and TP (75 µg/L) were exceeded at the watershed outlet at Site WC1 45 % and 14 % of the study period, respectively.

The TP and TN concentrations from the present study are higher than those measured in undisturbed watersheds as reported by Clark (2000); a data distribution plot shows that the median TP and TN concentrations for undisturbed watersheds are much lower than medians for all watersheds in the present study. Comparisons of yields per square kilometer show that the calculated TN and TP annual yields from daily flow data for Site WC1 is within the maximum range of yields for undisturbed watersheds.

5. **Relatively uniform land use between sample site watersheds does not appear to control nutrient sources and loads.**

Concentration and load differences were not attributable to land use differences between watersheds based on the land use classification used in the study. The City of Springfield used hydraulic models to determine the 1-Year Recurrence discharge at each sample site. This discharge provides a basis for common comparison between the sites that isn't provided by comparing loads per event, because the sampling procedure doesn't guarantee that each sample was taken from the same point on the hydrograph. These discharges were put in to the TN and TP load rating curves for each site and the resulting loads compared to an EPA "simple model" of land use-based TN and TP loading. The results were very similar, but did not single out a particular land use category or watershed as being a source for nutrient loads.

6. **Median concentration and discharge analysis points to springs as baseflow source of TN and downtown core area as source for storm TP.**

Based on analysis of the median concentration of TN and TP samples collected at each sample site, baseflow TN concentrations appear to follow at "point source" pattern with high values occurring at sites influenced by spring discharge. Baseflow TP follows a “nonpoint” pattern with a uniform pattern of values. Storm TP median concentration patterns suggest that pattern of land use within a watershed, rather than merely percent of land use, may control TP concentration. Storm median loads indicate that the downtown core area is major source of TP for the study watershed.

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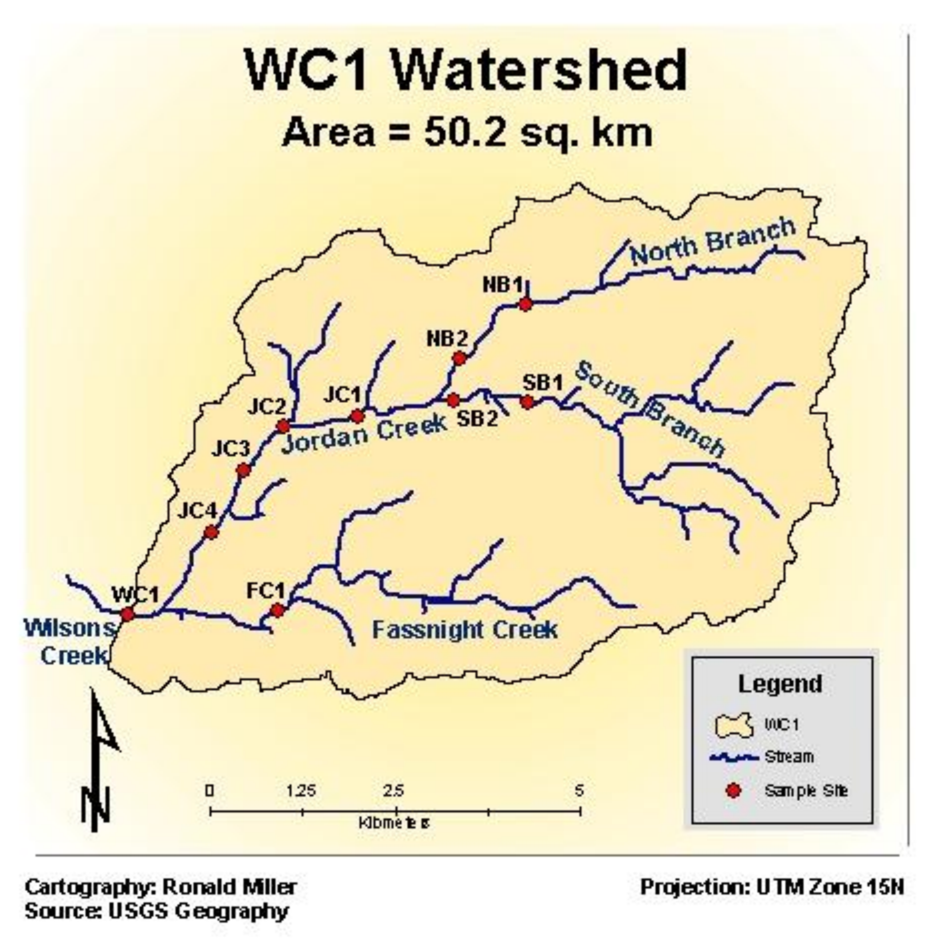
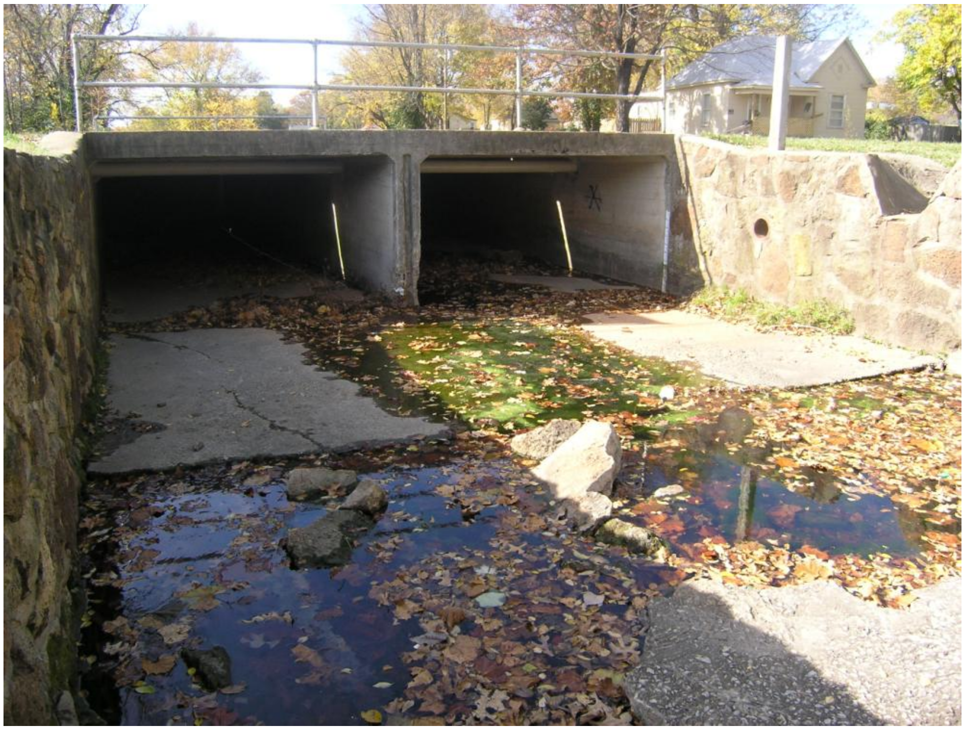
APPENDIX A

Watershed Maps, Pictures of Sample Sites, Survey Cross – sections and Discharge Rating Curves

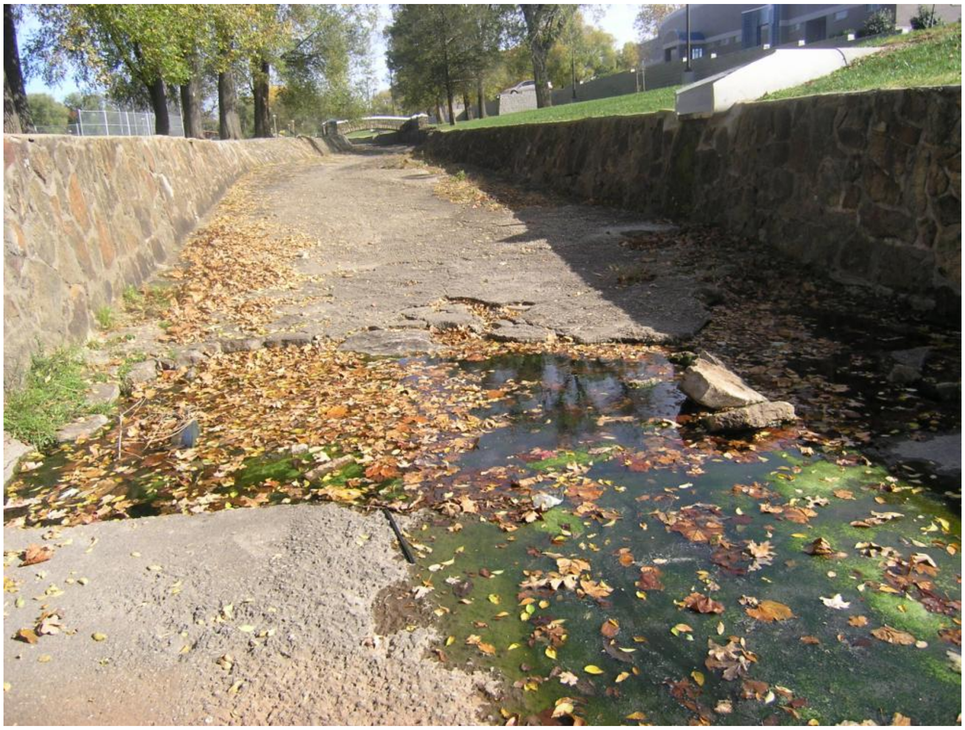

WC1 Watershed
Area = 50.2 sq. km
North Branch
NB1
NB2
SB1
South Branch
JC1
JC2
SB2
Jordan Creek
JC3
JC4
WC1
FC1
Wilsons Creek
Fassnight Creek
Legend
WC1
Stream
Sample Site
N
0
1.25
2.5
5
Kilometers
Cartography: Ronald Miller
Source: USGS Geography
Projection: UTM Zone 15N

WC1 watershed area (same as entire study area)

APPENDIX A (continued)



Site NB1 (North Branch Jordan at Fremont Ave): Downstream view showing gage location, dry channel and karst seep

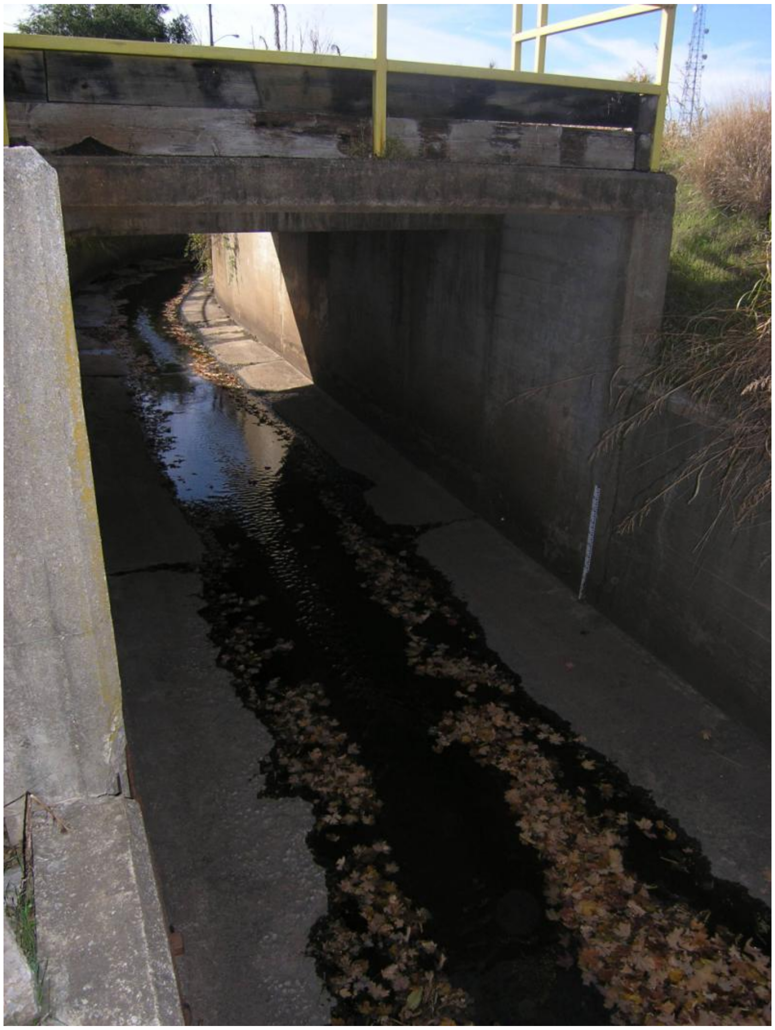


Site NB1: Upstream view showing dry channel and karst seep

APPENDIX A (continued)

Site NB2 (North Branch Jordan at Sherman Ave): Upstream view showing gage location and base flow

Site SB1 (South Branch Jordan at Fremont Ave): Downstream view showing gage location and base flow



Site SB2 (South Branch Jordan at Hammons Parkway): Downstream view showing gage location and base flow. Base flow stream gaging was done at channel center and event stages were reported as staff gage reading plus elevation difference between gage base and channel center.

APPENDIX A (continued)

Site JC1 (Main stem Jordan Creek at Main Ave): Upstream view showing gage location and base flow.

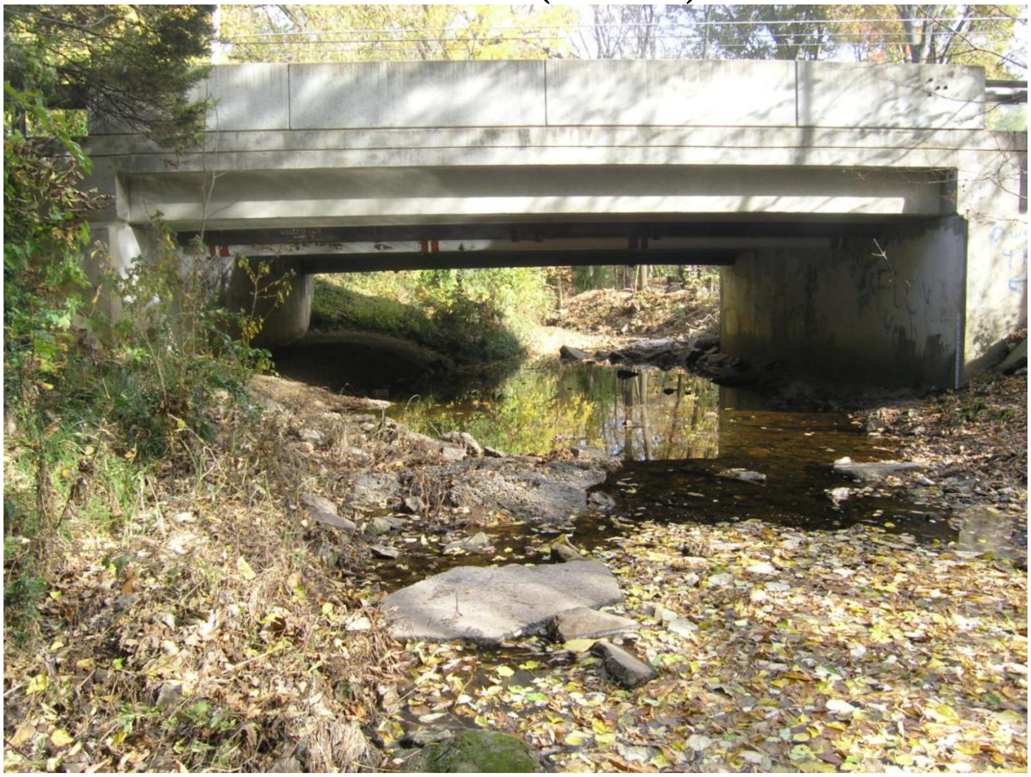
Site JC3 (Main stem Jordan Creek at Fort Avenue): Downstream view showing base flow (Staff gage is located on bridge base at right of picture).

APPENDIX A (continued)

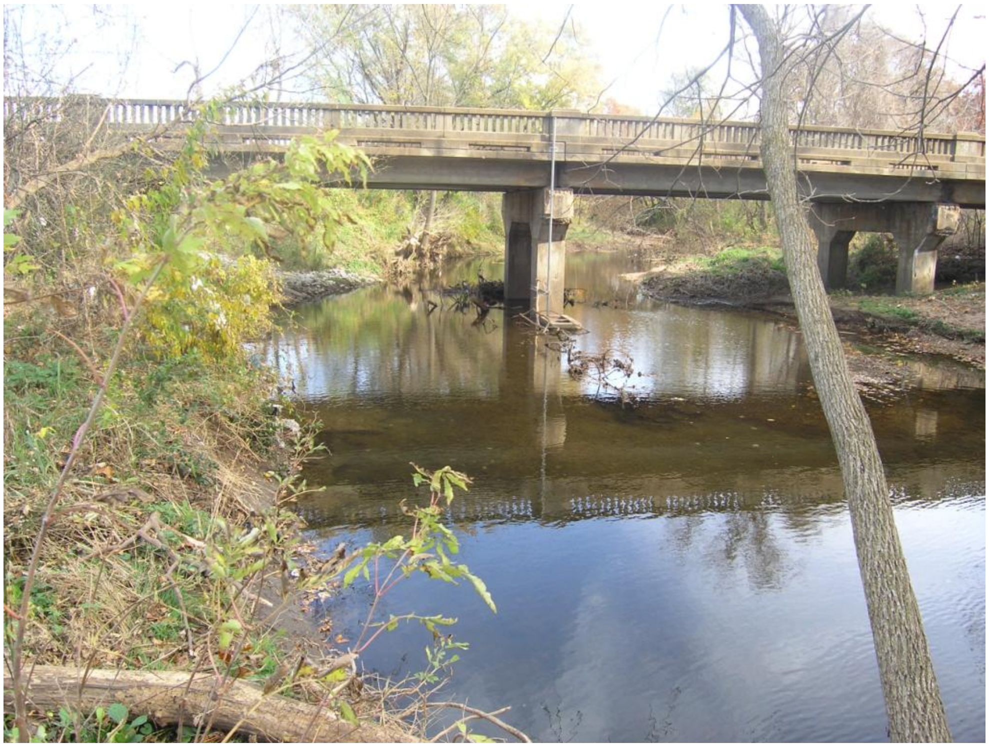
Site JC3 (Main stem Jordan Creek at Mt Vernon Ave): Downstream view showing base flow and staff gage location.

Site JC4 (Main Stem Jordan Creek at Grand Ave): Upstream view showing gage location and baseflow.

APPENDIX A (continued)

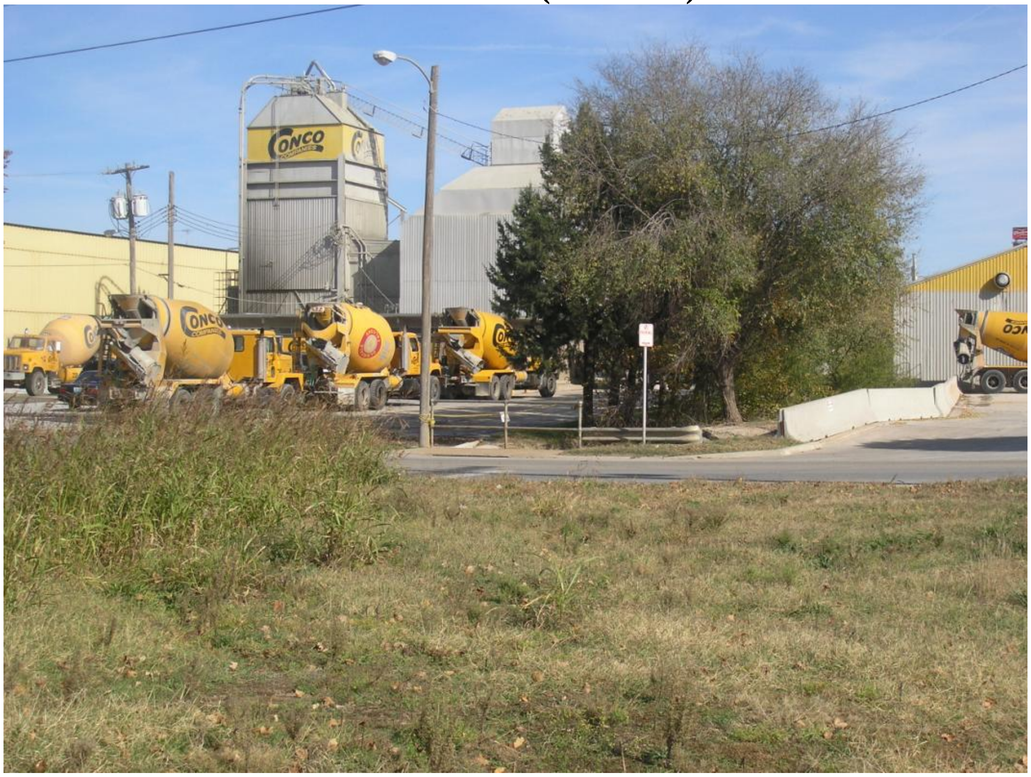


Site FC1 (Fassnight Creek at Fort Avenue): Upstream view showing baseflow (Staff gage is located on near side of bridge support at right of picture)

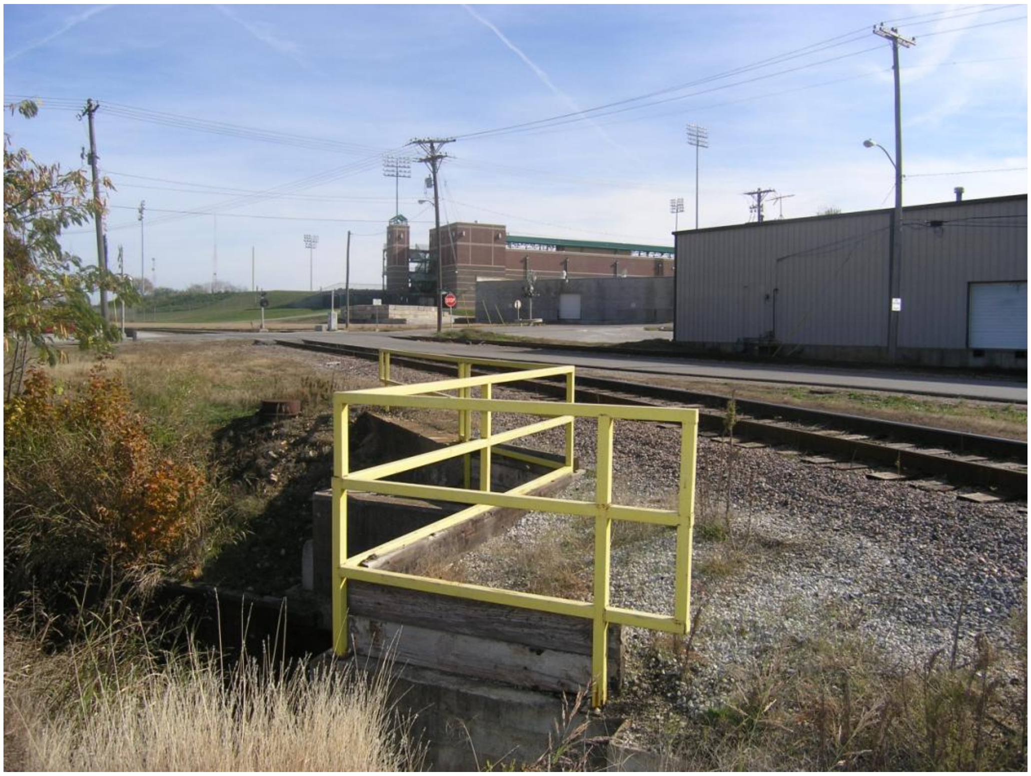


Site WC1 (Wilson Creek at Scenic Avenue): Upstream view showing baseflow. USGS gage is obscured by foliage at right of photo, gage sensor pipe on central bridge pier

APPENDIX A (continued)



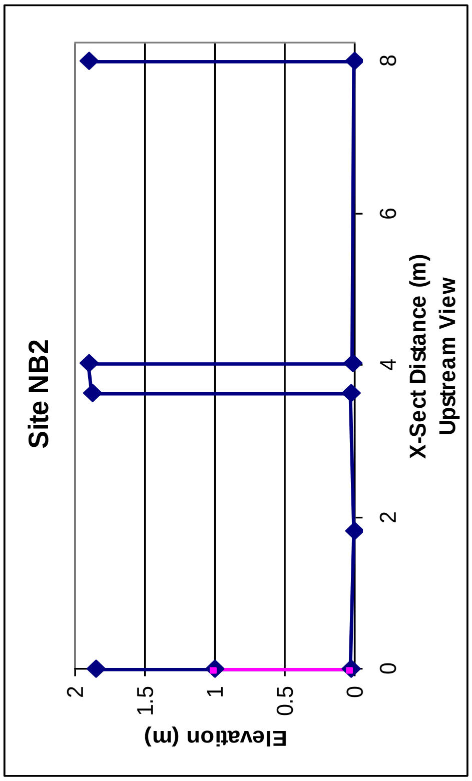
Concrete loading and truck wash station upstream of Site SB2

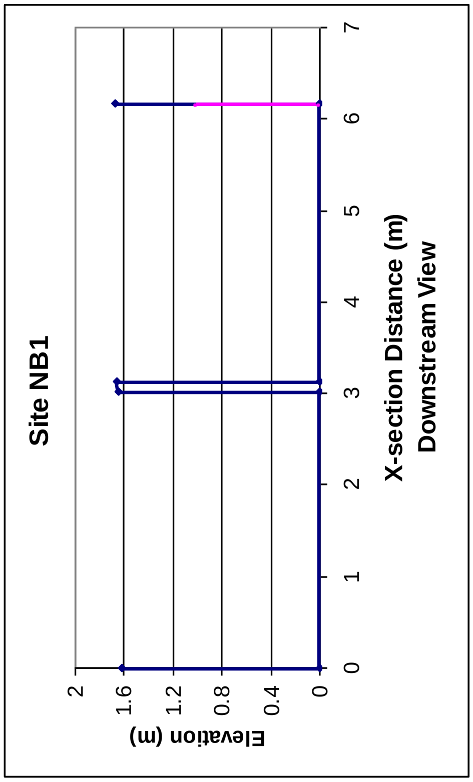


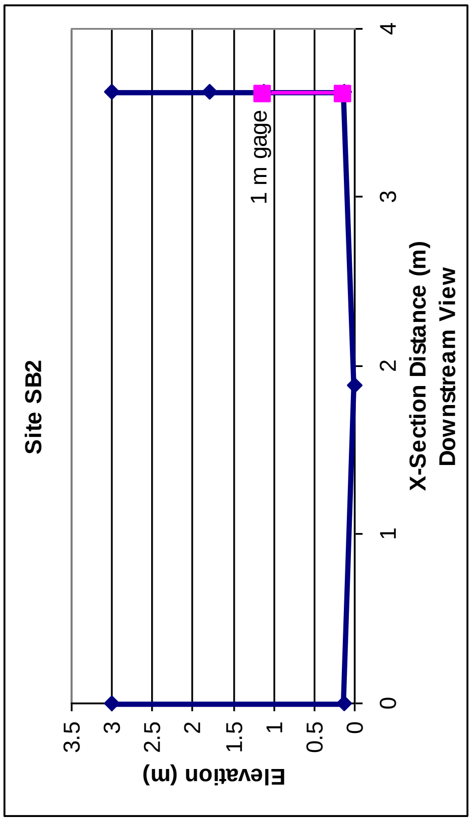
Upstream view of baseball stadium from Site SB2.

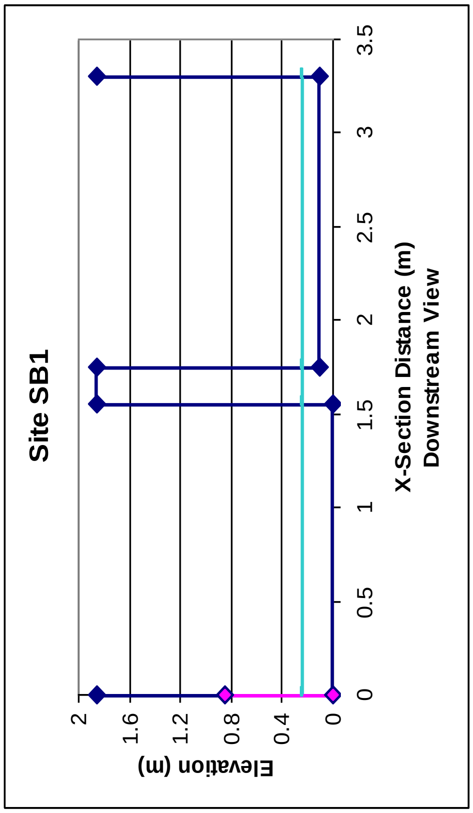
APPENDIX A (continued)

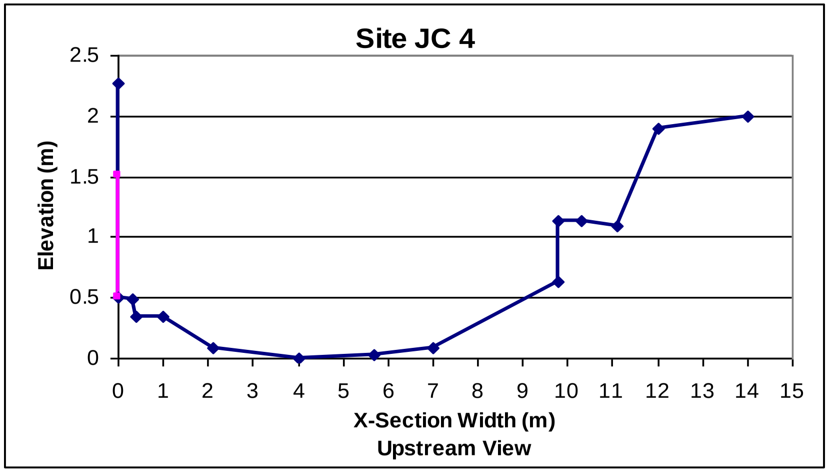
Site Surveys

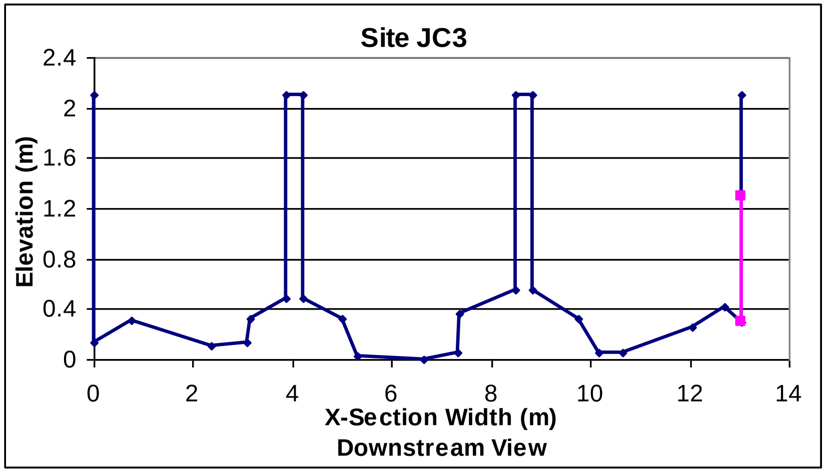


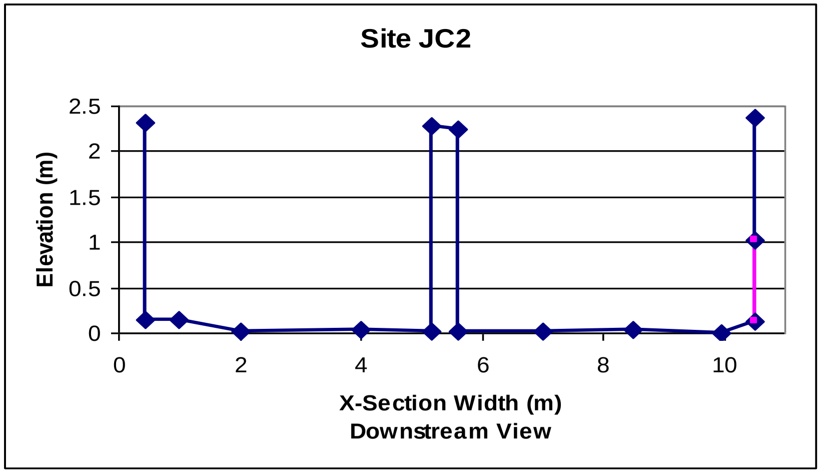


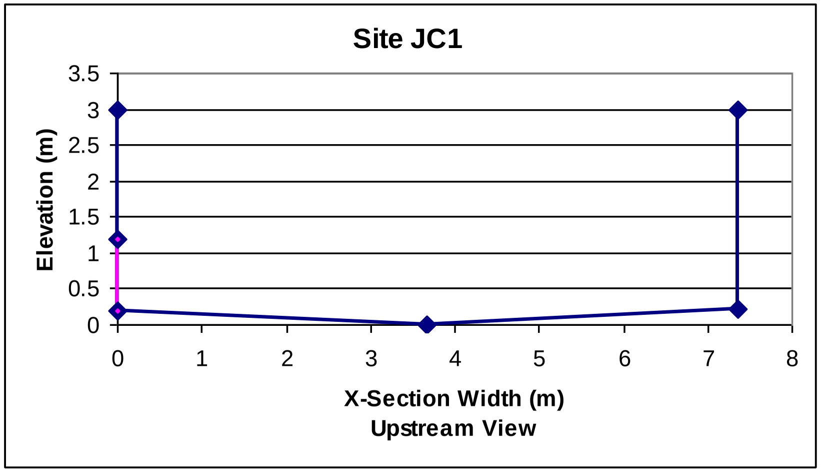


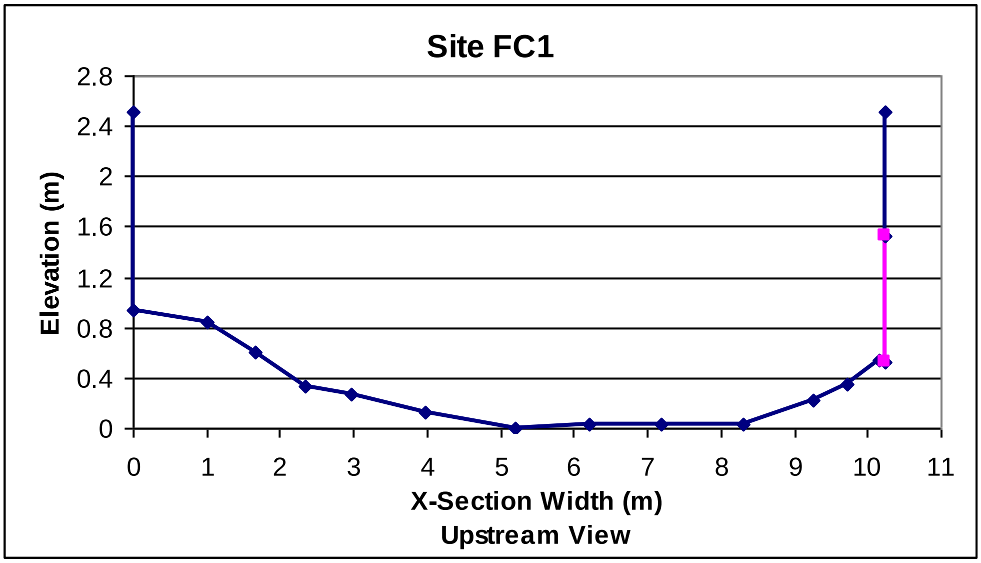



Site JC 4
Elevation (m)
2.5
2
1.5
1
0.5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
X-Section Width (m)
Upstream View

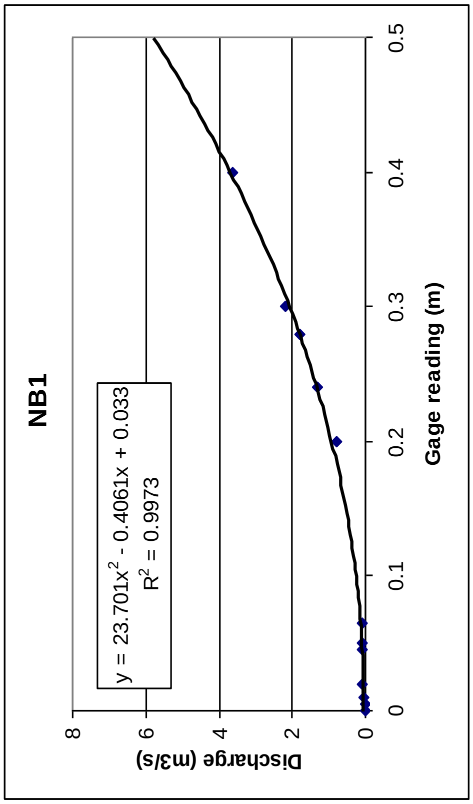

Site JC3
Elevation (m)
2.4
2
1.6
1.2
0.8
0.4
0
0 2 4 6 8 10 12 14
X-Section Width (m)
Downstream View

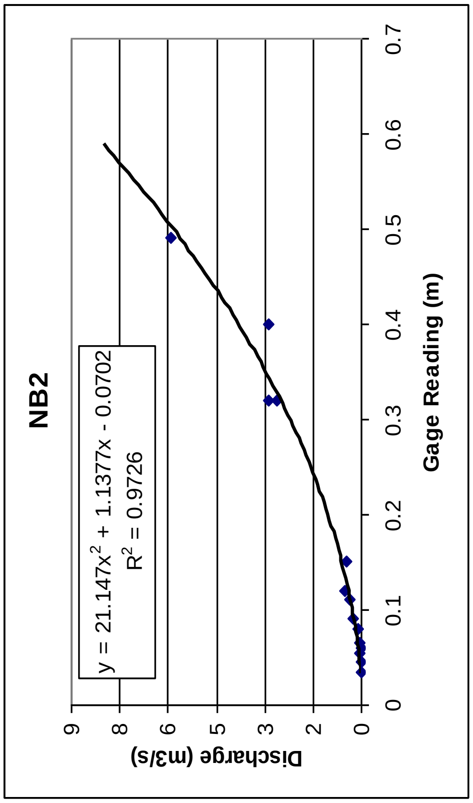

Site JC2
Elevation (m)
2.5
2
1.5
1
0.5
0
0 2 4 6 8 10
X-Section Width (m)
Downstream View

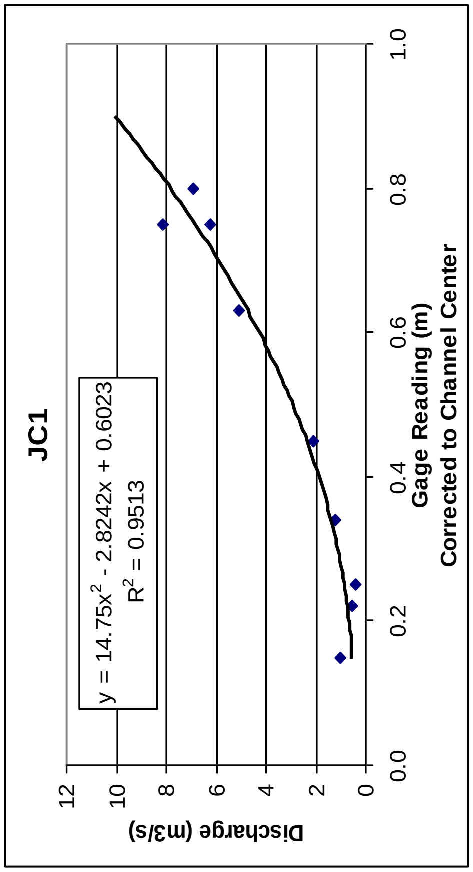

Site JC1
Elevation (m)
3.5
3
2.5
2
1.5
1
0.5
0
0 1 2 3 4 5 6 7 8
X-Section Width (m)
Upstream View

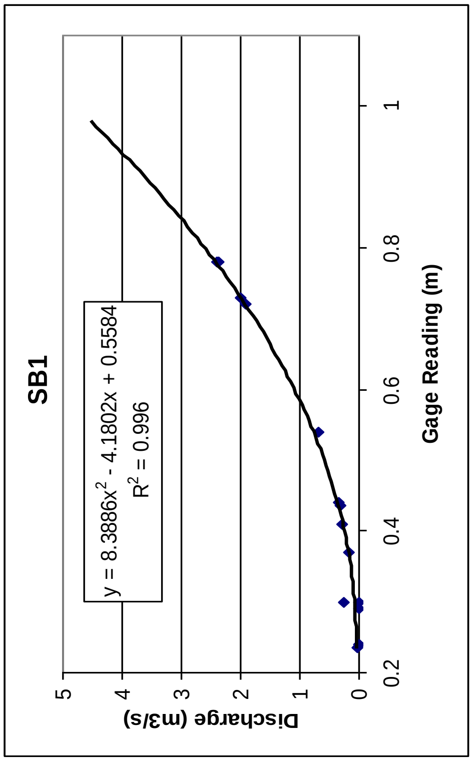


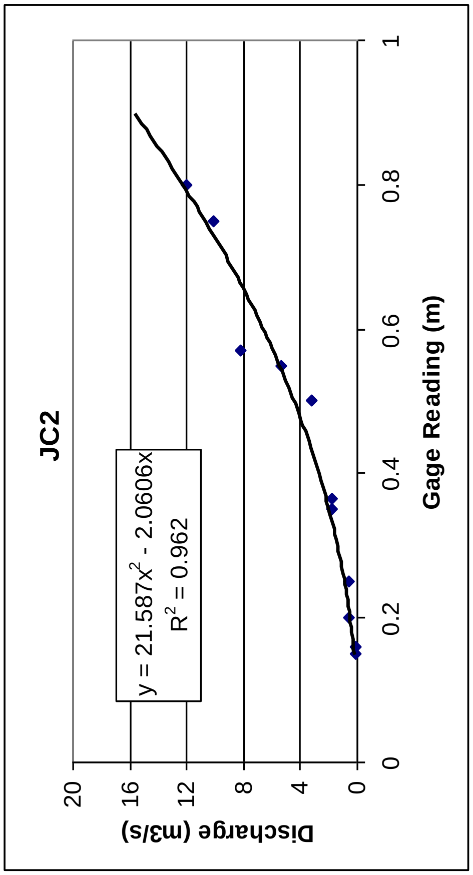
Site Discharge Rating Curves

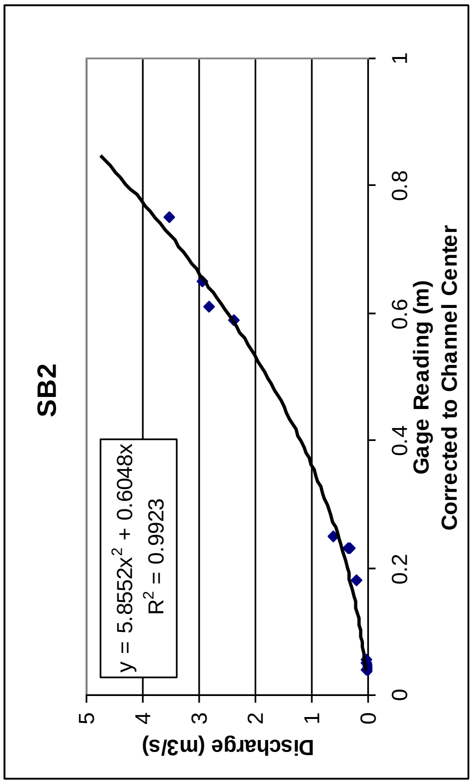


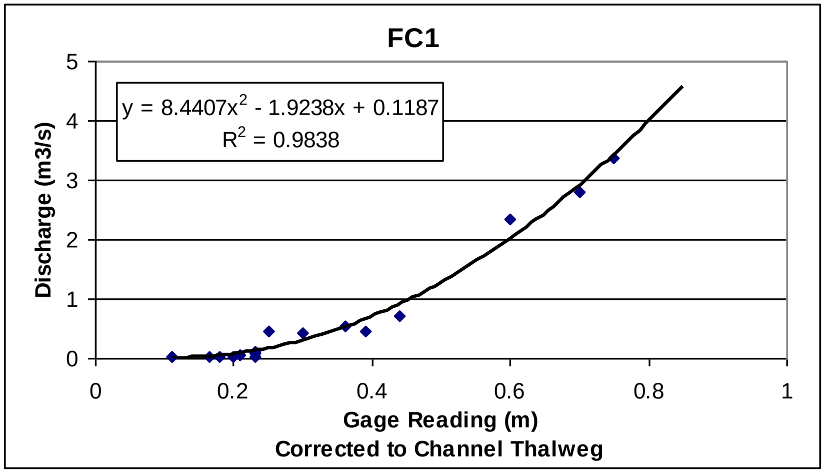


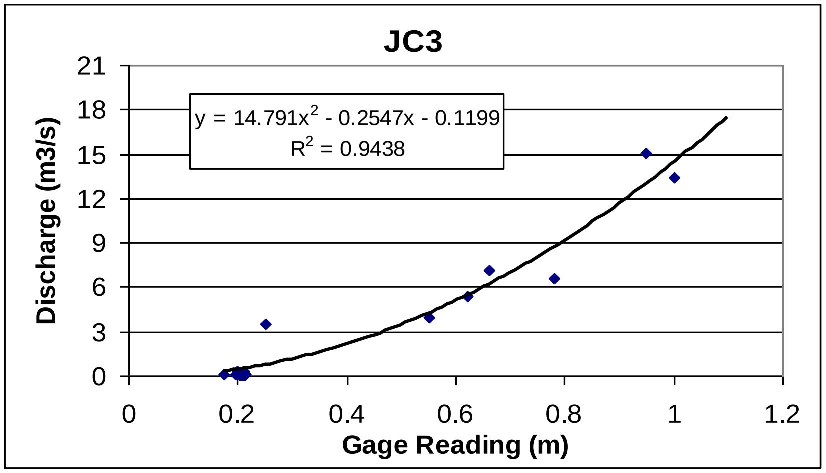

JC1
y = 14.75x^2 - 2.8242x + 0.6023
R^2 = 0.9513
Discharge (m3/s)
0
2
4
6
8
10
12
Gage Reading (m)
Corrected to Channel Center
0.0
0.2
0.4
0.6
0.8
1.0

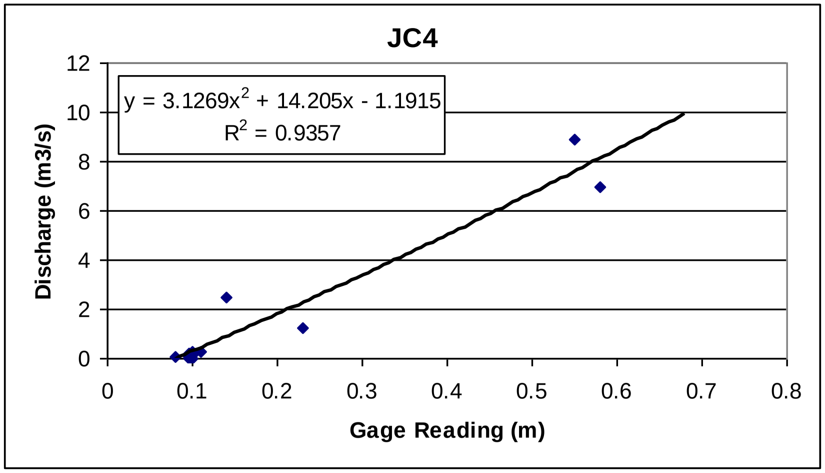

SB1
y = 8.3886x^2 - 4.1802x + 0.5584
R^2 = 0.996
Discharge (m3/s)
0
1
2
3
4
5
Gage Reading (m)
0.2
0.4
0.6
0.8
1


JC2
y = 21.587x^2 - 2.0606x
R^2 = 0.962
Discharge (m3/s)
0
4
8
12
16
20
Gage Reading (m)
0
0.2
0.4
0.6
0.8
1


SB2
y = 5.8552x^2 + 0.6048x
R^2 = 0.9923
Discharge (m3/s)
0
1
2
3
4
5
Gage Reading (m)
Corrected to Channel Center
0
0.2
0.4
0.6
0.8
1


FC1
y = 8.4407x^2 - 1.9238x + 0.1187
R^2 = 0.9838
Discharge (m3/s)
5
4
3
2
1
0
0
0.2
0.4
0.6
0.8
1
Gage Reading (m)
Corrected to Channel Thalweg


JC3
y = 14.791x^2 - 0.2547x - 0.1199
R^2 = 0.9438
Discharge (m3/s)
21
18
15
12
9
6
3
0
0
0.2
0.4
0.6
0.8
1
1.2
Gage Reading (m)


JC4
y = 3.1269x^2 + 14.205x - 1.1915
R^2 = 0.9357
Discharge (m3/s)
12
10
8
6
4
2
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Gage Reading (m)

APPENDIX B

Concentrations and Discharge by Date and Site

Site NB1

EVENT	DATE	TIME	STADIA (m)	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	Temp (ºC)	TDS (mg/L)	ORP	TP (µg/L)	TN (mg/L)	As (mg/L)	Cu (mg/L)	Zn (mg/L)	Pb (mg/L)	Cd (mg/L)	Q (m^3/s)
Storm	8/28/2004										293.8	0.85	0.000	0.010	0.433	0.040	0.000	0.79
Storm	9/5/2004	16:09:56	0.02	7.7	0.144	3.1	8.12	27.71	0.094	89	780.5	2.97	0.000	0.000	0.429	0.000	0.000	0.09
Base	9/7/2004		0								N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.02
Base	9/24/2004		0								N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.02
Storm	10/8/2004	8:15:16	0.045	7.79	0.198	0	7.68	18.08	0.129	196	284.0	1.52	0.105	0.006	0.387	0.001	0.000	0.09
Storm	10/11/2004	11:12:22	0.3	8.08	0.099	109	11.08	11.84	0.064	264	172.0	0.59	0.000	0.007	0.394	0.008	0.000	2.18
Storm	10/14/2004	10:07:56	0.065	7.24	0.166	124	10.86	10.77	0.108	252	167.0	1.10	0.013	0.016	0.490	0.009	0.000	0.07
Storm	10/26/2004	9:52:16	0.05	7.02	0.145	162	8.04	18.6	0.095	102	252.0	0.86	0.126	0.017	0.796	0.016	0.001	0.09
Base	11/23/2004	12:27:52	0.01	8.48	0.46	63.2	16.41	13.82	0.299	201	54.0	0.38	0.031	0.000	0.338	0.007	0.000	0.04
Storm	11/29/2004	11:26:30	0.28	7.85	0.17	173	13.21	6.01	0.11	240	238.0	0.73	0.031	0.000	0.245	0.000	0.000	1.78
Base	12/14/2004	10:22:02	0.005	7.24	0.61	4	12.59	0.81	0.39	202	18.0	1.03	0.000	0.009	0.360	0.000	0.000	0.01
Base	12/21/2004	10:27:42	TRACE	6.98	0.818	33.1	7.65	4.8	0.523	117	21.0	2.01	0.000	0.000	0.369	0.000	0.000	0.00
Storm	1/4/2005	11:03:04	0.24	7.2	0.154	201	12.77	6.3	0.1	239	289.0	0.38	0.073	0.018	0.546	0.011	0.003	1.30
Storm	1/5/2005	10:23:44	0.4	7.16	0.202	101	13.07	4.88	0.131	199	174.0	1.12	0.000	0.016	0.900	0.004	0.001	3.61
Base	1/21/2005	10:48:34	0.007	8.04	0.562	23.8	15.36	5.62	0.36	280	21.0	1.31	0.033	0.016	0.920	0.005	0.002	0.03
Base	2/10/2005	11:32:24	0.02	7.86	0.778	29.4	16.07	5.41	0.498	137	145.0	5.14	0.000	0.088	1.128	0.012	0.006	0.04
Base	2/24/2005	9:13:06	0.015	8.14	0.623	66.3	16.14	3.82	0.399	150	33.0	0.95	0.002	0.013	0.703	0.007	0.004	0.03
Base	3/15/2005	9:56:08	0.005	7.75	0.669	188	15.9	7.35	0.428	239	21.0	1.32	0.071	0.022	0.762	0.000	0.001	0.03
Base	3/24/2005	14:00:24	0.015	8.65	0.539	319	13.67	7.56	0.345	117	55.0	0.94	0.000	0.018	2.447	0.014	0.003	0.03
Base	4/22/2005	8:56:02	T	7.26	0.837	111	10.51	15.21	0.535	193	30.0	1.68	0.027	0.016	0.579	0.018	0.002	0.02
Base	4/30/2005	6:48:26	0.005	7.21	0.654	121	12.28	7.68	0.419	87	29.0	1.18	0.000	0.023	1.337	0.036	0.002	0.03
Base	5/18/2005	10:02:16	0	7.42	0.974	14.9	17.32	19.85	0.624	126	18.0	2.23	0.053	0.043	1.670	0.072	0.006	0.02
Base	5/30/2005	9:55:40	0	7.08	0.9	0	8.61	18.91	0.47	126	22.0	2.30	0.090	0.031	1.525	0.070	0.006	0.00
Storm	6/11/2005	12:14:26	0.02	7.48	0.244	41.1	8.36	23.16	0.158	249	213.0	1.57	0.062	0.073	2.462	0.122	0.010	0.04
Base	6/16/2005	9:15:38	0	7.4	0.337	122	7.94	20.7	0.22	113	966.0	4.75	0.293	0.061	3.094	0.299	0.022	0.00
Base	6/30/2005	11:10:42	0	7.19	0.887	0	15.85	27.79	0.568	107	52.0	1.64	0.033	0.010	0.604	0.022	0.001	0.00
Base	7/8/2005	9:05:48	0	7.25	0.9	24.8	16.92	24.02	0.42		31.0	1.21	0.062	0.023	0.649	0.041	0.003	0.00

Note: Flowing water not always present.

APPENDIX B: Concentrations and Discharge by Date and Site (Cont'd)

Site NB2

EVENT	DATE	TIME	STADIA (m)	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	Temp (ºC)	TDS (mg/L)	ORP	TP (µg/L)	TN (mg/L)	As (mg/L)	Cu (mg/L)	Zn (mg/L)	Pb (mg/L)	Cd (mg/L)	Q (m^3/s)
Storm	8/28/2004	14:57:24	0.12	7.71	0.211	22.3	8.36	22.57	0.137	142	182.3	1.18	0.066	0.007	0.357	0.008	0.000	0.51
Storm	9/5/2004	16:51:08	0.08	7.73	0.801	26.6	8.93	23.71	0.512	135	92.7	1.79	0.000	0.000	1.597	0.017	0.000	0.12
Base	9/7/2004	12:04:30	0.045	7.82	0.953	14	8.9	17.18	0.61	247	32.5	1.13	0.000	0.004	0.380	0.004	0.000	0.01
Base	9/24/2004	13:24:26	0.035	7.79	0.988	81.8	11.18	20.86	0.632	171	29.0	1.14	0.000	0.011	0.670	0.002	0.000	0.00
Storm	10/8/2004	8:53:42	0.09	7.62	0.268	0	6.53	18.01	0.174	205	230.0	1.51	0.087	0.007	0.505	0.009	0.000	0.25
Storm	10/11/2004	12:02:22	0.4	7.84	0.109	118	11.46	11.95	0.071	181	191.0	0.67	0.088	0.019	0.435	0.013	0.000	2.90
Storm	10/14/2004	11:01:42	0.15	7.3	0.349	121	9.61	11.56	0.227	226	107.0	1.06	0.088	0.004	0.633	0.001	0.000	0.44
Storm	10/26/2004	10:52:30	0.11	7.34	0.3	87.4	6.59	18	0.195	198	202.0	1.07	0.093	0.011	0.341	0.009	0.001	0.37
Base	11/23/2004	13:16:08	0.055	7.51	0.645	114	13.41	14.81	0.413	130	49.0	1.65	0.029	0.006	0.511	0.000	0.000	0.03
Storm	11/29/2004	12:19:18	0.32	7.28	0.19	160	12.76	6.41	0.124	216	210.0	0.95	0.033	0.004	0.449	0.000	0.000	2.88
Base	12/14/2004	11:16:54	0.065	7.44	0.728	60.3	12	7.51	0.466	149	11.0	2.79	0.000	0.024	0.198	0.000	0.005	0.05
Base	12/21/2004	11:36:40	0.06	7.45	0.744	31.2	13.72	9.97	0.476	167	11.0	2.58	0.000	0.006	0.361	0.000	0.001	0.02
Storm	1/4/2005	12:05:48	0.32	7.2	0.157	255	12.93	6.38	0.102	169	130.0	0.57	0.012	0.000	0.600	0.024	0.002	2.64
Storm	1/5/2005	11:11:06	0.49	6.87	0.238	126	12.87	5.42	0.154	225	167.0	1.35	0.000	0.009	0.714	0.001	0.003	5.89
Base	1/21/2005	11:33:58	0.065	7.53	0.668	34	15.43	11.2	0.427	178	25.0	3.59	0.005	0.016	1.256	0.007	0.002	0.09
Base	2/10/2005	12:08:28	0.07	7.24	0.783	35.7	16.41	9.91	0.501	235	50.0	3.99	0.037	0.018	1.644	0.013	0.007	0.11
Base	2/24/2005	9:50:34	0.075	7.57	0.756	45.2	15.07	8.03	0.484	162	19.0	2.12	0.000	0.010	0.573	0.013	0.002	0.13
Base	3/15/2005	10:32:48	0.07	7.75	0.898	98.7	17.69	10.41	0.575	162	19.0	2.06	0.069	0.009	0.892	0.019	0.001	0.11
Base	3/24/2005	14:09:20	0.07	7.76	0.718	196	13.89	10.87	0.459	255	16.0	1.75	0.000	0.009	0.931	0.010	0.002	0.11
Base	4/22/2005	9:07:04	0.075	7.72	0.906	97.1	12.68	14.85	0.58	105	286.0	2.16	0.013	0.024	1.186	0.022	0.003	0.13
Base	4/30/2005	7:02:30	0.07	7.15	0.856	122	9.73	10.63	0.548	198	16.0	2.45	0.012	0.024	0.477	0.023	0.004	0.11
Base	5/18/2005	10:16:08	0.055	8.04	0.953	30.1	17.34	18.67	0.61	67	6.0	1.66	0.002	0.020	0.731	0.034	0.003	0.06
Base	5/30/2005	10:05:40	0.05	7.82	0.999	2	11.27	19.88	0.639	112	13.0	1.65	0.031	0.031	2.276	0.082	0.003	0.04
Storm	6/11/2005	12:25:08	0.065	7.57	0.861	4.1	7.55	20.19	0.551	127	55.0	2.14	0.118	0.048	2.475	0.100	0.008	0.09
Base	6/16/2005	9:24:56	0.055	7.51	0.714	5.8	7.91	17.49	0.46	255	21.0	2.51	0.199	0.069	2.145	0.160	0.015	0.06
Base	6/30/2005	11:21:04	0.05	7.69	0.999	-10	7.01	24.93	0.662	88	23.0	1.43	0.000	0.005	1.593	0.011	0.001	0.04
Base	7/8/2005	9:16:08	0.045	7.67	0.999	71.7	8.21	20.48	0.665	94	20.0	1.40	0.017	0.013	0.486	0.018	0.001	0.02

APPENDIX B: Concentrations and Discharge by Date and Site (Cont'd)

Site SB1

EVENT	DATE	TIME	STADIA (m)	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	Temp (ºC)	TDS (mg/L)	ORP	TP (µg/L)	TN (mg/L)	As (mg/L)	Cu (mg/L)	Zn (mg/L)	Pb (mg/L)	Cd (mg/L)	Q (m^3/s)
Storm	8/28/2004	14:12:00	0.54	7.65	0.094	72.2	9.14	22.73	0.061	118	232	1.12975	0.000	0.004	0.618	0.012	0.000	0.67
Storm	9/5/2004	16:26:30	0.37	7.63	0.404	26.3	7.78	23.42	0.262	120	174	0.92322	0.000	0.002	0.491	0.009	0.000	0.16
Base	9/7/2004	11:38:48	0.24	7.78	0.618	0	10.27	21.1	0.396	252	63	0.48657	0.000	0.000	0.492	0.003	0.000	0.01
Base	9/24/2004	12:56:16	0.235	7.76	0.547	25.3	10.36	21.51	0.35	183	50	0.56863	0.000	0.000	0.497	0.004	0.000	0.02
Storm	10/8/2004	8:28:30	0.44	7.62	0.146	0	7.31	18.47	0.095	209	287	1.009	0.093	0.018	0.402	0.009	0.000	0.34
Storm	10/11/2004	11:21:22	0.78	7.97	0.067	73	11.68	11.65	0.044	198	184	0.603	0.093	0.009	0.444	0.015	0.000	2.38
Storm	10/14/2004	10:23:18	0.435	7.39	0.167	81.2	9.83	11.45	0.109	240	101	0.869	0.084	0.022	1.146	0.012	0.001	0.33
Storm	10/26/2004	10:11:12	0.41	7.08	0.157	63.7	13.99	18.81	0.102	287	142	0.659	0.118	0.077	0.528	0.020	0.000	0.28
Base	11/23/2004	12:41:48	0.3	7.36	0.562	67.7	11.79	14.15	0.359	117	50	0.08941	0.018	0.000	0.588	0.000	0.000	0.25
Storm	11/29/2004	11:45:50	0.73	7.28	0.131	128	12.8	6.61	0.085	209	227	1.11125	0.039	0.066	0.332	0.002	0.000	2.00
Base	12/14/2004	10:38:20	0.3	7.01	0.682	29.9	10.42	2.3	0.436	104	39	1.472	0.000	0.015	0.617	0.000	0.000	0.01
Base	12/21/2004	11:04:14	0.29	6.88	0.672	35.9	11.58	4.29	0.43	108	37	0.513	0.000	0.000	0.763	0.000	0.001	0.01
Storm	1/4/2005	11:19:58	0.72	7.04	0.074	246	13.31	6.09	0.048	155	141	0.36	0.156	0.003	1.141	0.017	0.001	1.92
Storm	1/5/2005	10:41:42	0.78	6.91	0.207	71.8	12.75	5.49	0.134	229	222	1.498	0.000	0.032	0.651	0.009	0.001	2.41
Base	1/21/2005	11:02:38	0.36	7.6	0.714	34.1	12.92	7.52	0.457	135	56	2.67645	0.074	0.027	1.233	0.005	0.001	0.14
Base	2/10/2005	11:46:46	0.36	7.37	0.632	35.8	14.48	5.66	0.405	239	39	1.05597	0.044	0.150	0.693	0.065	0.019	0.14
Base	2/24/2005	9:22:50	0.37	7.64	0.671	64.1	12.09	5.7	0.429	152	40	1.01608	0.007	0.021	0.842	0.001	0.006	0.16
Base	3/15/2005	10:06:42	0.34	7.82	0.595	103	15.63	8.37	0.381	150	24	0.483	0.030	0.011	1.472	0.008	0.000	0.11
Base	3/24/2005	13:48:28	0.36	7.53	0.662	135	11.02	8.58	0.424	263	43	0.603	0.054	0.010	0.696	0.010	0.001	0.14
Base	4/22/2005	8:44:12	0.435	7.75	0.778	65.9	11.84	14.47	0.498	96	42	0.431	0.021	0.015	0.451	0.021	0.002	0.33
Base	4/30/2005	6:34:24	0.335	7.15	0.699	123	9.56	9.22	0.447	166	47	1.132	0.000	0.039	0.903	0.012	0.022	0.10
Base	5/18/2005	9:43:56	0.32	7.76	0.711	28.9	12.33	17.43	0.455	73	44	0.356	0.077	0.041	1.093	0.055	0.001	0.08
Base	5/30/2005	9:42:06	0.22	7.87	0.657	0	9.92	19.08	0.42	180	43	0.6855	0.046	0.023	3.437	0.086	0.005	0.04
Storm	6/11/2005	12:05:26	0.335	7.76	0.567	0	8.4	21.89	0.363	126	126	0.739	0.166	0.083	0.854	0.127	0.016	0.10
Base	6/16/2005	9:02:26	0.365	7.67	0.528	10.2	7.41	19.74	0.34	253	83	0.648	0.287	0.002	2.588	0.258	0.024	0.15
Base	6/30/2005	11:01:24	0.32	7.77	0.569	554	10.55	25.76	0.364	84	48	0.545	0.031	0.010	0.360	0.022	0.002	0.08
Base	7/8/2005	8:56:08	0.32	7.76	0.639	11.3	9.1	21.03	0.409	88	48	0.267	0.026	0.023	0.797	0.041	0.003	0.08

APPENDIX B: Concentrations and Discharge by Date and Site (Cont'd)

Site SB2

EVENT	DATE	TIME	STADIA (m)	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	Temp (ºC)	TDS (mg/L)	ORP	TP (µg/L)	TN (mg/L)	As (mg/L)	Cu (mg/L)	Zn (mg/L)	Pb (mg/L)	Cd (mg/L)	Q (m^3/s)
Storm	8/28/2004	2:36:56 PM	0.25	8.14	0.102	45.2	9.08	22.81	0.066	129	211	0.72	0.061	0.005	0.304	0.020	0.000	0.63
Storm	9/5/2004	4:35:54 PM	0.18	7.6	0.298	17.4	8.66	24.92	0.194	123	244	1.68	0.000	0.000	0.491	0.011	0.000	0.20
Base	9/7/2004	11:52:58	0.04	7.62	0.723	5.4	8.64	17.81	0.462	249	59	0.96	0.000	0.000	0.524	0.000	0.000	0.01
Base	9/24/2004	1:14:24 PM	0.04	7.93	0.697	256	8.57	20.2	0.446	148	47	1.11	0.000	0.000	0.810	0.000	0.001	0.01
Storm	10/8/2004	8:41:14 AM	0.045	7.66	0.154	0	8.15	18.46	0.1	211	233	1.13	0.019	0.016	1.940	0.016	0.001	0.01
Storm	10/11/2004	11:45:48 AM	0.62	7.68	0.068	93	11.98	11.67	0.044	201	184	0.53	0.099	0.010	0.584	0.021	0.000	3.54
Storm	10/14/2004	10:43:56 AM	0.1	7.69	0.16	250	12.65	11	0.104	214	157	0.92	0.097	0.010	0.493	0.014	0.001	0.35
Storm	10/26/2004	10:27:48 AM	0.1	7.91	0.147	313	8.43	18.95	0.096	189	269	0.85	0.000	0.035	0.631	0.023	0.001	0.32
Base	11/23/2004	1:00:16 PM	0.055	7.43	0.696	75.3	10.93	14.19	0.446	119	43	1.50	0.004	0.000	0.538	0.000	0.000	0.03
Storm	11/29/2004	12:07:08 PM	0.46	6.91	0.132	133	12.82	6.63	0.086	226	236	1.12	0.015	0.001	0.544	0.000	0.000	2.37
Base	12/14/2004	10:55:00	0.05	7.26	0.767	81.6	10.69	5.01	0.491	112	49	2.16	0.000	0.014	0.531	0.000	0.006	0.04
Base	12/21/2004	11:22:16 AM	0.04	7.17	0.804	32.9	11.66	6.11	0.514	100	31	1.73	0.000	0.000	0.327	0.000	0.000	0.02
Storm	1/4/2005	11:45:10 AM	0.52	7.22	0.074	190	13.43	6.04	0.048	175	128	0.40	0.039	0.023	0.300	0.024	0.001	2.94
Storm	1/5/2005	10:58:40 AM	0.48	6.78	0.199	89.2	12.96	5.41	0.13	227	172	1.13	0.000	0.029	0.640	0.007	0.003	2.82
Base	1/21/2005	11:17:02 AM	0.065	7.57	0.814	42.3	13.47	9.02	0.521	116	1097	3.60	0.001	0.020	0.862	0.000	0.002	0.06
Base	2/10/2005	11:57:36 AM	0.05	7.19	0.785	38.1	13.66	5.77	0.503	161	30	1.99	0.000	0.011	1.142	0.008	0.003	0.04
Base	2/24/2005	9:39:20 AM	0.05	7.47	0.673	58.2	11.96	6.87	0.431	155	43	2.02	0.071	0.010	0.497	0.013	0.003	0.04
Base	3/15/2005	10:22:06 AM	0.05	7.78	0.778	107	16.74	8.14	0.498	155	933	1.21	0.012	0.006	0.684	0.008	0.000	0.04
Base	3/24/2005	2:16:26 PM	0.055	7.56	0.847	176	11.76	9.21	0.542	259	45	1.72	0.041	0.009	0.881	0.000	0.000	0.05
Base	4/22/2005	9:18:46 AM	0.035	7.74	0.893	88.7	12.09	14.71	0.572	107	320	1.53	0.027	0.030	2.034	0.020	0.003	0.03
Base	4/30/2005	7:18:36 AM	0.045	7.37	0.864	98.3	9.79	10.45	0.553	132	25	1.85	0.027	0.023	0.401	0.015	0.002	0.04
Base	5/18/2005	10:31:02 AM	0.047	7.83	0.914	50.1	11.76	16.78	0.585	70	32	1.20	0.035	0.017	0.700	0.011	0.002	0.04
Base	5/30/2005	10:19:00 AM	0.065	7.99	0.859	22.2	11.05	19.25	0.55	103	34	1.22	0.077	0.030	1.311	0.059	0.006	0.06
Storm	6/11/2005	12:33:10 PM	0.045	7.66	0.444	104	8.64	22.72	0.289	114	170	1.41	0.101	0.048	1.940	0.095	0.008	0.04
Base	6/16/2005	9:32:38 AM	0.085	7.62	0.553	31.9	7.91	19.44	0.35	263	114	2.00	0.168	0.060	4.042	0.155	0.013	0.09
Base	6/30/2005	11:33:28 AM	0.05	7.69	0.741	0	9.3	24.07	0.474	86	49	0.84	0.000	0.001	0.793	0.010	0.000	0.04
Base	7/8/2005	9:24:32 AM	0.05	8.83	0.804	117	11.7	21.52	0.515	45	41	1.11	0.021	0.010	0.001	0.017	0.001	0.04

APPENDIX B: Concentrations and Discharge by Date and Site (Cont'd)

Site JC1

EVENT	DATE	TIME	STADIA (m)	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	Temp (ºC)	TDS (mg/L)	ORP	TP (µg/L)	TN (mg/L)	As (mg/L)	Cu (mg/L)	Zn (mg/L)	Pb (mg/L)	Cd (mg/L)	Q (m^3/s)
Storm	8/28/2004	15:21:40	0.14	8	0.132	10.1	8.96	22.77	0.086	148	269	1.05	0.074	0.010	0.463	0.021	0.000	1.24
Storm	9/5/2004	17:07:24	0.02	7.81	0.264	12.5	8.49	24.94	0.171	121	216	1.64	0.028	0.018	2.642	0.014	0.000	0.56
Base	9/7/2004	12:21:46	L .07 R .1	8.33	0.76	13.8	11.04	18.88	0.487	209	66	1.06	0.000	0.012	0.620	0.008	0.000	0.17
Base	9/24/2004	13:48:10	L 0.08 R .105	8.29	0.831	67.2	9.85	20.25	0.532	169	76	1.41	0.000	0.000	1.427	0.003	0.003	0.02
Storm	10/8/2004	9:14:38	0.05	7.81	0.207	-10	8.1	18.31	0.135	201	221	1.19	0.019	0.007	0.637	0.012	0.001	0.39
Storm	10/11/2004	12:25:52	0.6	8.04	0.081	91.2	11.79	11.85	0.053	172	253	0.70	0.079	0.014	0.551	0.018	0.001	6.89
Storm	10/14/2004	11:20:52	0.15	7.78	0.174	200	11.44	10.92	0.113	196	141	0.86	0.090	0.023	0.533	0.018	0.001	1.01
Storm	10/26/2004	11:13:00	0.25	7.65	0.123	208	9.16	18.95	0.08	192	404	0.85	0.127	0.068	0.441	0.040	0.001	2.11
Base	11/23/2004	13:41:48	L 0.11 R 0.185	8.03	0.67	76.3	13.47	13.57	0.429	146	41	1.71	0.007	0.000	0.501	0.000	0.000	0.08
Storm	11/29/2004	12:42:36	0.43	7.44	0.16	146	12.82	6.69	0.104	205	203	1.06	0.025	0.017	0.503	0.001	0.000	5.11
Base	12/14/2004	11:38:56	L .105 R.16	7.99	0.757	55.7	12.42	5.32	0.485	160	17	2.92	0.000	0.006	0.293	0.000	0.003	0.08
Base	12/21/2004	11:53:50	L .11 R .14	8	0.778	31.7	12.97	6.57	0.498	185	17	2.55	0.000	0.018	0.482	0.000	0.000	0.06
Storm	1/4/2005	12:31:00	0.55	7.68	0.091	175	13.53	6.08	0.059	164	115	0.40	0.069	0.040	0.975	0.022	0.004	6.26
Storm	1/5/2005	11:26:00	0.55	6.97	0.235	96.5	13.24	5.63	0.153	183	197	1.52	0.000	0.007	0.676	0.002	0.001	8.15
Base	1/21/2005	11:54:52	0.14	7.91	0.744	37.6	14.06	8.7	0.476	199	23	3.35	0.007	0.013	1.146	0.000	0.000	0.57
Base	2/10/2005	12:20:28	0.15	7.9	0.804	37.1	15.21	5.53	0.515	237	19	3.46	0.000	0.009	0.741	0.012	0.005	0.51
Base	2/24/2005	10:08:44	0.145	7.81	0.73	40	13.72	6.92	0.467	159	28	2.42	0.000	0.012	1.036	0.014	0.002	1.38
Base	3/15/2005	10:47:16	0.15	7.99	0.846	106	15.07	8.14	0.541	160	22	1.65	0.002	0.091	0.710	0.010	0.000	1.42
Base	3/24/2005	14:32:32	0.17	7.75	0.783	213	12.41	8.93	0.501	233	983	3.00	0.005	0.022	0.745	0.013	0.002	1.58
Base	4/22/2005	9:39:34	0.12	8.21	0.855	70.6	12.9	14.62	0.547	99	16	2.01	0.000	0.023	1.221	0.017	0.002	0.48
Base	4/30/2005	7:46:10	0.095	8.07	0.729	28.8	11.53	11.01	0.47	229	21	2.04	0.000	0.012	0.132	0.015	0.002	0.47
Base	5/18/2005	11:05:34	0.11	8.33	0.953	34.1	12.22	16.11	0.61	57	29	1.52	0.026	0.034	0.957	0.014	0.003	0.47
Base	5/30/2005	10:29:52	0.05	8.26	0.894	319	10.72	18.58	0.572	99	14	1.56	0.104	0.029	2.136	0.068	0.005	0.50
Storm	6/11/2005	12:46:56	0.07	7.85	0.266	73.5	8.98	23.18	0.173	102	177	2.31	0.127	0.070	2.356	0.129	0.011	0.48
Base	6/16/2005	9:44:22	0.09	7.96	0.53	48.9	9.44	20.31	0.34	263	109	2.30	0.202	0.156	2.791	0.254	0.016	0.47
Base	6/30/2005	11:47:30	0.07	8.17	0.903	-10	10.28	23.63	0.578	68	42	1.35	0.000	0.009	0.389	0.010	0.001	0.48
Base	7/8/2005	9:37:22	0.065	8.22	0.93	95.3	11.06	21.72	0.595	69	44	1.18	0.009	0.012	0.515	0.023	0.002	0.48

Note: Some early stages were gaged at upstream site with two parallel channels

APPENDIX B: Concentrations and Discharge by Date and Site (Cont'd)

Site JC2

EVENT	DATE	TIME	STADIA (m)	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	Temp (ºC)	TDS (mg/L)	ORP	TP (µg/L)	TN (mg/L)	As (mg/L)	Cu (mg/L)	Zn (mg/L)	Pb (mg/L)	Cd (mg/L)	Q (m^3/s)
Storm	8/28/2004	15:35:18	0.35	7.89	0.161	25.2	8.83	22.74	0.105	129	188	1.05	0.056	0.006	0.787	0.011	0.001	1.80
Storm	9/5/2004	17:28:36	0.2	7.42	0.229	21.3	7.25	25.20	0.149	134	219	1.55	0.020	0.021	0.464	0.017	0.000	0.63
Base	9/7/2004	12:35:46	---------	7.23	0.881	27.9	6.56	19.32	0.564	76	67	1.00	0.000	0.000	0.779	0.006	0.000	
Base	9/24/2004	13:59:12	---------	7.18	0.901	71.2	7.69	20.31	0.577	108	115	1.10	0.000	0.000	0.524	0.011	0.001	0.03
Storm	10/8/2004	9:48:58	0.25	7.57	0.227	0	7.72	18.36	0.148	201	206	1.15	0.000	0.013	0.420	0.012	0.000	0.56
Storm	10/11/2004	12:57:06	0.8	8.06	0.097	83.7	11.61	12.31	0.063	139	164	0.58	0.063	0.013	0.304	0.020	0.000	12.05
Storm	10/14/2004	11:42:14	0.365	7.81	0.189	168	11.2	11.40	0.123	173	142	0.80	0.000	0.027	0.676	0.028	0.000	1.82
Storm	10/26/2004	11:36:30	0.5	7.78	0.114	260	8.37	19.03	0.074	169	311	1.13	0.097	0.080	0.678	0.043	0.000	3.19
Base	11/23/2004	14:03:00	0.16	7.34	0.787	71.3	12.04	14.85	0.503	35	49	1.68	0.000	0.000	0.275	0.000	0.000	0.16
Storm	11/29/2004	13:10:40	0.55	7.46	0.273	129	11.74	8.30	0.178	173	219	1.03	0.045	0.000	0.376	0.004	0.000	5.31
Base	12/14/2004	12:01:08	0.16	7.38	0.871	41.8	10.48	7.04	0.558	33	28	2.66	0.000	0.004	0.940	0.000	0.001	0.17
Base	12/21/2004	12:11:42	0.15	7.32	0.862	30.3	11.61	8.66	0.552	17	51	2.22	0.000	0.019	0.555	0.000	0.004	0.12
Storm	1/4/2005	13:07:28	0.57	7.57	0.104	174	13.03	6.32	0.068	151	121	0.35	0.000	0.028	0.913	0.030	0.003	8.20
Storm	1/5/2005	11:43:30	0.75	7.07	0.335	84	12.65	6.86	0.218	138	226	1.64	0.000	0.013	0.675	0.001	0.001	10.06
Base	1/21/2005	12:10:34	0.16	7.20	0.886	44.3	10.88	10.41	0.567	63	34	3.85	0.051	0.018	0.791	0.001	0.001	0.22
Base	2/10/2005	12:29:42	0.16	7.41	0.95	38.4	14.25	8.63	0.608	92	38	3.48	0.000	0.012	0.980	0.012	0.006	0.22
Base	2/24/2005	10:23:18	0.165	7.19	0.881	34.6	12.84	8.41	0.564	75	40	2.05	0.000	0.010	0.561	0.015	0.008	0.25
Base	3/15/2005	11:01:16	0.14	7.17	0.997	100	15.35	9.70	0.638	75	47	1.31	0.066	0.013	1.157	0.009	0.001	0.13
Base	3/24/2005	14:44:46	0.15	7.24	0.88	119	11.68	9.65	0.563	80	29	1.57	0.018	0.012	0.824	0.014	0.000	0.18
Base	4/22/2005	10:17:38	0.14	7.45	0.979	80	12.14	15.18	0.626	7	50	1.82	0.041	0.017	0.367	0.020	0.002	0.13
Base	4/30/2005	7:56:42	0.13	7.32	0.844	6.1	8.13	11.04	0.540	62	25	1.68	0.043	0.034	0.790	0.002	0.004	0.10
Base	5/18/2005	11:21:46	0.12	7.39	0.9	53.7	10.22	17.13	0.480	3	32	1.12	0.033	0.029	1.646	0.037	0.004	0.06
Base	5/30/2005	10:42:14	0.13	7.37	0.9495	16.6	8.375	18.31	0.592	40	55	1.29	0.055	0.029	2.149	0.077	0.006	0.10
Storm	6/11/2005	12:56:54	0.32	7.68	0.261	56.1	8.25	23.33	0.169	111	166	1.86	0.123	0.127	1.421	0.188	0.009	1.55
Base	6/16/2005	9:52:50	0.175	7.39	0.016	19.5	7.93	19.83	0.010	148	102	2.24	0.233	0.067	1.103	0.188	0.016	0.30
Base	6/30/2005	11:59:06	0.11	7.45	0.999	72.3	6.12	23.16	0.647	75	59	1.02	0.017	0.009	0.899	0.010	0.000	0.03
Base	7/8/2005	9:49:58	0.105	7.28	0.9	110	6.93	20.61	0.480	73	67	1.03	0.048	0.018	0.643	0.031	0.002	0.02

Note: Some stage readings not taken with discharge measurement

APPENDIX B: Concentrations and Discharge by Date and Site (Cont'd)

Site JC3

EVENT	DATE	TIME	STADIA (m)	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	Temp (ºC)	TDS (mg/L)	ORP	TP (µg/L)	TN (mg/L)	As (mg/L)	Cu (mg/L)	Zn (mg/L)	Pb (mg/L)	Cd (mg/L)	Q (m^3/s)
Storm	8/28/2004	16:04:22	0.55	7.78	0.186	27.3	8.7	22.88	0.121	151	201	1.41	0.050	0.008	0.525	0.015	0.001	3.94
Storm	9/5/2004	17:50:24	0.38	7.70	0.244	37.4	7.41	25.15	0.159	140	183	1.60	0.000	0.019	0.584	0.011	0.000	0.56
Base	9/7/2004	12:46:30	0.18	7.74	0.830	19.9	8.11	17.94	0.531	154	49	0.67	0.000	0.000	2.185	0.003	0.000	0.02
Base	9/24/2004	14:24:02	0.19	7.94	0.880	83.2	10.62	20.63	0.563	64	74	0.83	0.000	0.000	0.636	0.007	0.001	0.03
Storm	10/8/2004	10:03:50	0.36	7.63	0.233	0.0	7.6	18.35	0.151	202	171	0.97	0.097	0.017	0.732	0.001	0.000	0.50
Storm	10/11/2004	13:12:48	0.25	8.19	0.092	90.2	11.44	12.15	0.059	158	193	0.55	0.089	0.024	0.459	0.025	0.001	3.55
Storm	10/14/2004	12:01:42	0.62	7.76	0.221	167.0	10.8	11.12	0.144	156	146	1.09	0.101	0.050	0.671	0.031	0.000	5.36
Storm	10/26/2004	11:57:04	0.78	7.67	0.145	219.0	7.97	18.95	0.094	171	308	1.69	0.102	0.042	0.826	0.038	0.000	6.54
Base	11/23/2004	14:16:42	0.18	7.70	0.711	75.6	12.63	14.5	0.455	116	49	1.44	0.000	0.002	0.368	0.000	0.000	0.07
Storm	11/29/2004	13:39:34	0.66	7.57	0.205	166.0	12.16	7.2	0.133	88	236	1.16	0.018	0.015	0.839	0.003	0.000	7.10
Base	12/14/2004	12:17:34	0.18	7.99	0.884	31.8	10.96	4.99	0.565	78	23	2.37	0.000	0.003	0.502	0.000	0.000	0.09
Base	12/21/2004	12:25:18	0.165	7.76	0.883	38.5	12.12	6.35	0.565	102	25	5.89	0.000	0.018	0.447	0.000	0.000	0.07
Storm	1/4/2005	13:28:34	1	7.74	0.104	248.0	12.96	6.28	0.068	152	165	0.45	0.087	0.002	0.485	0.037	0.000	13.45
Storm	1/5/2005	12:00:44	0.95	7.22	0.283	127.0	12.6	6.22	0.184	128	212	2.15	0.000	0.037	0.632	0.019	0.004	15.07
Base	1/21/2005	12:47:10	0.21	7.70	0.886	25.3	12.47	9.53	0.567	132	29	3.56	0.002	0.022	0.765	0.000	0.002	0.36
Base	2/10/2005	12:55:52	0.2	7.71	0.933	23.2	14.75	7.22	0.597	103	41	3.48	0.050	0.016	1.889	0.007	0.002	0.28
Base	2/24/2005	10:43:36	0.21	7.63	0.838	37.8	12.53	7.26	0.537	128	33	2.03	0.041	0.015	0.574	0.010	0.003	0.16
Base	3/15/2005	11:16:20	0.175	7.83	0.985	117.0	15.89	8.24	0.631	68	26	1.21	0.000	0.023	0.717	0.012	0.001	0.06
Base	3/24/2005	14:56:18	0.195	7.69	0.863	129.0	12.45	9.33	0.553	136	41	1.69	0.065	0.013	0.778	0.007	0.009	0.08
Base	4/22/2005	10:32:40	0.21	7.86	0.900	84.5	10.64	14.75	0.48	60	23	1.42	0.044	0.027	1.265	0.020	0.005	0.05
Base	4/30/2005	8:10:32	0.215	7.54	0.771	7.3	8.26	10.07	0.49	128	18	2.47	0.032	0.009	0.464	0.016	0.002	0.06
Base	5/18/2005	11:35:52	0.205	7.97	0.999	58.7	10.65	17.27	0.697	51	31	1.21	0.039	0.043	1.071	0.042	0.003	0.03
Base	5/30/2005	11:02:24	0.195	7.91	0.950	18.8	7.295	18.495	0.545	40.5	25	0.80	0.110	0.039	1.544	0.068	0.007	0.39
Storm	6/11/2005	13:09:14	0.42	7.79	0.172	60.8	8.68	23.63	0.112	102	186	1.85	0.089	0.070	3.066	0.152	0.011	2.38
Base	6/16/2005	10:02:48	0.245	7.66	0.724	18.7	6.79	19.3	0.46	215	47	1.69	0.211	0.067	1.334	0.203	0.017	0.71
Base	6/30/2005	12:10:02	0.185	7.83	0.995	27.9	10.42	24.84	0.637	62	34	0.46	0.032	0.014	1.116	0.012	0.001	0.34
Base	7/8/2005	10:00:10	0.178	7.78	0.900	99.4	10.77	20.91	0.48	69	46	0.82	0.048	0.024	1.008	0.032	0.003	0.30

APPENDIX B: Concentrations and Discharge by Date and Site (Cont'd)

Site JC4

EVENT	DATE	TIME	STADIA (m)	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	Temp (ºC)	TDS (mg/L)	ORP	TP (µg/L)	TN (mg/L)	As (mg/L)	Cu (mg/L)	Zn (mg/L)	Pb (mg/L)	Cd (mg/L)	Q (m^3/s)
Storm	8/28/2004	16:26:56	0.23	7.82	0.209	34	8.7	22.8	0.136	155	194	1.20	0.000	0.000	0.272	0.010	0.000	1.25
Storm	9/5/2004	17:59:02	0.21	7.78	0.213	36.2	7.68	25.21	0.138	142	205	1.42	0.000	0.022	0.498	0.024	0.000	0.59
Base	9/7/2004	12:55:44	0.1	7.55	0.733	31	7.98	18.96	0.469	175	50	1.11	0.000	0.000	0.613	0.000	0.000	0.04
Base	9/24/2004	14:41:34	0.08	7.53	0.716	97.8	9.43	20.27	0.458	104	63	0.65	0.000	0.000	2.567	0.016	0.000	0.07
Storm	10/8/2004	10:15:42	0.16	7.70	0.227	0	7.85	18.31	0.147	198	168	1.11	0.096	0.008	0.373	0.008	0.001	0.88
Storm	10/11/2004	13:43:10	0.4	8.20	0.096	85.5	11.21	12.24	0.062	160	204	0.70	0.031	0.020	1.485	0.022	0.001	5.74
Storm	10/14/2004	12:17:30	0.1	7.79	0.237	175	10.8	11.15	0.154	175	161	1.26	0.079	0.028	0.577	0.029	0.000	2.46
Storm	10/26/2004	12:07:54	0.16	7.72	0.136	238	8.41	18.96	0.088	186	225	0.88	0.111	0.068	0.364	0.046	0.000	2.27
Base	11/23/2004	14:33:56	0.095	7.58	0.778	78.9	12.68	14.19	0.498	157	37	1.71	0.014	0.003	0.467	0.000	0.000	0.12
Storm	11/29/2004	13:51:26	0.36	7.61	0.206	136	12.18	7.25	0.134	146	229	1.10	0.048	0.000	0.290	0.000	0.000	5.74
Base	12/14/2004	12:34:28	0.1	7.66	0.822	51.4	10.84	6.06	0.526	101	24	3.01	0.000	0.023	0.270	0.000	0.000	0.28
Base	12/21/2004	12:43:38	0.09	7.56	0.818	41.1	11.89	7.18	0.523	114	20	2.56	0.000	0.026	0.395	0.000	0.000	0.10
Storm	1/4/2005	13:40:06	0.58	7.73	0.106	172	12.99	6.33	0.069	155	382	0.42	0.096	0.006	1.192	0.021	0.002	6.99
Storm	1/5/2005	12:22:24	0.55	7.33	0.287	121	12.84	6.31	0.187	152	263	2.05	0.000	0.028	0.612	0.014	0.003	8.90
Base	1/21/2005	13:03:20	0.1	7.58	0.893	28.5	12.75	9.62	0.571	166	27	4.55	0.073	0.013	0.914	0.001	0.000	0.03
Base	2/10/2005	13:09:10	0.1	7.55	0.901	31.2	15.15	7.71	0.577	121	28	3.95	0.000	0.037	0.732	0.007	0.005	0.25
Base	2/24/2005	10:59:24	0.1	7.52	0.832	37.6	13.33	7.58	0.532	154	26	2.91	0.000	0.006	0.547	0.011	0.004	0.13
Base	3/15/2005	11:26:38	0.08	7.61	0.912	123	15.43	9.12	0.584	124	16	1.71	0.000	0.019	0.559	0.011	0.005	0.09
Base	3/24/2005	15:14:16	0.095	7.59	0.852	126	12.33	9.31	0.545	179	25	1.81	0.066	0.015	1.115	0.008	0.003	0.23
Base	4/22/2005	10:45:06	0.095	7.69	0.956	76	12.02	15.14	0.612	81	18	1.77	0.036	0.029	0.465	0.013	0.004	0.10
Base	4/30/2005	8:17:36	0.095	7.58	0.756	7.5	9.88	10.79	0.48	157	25	1.77	0.000	0.073	0.513	0.022	0.004	0.10
Base	5/18/2005	12:00:36	0.095	7.73	0.995	126	11.54	17.58	0.637	68	19	1.84	0.084	0.077	2.355	0.067	0.005	0.07
Base	5/30/2005	11:12:14	0.07	7.73	0.912	26.8	7.69	18.34	0.584	66	29	1.19	0.100	0.023	1.102	0.056	0.006	0.07
Storm	6/11/2005	13:17:46	0.235	7.86	0.198	132	8.62	23.34	0.129	98	238	2.00	0.118	0.068	2.202	0.155	0.010	2.32
Base	6/16/2005	10:10:24	0.09	7.59	0.736	4.3	8.48	18.73	0.47	236	34	1.67	0.200	0.079	2.575	0.170	0.015	0.09
Base	6/30/2005	12:18:10	0.065	7.52	0.886	28.6	10.17	23.46	0.567	82	31	1.22	0.015	0.005	0.608	0.011	0.001	0.07
Base	7/8/2005	10:07:58	0.065	7.71	0.872	123	8.96	22.04	0.558	77	46	1.12	0.000	0.016	0.294	0.028	0.002	0.07

APPENDIX B: Concentrations and Discharge by Date and Site (Cont'd)

Site FC1

EVENT	DATE	TIME	STADIA (m)	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	Temp (ºC)	TDS (mg/L)	ORP	TP (µg/L)	TN (mg/L)	As (mg/L)	Cu (mg/L)	Zn (mg/L)	Pb (mg/L)	Cd (mg/L)	Q (m^3/s)
Storm	8/28/2004	17:35:50	0.39	7.88	0.154	57	9.02	22.95	0.100	161	135	1.05	0.000	0.000	0.821	0.008	0.000	0.47
Storm	9/5/2004	18:28:42	0.25	7.58	0.201	16.7	6.44	24.91	0.131	146	225	1.79	0.000	0.000	0.466	0.004	0.000	0.44
Base	9/7/2004	13:24:02	0.165	7.63	0.431	35.5	5.04	18.97	0.280	190	69	0.56	0.000	0.000	0.591	0.005	0.000	0.03
Base	9/24/2004	15:17:18	0.11	7.94	0.757	99.7	8.81	20.09	0.484	129	48	0.46	0.000	0.000	1.455	0.003	0.002	0.02
Storm	10/8/2004	10:41:18	0.23	7.70	0.174	-10	6.81	18.52	0.113	188	118	0.91	0.120	0.012	0.551	0.004	0.001	0.12
Storm	10/11/2004	14:21:52	0.7	8.16	0.09	62.4	10.93	12.95	0.058	152	120	0.60	0.086	0.011	0.444	0.011	0.000	2.81
Storm	10/14/2004	12:46:18	0.3	7.86	0.148	154	10.89	11.13	0.096	168	124	0.84	0.108	0.005	0.350	0.008	0.005	0.42
Storm	10/26/2004	12:33:42	0.44	7.53	0.113	117	8.16	18.96	0.073	170	188	0.92	0.103	0.024	0.938	0.015	0.001	0.71
Base	11/23/2004	15:07:56	0.21	8.01	0.723	72.9	12.38	13.02	0.462	169	35	2.52	0.044	0.000	0.536	0.000	0.000	0.06
Storm	11/29/2004	14:20:08	0.36	7.65	0.195	101	11.97	7.85	0.127	177	137	1.13	0.041	0.024	0.932	0.000	0.000	0.53
Base	12/14/2004	13:07:24	0.11	8.28	0.803	39.5	12.31	2.90	0.514	101	11	4.24	0.000	0.016	0.505	0.000	0.000	0.03
Base	12/21/2004	13:10:54	0.18	8.19	0.813	53.9	14.27	4.57	0.520	144	18	3.95	0.000	0.001	0.435	0.000	0.000	0.03
Storm	1/4/2005	14:30:12	0.75	7.73	0.101	149	12.68	6.83	0.065	157	82	0.46	0.150	0.020	0.706	0.006	0.004	3.38
Storm	1/5/2005	12:59:16	0.6	7.29	0.358	53.9	11.88	8.32	0.233	155	390	3.94	0.000	0.013	0.572	0.008	0.001	2.34
Base	1/21/2005	13:45:52	0.23	8.19	0.835	42.7	14.5	9.00	0.535	189	15	7.78	0.098	0.015	1.171	0.001	0.001	0.07
Base	2/10/2005	13:31:30	0.21	8.25	0.838	33.4	18.37	5.86	0.536	199	7	5.15	0.045	0.077	1.308	0.019	0.005	0.07
Base	2/24/2005	11:28:50	0.23	8.06	0.756	39.3	15.53	6.47	0.484	156	15	4.06	0.037	0.005	0.786	0.008	0.003	0.03
Base	3/15/2005	12:03:38	0.2	8.21	0.901	123	17.64	8.23	0.576	137	5	2.92	0.013	0.011	5.072	0.010	0.001	0.02
Base	3/24/2005	15:39:20	0.25	8.03	0.797	175	12.71	8.44	0.510	196	29	2.74	0.032	0.017	0.640	0.012	0.001	0.17
Base	4/22/2005	11:26:10	0.195	8.06	0.916	95.7	11.67	15.28	0.586	93	13	2.71	0.000	0.023	0.450	0.018	0.002	0.06
Base	4/30/2005	8:43:48	0.019	7.99	0.775	6	10.6	9.95	0.500	155	18	3.00	0.026	0.049	1.632	0.010	0.004	0.06
Base	5/18/2005	12:41:50	0.16	8.13	0.957	71.9	9.55	17.24	0.612	56	34	2.08	0.026	0.028	2.012	0.002	0.000	0.03
Base	5/30/2005	11:49:32	0.145	8.15	0.985	36.1	7.53	18.68	0.631	62	55	2.79	0.102	0.030	1.925	0.081	0.007	0.02
Storm	6/11/2005	13:42:48	0.3	7.66	0.182	38.4	7.53	23.32	0.118	103	206	1.88	0.152	0.058	1.540	0.140	0.011	0.30
Base	6/16/2005	10:32:44	0.245	7.69	0.497	19.1	6.22	20.20	0.320	243	127	2.69	0.196	0.104	3.536	0.309	0.028	0.15
Base	6/30/2005	12:46:38	0.125	7.84	0.945	28.2	9.5	24.84	0.605	71	62	1.79	0.000	0.009	0.370	0.011	0.001	0.01
Base	7/8/2005	10:37:36	0.14	7.92	0.937	113	9.31	21.60	0.600	74	50	1.20	0.027	0.018	0.386	0.027	0.002	0.01

APPENDIX B: Concentrations and Discharge by Date and Site (Cont'd)

Site WC1

EVENT	DATE	TIME	STADIA (m)	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	Temp (ºC)	TDS (mg/L)	ORP	TP (µg/L)	TN (mg/L)	As (mg/L)	Cu (mg/L)	Zn (mg/L)	Pb (mg/L)	Cd (mg/L)	Q (m^3/s)
Storm	8/28/2004	16:40:06		7.75	0.187	51.7	8.66	22.96	0.121	158	154	1.00	0.000	0.006	0.732	0.016	0.000	2.58
Storm	9/5/2004	18:15:06		7.54	0.326	61.9	7.79	24.79	0.212	158	146	1.22	0.000	0.000	0.468	0.006	0.000	1.39
Base	9/7/2004	13:04:42		7.69	0.700	47.3	8.03	18.39	0.448	188	50	0.44	0.000	0.000	0.837	0.005	0.000	0.17
Base	9/24/2004	14:52:36		7.73	0.803	105.0	9.01	20.37	0.514	115	40	0.73	0.000	0.000	1.689	0.065	0.000	0.16
Storm	10/8/2004	10:25:12		7.68	0.223	0	7.54	18.33	0.145	204	149	0.94	0.090	0.017	0.005	0.000	0.001	0.85
Storm	10/11/2004	13:56:50		8.12	0.098	81.1	11.27	12.25	0.064	169	178	0.60	0.094	0.017	3.052	0.028	0.000	15.11
Storm	10/14/2004	12:27:46		7.55	0.355	188.0	9.98	12.09	0.231	193	118	1.26	0.114	0.026	0.841	0.019	0.002	1.33
Storm	10/26/2004	12:19:18		7.48	0.200	191.0	8.06	18.64	0.13	195	246	1.11	0.134	0.030	0.595	0.027	0.001	6.40
Base	11/23/2004	14:48:36		7.65	0.726	78.0	13.12	14.05	0.465	161	51	1.68	0.038	0.000	0.872	0.000	0.000	0.68
Storm	11/29/2004	14:03:28		7.67	0.213	133.0	11.98	7.33	0.139	167	214	1.30	0.032	0.004	0.376	0.000	0.000	4.67
Base	12/14/2004	12:48:24		7.78	0.853	42.1	11.14	5.23	0.546	75	25	3.26	0.000	0.018	0.289	0.000	0.000	0.34
Base	12/21/2004	12:53:56		7.78	0.864	45.2	13.74	5.85	0.553	91	18	2.80	0.000	0.018	0.470	0.000	0.004	0.40
Storm	1/4/2005	14:00:16		7.75	0.115	179.0	12.79	6.42	0.075	155	116	0.46	0.097	0.011	0.498	0.010	0.001	17.32
Storm	1/5/2005	12:30:56		7.33	0.326	140.0	12.49	6.84	0.212	163	234	2.63	0.000	0.014	1.096	0.010	0.001	16.10
Base	1/21/2005	13:18:12		7.64	0.904	42.5	12.41	9.67	0.579	161	27	5.52	0.062	0.032	0.697	0.000	0.002	0.74
Base	2/10/2005	13:20:16		7.70	0.901	35.2	15.89	6.69	0.577	182	23	4.01	0.000	0.030	2.079	0.009	0.002	0.48
Base	2/24/2005	11:12:26		7.62	0.801	51.3	13.83	7.25	0.513	159	20	3.09	0.000	0.011	0.732	0.004	0.013	0.51
Base	3/15/2005	11:46:26		7.82	0.937	120.0	16.4	8.58	0.599	138	9	3.11	0.017	0.008	0.886	0.002	0.001	0.28
Base	3/24/2005	15:23:52		7.67	0.785	125.0	12.13	9.07	0.503	189	25	1.79	0.001	0.008	1.534	0.010	0.004	0.37
Base	4/22/2005	11:08:24		7.85	0.942	86.5	12.67	15.23	0.603	93	21	2.15	0.008	0.024	0.495	0.014	0.003	0.31
Base	4/30/2005	8:33:28		7.65	0.754	6.5	10.2	10.24	0.48	159	19	2.47	0.039	0.044	0.830	0.010	0.002	0.28
Base	5/18/2005	12:27:50		7.83	0.968	315.0	11.76	18.24	0.619	64	20	1.64	0.082	0.030	1.337	0.063	0.005	0.20
Base	5/30/2005	11:32:22		7.80	0.978	26.0	8.56	19.06	0.626	68	26	1.78	0.091	0.063	1.204	0.103	0.011	0.20
Storm	6/11/2005	13:27:26		7.51	0.411	55.2	7.67	22.7	0.267	117	211	1.99	0.175	0.083	1.518	0.227	0.022	3.57
Base	6/16/2005	10:19:44		7.70	0.688	5.6	8.52	19.11	0.44	248	42	1.84	0.312	0.111	2.827	0.288	0.025	0.17
Base	6/30/2005	12:31:04		7.71	0.929	41.2	10.21	24.8	0.594	75	35	1.21	0.026	0.009	0.311	0.010	0.001	0.10
Base	7/8/2005	10:20:42		7.69	0.999	87.7	4.88	21.78	0.667	79	33	1.20	0.052	0.018	0.431	0.031	0.003	0.05

Note: Stage and discharge from real-time USGS data (Appendix D)

APPENDIX C

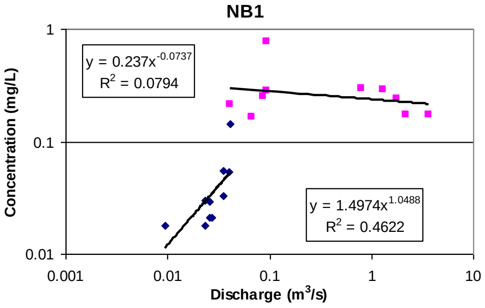
Concentration and Load Rating Curves for Sites

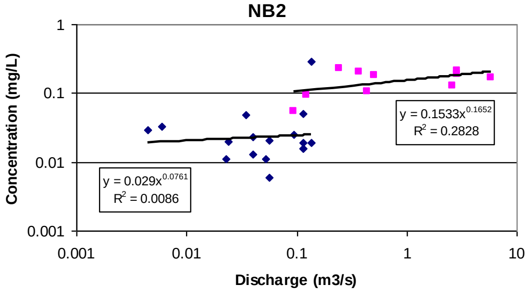
Site Total Phosphorus Concentration Rating Curves.

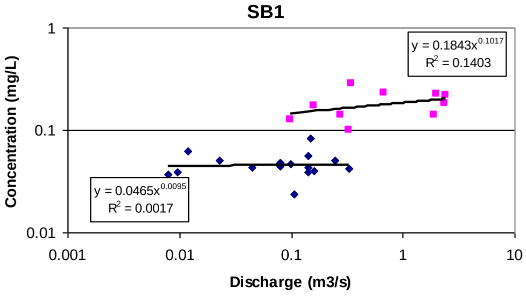
Legend

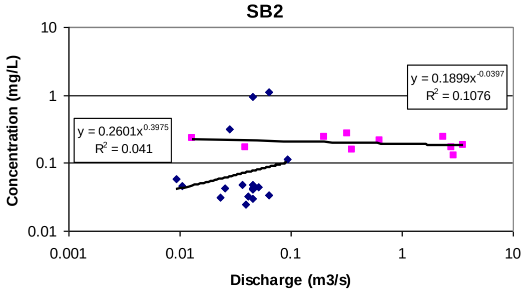
Base ◆

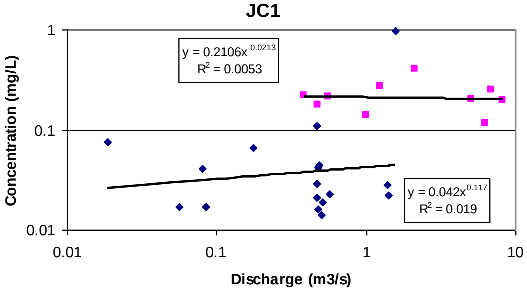
Storm ■

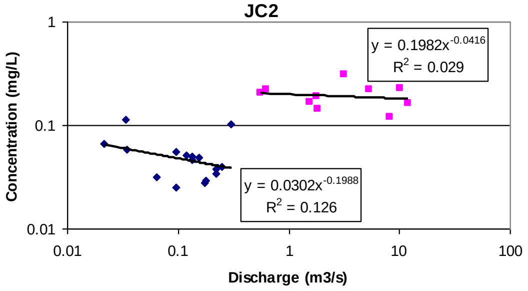












APPENDIX C (Continued)

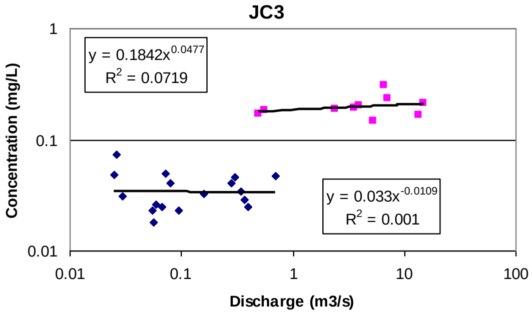
Site Total Phosphorus Concentration Rating Curves (Cont'd).

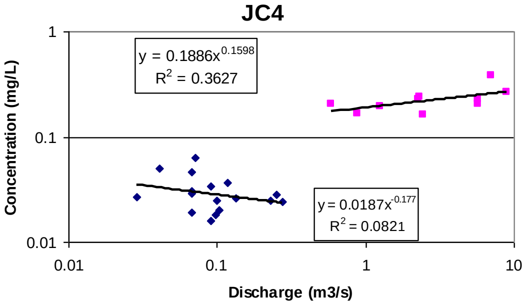
◆

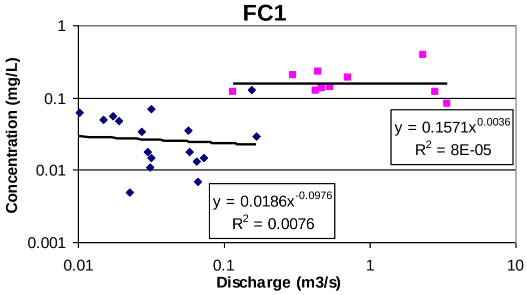
Legend

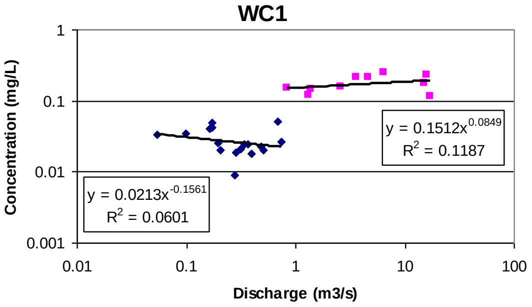
Base ■

Storm







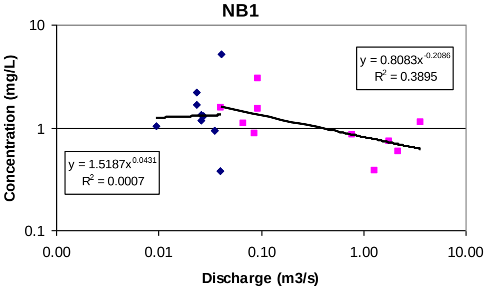


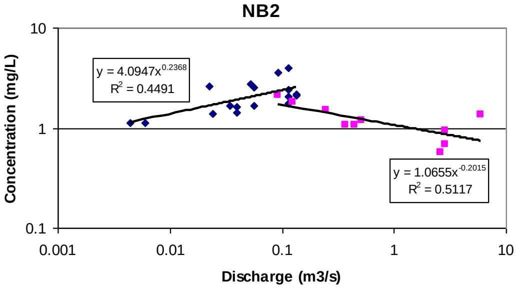
Site Total Nitrogen Concentration Rating Curves.

Legend

Base ◆

Storm ■





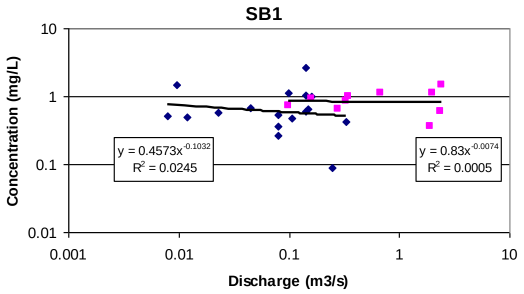
APPENDIX C (Continued)

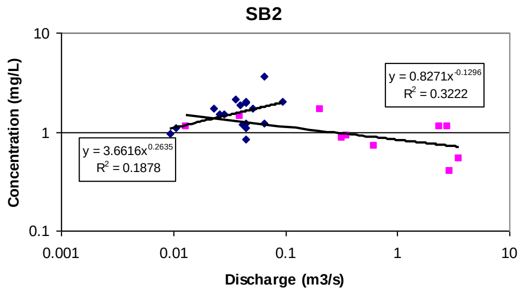
Site Total Nitrogen Concentration Rating Curves (cont'd).

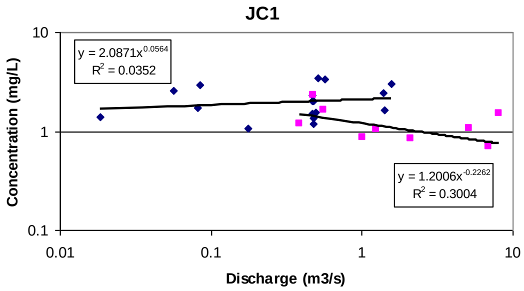
Legend

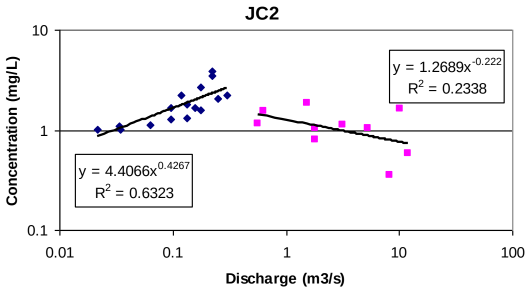
Base ◆

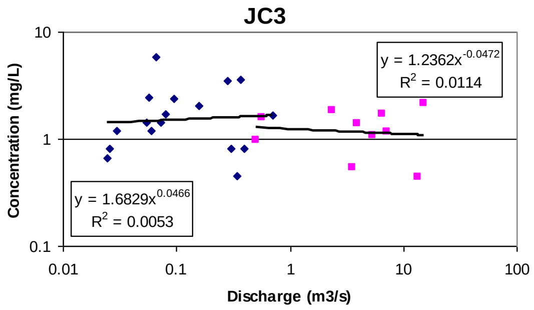
Storm ■

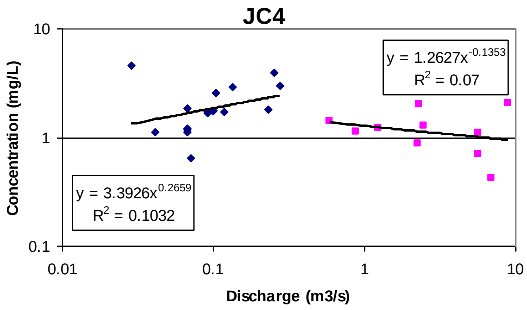


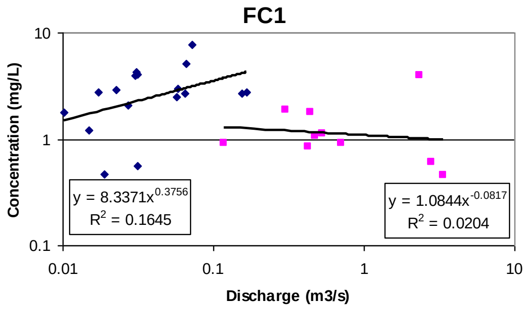


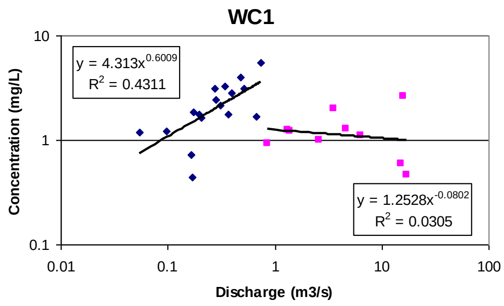












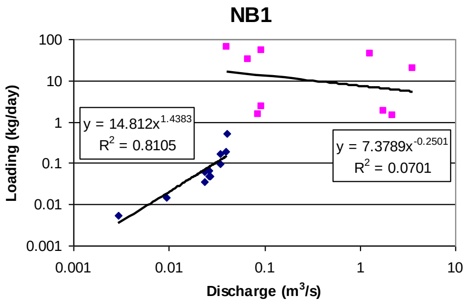
APPENDIX C (Continued)

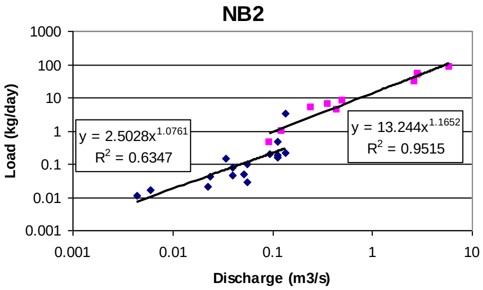
Site Total Phosphorus Load Curves.

Legend

Base ◆

Storm ■


NB1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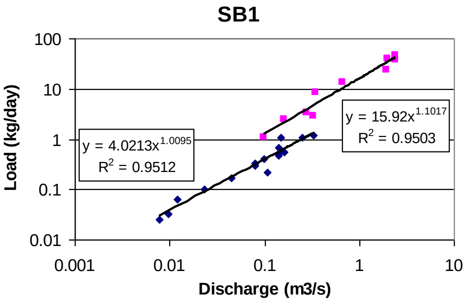
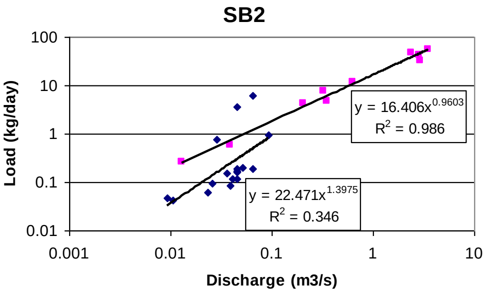

SB1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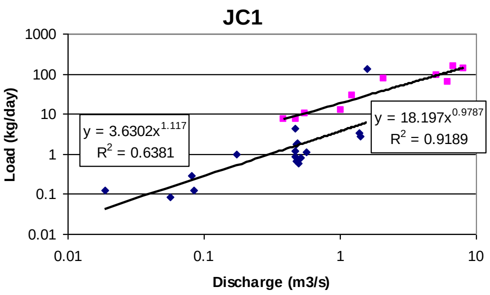
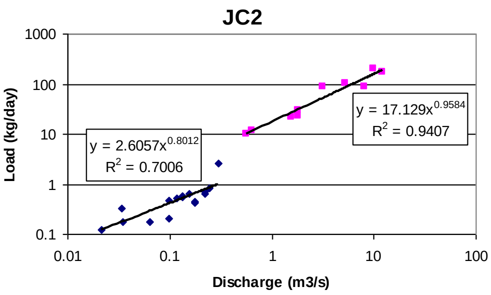
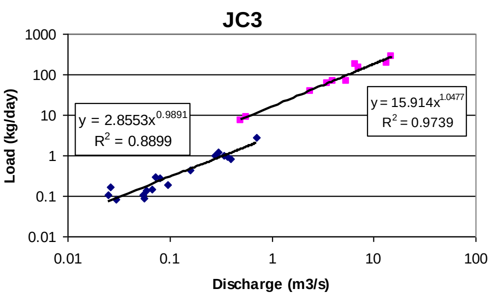

JC1


JC2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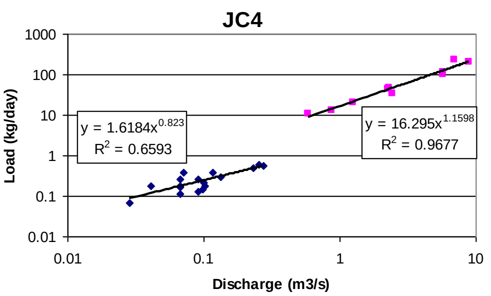

JC4

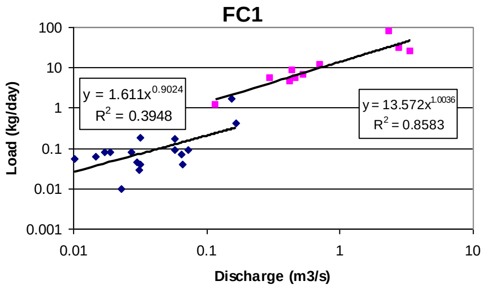
APPENDIX C (Continued)

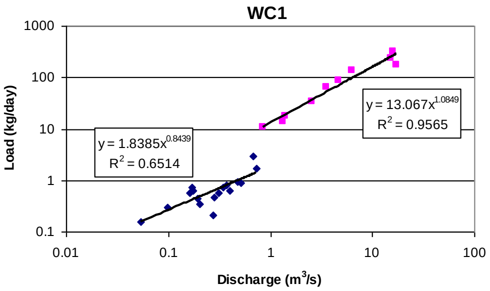
Site Total Phosphorus Load Curves.

Legend

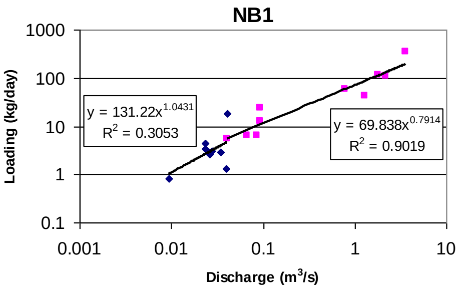
Base ◆

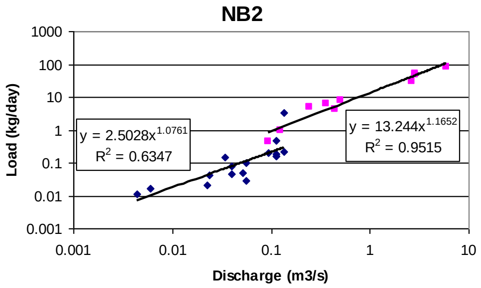
Storm ■

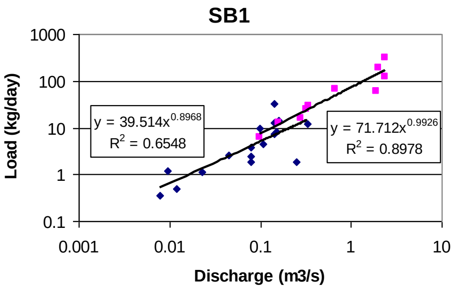


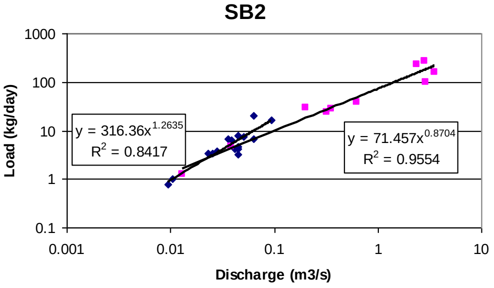


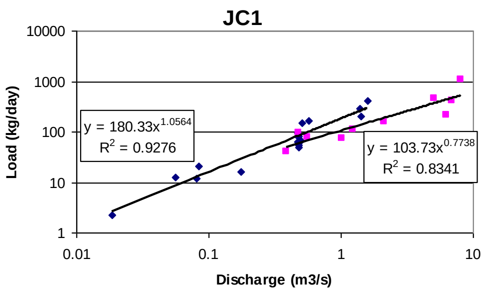
Site Total Nitrogen Load Curves.

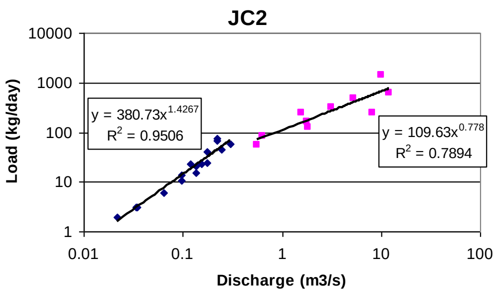












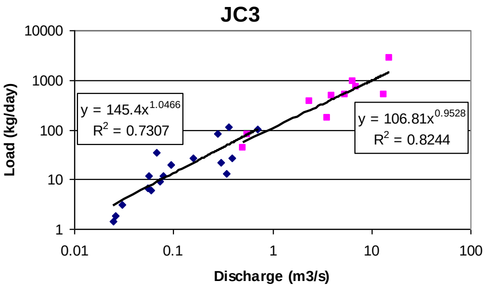
APPENDIX C (Continued)

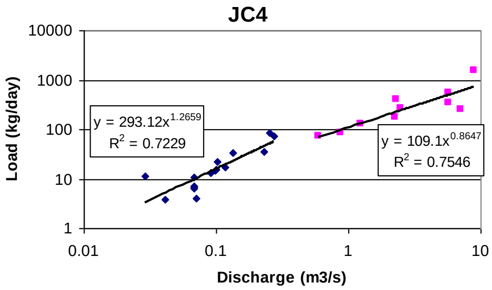
Site Total Nitrogen Load Curves.

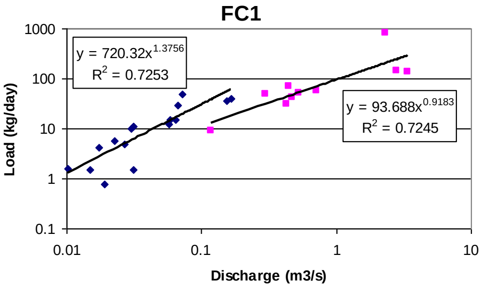
Legend

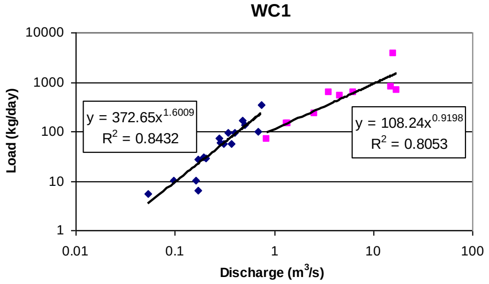
Base ◆

Storm ■









APPENDIX D

Storm Hydrographs, Average Daily Discharge, Peak Daily Discharge

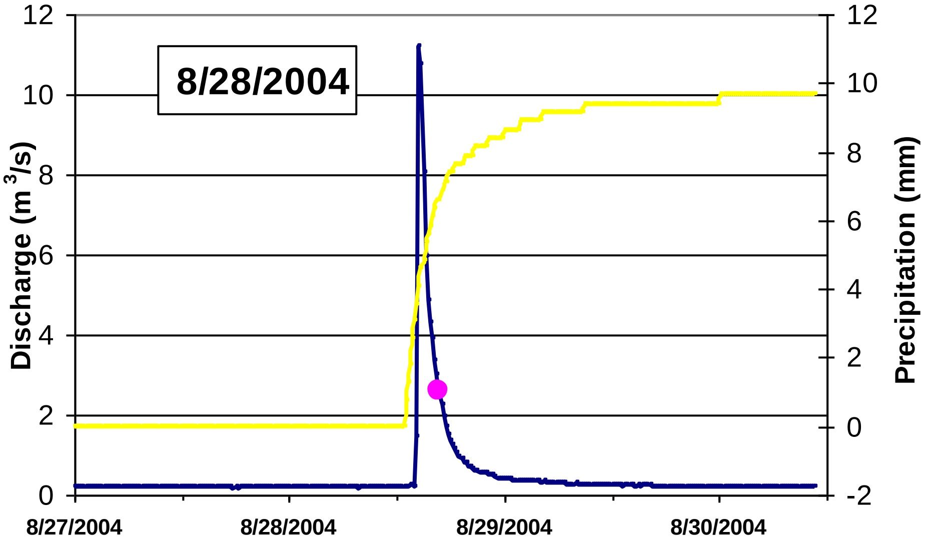
Storm Hydrographs.

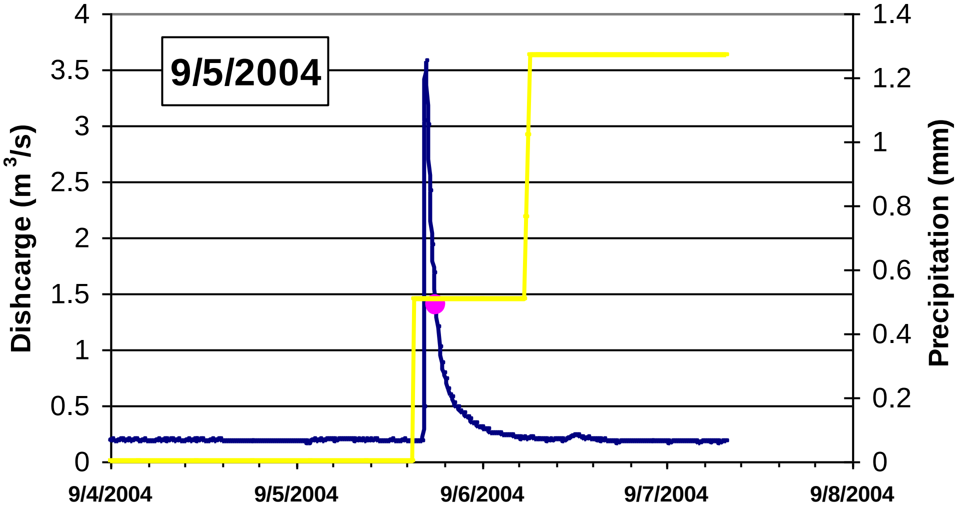
Legend

Hydrograph —

Precipitation —

Sample ●





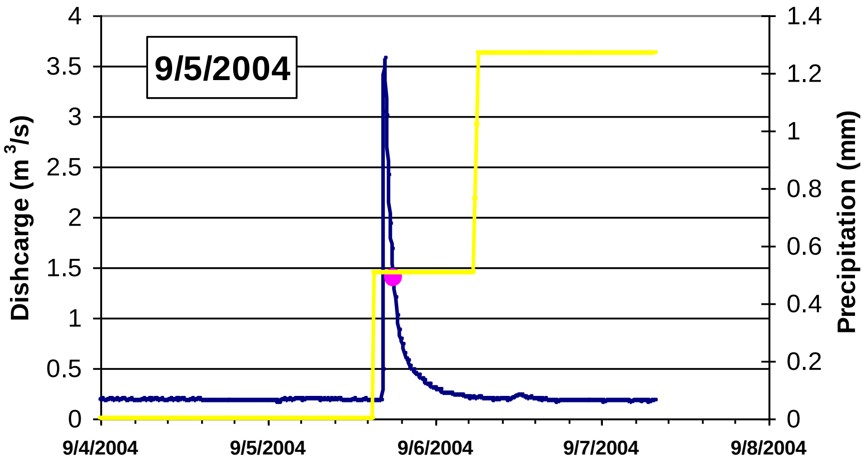
APPENDIX D: Storm Hydrographs (continued)

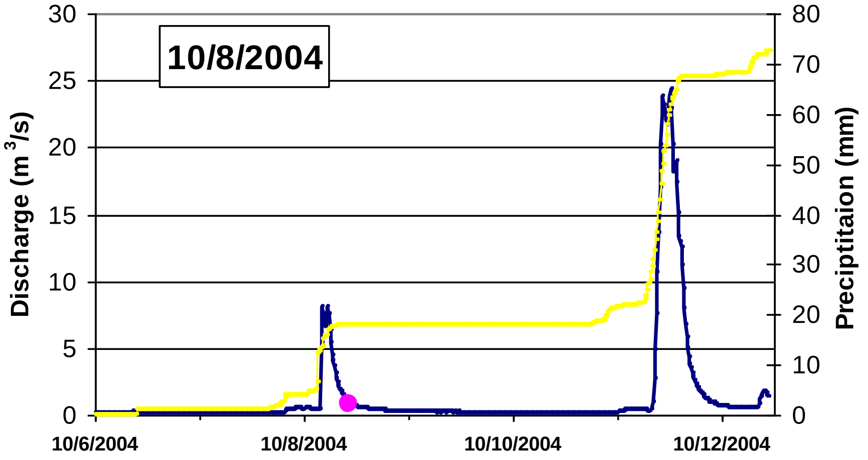
Legend

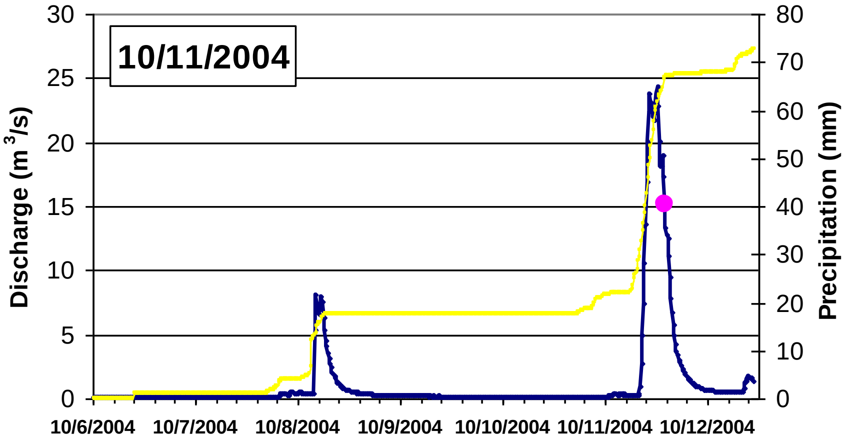
Hydrograph —

Precipitation —

Sample ●







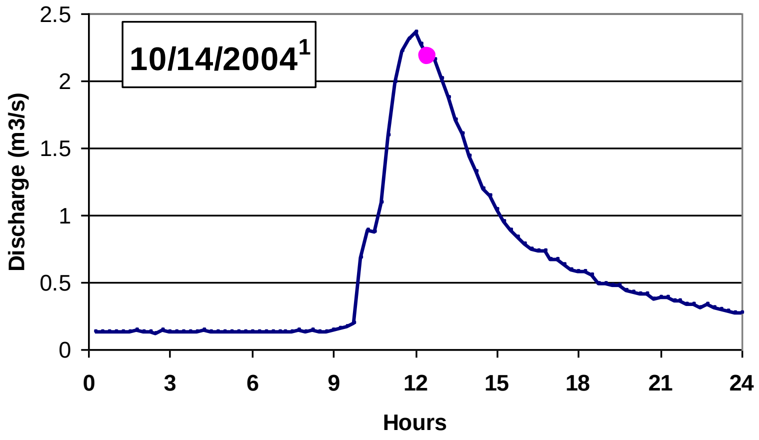
APPENDIX D: Storm Hydrographs (continued)

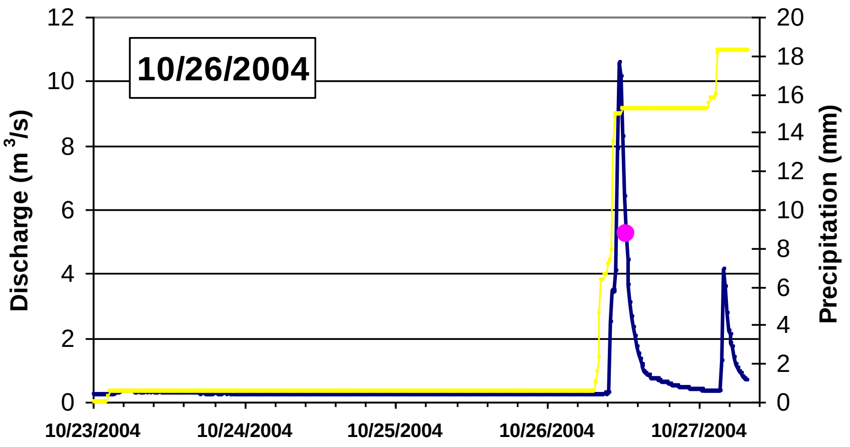
Legend

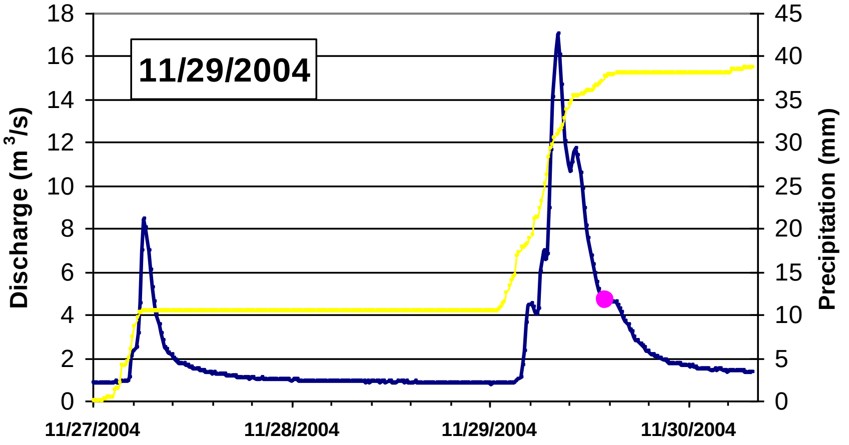
Hydrograph ▬

Precipitation ▬

Sample ●







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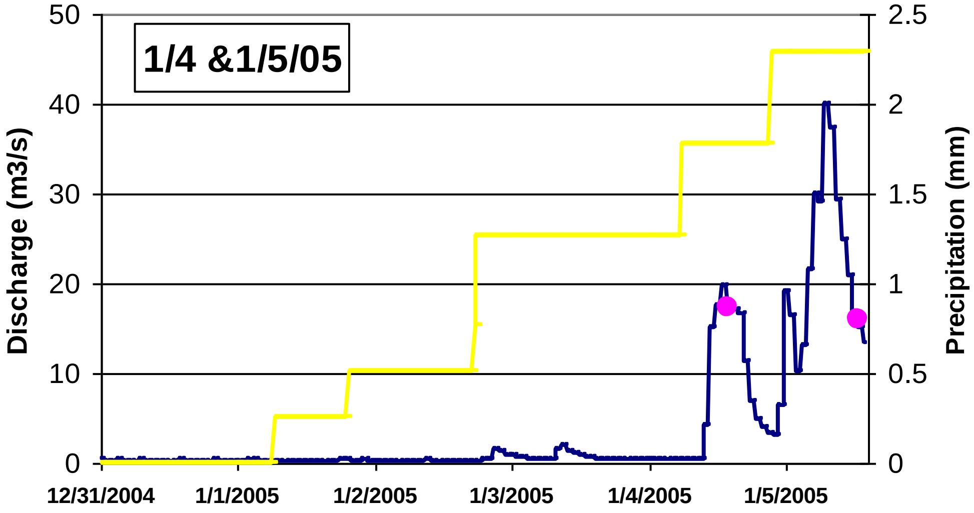
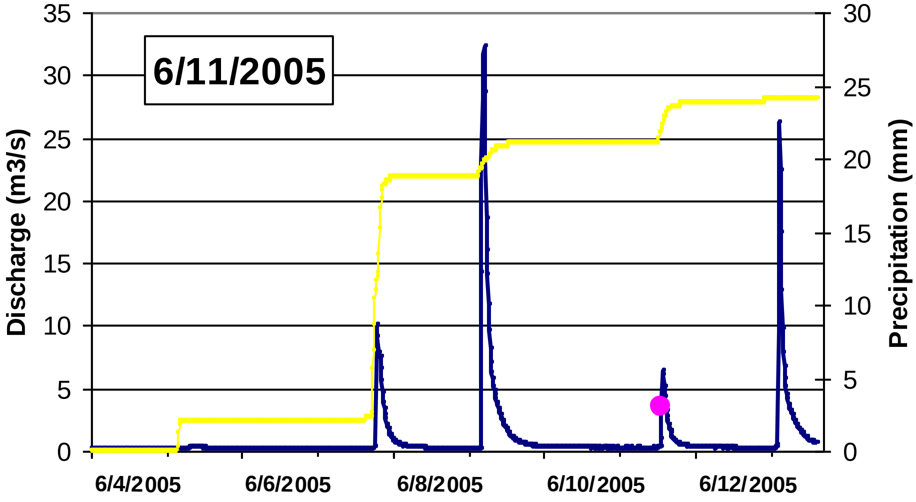
[1] Precipitation not available for this date.

APPENDIX D: Storm Hydrographs (continued)

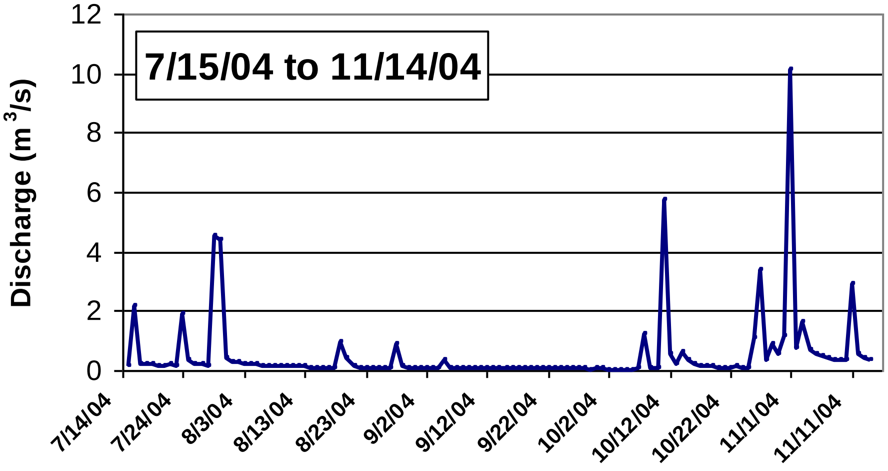
Legend

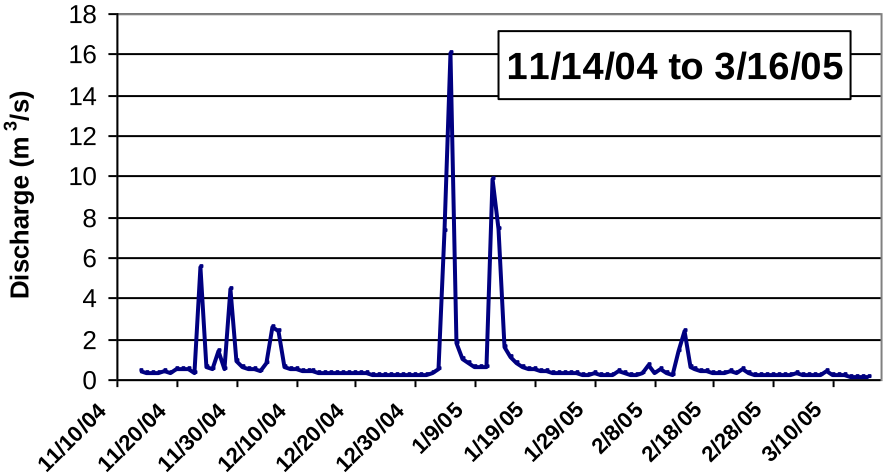
Hydrograph —
Precipitation —
Sample ●

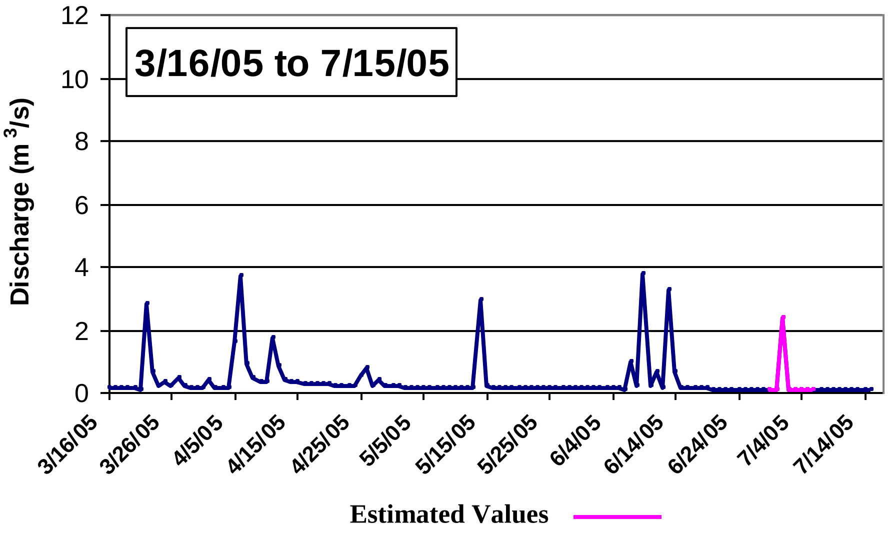




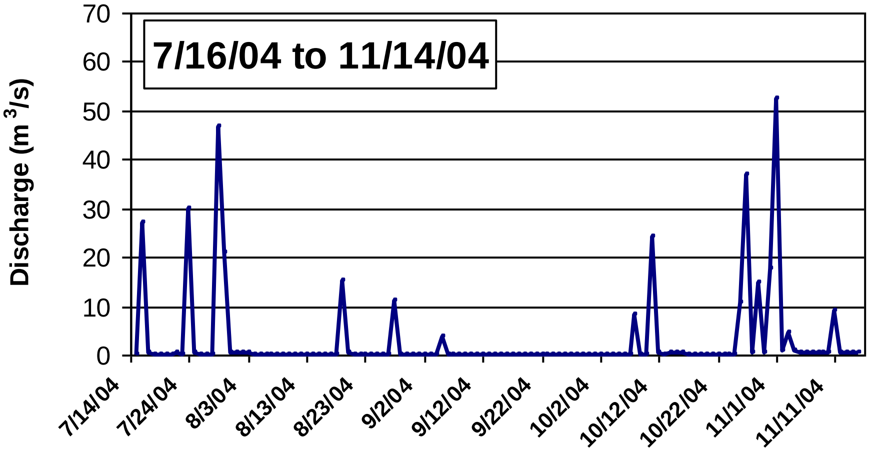
APPENDIX D: Average Daily Discharge (continued)

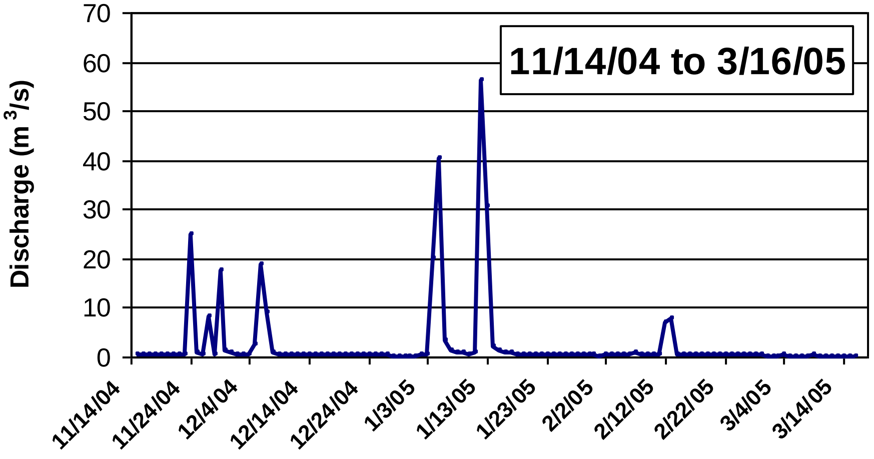


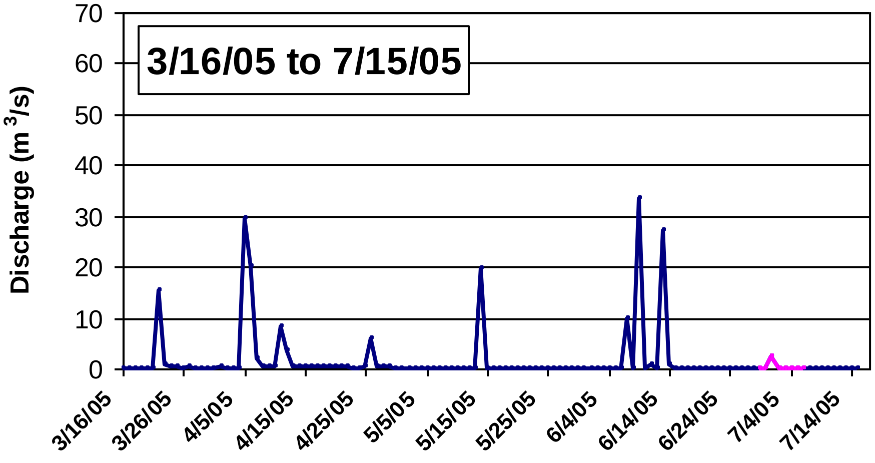




APPENDIX D: Peak Daily Discharge (continued)







Estimated Values —

APPENDIX E

Landuse Area Tables for Subwatersheds

Cell values are: area in hectares (percent total area)

	NB1	NB2	SB1	SB2	JC1
Roadway	88.9 (12.4)	128.2 (14.9)	187 (15.5)	239.3 (16.7)	434.3 (17.0)
Commercial	297 (41.5)	318.9 (37.1)	403.7 (33.6)	492.1 (34.3)	957.5 (37.5)
Multi-family Res	0.5 (0.1)	6.5 (0.8)	21.7 (1.8)	38.8 (2.7)	54.5 (2.1)
SF High-Density	6.9 (1.0)	10.8 (1.3)	14.7 (1.2)	19.7 (1.4)	37.6 (1.5)
SF Low-Density	158.7 (22.2)	217.9 (25.4)	352.3 (29.3)	409.7 (28.6)	646.4 (25.3)
Forest	107.4 (15.0)	110.7 (12.9)	130.6 (10.9)	139.6 (9.7)	258.9 (10.1)
Grass	13.7 (1.9)	23.6 (2.7)	91.7 (7.6)	92.4 (6.5)	123.6 (4.8)
Pasture	42.1 (5.9)	42.1 (4.9)	1.2 (0.1)	1.2 (0.1)	43.3 (1.7)
Total Area (ha)	715.1	858.8	1202.8	1432.9	2556.2
Total Area (km^2)	7.2	8.6	12.0	14.3	25.6

	JC2	JC3	JC4	FC1	WC1
Roadway	554.9 (18.6)	585 (18.9)	640.4 (19.0)	218.8 (18.0)	721.7 (14.4)
Commercial	1082.1 (36.3)	1133.5 (36.6)	1162.7 (34.5)	313.4 (25.8)	1858.8 (37.1)
Multi-family Res	62.2 (2.1)	62.6 (2.0)	86.8 (2.6)	53.2 (4.4)	145 (2.9)
SF High-Density	46 (1.5)	47.4 (1.5)	60.7 (1.8)	17.9 (1.5)	66.3 (1.3)
SF Low-Density	784 (26.3)	813.3 (26.2)	934.5 (27.7)	532.1 (43.7)	1544.1 (30.8)
Forest	281.8 (9.4)	284.5 (9.2)	305.2 (9.0)	44.3 (3.6)	424.6 (8.5)
Grass	130.1 (4.4)	130.1 (4.2)	140.7 (4.2)	30.9 (2.5)	193.9 (3.9)
Pasture	43.3 (1.4)	43.3 (1.4)	43.3 (1.3)	6.3 (0.5)	61.6 (1.2)
Total Area (ha)	2984.4	3099.7	3374.4	1216.9	5015.9
Total Area (km^2)	29.8	31.0	33.7	12.2	50.2

APPENDIX F

City Modeled Flood Discharges

Notes: 1) All discharges in cubic feet per second (cfs)
2) Top box indicates period of rainfall accumulation
3) Column headers indicates frequency magnitude of rainfall event (i.e. "1" indicates a 1-year recurrence event)

Study Site	City Point Code	2 Hour Peak Flows					
		0.5	1	1.5	2	3	5
NB1	HCNB27	332	472	615	691	827	1070
SB1	SJ37	301	432	584	672	833	1115
SB2	SJ44B	511	691	862	951	1108	1485
NB2	NB57	399	568	744	841	1004	1291
JC1	LJ31	948	1297	1686	1918	2357	3104
JC2	HCLJ15	1437	2005	2553	2854	3375	4389
JC3	HCLJ16	1459	2045	2611	2921	3455	4464
JC4	HCLJ19	1540	2208	2863	3229	3855	4961
FC1	COMB9	900	1223	1511	1653	1912	2346
WC1	COMB13	2313	3183	4057	4568	5408	6874

Study Site	City Point Code	3 Hour Peak Flows					
		0.5	1	1.5	2	3	5
NB1	HCNB27	312	444	584	660	801	1035
SB1	SJ37	266	432	605	693	842	1106
SB2	SJ44B	446	594	799	917	1116	1453
NB2	NB57	375	538	705	792	955	1232
JC1	LJ31	865	1238	1686	1921	2319	2996
JC2	HCLJ15	1309	1803	2365	2677	3215	4155
JC3	HCLJ16	1335	1840	2415	2734	3282	4235
JC4	HCLJ19	1427	2007	2661	3022	3642	4710
FC1	COMB9	822	1095	1348	1477	1696	2067
WC1	COMB13	0	0	0	0	0	0

APPENDIX F CONTINUED

Study Site	City Point Code	6 Hour Peak Flows					
		0.5	1	1.5	2	3	5
NB1	HCNB27	265	383	498	559	668	848
SB1	SJ37	262	401	541	611	734	957
SB2	SJ44B	344	525	714	810	978	1261
NB2	NB57	317	461	598	671	799	1023
JC1	LJ31	743	1116	1479	1670	1998	2562
JC2	HCLJ15	1049	1527	2020	2283	2744	3492
JC3	HCLJ16	1071	1555	2059	2327	2797	3560
JC4	HCLJ19	1161	1704	2263	2560	3085	3939
FC1	COMB9	647	849	1031	1137	1307	1586
WC1	COMB13	0	0	0	0	0	0

Study Site	City Point Code	12 Hour Peak Flows					
		0.5	1	1.5	2	3	5
NB1	HCNB27	260	373	470	519	602	742
SB1	SJ37	270	409	529	593	707	899
SB2	SJ44B	355	534	704	791	934	1180
NB2	NB57	310	444	561	622	726	900
JC1	LJ31	750	1096	1423	1587	1863	2330
JC2	HCLJ15	1021	1491	1932	2152	2518	3127
JC3	HCLJ16	1042	1521	1970	2195	2567	3188
JC4	HCLJ19	1145	1676	2173	2425	2840	3531
FC1	COMB9	447	597	780	881	1060	1354
WC1	COMB13	0	0	0	0	0	0

Study Site	City Point Code	18 Hour Peak Flows					
		0.5	1	1.5	2	3	5
NB1	HCNB27	258	359	446	489	561	682
SB1	SJ37	277	407	519	581	684	892
SB2	SJ44B	358	539	687	762	895	1128
NB2	NB57	307	427	534	587	676	823
JC1	LJ31	744	1078	1362	1506	1751	2164
JC2	HCLJ15	1022	1455	1833	2019	2341	2863
JC3	HCLJ16	1042	1482	1868	2057	2385	2916
JC4	HCLJ19	1148	1633	2062	2273	2637	3225
FC1	COMB9	422	607	785	874	1024	1272
WC1	COMB13	0	0	0	0	0	0

APPENDIX F CONTINUED

Study Site	City Point Code	24 Hour Peak Flows					
		0.5	1	1.5	2	3	5
NB1	HCNB27	227	313	387	423	483	582
SB1	SJ37	240	359	454	504	588	795
SB2	SJ44B	309	472	594	657	765	1015
NB2	NB57	269	372	463	507	580	699
JC1	LJ31	654	942	1180	1297	1498	1893
JC2	HCLJ15	892	1261	1571	1724	1987	2470
JC3	HCLJ16	910	1284	1600	1757	2024	2514
JC4	HCLJ19	1000	1412	1765	1940	2239	2771
FC1	COMB9	367	527	669	741	863	1062
WC1	COMB13	0	0	0	0	0	0

APPENDIX G

USGS Gage 07052000 Flow Frequency Data

Class	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Water Year	**# Days In Class**														
1933-1933							1	14	7	2	30	49	48	63	44
1934-1934									26	91	86	59	40	25	15
1935-1935								1	35	35	35	18	57	41	28
1936-1936							1	12	79	87	98	35	26	11	4
1937-1937									1	1	7	42	75	57	38
1938-1938										47	88	34	41	24	36
1939-1939										18	95	65	43	38	32
1999-1999			12	7	15	20	24	15	31	45	40	29	27	22	19
2000-2000		3	21	24	38	30	40	34	35	18	20	9	15	21	10
2001-2001			7	5	17	14	34	71	47	42	35	13	19	7	9
2002-2002		14	5	5	23	15	21	39	40	42	33	27	22	21	11
2003-2003		8	11	2	2	11	31	41	36	53	46	26	23	20	9
2004-2004			1	3	10	23	26	19	31	61	63	29	36	14	7
ClassSum	0	25	57	46	105	113	178	246	368	542	676	435	472	364	262
RunSum	0	25	82	128	233	346	524	770	1138	1680	2356	2791	3263	3627	3889
ClassValue	0.00	0.81	1.00	1.30	1.60	2.10	2.70	3.40	4.30	5.40	6.90	8.70	11.00	14.00	18.00
Percentage	100.00	99.47	98.27	97.30	95.09	92.71	88.96	83.78	76.03	64.62	50.38	41.22	31.28	23.61	18.09
Accum	4748	4748	4723	4666	4620	4515	4402	4224	3978	3610	3068	2392	1957	1485	1121
Value (cfs)	0	0.81	1	1.3	1.6	2.1	2.7	3.4	4.3	5.4	6.9	8.7	11	14	18

APPENDIX G (continued)

Class	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Water Year									**# Days In Class**							
1933-1933	30	18	19	12	10	4	4	5	2		2	1				
1934-1934	11	5	4	3												
1935-1935	22	22	18	16	16	3	5	3	3	1	2	1	3			
1936-1936	8	2	1	1	1											
1937-1937	35	23	28	20	15	8	5	5	1	1	2		1			
1938-1938	29	22	21	8	5	3	1	2	3		1					
1939-1939	17	14	32	6	2	2	1									
1999-1999	16	12	7	6	3	2	5	4		1	1	1	1			
2000-2000	9	8	4	4	2	6	2	2	6	3	1					
2001-2001	9	6	9	6	4	3	3	2	2					1		
2002-2002	9	4	7	4	5	5	5			5	2					1
2003-2003	9	8	4	4	3	9	2	3	3			1				
2004-2004	9	6	5	4	5	5	2	1	4	2						
ClassSum	213	150	159	94	71	50	35	27	24	13	11	4	5	1	0	1
RunSum	4102	4252	4411	4505	4576	4626	4661	4688	4712	4725	4736	4740	4745	4746	4746	4747
ClassValu	23.00	29.00	36.00	46.00	58.00	74.00	94.00	119.00	151.00	191.00	243.00	308.00	390.00	495.00	628.00	796.00
Percentag	13.61	10.45	7.10	5.12	3.62	2.57	1.83	1.26	0.76	0.48	0.25	0.17	0.06	0.04	0.04	0.02
Accum	859	646	496	337	243	172	122	87	60	36	23	12	8	3	2	2
Value (cfs	23	29	36	46	58	74	94	119	151	191	243	308	390	495	628	796

APPENDIX G (continued)

Class	32	33	34	35	Total Days
Water Year	**# Days In Class**				
1933-1933					365
1934-1934					365
1935-1935					365
1936-1936					366
1937-1937					365
1938-1938					365
1939-1939					365
1999-1999					365
2000-2000			1		366
2001-2001					365
2002-2002					365
2003-2003					365
2004-2004					366
ClassSum	0	0	1	0	4748
RunSum	4747	4747	4748	4748	
ClassValu	1010.0	1280.0	1620.0	2060.0	
Percentag	0.02	0.02	0.00	0.00	
Accum	1	1	1	0	
Value (cfs	1010	1280	1620	2060	