MASS TRANSPORT OF SUSPENDED SEDIMENT, DISSOLVED SOLIDS, NUTRIENTS, AND ANIONS IN THE JAMES RIVER, SW MISSOURI

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In Partial Fulfillment
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Master of Science, Geospatial Sciences

By
Erin C. D. Hutchison
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MASS TRANSPORT OF SUSPENDED SEDIMENT, DISSOLVED SOLIDS, NUTRIENTS, AND ANIONS IN THE JAMES RIVER, SW MISSOURI

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ABSTRACT

Dynamics of suspended solids and dissolved solids transport in the upper and middle James River Basin in southwest Missouri were studied. Water quality constituents in the basin and the degree of variation in constituent concentration throughout the year due to runoff, seasonality, hysteresis, and landuse were examined. Constituents evaluated include total suspended solids (TSS) and total dissolved solids (TDS); total and dissolved inorganic carbon; total and dissolved organic carbon; total nitrogen (TN) and total phosphorus (TP); anions; and water chemistry including dissolved oxygen, pH, specific conductivity, turbidity and temperature. Water samples were collected during storm events as well as at fixed intervals during baseflow. The monitoring phase of this project began in September 2008 and concluded in September 2009. Storm runoff, hysteresis, landuse, and seasonality were found to be a major influence on suspended solids (TSS, TP, and organic carbon) concentrations. Karst geology, urbanization, and seasonality were major influences on dissolved solids (TDS, inorganic carbon, TN, and anions) concentrations. Concentration data from this study were found to be similar to USGS data. Suspended yields ranged from 9 Mg/km^2/yr to 87 Mg/km^2/yr, and were found to be highest in the sub-watershed with the largest drainage area and most urban area. Dissolved yields ranged from 61 Mg/km^2/yr to 158 Mg/km^2/yr, and were greatly influenced by groundwater.

KEYWORDS: Mass Transport, Water Quality, Suspended Solids, Dissolved Solids, Carbon, Nutrients

This abstract is approved as to form and content

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TABLE OF CONTENTS

Introduction....................1

Solids and Pollution Transport in Rivers....................17
- Suspended Load....................17
- Dissolved Load....................26
- Water Chemistry Parameters....................33
- Watershed Processes....................34
- Solids Transport on the Ozarks Plateau....................35

Study Area....................38
- Location....................38
- Geology....................42
- Soils....................47
- Hydrology....................49
- Climate....................50
- Land use....................52

Methodology....................56
- Field Methods....................56
- Laboratory Methods....................59
- Load and Yield Calculations....................64
- Statistical Significance....................67
- Hysteresis Influence....................69

Results and Discussion....................70
- Study Period Hydrology....................70
- Water Chemistry Trends....................78
- Constituent Concentration Trends....................88
- Comparison to Long-Term Data....................138
- Summary of Concentration Influences....................148
- Mass Load Calculation/Mean Annual Yield....................151
- Land Use Influence....................159
- Constituent Concentration at Mean Annual Discharge....................161
- Hysteresis and Upper Limit Yields....................165
- Comparison to Yields from Other Regions....................168

Summary and Conclusion....................170

References....................179

Appendix....................190

LIST OF TABLES

Table 1.1 Summary of Mineral and Carbon Size Fractions 4

Table 1.2 Solids Yields of World Rivers 5

Table 1.3 Regional Constituent Yields 10

Table 2.1 Suspended Solids Yields for Ozarks Rivers 25

Table 2.2 Dissolved Solids Yields from Rivers Draining Karst-Carbonate Terrain 32

Table 3.1 Study Site Information 40

Table 3.2 Density of Karst Features in Study Area Sub-watersheds 45

Table 3.3 Chemical and Physical Properties of Major Study Area Soil Series 49

Table 3.4 USGS Gaging Station Information 50

Table 3.5 Landuse Percentages by Sub-watershed 54

Table 4.1 Measurement Performance Criteria 60

Table 5.1 Sample Site Gage Record 72

Table 5.2 Mean Daily Discharge for the Study Period 77

Table 5.3 Regression Equations relating TDS to Conductance 82

Table 5.4 Regression Equations relating TSS to Turbidity 85

Table 5.5 Instantaneous Concentration Equations (TDS and TSS) 89

Table 5.6 Regression Equation Relating TDS to Hysteresis 98

Table 5.7 Regression Equation Relating TSS to Hysteresis 98

Table 5.8 Instantaneous Concentration Equations (Carbon) 101

Table 5.9 Regression Equation Relating TIC to Hysteresis 110

Table 5.10 Regression Equation Relating TOC to Hysteresis 110

Table 5.11 Regression Equation Relating DIC to Hysteresis 112

Table 5.12 Regression Equation Relating DOC to Hysteresis..112

Table 5.13 Instantaneous Concentration Equations (Nutrients) 116

Table 5.14 Regression Equation Relating TN to Hysteresis..123

Table 5.15 Regression Equation Relating TP to Hysteresis 123

Table 5.16 Instantaneous Anion Concentrations Equations 125

Table 5.17 Regression Equations Relating Chloride to Hysteresis 135

Table 5.18 Regression Equations Relating Sulfate to Hysteresis 135

Table 5.19 Regression Equations Relating Nitrate to Hysteresis 137

Table 5.20 Regression Equations Relating Fluoride to Hysteresis.................................137

Table 5.21 Equation Comparison for Finley Creek Data..147

Table 5.22 Equation Comparison for Middle James Data 147

Table 5.23 Influences on Constituent Concentration..150

Table 5.24 Solids Loads..152

Table 5.25 Carbon Loads...154

Table 5.26 Nutrient Loads 156

Table 5.27 Anion Loads...158

Table 5.28 Cumulative Annual Nutrient Loads for Different River Systems 169

Table 5.29 Nutrient Loads from Urban Ozarks Streams 169

LIST OF FIGURES

Figure 2.1 Hysteresis Loop 22

Figure 2.2 Examples of Hysteresis Loop Types 22

Figure 3.1 The Ozarks....................39

Figure 3.2 Study Area and Sample Site Locations 41

Figure 3.3 Study Area Geology 43

Figure 3.4 Karst Features in the Study Area 46

Figure 3.5 Monthly Mean Temperature of Study Area 51

Figure 3.6 Monthly Rainfall Totals of Study Area 52

Figure 3.7 Study Area Land Use 55

Figure 4.1 Depth-integrated Sampler 57

Figure 4.2 Sampling at Pearson Creek 58

Figure 4.3 Flowchart of Laboratory Analyses 61

Figure 5.1a-e Study Period Discharge 73-75

Figure 5.2 Flow-Duration Rating-Curves for Each Sub-watershed 77

Figure 5.3a-c Temperature, pH, and Dissolved Oxygen by Site and Season 79

Figure 5.4a-e Discharge Influences on Conductance and Turbidity....................81

Figure 5.5a-e Relationship between TDS and Conductance....................83

Figure 5.6 Conductance by Site and Season....................84

Figure 5.7 Relationship between TSS and Turbidity....................86

Figure 5.8 Seasonal Influences on Turbidity....................87

Figure 5.9a-e Discharge Influence on TDS and TSS Concentrations....................90

Figure 5.10 Percent Fine Suspended Sediment by Site 92

Figure 5.11a-b Seasonal Influences on TDS Concentration 93

Figure 5.12a-b Seasonal Influences on TSS Concentration 95

Figure 5.13a-e Hysteresis Influence on TDS and TSS Concentration 97

Figure 5.14a-e Discharge Influence on Carbon Concentration.......................................102

Figure 5.15 Seasonal Influences on TIC Concentration 104

Figure 5.16 Seasonal Influences on DIC Concentration 104

Figure 5.17 Seasonal Influences on TOC Concentrations 106

Figure 5.18a-b Seasonal Influences on DOC Concentrations...107

Figure 5.19a-e Hysteresis Influence on Total Carbon Concentration 109

Figure 5.20a-e Hysteresis Influence on Dissolved Carbon Concentration 111

Figure 5.21a-e Discharge Influence on Nutrient Concentration 115

Figure 5.22a-b Seasonal Influences on TN Concentration 118

Figure 5.23a-b. Seasonal Influences on TP Concentration 120

Figure 5.24a-e Hysteresis Influence on Nutrient Concentration.....................................122

Figure 5.25a-e Discharge Influence on Anion Concentration 126

Figure 5.26a-b Seasonal Influences on Chloride Concentration.....................................128

Figure 5.27a-b Seasonal Influences on Sulfate Concentration 129

Figure 5.28a-b Seasonal Influences on Nitrate Concentration 131

Figure 5.29a-b Seasonal Influences on Fluoride Concentration 132

Figure 5.30a-e Hysteresis Influence on Chloride and Sulfate Concentration 134

Figure 5.31a-e Hysteresis Influence on Nitrate and Fluoride Concentration 136

Figure 5.32a-b Comparison of TDS Concentrations 139

Figure 5.33 Comparison of TSS Concentrations 140

Figure 5.34 Comparison of TN Concentrations 142

Figure 5.35 Comparison of TP Concentrations 144

Figure 5.36a-b Comparison of Chloride Concentrations 145

Figure 5.37a-b Comparison of Sulfate Concentrations..146

Figure 5.38 Mean Annual Solids Yields by Site..152

Figure 5.39 Mean Annual Total Carbon Yields by Site 154

Figure 5.40 Mean Annual Dissolved Carbon Yields by Site 155

Figure 5.41 Mean Annual Nutrients Yields by Site 156

Figure 5.42 Mean Annual Anion Yields by Site..158

Figure 5.43 Mean Annual Anion Yields by Site..159

Figure 5.44a-f Concentrations at Mean Annual Discharge 164

Figure 5.45a-h Upper Limit Yields..167

INTRODUCTION

Watershed geology, climate, and topography influence how sediment and dissolved material are introduced into water bodies (Montgomery, 1999). However, anthropogenic, or human-induced, actions have caused many changes to the watersheds of the earth in a relatively short period of time (Syvitski, et al., 2005).Soil erosion due to land clearing, agriculture, and urbanization may have caused a global degradation in primary productivity (Lal, 1997).Additionally, poorly managed stormwater runoff may deliver pollutants and water-borne microorganisms to surface water bodies used as sources of drinking water (Gaffield et al., 2003).Consequently, the quality of surface water bodies such as streams, lakes, and wetlands has been impacted worldwide by anthropogenic inputs. Once watersheds are damaged from soil erosion, stormwater runoff, and pollutants, long-term consequences may arise that are not easily mitigated. For instance, deforestation in the Mediterranean Basin by ancient Romans led to erosion so severe that the land is no longer able to support vegetation (Henry, 1977).

In modern times, human induced landscape changes have caused an increase in sedimentation rates thus contributing large quantities of sediments, chemicals, and organic material into surface water bodies (USEPA, 2003). Estimated amount of sediment being delivered to the world‘s oceans is about 13.5 billion Mg/yr, and the amount of dissolved material (solute) is approximately 3.7 billion Mg/yr (Walling and Webb, 1987). While the amount of suspended material being delivered to the world‘s rivers has been thought to have increased since prehistoric times, the amount of sediment actually reaching the world‘s oceans has decreased by 1.4 billion Mg/yr due to sediment retention by dams and reservoirs (Syvitski, et al., 2005). The decrease in sediment delivery to coasts is believed to be responsible for increases in coastal erosion rates (Syvitski ,et al., 2005). Globally, dissolved material present in streamwater may include pesticides, pathogens, and nutrients from wastewater effluent, which may negatively affect the health of humans and the environment as a whole (Gaffield, et al., 2003). Monitoring of water bodies can help understand the condition of watersheds and the nature of changes occurring.

Suspended and dissolved solids transported by streams, while necessary to maintain a natural equilibrium between streams and watersheds, may contribute to the overall degradation of surface waterbodies (Wolman, 1967). However, identifying human induced changes among variability of natural processes is an ongoing problem. More information is needed on relationships between rainfall and runoff, solids and pollutant loads from watersheds, as well as geologic and natural contributions versus anthropogenic contributions of suspended and dissolved solids.

Material Transport

Loading rates of suspended and dissolved solids in streams have been widely studied over the years through scientific-based monitoring (Wolman, 1967; Meybeck, 1982; Walling and Webb, 1987). Calculation of the masses of materials exported from watersheds provides information on rates of landscape change due to weathering and erosion and deposition (Allan, 2004). Further, the comparison of loading rates among watersheds provides understanding of linkages between solids transport and watershed geology, land use, and hydrology. Estimates of the amounts of suspended and dissolved material that is deposited into lakes, reservoirs, and oceans from streams can be made to provide understanding of the chemical balance between land and waterbodies (Meybeck, 1982). Typically, material transport differs among physiographic regions (Simon, 2004). However, streams located in relatively close proximity may also have dissimilar transport behavior due to subtle differences in the factors that control material transport patterns such as land use and local precipitation (Simon, 2004).

Solids Transport Definitions

Material transport in streams involves movement of different types and sizes of materials. The largest-sized materials are included in the bed load, followed by materials in the suspended load, and finally the smallest materials comprise the dissolved load. Material in the bed load is generally larger than 62 µm and includes detritus, large woody debris, and rocks (Knighton, 1998).If bed material is adequately sized (in the cobble range) it can provide habitat for aquatic organisms such as macroinvertebrates and small fish. Minerals and organic materials that are transported as part of the suspended load range in size from 62 µm to 1.5 µm, or from 62 µm to 0.45 µm, depending on the method used to determine suspended load (Gurtz, et al., 1988; Standard Methods, 2005). For the purpose of this project, the suspended load was defined as materials larger than 1.5 µm.

Suspended materials do not readily settle out of the water column and can be transported further downstream than bed material due to their smaller size. Inorganic and organic particles, dissociated ions and other materials (solute) smaller than 0.45 µm are classified as dissolved solids. Dissolved material in the water column includes colloids which are range in size from 1 µm to 1 nm (Standard Methods, 2005). Material dissolved in the water column is smaller than both bed and suspended material and as a result can be transported much farther downstream and at faster rates (Knighton, 1998).

Carbon present in waterbodies occurs in different size fractions, as well. Inorganic carbon can be classified as either particulate inorganic carbon (PIC, >10 µm) or dissolved inorganic carbon (DIC, < 0.45 µm). Organic carbon, however, is generally broken down into three size fractions: coarse particulate organic carbon (CPOC, >10 µm), fine particulate organic carbon (FPOC, 10 µm - 0.45 µm), and dissolved organic carbon (DOC, < 0.45 µm) (Bilby and Likens, 1979).

Table 1.1 Summary of Mineral and Carbon Size Fractions

Load Type	**Size Fraction**
Bed Load	> 62 µm
Suspended Load	62 µm – 1.5 µm
PIC/CPOC	> 10 µm
FPOC	10 µm – 0.45 µm
Dissolved Load	< 0.45 µm
DIC/DOC	< 0.45 µm

Concentration, Load, and Yield

Quantity of transported material is usually described in terms of concentration, load, and yield. Concentration, or the intensity of occurrence, is used along with discharge to construct a rating curve, which can be used to estimate the load of a constituent (Walling, 1977). The load is the total amount of material (bed, suspended, or dissolved) that passes through a given point in a stream during a period of time. Load is calculated as follows: Load (mass/time) = Concentration (mass/volume) x Q (volume/time). Where load is mass transport or amount of constituent delivered by a given watershed, yield is the production rate of a particular constituent per unit area watershed. Yield values indicate how much material is contributed by a particular watershed. Material load is normalized by dividing the drainage area of a given watershed to obtain yield. Table 1.2 shows suspended and dissolved yields of several rivers around the world.

Table 1.2. SolidsYields of World Rivers

River	Constituent	Yield (Mg/km^2/yr)	Source
Congo	TSS	8	3
Missouri	TSS	48	1
Madeira, Bolivian Andes	TSS	290	2
Congo	TDS	5	3
Madeira, Bolivian Andes	TDS	15	2

1) Turner and Rabalais, 2004 2) Guyot, et al., 1996 3) Gaillardeta, et al., 1995

Suspended Material Transport

Sediment is recognized as the primary nonpoint source pollutant in most water bodies by the United States Environmental Protection Agency (USEPA, 1998). Drainage basins having high amounts of sediment available from soils and erosion plus a high degree of overland transport (runoff) are likely to have high suspended loads compared to drainage basins that have little available sediment from soils and erosion plus a low degree of runoff (Walling and Webb, 1982). Frequency of floods is another important factor. For example, little sediment transport will occur if there is not enough precipitation to bring available sediment into the stream. Most of the suspended material in streams tends to be transported by floods of low to moderate discharge (bankfull discharge)and high frequency (recurring approximately every 1.5 years or less) (Leopold, et al., 1964; Wolman, 1967).

Problems may arise once excess sediment enters the water column of a stream. Nutrients, heavy metals, and other ions may adsorb onto small particle sediments, such as clay. If these sediments are mobilized they can be transported downstream or deposited in channel or floodplain areas (Thoms and Theil, 1995; Goodfellow, et al., 2000). In addition, prolonged exposure to high concentrations of fine sediment in streams can be detrimental to aquatic life (Davis, et al., 1996).

Dissolved Material Transport

Solution of bedrock and/or bed material in a stream can contribute large quantities of solute to the dissolved load (Peters, 1984). This occurs mostly in areas where the underlying geology is conducive to solution such as carbonate regions like southwest Missouri. In urban areas, chemical pollutants such as oil, grease, and household wastes can accumulate on impervious surfaces. Storm runoff from precipitation washes the accumulated pollutants into storm drains that deliver floodwater and pollutants rapidly into surface water bodies (Richards and Thompson, 2002). Additionally, dissolved solids are introduced into streams by leaching from leaf litter and other decaying material. This material may lie on top of soil or be part of the A-horizon (Knighton, 1998). Because dissolved material is so small it constantly remains in the water column and does not tend to settle or become deposited (Knighton, 1998).

Pollutant Transport

Pollutants come from two distinct sources, point and nonpoint sources. Point source pollutants enter water bodies from a discrete ―end of pipe” source such as discharge from a factory or wastewater effluent (USEPA, 2003). Nonpoint source pollutants enter water bodies in a diffuse fashion from non-uniform and different sized areas in association with diffuse sources of storm runoff. This type of pollution depends on runoff source. Agricultural and urban landuses are typically associated with nonpoint sources of pollution. Pollutants from these sources cannot be traced back to one single or multiple sources, thus they are not as readily controlled or regulated as point source pollutants (USEPA, 2003).

Because nonpoint source pollutants continue to be a problem, some of these pollutants are regulated by federal or state agencies. For instance, many municipalities require erosion control practices to be in place at all construction sites (Novotny and Olem, 1994). Furthermore, Phase II of the National Pollutant Discharge Elimination System (NPDES) program requires permits from runoff sources such as municipal separate storm sewer systems (MS4s) in Greene and Christian Counties as well as the Cities of Battlefield, Nixa, and Ozark (OEWRI, 2009).

Anthropogenic and Natural Sources

Many natural and anthropogenic sources of suspended and dissolved materials exist. Natural sources of suspended and dissolved materials include chemical and physical weathering of soils and rocks unrelated to agriculture or urbanization, atmospheric inputs, and inputs from plants and animals (Meybeck, 1982; Peters, 1984; Rabalais, 2002). Agricultural land and urban areas are anthropogenic sources of transportable materials. Clearing of forests, prairies, and wetlands for agricultural use has caused large volumes of sediment and organic material to enter water bodies due to the loss of vegetation and roots that hold the soil in place (Pimentel, et al., 1995). In urban areas ongoing construction, which increases the amount of impervious area and disturbs soil, has also caused an increase in the amount of material available for transport (Wolman, 1967; Novotny and Olem, 1994; Trimble, 1997). Grazing of pasture lands by domestic animals such as cows and horses can increase the amount of sediment available for erosion by causing removal of vegetation and damage to stream banks and beds (Trimble and Mendel, 1995). Physical and chemical weathering of rocks and soils are natural sources of suspended and dissolved materials.

Currently, the amount of impervious area is increasing rapidly as humans continue to develop forests, prairies, wetlands, and even pasture lands for economic gain and livelihood. Impervious areas are human-built surfaces that reduce or impair infiltration of water into soil and increase runoff. Roads, side-walks, and roofs are all examples of impervious areas (Booth and Jackson, 1997). High percentages of impervious area can cause an increase in ―flashiness" of streams (Baker, et al., 2004). Flashiness refers to the occurrence of short-term changes in discharge, mostly during storm events. A high degree of variation in discharge increases the flashiness of a stream. Furthermore, changes in landuse, such as loss of native vegetation due to urbanization or conversion to agriculture, can greatly increase the flashiness of a stream by decreasing surface roughness and increasing flow velocity (Baker, et al., 2004).

Material Transport in Ozarks Rivers

Natural material loads tend to vary by physiographic region. Some regions are underrepresented in our knowledge base. The Ozarks Physiographic Region is one such region. Fine-grained sediments, carbon, nutrients, and ions, as well as organic compounds from wastewater, fecal bacteria, trace metals, and a variety of other chemical pollutants have all been found to be part of the suspended or dissolved load in area streams (Smith, et al., 2007; Pulley, et al., 1998; Richards and Johnson, 2002; Davis, et al., 1996). Table 1.3 displays loads and yields of constituents commonly occurring in Ozarks region streams.

While Ozarks streams are noted for their clarity, sediment may be transported in fairly large quantities during stormflow, especially downstream from land that has been disturbed by construction or agriculture (Davis and Bell, 1998). Historically, early settlement of the Ozarks may have caused an increase in sedimentation due to removal of existing vegetation, particularly when hill slopes were cleared for crops. Some land has been allowed to return to its pre-settlement state, which may reduce the amount of sedimentation; however, construction of urban areas continues to contribute sediment to Ozarks streams (Jacobson and Primm, 1994).

Table 1.3. Regional Constituent Yields

Constituent	Ad (km^2)	Yield ($Mg/km^2/yr$)	Source
TDS	Rattlesnake Creek, KS	25.3	1
TSS	Rattlesnake Creek, KS	1.67	1
TOC	Arkansas-White River, AR	0.78	3
TP	Rattlesnake Creek, KS	0.003	1
TP	White River, AR	0.043	2
TN	White River, AR	0.53	2
Cl^-	Rattlesnake Creek, KS	11.9	1
SO_4^{2-}	Rattlesnake Creek, KS	1.43	1
NO_3^-	Rattlesnake Creek, KS	0.02	1
Fl^-	Rattlesnake Creek, KS	0.007	1

1) Christensen, 2001 2) Haggard, et al., 2003 3) Turner and Rabalais, 2004

The calcareous bedrock is one of the defining features of the Ozarks Physiographic region. In addition to forming the gently rolling hills found in the Ozarks, the limestone bedrock is susceptible to chemical weathering from acidic precipitation and surface water. The chemical weathering produces geologic formations known as karst. Carbonate, form of carbon, is a byproduct of chemical weathering that occurs in the Ozarks. Carbon found in streamwater has also been found to be a sink of atmospheric carbon (Gaillardeta, et al., 1999). Particulate and dissolved organic and inorganic carbon are readily found in Ozarks streams. Sedimentary (carbonate) rock weathered by carbonic acid (formed by mixing of water and dissolved carbon dioxide) is the main source of dissolved inorganic carbon in streams similar to those in the study area (Carling, 1983). The chemical equation for solution of calcium carbonate (solid) by carbonic acid into bicarbonate is as follows (White 2006):

$CO_2\ (g) + H_2O\ (l) \leftrightarrow H_2CO_3\ (aq)$ (carbonic acid) (1)

$CaCO_3(s) + H_2CO_3\ (aq) \leftrightarrow Ca^{2+} + 2\ HCO^-$ (2)

Bicarbonate may then dissociate further into carbonate ion:

$HCO_3^-\ (aq) \leftrightarrow H^+\ (aq) + CO_3^{-2}\ (aq)$ (3)

Decaying leaves, trees from forested and agricultural areas provide inputs of particulate and dissolved organic carbon (Finlay, et al., 2002). In the Ozarks, DOC concentrations were found to be highest in watersheds containing a high percentage of agricultural land (Davis and Bell, 1998). Both forms of carbon are important food source for many aquatic organisms; however some forms of carbon are toxic and may cause harm to stream ecosystems (Gurtz, et al., 1988; Finlay, 2001). Furthermore, oxidation of organic carbon releases carbon dioxide gas which can then become carbonic acid (White, 2006).

Nitrogen and phosphorus species are naturally occurring macronutrients (needed by plants in large quantities) often found in streamwater (Vézie, et al., 2002). However, nitrogen and phosphorus are occurring in streamwater in greater quantities due to anthropogenic inputs, such as wastewater effluent, crop fertilizer, and animal waste (Rabalais, 2002; Smith et al., 2007). Nitrogen most often occurs as nitrate in streamwater, while orthophosphate is the most common form of phosphorus (Rabalais, 2002). Nitrogen is naturally found in the atmosphere and in plants, while phosphorus naturally occurs in bone and shells of living organisms (Vézie, et al., 2002). Nitrogen found in streamwater tends to be in dissolved form, while phosphorus adsorbs to small soil particles.

Nutrients may have appeared in greater quantities in Ozarks streams over the past several years possibly due to effluent from sewage treatment plants and an increase in large farms that produce animals (Smith, et al., 2007). Excess nutrients in streamwater can cause an excess growth of algae, which may lead to a lack of oxygen and sunlight in the stream. Poultry litter, which contains nitrogen and phosphorus, has been used as crop fertilizer. If the poultry litter is not applied carefully, it can wash into streams with runoff (Pirani, et al., 2007). Additionally, sediment bound nutrients may be lost along with soil during erosion (Pimentel, et al., 1995). As a result, nutrients have to be applied to crops in manufactured fertilizer form. Plants are only able to uptake a limited quantity of fertilizer, consequently the excess nutrients either wash away with eroded sediment or become dissolved and leach into the groundwater which may enter streams via groundwater conduits (Mitsch, et al., 2001).

Negatively-charged ions (anions) are small enough to be part of the dissolved load. Anions that occur in streamwater include chloride, sulfate, nitrate, and fluoride (Cl^-, SO_4^{2-}, NO_3^-, and F^-, respectively). Chloride ion tends to occur in fairly high concentrations in streams compared to other anions (Smith, et al., 2007). Landfill leachate, municipal drinking water, and wastewater effluent are major sources of chloride (Christensen, 2001). Additionally, chloride may enter streams from excess road salt applied during cold months (Gardner and Royer, 2010).Sulfate ion is generally present in streams in quantities less than chloride (Smith, et al., 2007). Fossil fuel power plant emissions are a major anthropogenic source of sulfur in streamwater. Sulfur dioxide from plant emissions forms sulfate, which enters streamwater through precipitation (Shanley, et al., 2005). Nitrate is another ion commonly present in streamwater, though this ion is not as abundant as sulfate or chloride (Smith, et al., 2007). Natural and synthetic fertilizers are both common sources of nitrate as well as septic tanks and wastewater. Fluoride ion is also part of the dissolved load, though usually in very small concentrations (Smith, et al., 2007). The most common sources of fluoride in regions lacking igneous rock, such as the Ozarks, are municipal water supplies, as well as fluoridated toothpaste and mouthwash (ATSDR, 1993). Table 1.3 shows regional yields of the constituents examined in this study.

Research Questions

Currently, there is a lack of knowledge regarding transport of suspended and dissolved solids in the Ozarks. In order to address this lack of information for Ozarks streams this study will focus on understanding material transport in the James River. A better understanding of the James River is necessary because it not only drains many counties in Southwest Missouri and supplies drinking water to Springfield, Missouri, but it also drains into Table Rock Lake, a popular recreational reservoir used by many. The Ozarks are noted for clean, clear streams which are popular for fishing and nature lovers. Many popular streams are tributaries of the James River. The health of the James River may also be used as an indicator of the overall health of the land in the James River Basin.

Consequently several questions need to be addressed in order to better understand material transport in the James River Basin. First, how does discharge influence material transport? Specifically, which constituents are transported in greatest concentration during baseflow versus stormflow? Peak suspended solids concentrations are expected to occur during stormflow, while dissolved material is expected to be most readily transported during baseflow (Walling and Webb, 1982; Walling, 1984). The influence of hydrology and discharge variation on transport is important for evaluating watershed dynamics and regulating water quality. It is also important to determine how material transport differs during baseflow and during the rising and falling limbs of stormflow because sources of materials can be determined based flow type or hydrograph limb.

Second, how do geology, seasonal changes, and land use affect material transport in the James River Basin? The carbonate geology of the Ozarks is expected to especially affect the transport of dissolved materials; karst features of the study area may act as conduits for both suspended and dissolved materials. Variances in soil type and relief among sub-watersheds may also affect materials transport. Differences in land use among each sub-watershed in the study area may also influence materials transport. Constituent loads and yields for sub-watersheds in the Upper and Middle James River Basin need to be compared across an urban gradient to demonstrate potential effects of urbanization on materials transport.

Third, how do the yields from this study compare to those of other regions? Yields of water quality constituents have been determined for many rivers across the world. It is important to compare yields calculated for this study to those from similar studies in order demonstrate consistency and determine the relative magnitudes of material loads in an Ozarks watershed.

Purpose and Objectives

The purpose of this thesis study is to quantify suspended and dissolved material loads in the James River Basin and describe how they are influenced by discharge, land use, seasonal changes, and sampling methods. Specific constituents to be evaluated include total suspended sediment, total dissolved solids, organic and inorganic carbon, nutrients, and anions. Behavior of water chemistry parameters (pH, turbidity, specific conductance, and dissolved oxygen) in comparison to constituents is also discussed.

The objectives of this thesis study are:

1. Implement a 1-year monitoring program at five USGS gage sites in the James River Basin. Bridges on tributaries and the main stem in the upper and middle portion of the James River Basin that are monitored by the USGS were chosen as sampling sites. Sampling occurred during baseflow and stormflow.
2. Evaluate water chemistry trends. Generally, water chemistry trends are affected by seasonal changes. Many constituents are also affected by variances in water chemistry parameters.
3. Evaluate baseflow and runoff contributions and influence of seasonal change on constituent concentration. Materials are transported differently during baseflow and stormflow. Constituent concentrations during baseflow and stormflow were compared to explain under which flow conditions constituents are most readily transported and to characterize source input behavior. Constituents are also transported differently throughout the year. Comparing constituent concentrations during each season can explain how seasonal changes affect materials transport.

4. Compare concentration data from this study to long-term concentration data from the United States Geological Survey.
5. Develop concentration-discharge rating curves, determine load duration characteristics, and calculate river loading of material. After water samples were analyzed to determine various constituent concentrations, a rating curve was created for each constituent. Loads and yields were estimated from the rating curves. Estimating amount of material transported by rivers can be done by calculating load. Load duration rating curves can also be used to estimate the percentage of load transported by different types of flow.
6. Compare yields from urban and agricultural areas. Constituent yields are expected to be influenced by land use. Comparing yields from areas of differing land use will help to explain which types of land use control different constituents.

Benefits of study

The Ozarks region is expected to experience the one of the highest growth rates in Missouri over the next 20 years, which will indirectly impact local streams. The benefits of this thesis study include a better understanding of regional variations in mass transport in the Ozarks. Material transport analyses are important for water quality management of streams and other water bodies. Furthermore, studies on material transport provide a link between land use and water resources in watersheds.

CHAPTER 2

SOLIDS AND POLLUTION TRANSPORT IN RIVERS

Research has been conducted describing suspended and dissolved load characteristics, transport mechanisms, sources, and effects on water quality in many regions of the world (Wood, 1977; Walling and Webb, 1982; Prowse, 1987; Trimble, 1997; Pip, 2005). Describing differences between the suspended load and the dissolved load helps to demonstrate how they are transported differently. Effects of land use, including effects of urbanization and agricultural practices, on transport of suspended and dissolved materials have also been a topic of interest because disturbance from different land uses has caused an increase in sedimentation processes (Wolman, 1967; Jordan, et al., 1997, Thomas, et al., 2004).Seasonal effects on material transport are also a commonly studied subject because constituent concentrations vary depending on amount of precipitation and other climatic factors (Douglas, 1964; Tilman, 1982). Studies on Ozarks streams have examined pollutant sources and loads, effects of stormflow versus baseflow, and the influence of land use conditions on material transport (Davis, et al., 1996; Davis and Bell, 1998; Pulley, et al., 1998). These regional studies provide important background information that helps to describe how solids and pollutants are transported in the James River Basin.

Suspended Load

Characteristics. Material in the suspended load tends to be carried in the water column due to the effect of flow turbulence and mixing by currents. When flow velocity slows, suspended material, especially larger size particles, will settle out of the water column and become deposited in the bed, on banks, or on floodplains (Knighton, 1998). While eroded soil and other inorganic sediments comprise a large portion of the suspended load, carbon from organic material is also part of the suspended load. Particulate organic carbon as part of the suspended load originates from decomposing plant or animal matter and can exist in streams in different size fractions including fine (size range), and coarse particulate (size range) organic carbon (Newbold, et al., 1982). Suspended materials can act as a mechanism of transport for other more toxic pollutants due to the tendency of these pollutants to adsorb onto sediments (Sansalone and Cristina, 2004). While presence of excess sediment in the suspended load can have negative effects, it is normal for some fine-grained sediment to be eroded or deposited in a stream channel and transported as a component of geomorphic work (Wolman, 1967).

Sources. Suspended material originates from both natural and anthropogenic sources. While runoff delivers suspended material to the stream channel; different source inputs may be active during different limbs of the hydrograph (Asselman, 2000). Suspended material introduced during the rising limb tends to be from sources close to the stream channel, while material contributed to the suspended load during falling limb tends to come from sources that are far from the stream channel (Asselman, 2000).Wolman (1967) found that active construction sites can contribute large loads of suspended sediment to nearby streams, often 10 to 100 times yields from undisturbed land. Impervious surfaces, another consequence of urbanization, were found to be an indirect cause of bank erosion in nearby streams causing an increase in suspended sediments (Trimble, 1997). Bed and bank erosion, mass wasting, and karst conduits are other contributors of suspended sediment in streamwater (White, 1988; Trimble, 1997). Sediment contribution from bank erosion, however, is variable. Large-scale bank erosion and mass wasting can supply a large percentage of the suspended load. If mass wasting occurs during a dry period, the resulting sediment input may enter the stream channel, but not become suspended immediately (Bull, 1997).

Various organisms may indirectly contribute to the suspended load. For instance, aquatic invertebrates can produce suspended material by converting large pieces of organic material (large woody debris, decaying plants and animals) that are in or near a stream into FPOC. Physical processes, such as abrasion, also convert large pieces of organic material into FPOC (Bilby and Likens, 1979). Runoff moving through leaf litter provides organic carbon inputs to streams by picking up FPOC that is later deposited in a stream (Moore, 1987; McGlynn and McDonnell, 2003). In most situations inorganic carbon concentrations are relatively low. Particulate inorganic carbon (small pieces of carbonate rock) rarely exists in the water column because it tends to either be too large to stay in suspension or become dissolved (White, 2006).

Transport. Material becomes entrained (suspended in the water column) only when the flow velocity is fast enough to exceed critical shear stress. Baseflow velocity is usually not fast enough for entrainment of larger suspended solids to occur. In addition, suspended solids input rate to the stream are related to the intensity of rainfall and runoff. Consequently, concentrations of suspended material tend to be much lower at baseflow. Materials settle out of suspension when the settling velocity, a function of grain size, water temperature, and gravity, is reached. Suspended material tends to be carried in the lower to middle part of the water column, while bedload is transported by saltation along the bed. Much of the suspended load may be transported during the early rising limb of floods, also known as the first flush (Sansalone and Cristina, 2004). Johnson and East (1982) found that storm discharge and suspended material transport depends not only upon amount of precipitation from a storm event, but also antecedent soil moisture, and accumulation of transportable material in the watershed. Once the supply of material is exhausted, concentrations decrease even though discharge may still be increasing.

Hysteresis. The cyclical relationship between discharge and constituent concentration during a storm event is known as hysteresis (Johnson and East, 1982; Klein, 1984). Hysteresis can be best described by plotting constituent concentration during the duration of a given storm event over discharge to create a so-called hysteresis loop (Figure 2.1) (Johnson and East, 1982). Although many types of hysteresis loops emerge when concentration of suspended material and related constituents (e.g. POC and sediment-bound phosphorus) are plotted, three main types of loops seem to dominate: clockwise, counter-clockwise, and none/minimal (Figure 2.2) (Asselman, 2000; Seeger, 2004). Hysteresis loop type depends upon drainage area, amount of precipitation, and antecedent soil moisture (Seeger, 2004).

Clockwise, or first-flush hysteresis loops (Figure 2.2a) occur when the suspended sediment concentration peaks before discharge peaks (Wood, 1977; Asselman, 2000; Seeger, 2004).These loops occur when the available sediment supply becomes rapidly exhausted because the main supply is located either in or near the channel. Two studies found clockwise hysteresis loops to be the most common (Asselman, 2000; Seeger, 2004). However, Asselman (2000) found that clockwise loops occurred during high discharge floods, while Seeger (2004) found these loops occurred during floods of moderate to low discharge.

In contrast, a counter-clockwise hysteresis loop (Figure 2.2b) emerges when the suspended sediment concentration peaks after the maximum discharge occurs. The suspended sediment that is transported comes from sources relatively far from the sampling site, and is not as readily exhausted (Asselman, 2000).

Hysteresis loops are not seen when antecedent soil moisture is low and soil infiltration is the source of storm flow instead of runoff (Wood, 1977; Seeger, 2004). When the concentration is similar for equal discharges during both rising and falling limbs a linear instead of a loop pattern is produced (Figure 2.2c), indicating little hysteresis effect (Wood, 1977).

Like suspended sediments, FPOC has been found to exhibit hysteresis. A study on a small stream in New Hampshire found that FPOC concentrations increased with discharge, and the highest concentrations were seen on the early rising limb. However, FPOC concentration peaked just before peak discharge and then decreased rapidly (Bilby and Likens, 1979).

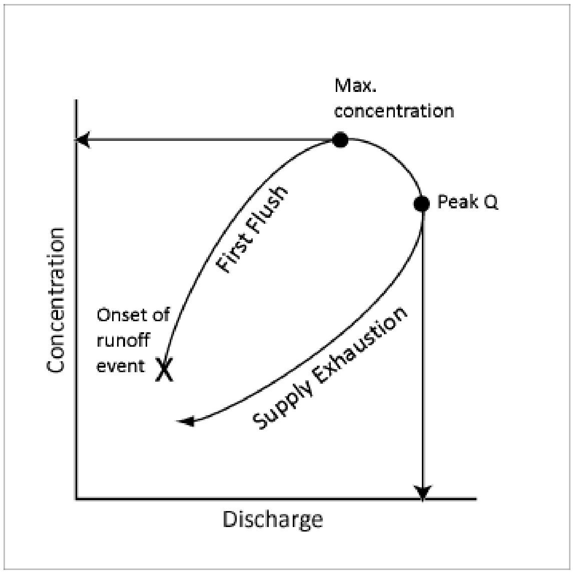


Figure 2.1. Hysteresis Loop

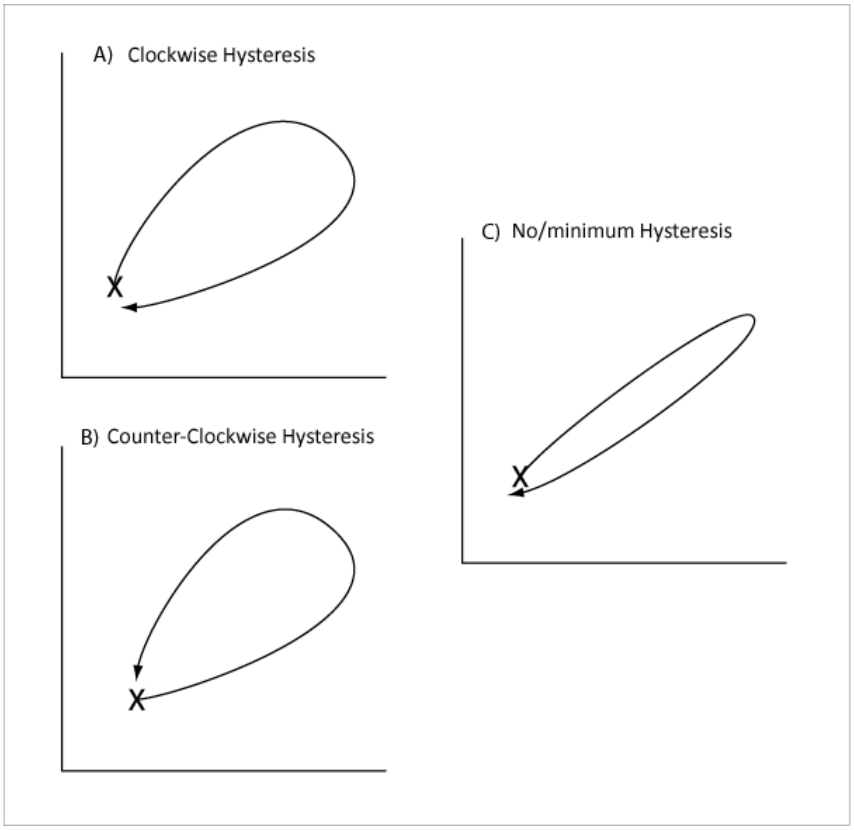


Figure 2.2a-c. Examples of Hysteresis Loop Types

Land Use Trends. The quantity of suspended load also depends upon the land use in the watershed. Land use generally varies within a watershed among urban, agricultural, and forest areas. While urban areas in a watershed may take up a small amount of space, they can have a great effect on the overall water quality of a stream. Agricultural inputs are often associated with grazing land, animal feeding operations and row crops (Smith, et al., 2007). Some agricultural land usage contributes fewer inputs to streams than others. Row cropping, for instance, can contribute large quantities of suspended sediments and nutrients to streams during storm events, while grazing and pastureland may contribute less.

Seasonal Trends. Transport of suspended material fluctuates throughout the year. Materials that have accumulated in the watershed during the dry season are often flushed out during the first rain events of the wet season (Sansalone and Cristina, 2004). Consequently, concentration of suspended sediments and organic material is expected to be higher during the beginning of the rainy season because of this primary first flush of materials and due to increased frequency of storm events. Riparian vegetation also contributes FPOC to the suspended load during the wet season. Wallace, et al. (1982) found suspended material concentration was significantly higher during the first storm after leaf-fall occurred. Additionally, when plants are still dormant, but precipitation begins to increase, large amounts of runoff may occur due to lack of water uptake by plants.

Availability of suspended material may have more of a role in suspended sediment concentration than storm frequency in some cases. Three years of data from the Green River, Kentucky and the Mississippi River were examined by Carling (1983) and analyzed using the frequency distribution curve method of Wolman and Miller (1960). The analysis revealed that suspended sediment concentrations during the rainy season decreased as time progressed because the sediment supply became exhausted. The suspended sediment concentrations during storms that occurred in rapid succession exhibited a progressive decrease in concentration, known as secondary peaking, because there was little time between storms for material to reaccumulate in the watershed. As a result, it is suggested that sediment supply could be as much of a control as storm event frequency (Carling, 1983).

Rating Curves. Concentration of suspended material is affected by changes in discharge. Suspended sediment concentration typically exhibits a positive relationship with discharge because the material is brought into streams from the watershed by runoff during storm events. Runoff tends to add material to the suspended load while diluting the dissolved load. During baseflow streams do not receive inputs of suspended material, while dissolved material concentration tends to increase between storm events as groundwater weathering and point source inputs become more concentrated, not diluted by rainfall. In general, suspended sediment concentration is highest during floods with very high discharges, although those discharges occur rarely. More intense rainfall will dislodge sediment particles from soils and other sources. Large floods can cause bed and bank erosion in tributaries and the mainstem, thus increasing sediment supply. Most of the suspended load is transported during floods that have lower discharge, but higher frequency (Wolman and Miller, 1959). However, baseflow has been found to be ineffective at transporting suspended material because of the lack of runoff to deliver material from watershed surface to the channel network (Webb and Walling, 1982).

Load and Yield. While little information exists concerning the transport of suspended sediment in the James River Basin, a study by Davis, et al. (1996) which assessed the entire Ozarks Plateau region, reported suspended solids loads from some nearby rivers (Table 2.1). While the White River has a larger drainage area than the Neosho and Gasconade Rivers the suspended solids load from the White River is an order of magnitude smaller. This may be due to a number of factors including the presence of dams on the White, soil composition, and land use practices.

Table 2.1. Suspended Solids Yields for Ozarks Rivers (from Davis, et al., 1996).

River	Area	Load (Mg/yr)	Yield Mg/ km^2/yr)
White	16,054	107,046	6.6
Neosho	7892	644,887	81
Gasconade	4135	353,687	86

Water Quality Concerns. Effects of suspended sediment on water quality of streams have been studied extensively (Davis, et al., 1996; Richards and Johnson, 2002; Smith, et al., 2007). Some pollutants, such as phosphorus and trace metals, can adsorb onto the small-sized sediment particles commonly found in Ozarks soils (Smith, et al., 2007). Once mobilized, the sediment bound pollutants can enter streams and cause a number of problems. Phosphorus is often a limiting nutrient for aquatic vegetation. Excess phosphorus can cause an over growth of nuisance algae and plants which can lead to a reduction in species diversity of other aquatic organisms (Tilman, 1982). Likewise, mercury and other trace metals from a variety of anthropogenic sources can be transported to streams where they can become part of the trophic web. Bioaccumulation of a toxic form of mercury, methylmercury, in tissues can lead to neurological problems in aquatic organisms and in people who eat large quantities of those organisms (Steevens and Benson, 1999). Locally, Richards and Johnson (2002) determined that the water quality of Pearson Creek and Wilson Creek has been degraded by runoff from urban areas, namely the City of Springfield, MO.

Recently, many steps have been taken to address nutrient pollution in the James River Basin. For instance, 319 grants provided by the federal government have been used by local agencies such as the Watershed Committee of the Ozarks and James River Basin Partnership, to implement best management practices (BMP) to help reduce the amount of nonpoint source pollutants, such as nutrients and mercury, which is delivered to the James River. Additionally, in 2001 the Southwest Wastewater Treatment Plant (SWWWTP) underwent upgrades to improve phosphorus removal. These upgrades have significantly reduced phosphorus levels in the James River downstream from Wilson Creek.

Dissolved Load

Characteristics. Until relatively recently, the transport of dissolved solids was not deemed as important as transport of suspended solids because physical removal of material was thought to contribute more of the material transported by streams. However, studies have found that chemical weathering is a major contributor of materials transported by the world‘s rivers (Meybeck, 1976). Dissolved inorganic carbon found in streamwater is largely comprised of bicarbonate (HCO_3^-), carbonate (CO_3^{2-}) ions, and dissolved carbon dioxide derived from non-living or artificial sources such as sedimentary rock, soil, and the atmosphere (Holland, 1978; Meybeck and Vorosmarty, 1999; Groves and Meiman, 2001; Finlay, 2003). Dissolved solids concentration of groundwater in the Springfield Plateau Aquifer ranged from 200 mg/l to 300 mg/l (Imes and Davis, 1990).

Organic carbon, commonly found in the dissolved load of Ozarks streams, is material originating from decaying plants or animals and exists in streams in different size fractions. Many studies have found that dissolved organic carbon (DOC) is more prevalent in streamwater than particulate organic carbon (POC) (Newbold, et al., 1982; Jordan, et al., 1997; Findlay, et al., 2001).

Sources. Weathering of carbonate rock, such as limestone and dolostone, by carbonic acid formed in groundwater and streamwater is perhaps the major contributor to the dissolved load and also inorganic carbon load in regions with sedimentary carbonate rock, such as the Ozarks (Peters, 1984). Indeed, dissolved loads have been found to be much higher in watersheds with soluble bedrock than in watersheds with insoluble bedrock (Carling, 1983). Consequently, bicarbonate ion is the dominant anion in these streams (Raymond, et al., 2008). An important function that occurs in streams is the sequestration of atmospheric carbon by the formation of bicarbonate (Raymond, et al., 2008).

Groundwater has a higher concentration of solutes than streamwater because it is in contact with soluble rock for a greater amount of time than streamwater even at baseflow (Douglas, 1964). Therefore, streams receiving groundwater from springs often have higher dissolved loads. Small amounts of dissolved inorganic carbon (DIC) can enter streams as runoff infiltrates through soil and other areas of the terrain. Likewise, DOC can be introduced into stream water as storm runoff infiltrates soils with high organic content and as runoff leaches through decomposing plant material (Meyer and Tate, 1983).

Atmospheric salts originating from denudation and atmospheric ions dissolved in precipitation originating from industry, volcanoes, sea water, and organic material can also contribute to the dissolved load of streamwater (Douglas, 1964; Willey, et al., 2000). However, upon coming in contact with streamwater, solutes occurring in rain water may be buffered by carbonate ions, if present (Douglas, 1964).

Increased presence of impervious surfaces built by humans in recent times has been shown to negatively impact surface water bodies by acting as a delivery system of chemicals and other accumulated pollutants (Prowse, 1987). Soluble chemicals such as benzene, toluene, xylene and organic solvents that accumulate on impervious areas can also become part of the dissolved load (Klein, 1981; Barac, et al., 2004).Wastewater is another urban source of dissolved nutrients and other pollutants. During treatment, large particles are physically removed and smaller particles are settled out after flocculants are added, however, dissolved nutrients and chemicals may remain in the effluent. Soluble nitrogen species from crop and lawn fertilizers can leach into groundwater and become part of the dissolved load.

Transport. Dissolved load is transported differently from the suspended load. Dissolved material is generally transported in the upper part of the water column, while suspended load is generally transported in the middle and lower part due to particle size and weight (Knighton, 1998).Because dissolved material is so small it constantly remains in the water column and does not tend to settle or become deposited. Concentrations of dissolved solids are typically highest during baseflow because during this time more of the flow is in contact with the bed material, which can be dissolved by the carbonic acid formed in the water, thus allowing ions to enter into solution. Dissolved organic carbon concentrations tend to be relatively high during baseflow because concentration of groundwater input and point source inputs are highest (Jordan, et al., 1997). When storm events occur, the first flush of solute-laden runoff may increase concentration, but after the introduction of precipitation with low solute concentrations, dissolved solids concentrations become dilute. Furthermore, because water moves at higher velocities during storm events runoff may not come in contact with soluble organic material long enough for much dissolution to occur (Knighton, 1998). Dissolved solids concentrations are not as affected by storm flow, however, when an increase in discharge occurs faster than weather rate dilution may occur (Webb and Walling, 1982).

Hysteresis. Concentration of dissolved solids varies during the rising and falling limb of the storm hydrograph much like suspended sediment concentration. Klein (1981) sampled streams and found that when dissolved solids accumulated on watershed surfaces between rain events a flushing effect occurred during early rising limb of the next storm hydrograph. Unlike suspended sediments, Jordan, et al. (1997) found that the DOC concentrations did not increase with discharge but rather decreased with discharge.

Proximity of source to streams is also a factor in transport of dissolved solids. DOC contributed from the riparian zone of the watershed was delivered to the stream during the early rising limb or first flush of storm runoff. However, DOC that was transported during the falling limb was found to originate from the hillslope zone of the watershed which took longer to reach the stream (McGlynn and McDonnell, 2003).

Land Use Trends. Application of water-soluble nutrients to crops, chemicals accumulated on urban surfaces, and other chemical influences of land use can contribute to the dissolved load. The urbanization process leads to an increased rate at which dissolved solids enter streams from a watershed (Prowse, 1987). Atmospheric acidity was increased in urban areas due to pollution, which caused further increase of dissolution of carbonate rock in streamwater.

Raymond, et al. (2008) analyzed 100 years of data collected in the Mississippi River Basin by various agencies. They found that an increase in land disturbance from agricultural land was increasing the bicarbonate ion concentration in streamwater. Aside from major disturbance of the land, practices that were thought to contribute bicarbonate included liming the fields and general refining of soils. Land disturbance (e.g. irrigation, draining practices, and some forms of crop rotation) was also found to increase discharge, which in turn increased bicarbonate ion concentration, therefore increasing the amount of carbon exported by rivers.

Seasonal Trends. Seasonal changes can cause fluctuations in dissolved solids concentrations and daily loads. In a study on seasonal concentration changes, total dissolved solids concentrations were found to fluctuate during three phases (Douglas, 1964). The first phase was flood phase when streams were fed mostly by surface runoff. Results indicated that dissolved solids concentration was lowest at this time of the year because of dilution. The second phase was a low water transition phase when streams were mostly fed by groundwater. Dissolved solids concentrations were higher during this phase than during the flood phase due to lack of dilution causing runoff. The last phase was the low water phase during which streams were fed exclusively by sources of groundwater that flowed year-round. This phase had the highest dissolved solids concentration of all phases because groundwater feeding the streams had high concentrations of dissolved solids.

Dissolved solids concentration is expected to be higher in months with few storm events because dilution does not occur as much in these months. Wallace, et al., (1982) found that the ratio of DOC to POC was lowest during the month of August. This was because aquatic organisms were consuming DOC at a high rate even though watershed inputs of POC were low of the lack of storm events.

Rating Curves. The dissolved solids concentration does not increase with discharge as much as the suspended sediments concentration. Instead, dissolved solids concentration tends to decrease with increasing discharge as solutes become dilute (Meybeck, 1976). However, annual dissolved loads tend to be higher than annual suspended loads because chemical weathering of materials is a continuous process (Webb and Walling, 1982). Concentration of inorganic carbon is higher if the streamwater remains in contact with the carbonate rock for a long period of time by not being diluted by storm runoff (Holland, 1978; Groves and Meiman, 2001; Finlay, 2003). A study on solutes in streamwater by Webb and Walling (1983) found that ions commonly found in the dissolved load of streamwater were generally inversely related to discharge. However, some ion species were found to be more readily diluted than others due source availability and buffering by bicarbonate ion (Webb and Walling, 1983). To compensate for seasonal differences in dissolved solids concentrations Webb and Walling suggest that separate rating curves may need to be developed. An increase in biological uptake of dissolved nutrients occurs in summer when productivity is high, thus reducing the concentration of total dissolved solids; this effect is not seen in winter when productivity slows (Webb and Walling 1983).

Load and Yield. Information on loads and/or yields of dissolved solids from Ozarks rivers are not readily available. However, dissolved solids loads and yields from rivers in other karst areas of the world are available (Table 2.2). Dissolved solids yields in the Ozarks should be on the same order as rivers draining karst terrain. Dissolved solids yields from rivers draining non-karst areas are comparatively much less than those from rivers draining karst areas (Table 1.1).

Table 2.2. Dissolved Solids Yields from Rivers Draining Karst-Carbonate Terrain

Location	Yield (Mg/km^2/yr)	Source
Southwest China	67-116	1
Central Italy	258	2

1) Han, et al., 2010 2) Bono and Percopo, 1996

Water Quality Concerns. High concentrations of dissolved solids in a stream can indicate the presence of pollutants such as nutrients, trace metals and other soluble chemicals (Pip, 2005). Like phosphorus sorbed onto sediments in the suspended load, dissolved nitrogen species found in the dissolved load can cause an excess of algal growth. Dissolved nitrogen as nitrate is the major form of nitrogen in streams from a range of sources (Rabalais, 2002). Additionally, potentially toxic dissolved trace metals, such as cadmium and zinc, have been found in streams near active or abandoned mines. Much like trace metals transported as part of the suspended load, dissolved trace metals may bioaccumulate in the tissues of organisms (Hare, 1992).

Water Chemistry Parameters

Data from water chemistry parameters provide ancillary information about suspended sediment and dissolved solids transport. Correlations may be made between some water chemistry parameters and TSS and TDS. Other parameters can affect the rate at which materials are transported or behave chemically and physically.

Water temperature is important to monitor because abrupt changes may indicate problems with water quality. Sudden or drastic increases in temperature in streamwater can cause organisms to die. In addition, dissolved oxygen is released from water as temperature increases (Cech, 2003). Aquatic organisms may not be able to survive if water temperatures continue to stay elevated (Cushing and Allan, 2001). According to the Missouri Clean Water Commission (MoDNR, 1996), water temperature of Ozarks streams fluctuates throughout the year but should not exceed 20°C for cold-water fisheries and 30° C for cool water fisheries.

Presence of dissolved ions and solids in streamwater allows electrical currents to pass through the water column. Conductivity is a measure of the electrical conductance of the water. Conductivity has a general relationship with total dissolved solids concentration; it is higher in areas where solution of bedrock or bed material takes place (Klein, 1981). Conductivity is measured in microsiemens per cm (µS/cm). Normal measurements in Ozarks streams range from 150 µS/cm to 500 µS/cm.

The degree of acidity or alkalinity of water is measured by pH, a dimensionless value. Stream ecosystems cannot support life if the pH of the water is too high or too low pH can be altered when streamwater comes in contact with carbonate bed material

(Holland, 1978). The acceptable Missouri Clean Water Commission pH range for Ozarks streams is from 6 to 9(DNR, 1996).

The clarity or turbidity of streamwater is an important parameter because it is an indicator of the amount of light that can penetrate the water column. If light cannot penetrate the water column adequately, aquatic organisms may not be able to survive. Turbidity is also an indicator of the concentration of suspended sediments in the water column. Additionally, simple linear regression of turbidity data may be used to estimate suspended sediment loads from turbidity measurements (Lewis, 1996). Turbidity is measured in Nephelometric Turbidity Units (NTUs). Turbidity levels of Ozarks streams at base flow range from zero to less than five NTU (Cech, 2003).

Oxygen can become dissolved when water at the surface mixes with the atmosphere and as a byproduct of photosynthesis. Dissolved oxygen (DO) in water provides oxygen organisms need for respiration. Low levels of DO can lead to a decrease in species richness and diversity of aquatic ecosystems (Cech, 2003). Percent saturation of DO is more meaningful than an actual concentration. This is because DO concentration is dependent on water temperature. A percent saturation of 80% or higher is desirable in Ozarks streams. Acceptable Missouri Clean Water Commission (DNR, 1996) dissolved oxygen levels should not be lower than 5 mg/L for warm water fisheries and no lower than 6 mg/L for cold-water fisheries.

Watershed Processes

Watershed size, or drainage area (Ad), and shape, topography, geology and soils, and land use all influence runoff and materials transport (Montgomery, 1999; Ward and

Trimble, 2004). Generally, streams with larger drainage areas will have more runoff than streams with smaller drainage areas. Consequently, more material will be brought into the stream with a larger drainage area. However, a stream that drains a very large watershed, but has relatively undisturbed soils, may have a smaller material load than a stream with a smaller drainage area that has disturbed soil. In the same manner that steeper streambeds have higher flow velocity, precipitation tends to runoff faster on steeper slopes than gentle slopes.

Watersheds shaped in such a way that allows runoff to enter a stream at many points are more likely to have more runoff reach the stream than watersheds that have few points in which runoff can enter a stream. Additionally, both geology and soil are major influences on runoff and material transport in watersheds. Differing rock types are more conducive to forming steep slopes or solutional features, as well as allowing for formation of different soils. Soil type controls infiltration and to some extent runoff rates (Montgomery, 1999; Ward and Trimble, 2004).

Solids Transport on the Ozarks Plateau

Several studies have been conducted in the James River Basin dealing with nutrient loads (Davis, et al., 1996; James River TMDL, 2001), toxins (Pulley, et al., 1998; Richards and Johnson, 2002), and bacteria levels (Neill, 2004). However, these studies do not address the specifics of suspended and dissolved material transport. Davis et al. (1996), Davis and Bell (1998) and Smith, et al. (2004) do provide some background information on materials transport in the Ozarks.

Davis, et al. (1996) assessed the water quality of the entire Ozarks Plateau region, including portions of Missouri, Kansas, Arkansas, and Oklahoma. This study investigated nutrients, suspended sediments and suspended solids from 1970 to 1990. Data were gathered by several different agencies; consequently constituents were not always analyzed using the same methods, which may have contributed to discrepancies in the data. The results of this study indicated that suspended sediment concentrations in the Springfield Plateau region increased in areas where the land use practices disturbed the soils.

According to the Federal Clean Water Act, Section 303(d) all states must investigate and report the streams that are impaired by pollutants for which there are no pollution controls. The James River and tributaries were classified as impaired by nutrients and mercury from multiple point and nonpoint source pollutants according to the Missouri Department of Natural Resources 303(d) list in 1998 (MoDNR, 2002).In order to create pollution controls, a Total Maximum Daily Load study for the James River was conducted by the Missouri Department of Natural Resources and completed in 2001 (MoDNR, 2001). The purpose of this study was to determine target nutrient concentrations for total nitrogen (transported as part of the dissolved load) and total phosphorus (transported as part of the suspended load) so that nutrient pollution could be reduced to below a specified level that would reduce nuisance algal blooms. The study noted that both point and nonpoint source pollutants have contributed to the degradation of the water quality of several segments of the main stem of James River. Eutrophication and resulting algal blooms have occurred more frequently than in the past as a result of excess nutrients in the river. In conclusion, the target maximum limits set by the TMDL study for the James River were 1.5 mg/L for TN and 0.075 mg/L for TP (MoDNR, 2001).

Richards and Johnson (2002) evaluated water quality trends in Wilson Creek and Pearson Creek (major tributaries of the James River) in Greene County, Missouri. Additionally, water chemistry parameters were measured at each sample site. Results indicated that nutrients, bacteria, trace metals, and a variety of organic pollutants, such as those found in pesticides, were present in baseflow and stormflow water samples in both Wilson and Pearson Creek due to the influence of the urban area of Springfield, Missouri. Similarly, Pulley, et al. (1998) studied the toxicity of water from Wilson Creek. A chronic daphnid bioassay was performed using water collected from Wilson Creek. Water samples were also analyzed for pollutant concentration (metals and organic chemicals). The study found that pollutant concentrations in streamwater from Wilson Creek were high enough to be acutely toxic to *Ceriodaphnia*. The toxic pollutants were thought to be from urban and industrial nonpoint sources located in and around Springfield, Missouri.

Studies conducted in the Ozarks have concluded that land use practices are related to elevated suspended solid concentrations. Additionally, pollutants originating from point and nonpoint sources have degraded the water quality of Ozarks streams. Specifically, major tributaries of the James River have been found to be impaired by pollutants; consequently, these creeks may be delivering pollutants to the James River, causing further degradation of water quality.

CHAPTER 3

STUDY AREA

Location

The Ozarks Plateau physiographic region (Figure 3.1) spans most of southern Missouri as well as parts of Kansas, Oklahoma, and Arkansas (Hughes, 1982; Jacobson, 1995). Sub-regions of the Ozarks Plateau include Salem Plateau, Osage Plains, St. Francois Mountains, Boston Mountains, and Springfield Plateau. Topography of the Ozarks Plateau is generally covered with rolling hills that have slopes ranging from 0-12°. Relief of the Ozarks Plateau ranges from less than 75 meters in the Osage Plains to 300 meters in the Boston Mountains (Jacobson, 1995; Davis and Bell, 1998). The Springfield Plateau sub-region encompasses the entire James River Basin. It has a relief of approximately 150 meters and is underlain with sedimentary rock, most of which is Mississippian-aged limestone. Physical and chemical weathering of this limestone formation has created the rolling hills that are prevalent in the region (Unklesbay and Vineyard, 1992). Additionally, weathering of limestone present in the Ozarks has created many karst features, such as caves, sinkholes, and springs. Presence of karst features has been known to affect the chemical content of surface water and affect transport of suspended and dissolved materials (White, 1988).

Figure 3.1. The Ozarks

Sampling Sites. This study involves water quality monitoring in the upper half of the James River Basin. The James River has a drainage area of 2,556 km², and originates in Webster County and empties into Table Rock Lake near Galena, Missouri. Webster, Greene, Christian, Stone, Barry, and to some extent Lawrence and Douglas Counties are all drained by the James River. Major tributaries include Flat Creek, Finley Creek, Crane Creek, Wilson Creek and Pearson Creek. The study area (Table 3.1, Figure 3.2) consists of five sub-watersheds in the middle and upper area of the James River Basin. Two sampling sites were on the main stem of the James River (Kinser Bridge and Shelvin Rock Bridge) and three sampling sites were on tributaries of the James River (Pearson Creek, Finley Creek and Wilson Creek). Sample sites were selected based on proximity to USGS gage locations. These sites shall be referred to by the following codes: Upper James River – Kinser Bridge (UJ), Middle James River – Shelvin Rock Bridge (MJ), Pearson Creek (P), Finley Creek (F), and Wilson Creek, (W). All of the sub-watersheds are monitored by United States Geological Survey (USGS) continuous discharge gaging station.

Table 3.1. Study Site Information

Site ID	Location	UTM Northing	UTM Easting	Drainage Area (km^2)
F	Finley Creek at Seneca Bridge	4,092,114.741	470,810.641	676
UJ	James R. at Kiser Bridge	4,111,529.732	481,982.022	637
MJ	James R. at Shelvin Rock Bridge	4,095,680.404	467,576.888	1,197
P	Pearson Creek at FR 148	4,114,633.632	482,384.734	54.4
W	Wilson Creek at Scenic Ave.	4,115,662.167	470,591.075	46.1

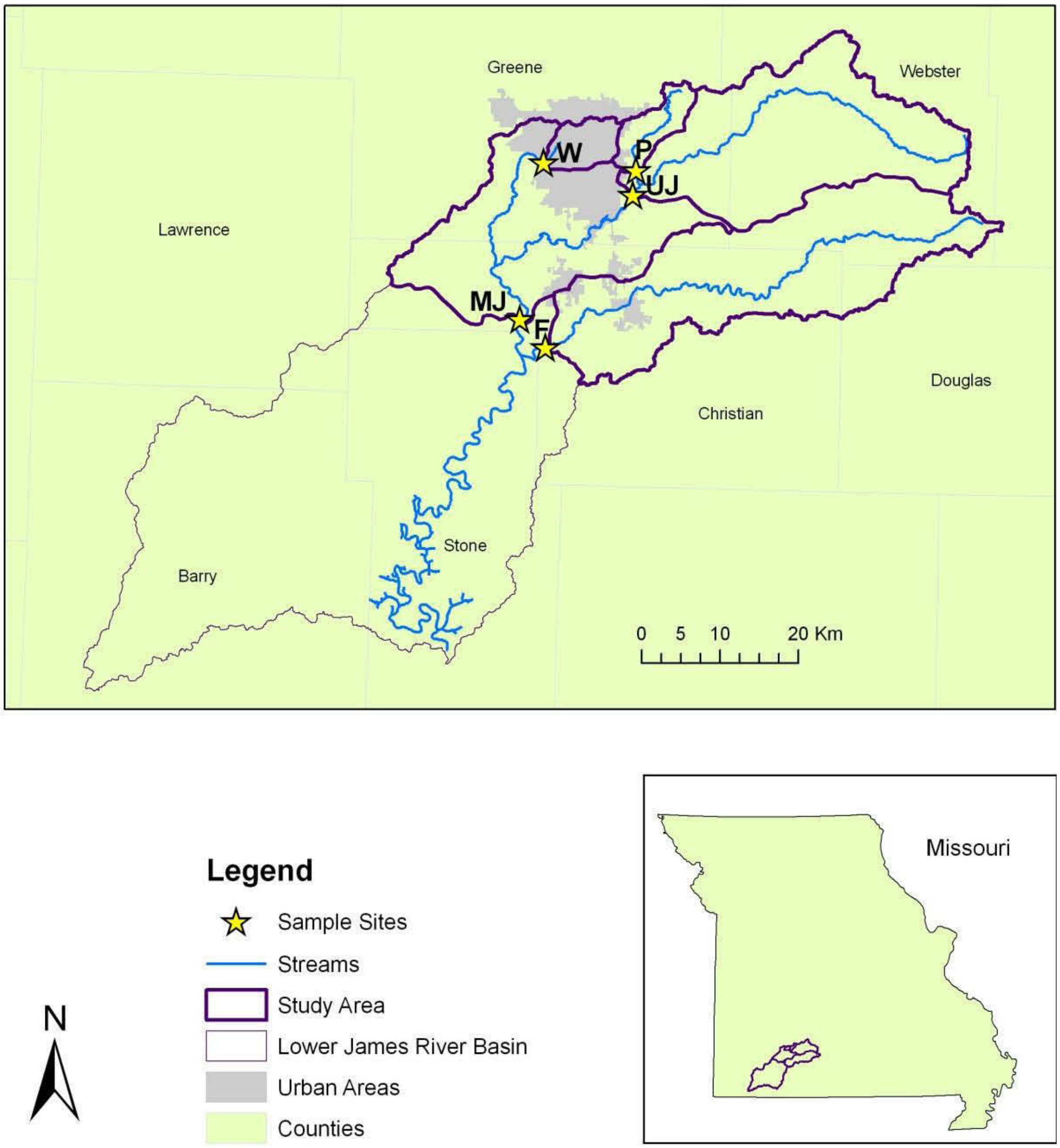


Figure 3.2. Study Area and Sample Site Locations

Geology

The Ozarks Plateau is an uplifted area of dissected limestone. The major geologic unit is the early Mississippian-Kinderhookian Series with the primary rock types being limestone and dolostone; secondary rock type is siltstone (Howe and Koenig, 1961). Many formations of sedimentary rock are found in the Springfield Plateau (Unklesbay and Vineyard, 1992).Most of the rock is Mississippian in age but, rocks of Pennsylvanian and Ordovician age are present in the study area as well (Hughes, 1982).Mississippian-age formations include (from lowest to highest strata) the Compton limestone, Northview shale, Pierson limestone, Elsey limestone, and Burlington-Keokuk limestone. The dominant formation in the study area is the Burlington-Keokuk limestone, which has low chert content and fractures easily, thus forming solution channels (Hughes, 1982). Outcrops of Burlington-Keokuk limestone occur widely in the study area and this rock is quarried to make cement due to its low chert content and high calcium carbonate content (Hughes, 1982). Elsey limestone has the highest chert content of limestones in the study area. Sandstones are found in the younger Pennsylvanian age formations while cherty dolomites and sandstones make up most of the Ordovician age formations (Hughes, 1982).

The limestone formations in the Ozarks exhibit horizontal bedding, which allows for the formation of karst features such as connected cave conduit systems (Dom and Wicks, 2003). Ground and surface water both tend to move through cave conduit systems relatively quickly (White, 2006). Other karst features including springs and sinkholes are prevalent in the Ozarks, as well. Springs provide large quantities of dissolved solids, especially carbonate and bicarbonate ions. Additionally, abrupt changes in pressure at spring outlets cause the release of dissolved CO_2 from groundwater, which can lead to precipitation of calcium carbonate into streamwater (Herman and Lorah, 1987). Portions of some streambeds in the study area are comprised of limestone bedrock (Figure 3.3). Additionally, cherty gravel that has entered streams via hillslope erosion and upstream inputs makes up a large portion of the bedload of streams in the study area (Jacobson, 1995).

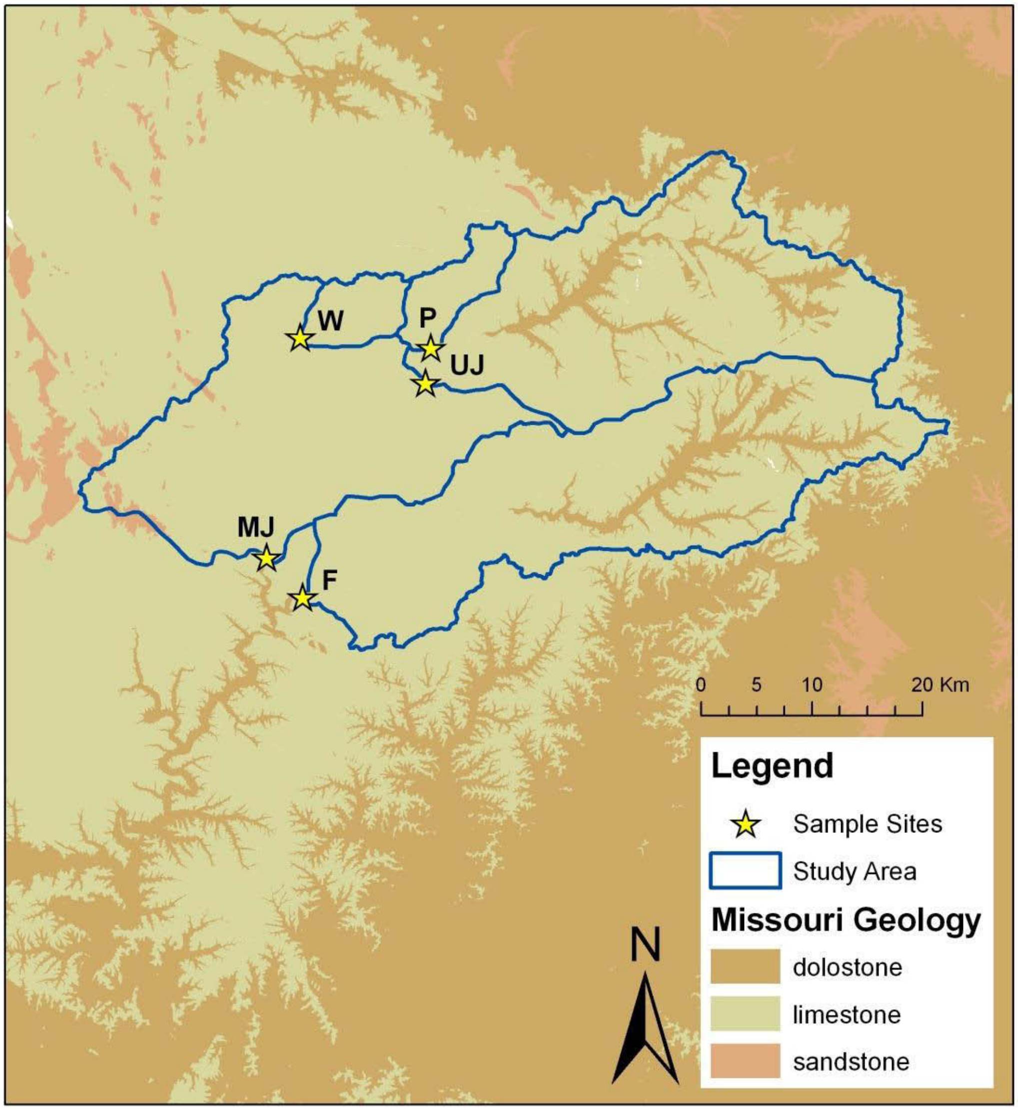


Figure 3.3. Study Area Geology

Karst. Areas such as the Ozarks underlain with soluble rock, usually carbonates such as limestone and dolostone, may contain karst features. Carbonic acid that is formed in water (Eqn. 1) slowly dissolves the carbonate bedrock. As a result sinkholes, springs, caves and underground conduits are formed, all of which are characteristic geologic formations found in karst regions. Sediment from the watershed as well as from weathering may move through underground karst conduits, if the velocity of the water is high enough (White, 1988). In addition, dissolved carbonate from dissolution of carbonate bedload or bed rock in the form of bicarbonate (HCO_3^-) carbonate (CO_3^{2-}) greatly contributes to the dissolved solids load of streams in karst regions (White, 1988).

Springs and sinkholes and other karst features are numerous in the Ozarks. Density (number of features divided by the sub-watershed area) of karst features in each sub-watershed may play a role in transport of suspended materials, but springs especially impact the dissolved load because they supply streams with solute-laden groundwater. Sub-watersheds with a high density of karst features may have higher suspended sediment and dissolved solids concentrations than sub-watersheds that have lower densities. Table 3.2 and figure 3.4 show the number and density (number of features divided by drainage area) of sinkholes and springs in each sub-watershed of the study area (MoDNR GSRAD, 2001a; MoDNR GSRAD, 2010b). The Wilson Creek sub-watershed has the highest density of sinkholes and the Upper James sub-watershed had the lowest density of sinkholes. The Pearson Creek sub-watershed had the highest density of springs, while the Wilson Creek sub-watershed had the lowest density of springs. A major spring cluster is located just upstream from the Pearson Creek sampling site, and according to a dye trace in 1988 outflow from these springs is resurgence water from

Jones and Bonebrake Springs. Several sinkholes located on the East side of Springfield drain directly to Jones and Bonebrake Springs, thus creating a direct conduit of urban pollutants from the East side of Springfield to the Pearson Creek sampling site (Bullard, et al., 2001).

Table 3.2. Density of Karst Features in Study Area Sub-watersheds (from MoDNR GSRAD 2010a and b)

	F	UJ	MJ	P	W	Total (Study Area)
No. Sinkholes	270	68	8,840	18	68	9264
Density	0.40	0.11	0.71	0.33	1.48	
No. Springs	74	104	262	19	12	471
Density	0.11	0.16	0.22	0.35	0.26	

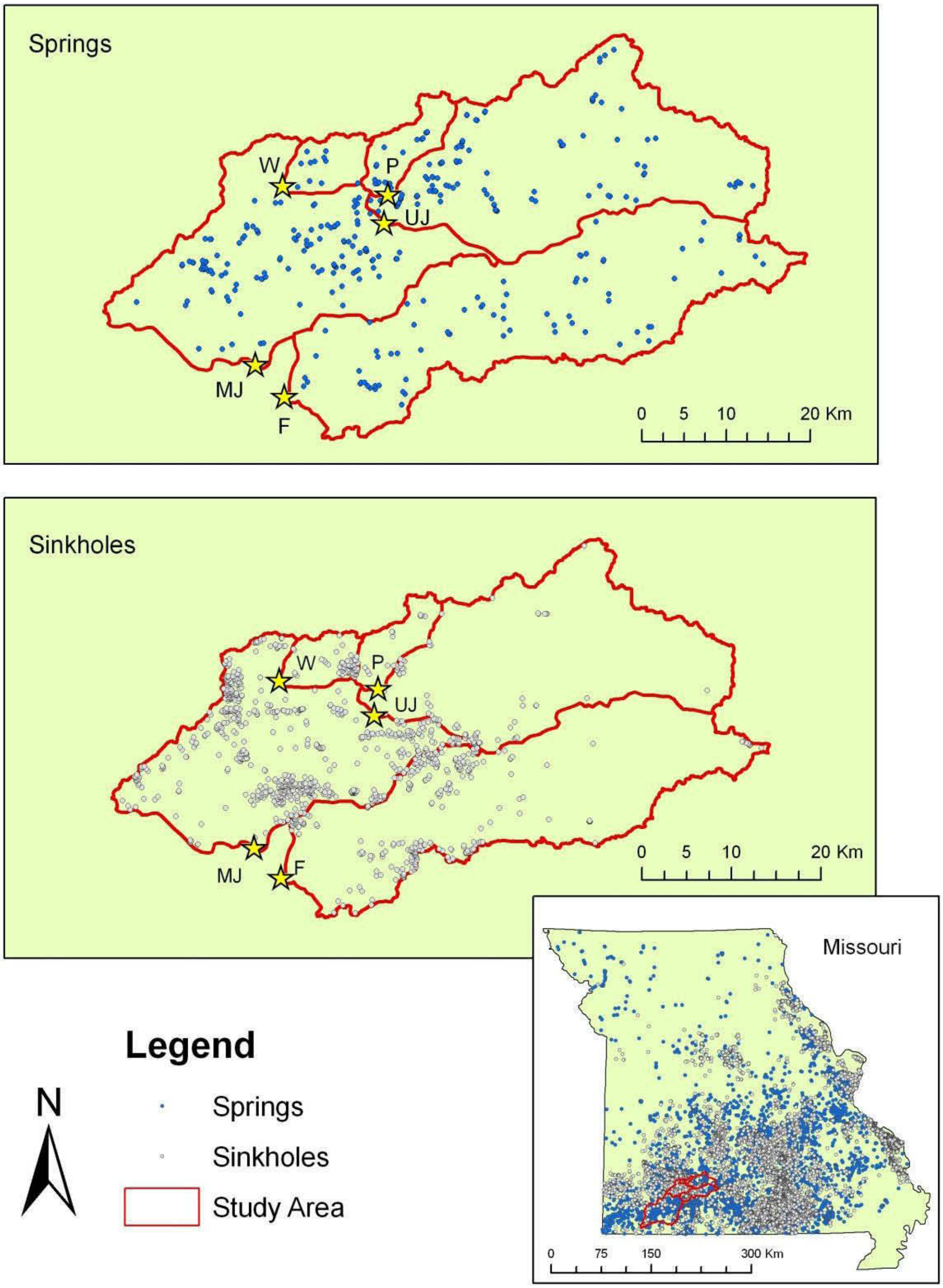


Figure 3.4. Karst Features in the Study Area (source: MoDNR GSRAD)

Soils

Ozark soils are residuum created by weathering of the local limestone bedrock. Due to presence of chert in some formations, cherty residuum may also be present (Davis, 2003). A thin cap of wind-blown glacial sediment (loess) may exist in the soil A and B-horizons if it has not been eroded away by agricultural practices or urban development. Additionally, a dense fragipan is present in some soil series, and can act as a barrier to water and roots. Associations of two or more soil series reflect the slope and topography of immediate surroundings. According to the Natural Resources Conservation Services (NRCS) online soil database (2009) soil associations that occur in the James River Basin include Wilderness-Tonti, Pembroke-Keeno-Eldon-Creldon, Viration-Ocie-Mano, Tonti-Goss-Alsup, Ocie-Moko-Gatewood, and Reuter-Moko-Clarksville. The soil series found in the study area are all part of the Ozark Border soils (Hughes, 1982; NRCS, 2009).

Soil series that are present in the study area are mostly upland soils that occur on low, moderate, and high slopes. The predominant parent material of the soil series in the study area is the underlying cherty residuum or colluvium from limestone or other sedimentary rock. Wilderness, Keeno, Credon and Viration series all have a fragipan present between 18 to 35 inches deep, which can slow infiltration. Most of the soil series are deep or very deep and are moderately to well drained, while Reuter, Moko, and Clarksville series are all somewhat excessively drained (Hughes, 1982; NRCS, 2009).

Erodibility of soil, the factor *K* in the universal soil loss equation, depends upon particle size, water content, chemical composition, organic material content, and most notably texture (Young, 1980; Ward and Trimble, 2004). *K* values close to one mean that a particular soil series is more easily eroded by water (Hughes, 1982). Soils high in organic material content and low in silt content with well developed subsoil structure tend to have lower erodibility, while land use practices, such as row cropping, may increase soil erodibility (EPA, 2003; Ward and Trimble, 2004). Sheet, rill and hillslope erosion are common forms of soil loss in the Ozarks. Loss of soil nutrients and organic matter can also occur through erosion (Pimentel, et al., 1995). The amount of sediments actually delivered to a stream is only a small percentage of soil lost by erosion, even if no erosion control is in place (EPA, 2003).

The expected amount of runoff can also be estimated using the hydrologic soil group classification, which is based on the infiltration rate of a particular soil when it is saturated. Soil series in the study area are either classified as Group B or Group C. Soils in Group B have moderate infiltration rates when saturated and moderate rate of water transmission. Group C soils have a slow rate of infiltration and transmission (Hughes, 1982). Soils with slow rates of infiltration are more conducive to shed runoff rather than allow it to infiltrate. Areas with these soils may have higher rates of runoff than other areas. Table 3.3 shows chemical and physical properties of major soil series in the study area.

Table 3.3. Chemical and Physical Properties of Study Area Soil Series

Soil Name	*K*	% Organic Matter	Hydrologic Soil Group
Pembroke	0.32	2-3	B
Eldon	0.24	0.5-2	B
Wilderness	0.28	0.5-2	C
Creldon	0.37	1-3	C
Needleye	0.37	0.5-2	C
Keeno	0.24	1-3	C
Alsup	0.37	0.5-2	C
Clarksville	0.28	1-2	B
Goss	0.24	1-2	B
Viration	0.43	0.5-2	C

Hydrology

Water moves from the atmosphere to the earth‘s surface and then back to the atmosphere; a process known as the hydrologic cycle. Water collected in the atmosphere is eventually released as some form of precipitation. Upon reaching the Earth‘s surface precipitation will undergo several processes before returning to the atmosphere through evaporation and/or transpiration. Precipitation may infiltrate, or seep into the soil if the soil dry or has not been compacted. Additionally, the precipitation may percolate, or migrate deep into the soil layer, and eventually reach an aquifer and become part of the groundwater supply. If soils are too compacted or saturated to allow for water to permeate the surface, the precipitation will move over the soil surface and down gradient until reaching surface water bodies.

Gaging Stations. United States Geological Survey (USGS) gaging stations are widely used to obtain data about stream discharge and other flow conditions during sampling (Cohn, et al., 1992; Richards and Johnson, 2001). Additionally, these USGS gage sites formed the outlet point of the study sub-watersheds. Real-time discharge from the USGS website was examined after sampling to determine if the samples were collected during baseflow, rising, or recessional (falling) limb of the hydrograph as well as to obtain the instantaneous discharge. Table 3.4 provides information on each gaging station used.

Table 3.4. USGS Gaging Station Information

Site Code	Number	Period of Record	Location
P	07050690	1999–2009	Pearson Creek near Springfield, MO (Greene Co.)
UJ	07050700	1956–2009	James River near Springfield, MO (Greene Co.)
F	07052345	2002–2009	Finley Creek below Riverdale, MO (Christian Co.)
MJ	07052250	1972–2009	James River near Boaz, MO (Christian Co.)
W	07052000	1933–2009	Wilson Creek at Springfield, MO (Greene Co.)

Climate

The climate of the study area varies from season to season. Data from the National Oceanic and Atmospheric Administration (NOAA) show that temperatures are near 0 º C in the winter and range from 7 to 17 º C in the spring. During the summer months, temperatures range from 22 to 25 º C; fall temperatures range from 20 to 7ºC. The highest recorded temperature was 46 º C and the lowest was -32 º C (NOAA).Greene

County and Christian County monthly mean temperature data for 2008 from NOAA web database are plotted in Figure 3.5.

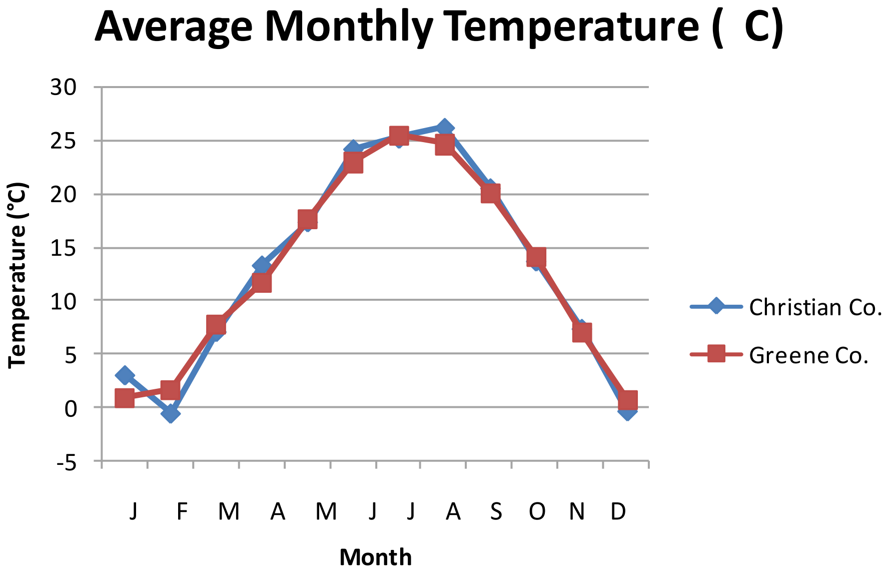


Figure 3.5. Monthly Mean Temperature of the Study Area for 2008

Monthly rainfall totals in the study area also vary from season to season. Data from NOAA shows that during the winter months the monthly rainfall totals range from about 4 cm to about 8 cm. In spring and summer the monthly totals range from 8 cm to 10 cm. In the fall rainfall ranges 10 cm to 9 cm. Lowest monthly precipitation totals occur in January and February, and highest totals occur during the months of May and September. The average annual rainfall is about the same in each of the study area counties. The average annual rainfall in Christian County is 110 cm, and the average annual rainfall in Greene County is 114 cm. Monthly rainfall totals from 1971 to 2000 for Greene County and Christian County are plotted in Figure 3.6.

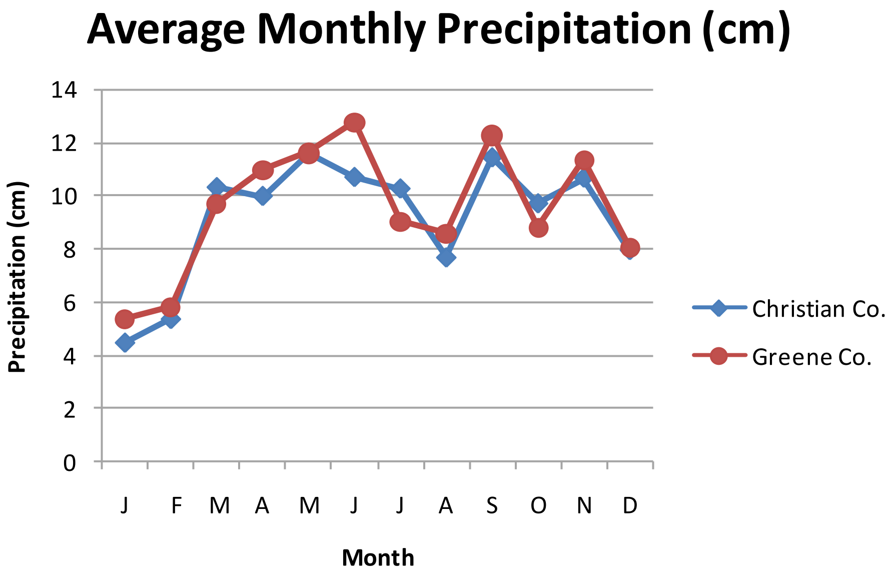


Figure 3.6. Monthly Rainfall Totals of the Study Area for 1971-2000

Land Use

Prior to the early 1800's, Native American tribes used portions of the study area for hunting and fishing. The first European American settlement on the James River occurred in 1818. After the study area was settled by European Americans a large portion of the existing oak/hickory and pine forests were cleared to construct homesteads, make railroad ties and to clear land for farming. Some tall grass prairieland was also cleared to make way for agriculture and urban areas (Rafferty, 1970). Agricultural use of the land in the study area is mostly for grazing purposes; however rowcrops, such as corn, wheat, and soybeans, are occasionally grown (USEPA, 2009).

Springfield, Missouri, the county seat of Greene County, was settled around 1830 and quickly grew into the area's largest city. The 2000 Census found that the population of Springfield was 151,580. The Springfield Metro population is estimated to be around 400,000. The population of nearby Ozark and Nixa in Christian County has increased greatly in the past decade. Many family farms in this county have been sold and converted into subdivisions. As a result, the increase in urban development in these areas has contributed to the loss of forest and agricultural land and an increase in impervious surfaces.

The James River, in addition to two reservoirs, plays an instrumental role in supplying Springfield‘s drinking water. The James River intake at Blackman Water Treatment Plant, just upstream from Kinser Bridge, was implemented in 1980 (Bullard, 2005). The amount of water removed from the James River to supplement Springfield‘s drinking water supply depends upon the discharge of the river as well as the amount of treated water stored at a given time (Bullard, 2005).

The James River also receives treated effluent from the Southwest Wastewater Treatment Plant. The City of Springfield, Missouri constructed the SWWWTP in 1959. The facility treats an average of 39 million gallons of wastewater per day. Once treated, the effluent is discharged into Wilson Creek approximately seven miles upstream from the confluence of the James River. Other municipalities, e.g. Ozark, Nixa, and Fremont Hills, and industries have permits to discharge wastewater into the James River and its tributaries as well. Some dams and small low water impoundments have also been constructed on the James River and some tributaries. Most notable of these in the study area is the dam at the Springfield City Utilities coal-fired power plant that creates 1.3 km^2 Lake Springfield (MDC, 2010).

Urban Gradient. Percentage of urban land use (high and low density combined) varies among the sample sites for this study (Figure 3.7). Table 3.5 shows percentages of different land uses in each sub-watershed. Sub-watersheds are ranked in order of lowest percent urban area to highest percent urban area. Upper James and Finley sub-watersheds are both about 5% urban, while the Wilson sub-watershed, located entirely within the Springfield, Missouri city limits, is almost 90% urban in land use. The middle ranked sub-watersheds, Middle James and Pearson, both have about 20% urban area. Constituent mean annual yields of each sub-watershed can be compared along this urban gradient to demonstrate differences between urban and non-urban sub-watersheds.

Sewage treatment plants (STP) for area municipalities discharge effluent into many tributaries of the James River. Finley Creek receives STP effluent from the City of Ozark and Nixa (via a tributary). The SWWWTP discharges effluent into Wilson Creek downstream of the sample site for that creek. However, because Wilson Creek enters the James River upstream of the Middle James sample site the effluent from the SWWWTP may also affect the water quality at the Middle James site.

Table 3.5. Land Use Percentages by Sub-watershed

% Land Use Type	UJ	F	MJ	P	W
Urban	4	5	17	19	86
Forest	34	30	24	14	3
Agriculture	59	62	55	66	8
Other	3	3	6	1	3
Urban/Forest Ratio	0.12	0.17	0.71	1.4	29
Receives Effluent	No	Yes	Yes	No	No

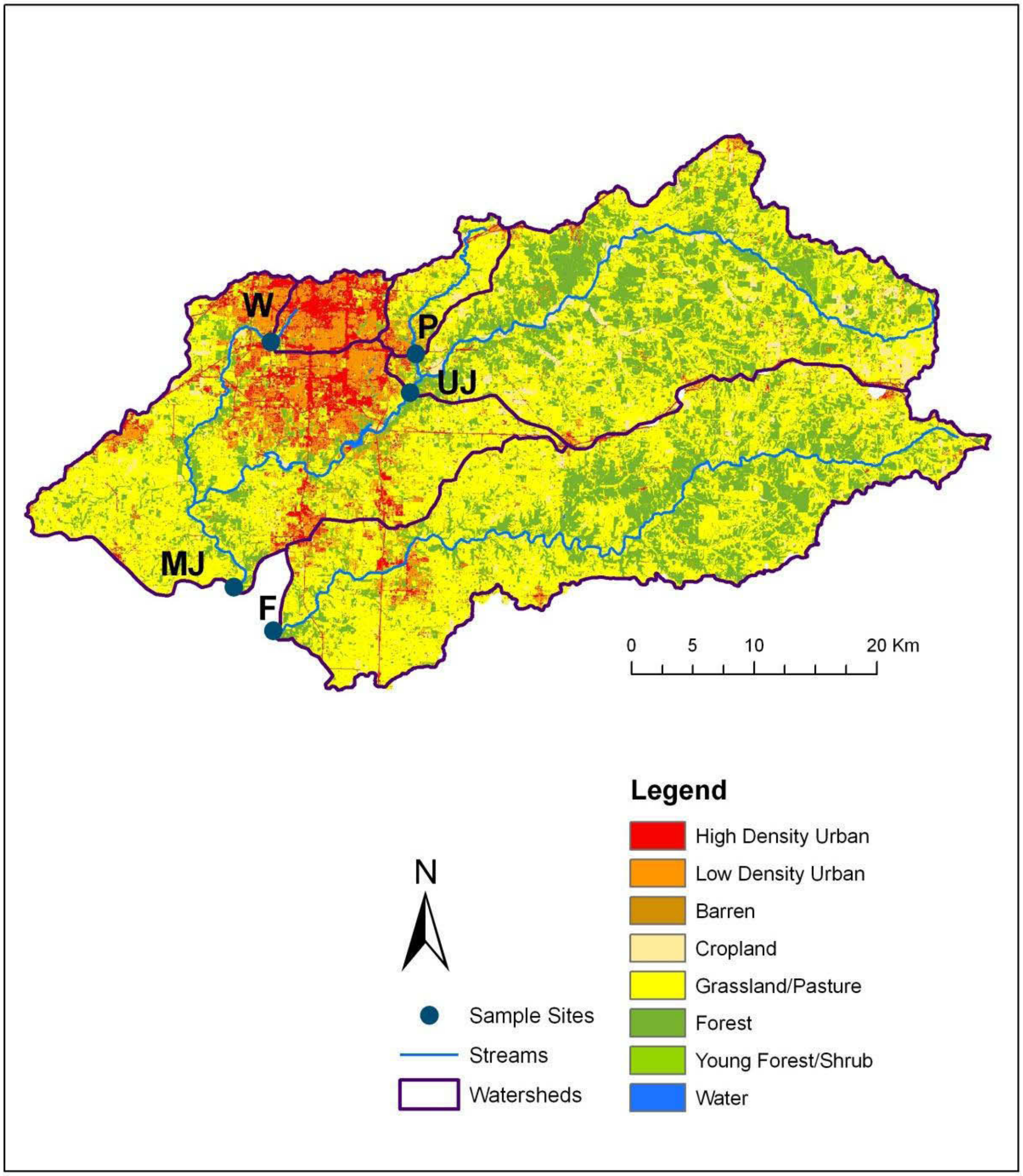


Figure 3.7. Study Area Land Use

CHAPTER 4

METHODOLOGY

Field Methods

Field collection methods for this study involved collecting water samples at two-week intervals during baseflow and during storm events. Storm event sampling occurred when there was enough runoff from precipitation to cause a spike in the hydrograph. No more than four storm events per month were sampled. Additionally, the following water chemistry parameters were recorded *in-situ* using a Eureka Amphibian Manta multiprobe during each sampling session: temperature, specific conductivity, pH, turbidity, and dissolved oxygen.

Baseflow and Stormflow. Many methods have been developed to collect suspended sediment and dissolved solid samples from streams. Collecting samples during both baseflow at fixed-intervals and storm flow events is desirable because runoff from storm events tends to bring in heavier loads of sediment (Edwards and Glysson, 1988; Thomas, 1988; Thomas, 1991). In addition, sampling bias may occur if water samples are taken only at fixed-intervals. Targeting sample collection during storm events can help to alleviate sampling bias (Thomas, 1991). For the purposes of this project baseflow sampling occurred when rain had not fallen in the study area for several days and the hydrograph had dropped down near the median daily statistic provided by the USGS. Stormflow sampling occurred when rain began to fall in the study area and the hydrograph had started to rise. Rising and falling limb were determined by plotting the time the sample was taken on the USGS 15-minute discharge data.

Depth-integrated Sampling. Water samples for this study were collected using a US DH-48 depth-integrated sampler (Figure 4.1). This method allows water from the entire water column to be collected in equal volumes regardless of the particular velocity at different points in the water column. Traditionally grab sampling (dipping a bottle into the stream near the surface) was used to get water samples from streams, however, this method has been found to under-represent suspended solids concentrations because a sample of the entire water column is not collected (Martin, et al., 1992).

Depth-integrated sampling involved inserting a 500 ml plastic bottle into the sampler and then lowering the sampler off the bridge using a long strap tied securely to the handle of the sampler (Figure 4.2). Samples were taken from the thalweg. The sampler was allowed to sink slowly to the streambed in one motion to fill the sample bottle. If the sample bottle did not fill in one motion the sampler was raised and lowered slowly until full. The bottle was removed and placed on ice in a cooler until arrival at the laboratory.

Figure 4.1. US DH-48 depth-integrated sampler

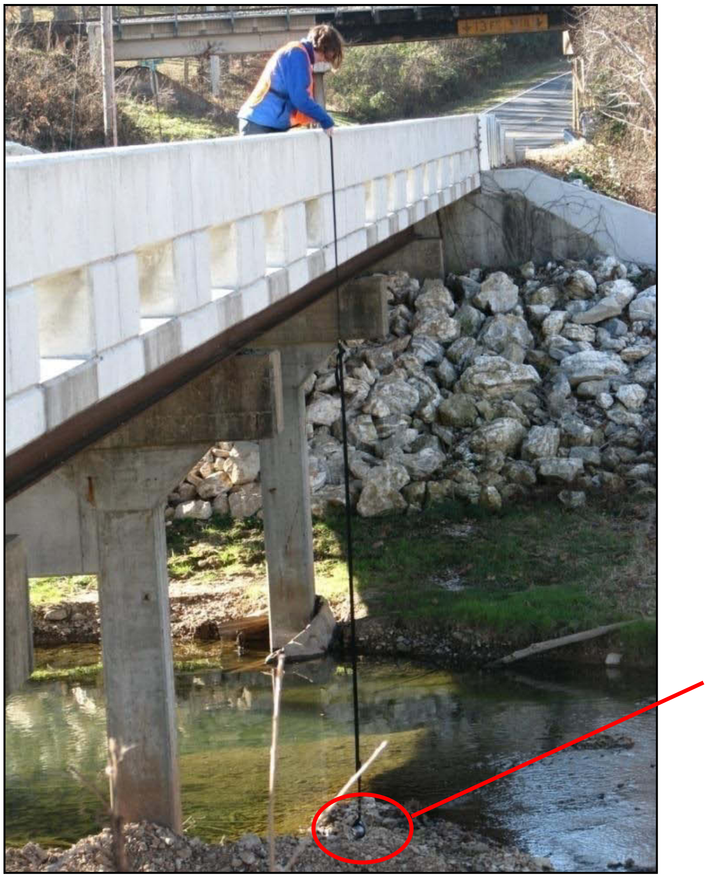


Figure 4.2.Sampling at Pearson Creek

Quality Control. A duplicate sample (field duplicate) was taken at one site each sampling event and analyzed in the same manner as the other samples. The field duplicate served as a measure of the precision of field collection methods and analysis techniques. Similarly, a field blank of high performance liquid chromatography (HPLC) water was taken in the field. The field blank was treated and analyzed in the same manner as the other samples and was used to determine if any contamination occurred during collection or transporting samples (Gray, 2000).In addition, one site per sampling event was sampled using a cross-channel triplicate method for additional quality control and error determination. The stream channel was divided into thirds, taking into account bridge supports and a sample was taken from the middle of each third. Sites were rotated for triplicate samples from sample event to sample event. These samples were analyzed in the same manner as other samples. The average of the triplicate sample concentrations was used to check for the degree of mixing of water from various sources across the channel. Laboratory duplicates, laboratory blanks, and standard duplicates were also analyzed to measure instrument drift and for error determination.

Laboratory Methods

Once all samples were collected they were taken back to the laboratory and analyzed immediately according to Ozark Environmental and Water Resources Institute (OEWRI) Standard Operating Procedures (SOP), which have been approved by the USEPA (Standard Methods, 2005).Accuracy, precision, bias and sensitivity of each method are reported in Table 4.1.A flow chart (Figure 4.3)

TDS and TSS Analysis.200 ml of the 500ml water sample was filtered through a 1.5 µm Whatman nominal pore size glass microfiber filter and then filtered through a 0.45 µm Millipore nominal pore size glass microfiber filter. 100 ml of the filtrate was reserved for total dissolved solids (TDS) determination (a mass differential of a known volume of filtrate heated at 180 ºC). The 1.5 µm filter was heated at 104 ºC for one hour. A mass differential of the filter gave the concentration of TSS in mg/L. It should be noted that mid-way through the study the 0.45 µm filters were saved and mass differential for these filters was performed in the same manner as the 1.5 µm filters to find out the percentage of solids that were in the <1.5 µm to >0.45 µm size fraction, called fine suspended solids (FSS). However, only the data from the 1.5 µm filters were used to calculate TSS instantaneous concentration. Additionally, filtrate that had passed through both the 1.5µm and 0.45µm filters was used for dissolved carbon and anion analyses as outlined in the National Field Manual for the Collection of Water-Quality Data (USGS, 2002).

Table 4.1. Measurement Performance Criteria

Parameter	SOP	Data Quality Indicator	Measurement Performance Criteria	QC Sample Type
TDS	TDSolids	Accuracy	± 20%	LB[1]
		Bias	± 20%	LB
		Precision	± 20% RPD[5]	LD[2]
		Sensitivity	≤ 0.1 mg/L	MDL[3], LRB[4]
TSS	TSSolids	Accuracy	± 20%	LB
		Bias	± 20%	LB
		Precision	± 20% RPD	LD
		Sensitivity	≤ 0.5 mg/L	MDL, LRB
TN	3020R02 Total N	Accuracy	± 20%	LB
		Bias	± 20%	LB
		Precision	± 20% RPD	LD
		Sensitivity	≤ 0.1 mg/L	MDL, LRB
TP	3010R02 Total P	Accuracy	± 20%	LB
		Bias	± 20%	LB
		Precision	± 20% RPD	LD
		Sensitivity	≤ 0.005 mg/L	MDL, LRB
TIC/TOC DIC/DOC	TICTOC-R01	Accuracy	± 20%	LB
		Bias	± 20%	LB
		Precision	± 20% RPD	LD
		Sensitivity	≤ 0.5 mg/L (all forms)	MDL, LRB
All Anions	IC R01	Accuracy	± 20%	LB
		Bias	± 20%	LB
		Precision	± 20% RPD	LD
		Sensitivity	≤ 0.03; 0.2 (SO_4) mg/L	MDL, LRB

1) Laboratory Blank 2) Laboratory Duplicate 3) Method Detection Limit 4) Laboratory Reagent Blank 5) Relative Percent Difference

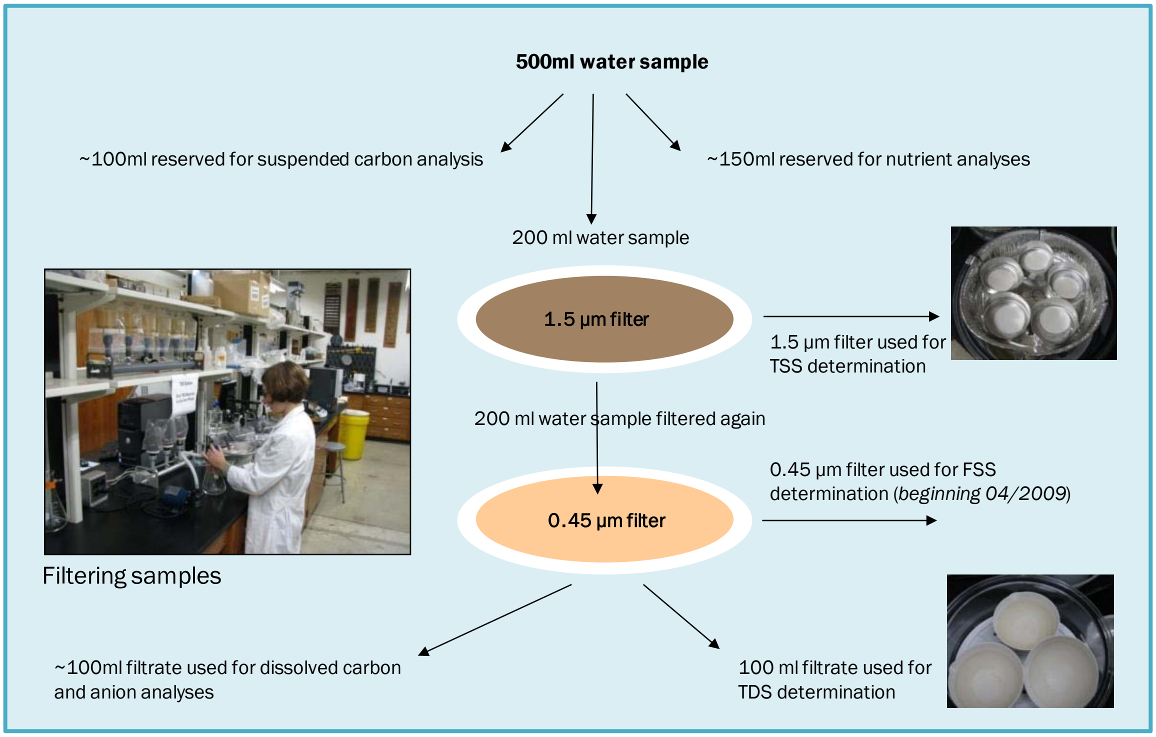


Figure 4.3. Flowchart of Laboratory Analysis

Carbon Analysis. Inorganic and organic carbon in both total carbon (unfiltered sample) and dissolved carbon (filtered sample) form were analyzed using a liquiTOCII High Temperature TOC/TN_b analyzer. A monthly calibration standard was made using 1062.7 mg potassium hydrogen phthalate and 4412.1 mg sodium carbonate dissolved in one liter HPLC water. The instrument was calibrated using a daily standard solution prepared from 12.5 ml of monthly standard diluted with 250 ml HPLC water before each sample analysis run. Unfiltered samples along with two standard checks, two blank checks and two different laboratory duplicates were analyzed. Dissolved samples, which were first filtered through a 0.45 µm micropore filter, were analyzed in the same manner as the unfiltered samples. Once loaded in the autosampler carousel, a lid was placed over the samples before the analysis began to prevent contamination.

A dosing syringe delivered the sample to the combustion system and the sample was heated to 70 ºC to purge the sample of volatile CO_2 gas. The organic carbon remaining in the sample after purging the sample of volatile organic carbon is referred to as non-purgeable organic carbon (NPOC), and provided a measure of the amount of organic carbon in the sample. The inorganic carbon in the sample was digested with 0.8% hydrochloric acid. The sample underwent a dynamic combustion at 850 ºC and catalytic post combustion at a maximum temperature of 800 ºC. Synthetic air from a zero-air generator transferred the CO_2 gas through a three-step drying process and then to the detector for measurement. The detector measured the amount of inorganic carbon concentration in each water sample as total inorganic carbon (TIC) and amount of organic carbon as NPOC (but called TOC to avoid confusion) in each sample in mg/L (liquiTOCII Operating Instructions, 2006). The TIC concentration from the filtered water samples were called dissolved inorganic carbon (DIC) and TOC concentration from the filtered samples was called dissolved organic carbon (DOC) because any suspended carbon in the sample had been removed during filtration.

Anion Analysis. Anions, including fluoride (F^-), chloride (Cl^-), sulfate (SO_4^{2-}), and nitrate (NO_3^-), were measured using a Dionex ICS-1000 Ion Chromatography System (ICS) with IonPac AS14A exchange column according to Standard Methods for the Examination of Water and Waste Water Method 4110B. The first sample cassette in the autosampler was loaded with three dilutions of factory-made standard solution and laboratory reagent blanks (LRB), which created the calibration curve. The remaining sample cassettes were loaded with streamwater samples that had already been filtered through 0.45 um filters (see TDS Analysis). Another set of LRBs, and a standard check, which was used to evaluate instrument drift, followed the sample set. All samples, LRBs, and standard checks were analyzed in the same manner by the ICS.

The analytical batch was delivered to the ICS via an autosampler. Samples were deposited into a stream of sodium carbonate and sodium bicarbonate eluent solution, which helped to transport and separate ions. The sample and eluent were pumped through the guard and separator columns that separate the ions. Migration of different ions through the separator column occurs at various rates, thus separating the ions. The sample and eluent then passed through the suppressor. Here, ion detection is selectively enhanced and the eluent conductivity is suppressed. Next, the conductivity cell measured the electrical conductance of ions in the sample as they emerged from the suppressor and produced a signal based on a chemical or physical property of the analyte. The conductivity cell transmitted this signal to a computer. The Chromeleon software identified each anion based on retention time, and also calculated concentration of each anion (ICS-1000 Operating Manual, 2005). These data were exported as an Excel file.

Nutrient Analysis. Total nitrogen (TN) and total phosphorus (TP) were measured using the USEPA standard methods (USEPA 1983, 1987). Unfiltered sample water was preserved with $H_2SO_4$to pH < 2 (~ 5ml) and refrigerated until the nutrient analyses could be performed (up to 28 days) (3010R02 Total P, 2006 and 3020R02 Total N, 2007).

Total nitrogen is a measure of all species of nitrogen present in each water sample (e.g. nitrate, nitrite, organic nitrogen). Concentration of TN was measured using the second-derivative spectroscopic method. The spectrophotometer was first calibrated to ensure proper readings and results. Digested samples were then analyzed using the calibrated spectrophotometer. A laboratory control check, reagent blank, matrix spike, laboratory duplicate and field duplicate were also analyzed after every 12 samples were analyzed to measure instrument drift. Software displayed TN concentration in ppm (mg/L) (3020R02 Total N, 2007).

Total phosphorus is a measure of all phosphorus species present in each water sample, such as, orthophosphate and organic phosphorus. Concentration of TP was measured using the ascorbic acid reduction phosphomolybdate method (Eaton et al., 1995).Samples were analyzed using a spectrophotometer. Absorbance readings were recorded and entered into an Excel spreadsheet to calculate TP concentrations in mg/L using a calibration curve (3010R02 Total P, 2006).

Load and Yield Calculations

Load duration curve. Different methods of statistical analysis have been used to estimate suspended and dissolved loads. Thomas, et al. (2004) used a two-way ANOVA to differentiate among constituent concentrations from different stream reaches and between storm and base-flow. Linear regression was used to compare loads from different reaches in Wolman (1967). Rating-curve methods have been widely used to calculate loads and yields of water quality constituents (Walling and Webb, 1982; Crawford, 1996).

The flow-duration rating-curve (FDRC) method is beneficial because only a relatively small number of constituent concentration measurements are needed to give an estimate of the mean constituent load. It should be noted that a long period of record (>30 years is ideal) for discharge measurements is needed to obtain a good estimate of the mean annual load (Crawford, 1996; Wilson, 2005). However, the FDRC is not without its problems. For instance, the FDRC may underestimate loads (Walling, 1977; Crawford, 1996). Variability of stream conditions, data collection, and analytical methods may also contribute to error (Crawford, 1996).

Least squares linear regression was used to estimate the parameters of the rating curve. Additionally, every effort must be made during sample collection to ensure the sample data being used is a good representation of the population (the actual load of the stream).

There are five steps in the flow-duration rating-curve method:

1) Calculate instantaneous load, and plot against instantaneous discharge using $\log_{10}$ scale;
2) Fit a curve to the plot from step one, and obtain a trendline equation using linear regression;
3) Create a flow exceedence probability curve to get 100 discharge bins, and calculate frequency of each bin in a year;
4) Calculate average loads for each bin and bin frequency to get mean annual load;
5) Calculate mean annual yield from mean annual load.

The instantaneous load was calculated using the following equation:

$$L_a = C*Q*c_t \tag{4}$$

Where:

L_a = Daily load (kg/day)

C = concentration (mg/L)

Q = Instantaneous discharge (from USGS gages)

c_t = mass/time/volume conversion constant (86.4)

These log daily loads were then plotted against the log instantaneous discharge to create a load rating curve with a trendline equation in the form:

$$L_e = b_0 * Q^{b1} \tag{5}$$

Where:

L_e= Estimated load

b_0=Y-intercept

Q = discharge

b1= slope of the line

The rating curve came from the regression trendline equation. The slope of the line indicates the correlation of discharge to constituent concentration. Positive correlations have a positive slope and negative correlations have negative slopes. Error not explained by the equation (residuals) should also be taken into account. Standard error is a measure of the standard deviation of the residuals and can be used to predict the accuracy of the equation. The R^2 value is also displayed along with the trendline equation and can be understood as the percentage of variability in the *y* variable that is explained by *x* (Rogerson, 2006).

A flow exceedence probability curve (cumulative flow exceedence curve) was created by placing flow exceedences (1-100%) into 100 bins of 1% increments. The geometric mean value was calculated for each of the 100 bins. From these values the bin frequency was determined. The flow probability curve is used to predict the load for each bin. From this information the probable annual load can be determined.

$L_b = (L_{pQ} + L_{pQ}- 1) / 2$ (6)

Where:

L_b = Average load for bin

L_{pQ} = Upper limit of bin

L_{pQ}-1 = Lower limit of bin

The mean annual load (Mg/yr), L_m, is calculated by averaging all of the means of each bin and then multiplying by 365 days. This amount is divided by 1000 to obtain the Mg/yr unit.

$L_m = \{[(L_{b1} + \ldots + L_{b100})/100]*365\}/1000$ (7)

The mean annual yield is the ratio of the mean annual load to sub-watershed drainage area (A_d). It is calculated by dividing the mean annual load by the drainage area to get a value with the unit Mg/km^2/year.

Error is reported as the mean, standard deviation and coefficient of variation. Sampling error deals with differences among cross-channel triplicate samples that were taken at one site per sampling session. Field method error is reported as differences between a sample and a field duplicate sample. Finally, laboratory instrument error is reported as differences between a sample and a laboratory duplicate. Error data is used to determine the accuracy and precision of methods used in this study.

Statistical Significance

Slope, trendline scatter, and R^2 values are all indicators of how well the dependent variable (constituent concentration or load) is influenced by the independent variable (discharge) (Rogerson, 2006). Slope may be either positive, negative, or zero. A high positive slope value indicates that constituent concentration increases greatly with discharge, while a high negative value indicates that constituent concentration decreases greatly with discharge. A slope close to zero indicates discharge does not affect constituent concentration or load. Although a statistical measure of the residuals is not discussed, a visual inspection of the distance from data points to the trendline (scatter) can give a general idea of the strength of the relationship between independent and dependent variables (Rogerson, 2006). A lot of scatter about the trendline is an indicator that constituent concentration or load is not as closely related to discharge, while little scatter indicates a close relationship between concentration or load and discharge. Likewise, a low R^2 value (R^2 may be thought of as a percent of variance explained by the regression equation) indicates that little of the variation in concentration can be explained by variations in discharge. A high R^2 value means that changes in discharge accurately reflect changes in concentration.

Statistical significance of the regression analyses was determined using Excel Data Analysis Tools. The $\log_{10}$ of each instantaneous concentration and associated discharge value had to be calculated before data sets were entered into the Regression Tool because a power function was used to determine the rating curves. Standard error (e.g. standard error of the regression), F statistic (F stat), Significance F (Sig. F), and the 95% confidence intervals were all obtained from the output. The standard error is a measure of the amount of variability in the points scattered about the trendline. A low number for the standard error generally means that there is a low amount of variability. The F stat gives the results of the F test of the null hypothesis and the Sig. F is the p-value associated with the F stat. If the Sig. F value is $> \alpha$ ($\alpha = 0.05$) then the null hypothesis is not rejected. However, if the Sig. F value is $\leq \alpha$, then the null hypothesis is rejected (Rogerson, 2006). The 95% confidence interval is the range in which 95% of the instantaneous constituent concentrations fall; this information is supplied in Appendix B.

Hysteresis Influence

Regression plots were created in order to determine when constituent inputs and dilution occurred in relation to hydrograph limb. A hydrograph of the entire study period was plotted using 15-minute discharge data provided by USGS for each sample site. Each sample point was then plotted on the hydrograph and examined to determine if the sample point fell on the rising or falling limb of the hydrograph, or during baseflow. Each sample site had a different number of rising, falling, and baseflow samples due to differences in storm movement through each sub-watershed. Regression plots were created for each sample site for baseflow, rising limb, and falling limb using the instantaneous constituent concentration and discharge measurement during sample collection. A trendline was fit and the resulting equation, R^2 value, and amount of scatter were examined to determine which part of the hydrograph had the most influence on constituent inputs and dilution.

CHAPTER 5

RESULTS AND DISCUSSION

This chapter includes results and discussion of sampling period hydrology, daily discharge trends, and an analysis of the flow-duration rating-curve. Water quality concentrations are compared among the five sub-watersheds as well as the effects of hydrograph timing, discharge, and season on concentrations. In order to validate sampling and analytical competence, selected data are compared to long term data collected by the USGS.

The second part of this chapter provides information on calculated loads and yields of dissolved and suspended constituents. Additionally, influence of land use on constituent load is examined. Finally, watershed sources of constituents are discussed and calculated yields in this study are compared to yields estimated in regions with differing climates, elevation, slope, and land use.

Study Period Hydrology

Gage Record. Mean annual flow, minimum flow, maximum flow, as well as 10%, 50%, and 90% flow exceedence probability (FEP) for the entire period of record of each sample site were obtained from USGS Water-Data Reports (USGS, 2009). The long-term discharge records were compared to the discharge during the study period (Table 5.1). Also presented in Table 5.1 are the same parameters as determined from the study period 15 minute discharge data and from the instantaneous discharge data taken during each sampling session. Higher maximum flows occur during the period of record, which is expected because longer periods of record have more extreme flow measurements. The period of record annual mean was higher than that of the study period. Similarly, minimum flows during the study period were also somewhat higher than the period of record minimum flows. Maximum flows during the study period were generally much lower than the period of record maximum flows.

A similar pattern is seen between instantaneous discharge and study period discharge. The ten percent flow exceedence has the most difference among period of record, study period discharge, and instantaneous discharge. Upper James, Middle James, and Finley all have higher annual mean flow during the entire period of record compared to during the study period and instantaneous discharge. Pearson and Wilson had similar annual mean flow for period of record, study period, and instantaneous discharge, which may indicate that there is a higher degree of variability.

When discharge data were examined, sample sites with similar drainage areas have similar discharge. For instance, discharge at the Upper James and Finley Creek sites is similar for all flow types. The only major difference is that during the study period a higher maximum flow was measured at the Upper James site than at the Finley site (268 m^3/s vs. $88m^3/s$). Likewise, discharge at the Pearson Creek and Wilson Creek sites is similar, except maximum flow is higher at Wilson Creek. Overall, Pearson Creek and Wilson Creek have lower discharges for all flow types than the Upper James and Finley Creek due to their much smaller drainage areas. The Middle James site has the largest drainage area and consequently has the highest discharge for all flow types.

Table 5.1. Sample Site Gage Record (Discharge in m^3/s)

Site	Years	Annual Mean	Minimum Flow	10% exceeds	50 % exceeds	90 % exceeds	Maximum Flow
UJ	53	15.9*	0.1	22.4	3.3	0.5	1,164
	1	6.4**	0.4	13.3	2.6	0.9	268
	1	6.6***	0.2	18.1	2.4	0.7	54.9
F	7	15.3	0.2	27.3	4.6	1.0	1,048
	1	6.2	0.8	16.8	2.9	1.4	88
	1	6.3	0.9	14.7	3.0	1.4	58.4
MJ	37	31.1	0.8	58.6	12.2	2.5	1,186
	1	12.7	2.5	33.4	6.9	3.4	247
	1	16.6	3.2	39.3	8.0	3.3	143
P	10	1.7	0.04	3.7	0.8	0.1	84
	1	0.8	0.10	2.0	0.5	0.2	62
	1	1.2	0.14	1.7	0.5	0.2	13.2
W	76	1.1	0.01	1.6	0.3	0.08	191
	1	0.6	0.04	1.1	0.2	0.09	109
	1	1.7	0.05	1.8	0.3	0.10	10.6

* Period of Record; ** Study Period; *** Instantaneous Discharge

Discharge Trends. Hydrographs for each sample site were constructed using 15-minute discharge data for the entire study period supplied by the USGS (Figures 5.1a-e). Instantaneous discharge was noted on the hydrographs as orange squares. The site with the flashiest hydrograph was Wilson Creek, which is the sub-watershed with the highest percentage of urban area. Due to the comparatively flashy nature of Wilson Creek, it was difficult to collect samples during the rising limb because the hydrograph would peak very quickly compared to the other sites leaving only a short window for sampling. Despite having the largest drainage area and highest mean annual discharge, the Middle James site also had a relatively flashy hydrograph, though not as flashy as Wilson Creek. The Upper James and Pearson Creek hydrographs both had some normal and flashy peaks. Finley Creek hydrograph peaks were more sluggish, meaning high discharges were spread out over a longer period of time, than all other study period hydrographs.

All study period hydrographs showed that the highest discharge occurred during late spring, however, lowest discharge occurred during different seasons among the sample sites. The lowest discharge occurred during the late fall and summer months in the Upper James River and Pearson Creek and summer for Finley Creek, Wilson Creek, and Middle James River.

Number of peaks in the hydrographs varied for each study site, as well. The most peaks in the hydrograph occurred during the summer at the Upper James, Middle James, Pearson, and Finley study sites. The most peaks in the Wilson Creek hydrograph occurred during the spring. The least number of runoff events occurred during the winter for all study site hydrographs.

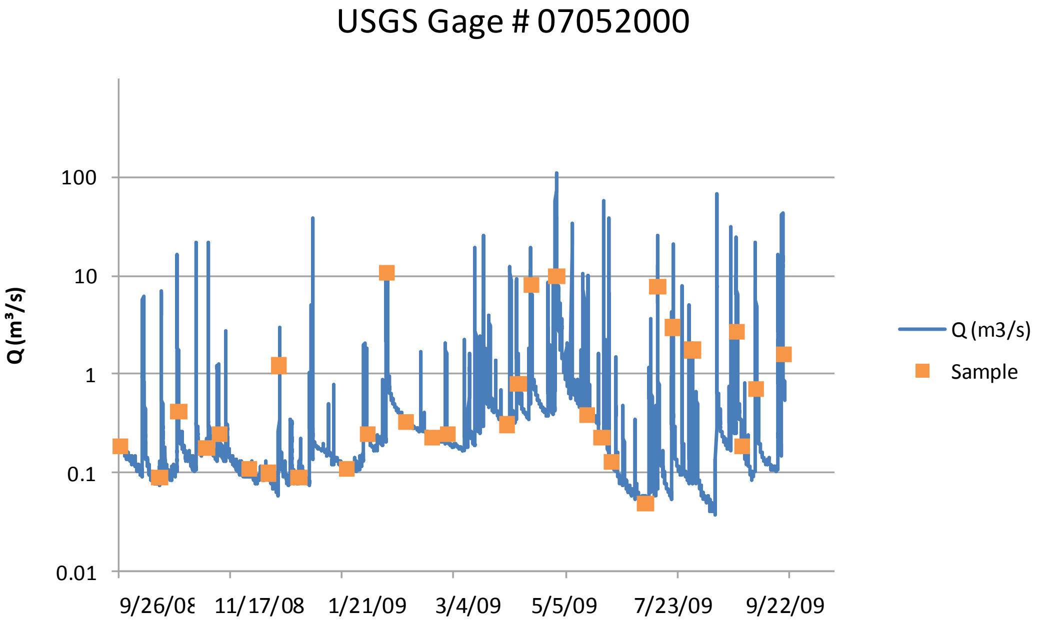


Figure 5.1a. Wilson Creek Study Period Discharge (every 15 minutes)

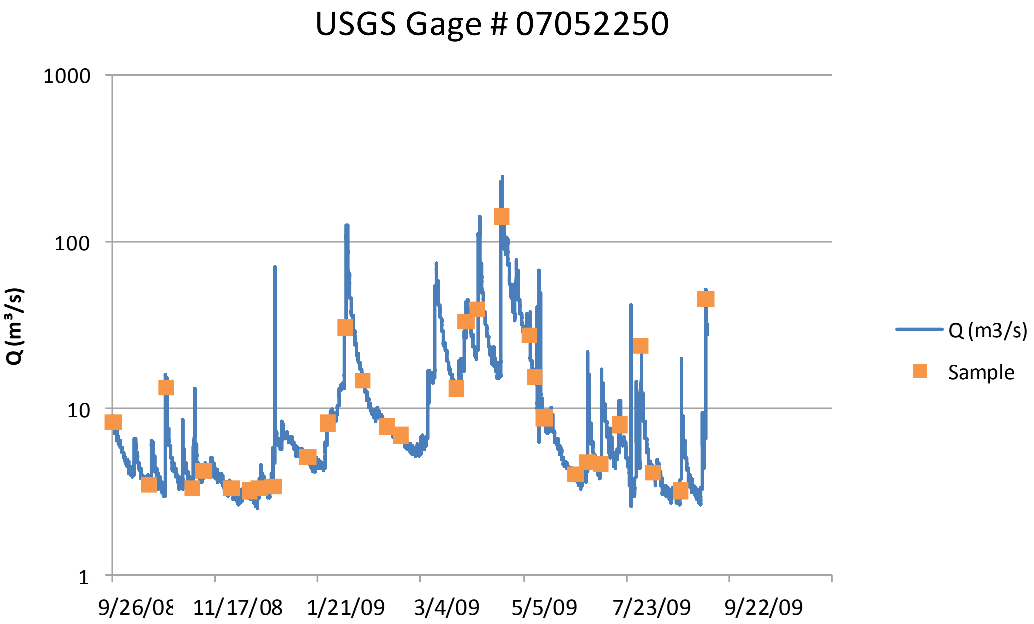


Figure 5.1b. Middle James Study Period Discharge (every 15 minutes)

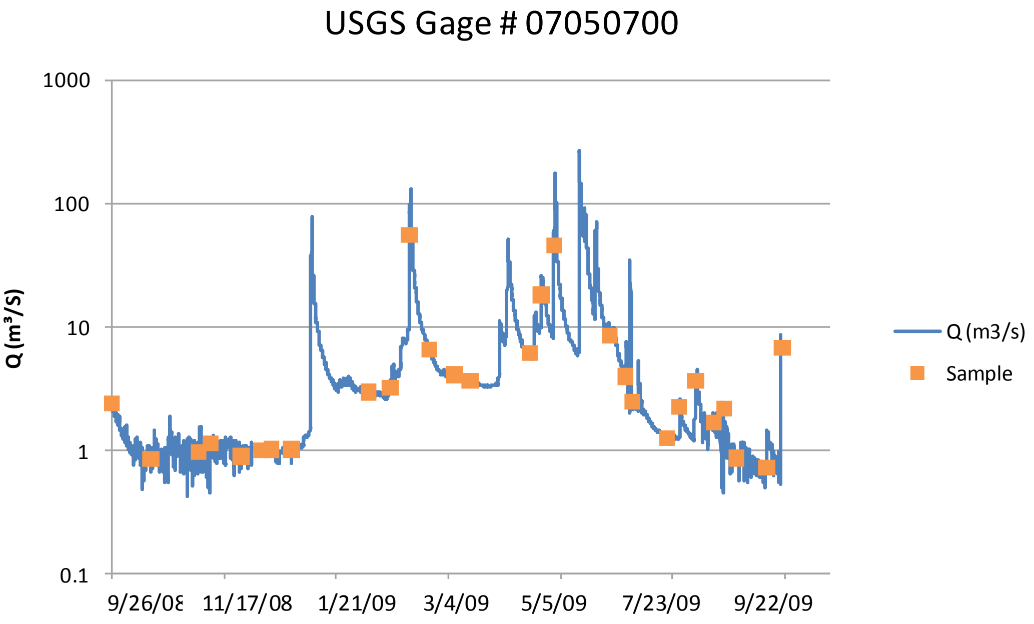


Figure 5.1c. Upper James Study Period Discharge (every 15 minutes)

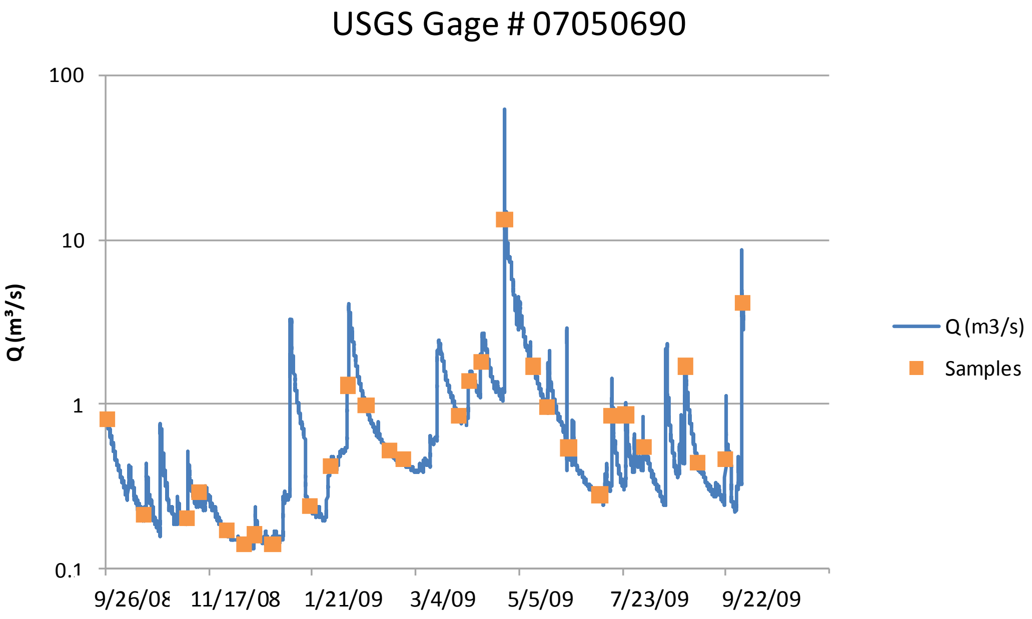


Figure 5.1d. Pearson Creek Study Period Discharge (every 15 minutes)

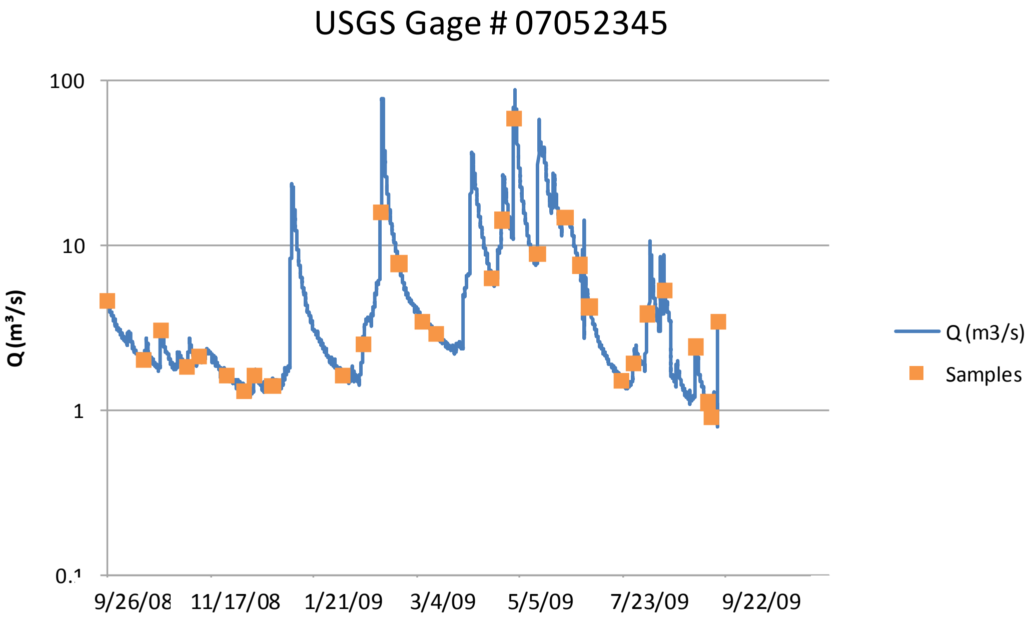


Figure 5.1e. Finley Creek Study Period Discharge (every 15 minutes)

Flow Duration Analysis. Flow-duration rating-curves (FDRC) created for this study report the percent of time that a particular discharge value was exceeded during the sample period (September 2008 – October 2009). The discharge values are ranked from largest to smallest, not according to time of occurrence as with a hydrograph plot (Searcy, 1960). The FDRC is also needed to calculate constituent load and these calculations depend somewhat on the quality of the discharge data so care must be taken in constructing curves from reliable data.

The flow-duration rating-curves show the range of discharge for the each site‗s period of record as well as the mean annual discharge for the study period (Figure 5.2 and Table 5.2). Due to environmental conditions several similar low flow measurements occurred in the 90th percent exceedence at Middle James, Upper James, and Pearson Creek sites creating a ‗tail‗ at the end of the rating curve. Most likely, these measurements do not affect the load calculations because samples were not collected during such low flows. Middle James had the highest daily mean discharge values than any other sample site, which is to be expected since this site is located in the middle section of the main stem of the James River and has the largest drainage area. Daily mean discharge values for the Middle James site were higher than those at other sites. Upper James and Finley sites have similar flow-duration curves although Finley had more high flow discharge values, while the Upper James had more low flow discharge values. However, the median daily mean discharge of Upper James and Finley were similar. Daily mean discharge ranges measured at Wilson and Pearson were similar, however, median daily mean discharge at Pearson was higher than Wilson. Additionally, more low flow values were measured at Wilson than at Pearson, most likely due to the flashy nature of Wilson Creek and the presence of groundwater inputs at Pearson Creek. Overall, there is a wide range of daily mean discharge among all sites, which reflects subtle differences in geology, land use and climate.

Table 5.2 Mean Daily Discharge for Study Period (Discharge in m^3/s)

Site	Fall	Winter	Spring	Summer
Upper James	1.09	6.05	15.2	1.64
Finley	2.20	5.30	17.4	2.70
Middle James	4.80	11.0	28.0	6.22
Pearson	0.36	0.62	1.73	0.50
Wilson	0.40	0.29	1.13	0.51

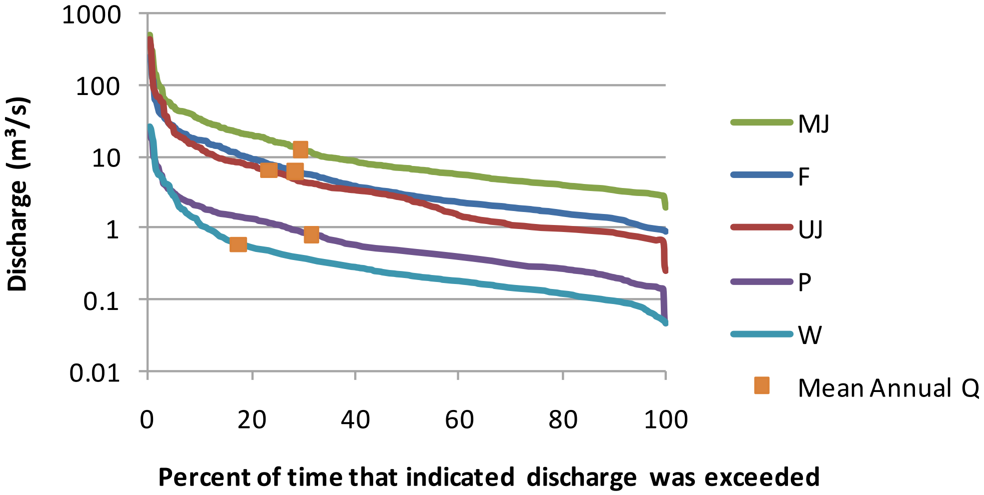


Figure 5.2. Flow-Duration Rating-Curves for Each Sub-watershed

Water Chemistry Trends

Temperature. pH, and Dissolved Oxygen. Temperature, pH, and dissolved oxygen varied among sites and season during the study period. However no trend with discharge was demonstrated. Consequently only seasonal averages of these parameters were plotted for each sample site to show trends (Figure 5.3a-c). Measurements of pH were higher in the winter and spring, but lower in fall and summer. Water temperature followed seasonal air temperature patterns being cooler when seasonal air temperatures were cold and warmer when air temperatures were high. Pearson Creek had a more constant year-round temperature (temperature was cooler in the summer and warmer in the winter than other sites) possibly due to the influence of groundwater control from springs (Cushing and Allan, 2001). Dissolved oxygen concentration was highest in the winter months when stream temperatures were coldest and concentrations were lowest during summer months when water temperatures were highest as expected. Dissolved oxygen concentration is inversely related to temperature because DO concentration tends to decrease in the summer because it is less soluble when water temperatures increase (Cech, 2003).

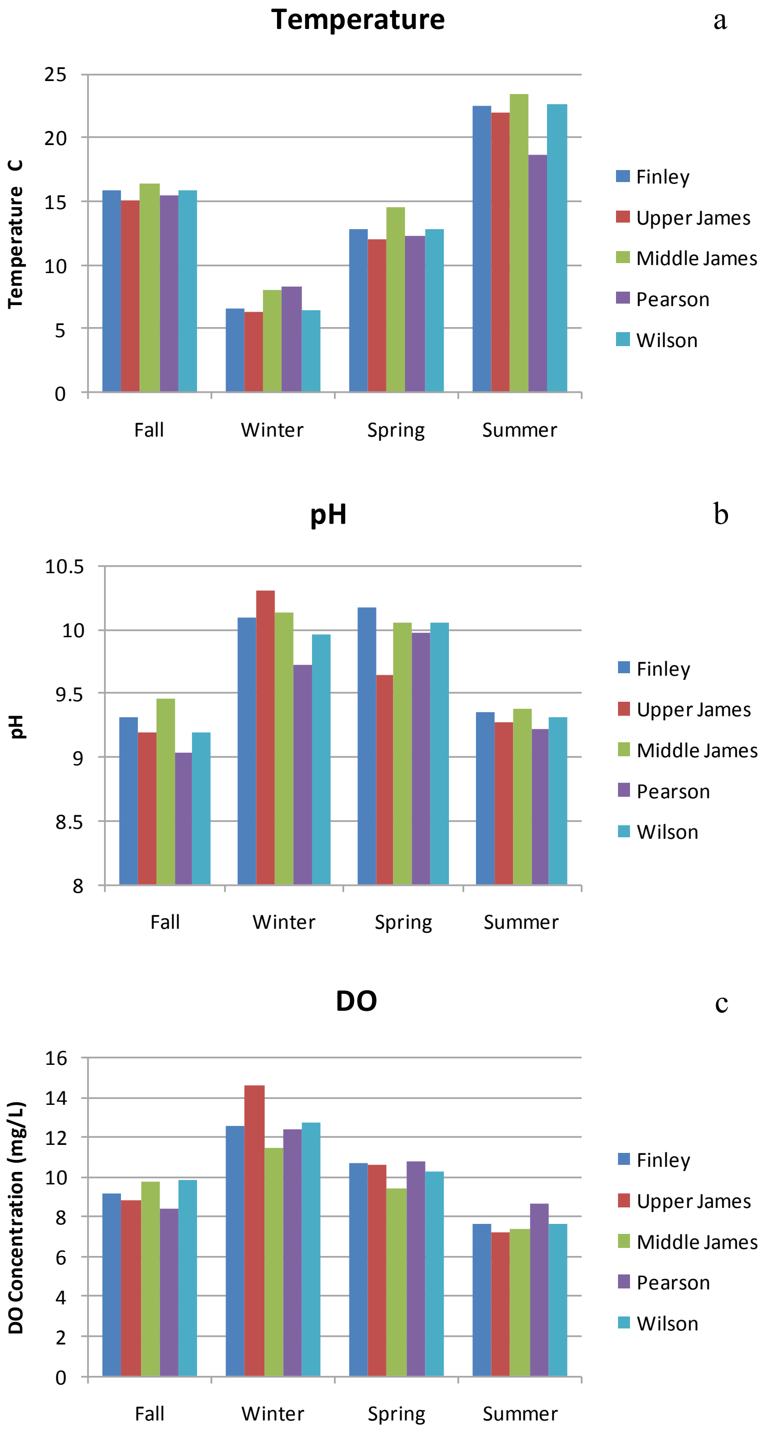


Figure 5.3a-c. Temperature, pH, and Dissolved Oxygen by Site and Season

Specific Conductance and Turbidity. Recall that conductivity and turbidity have opposite relationships with discharge; conductivity decreases and turbidity increases with discharge (Klein, 1981; Walton, 1989; Lewis, 1996). Conductivity is related to the quantity of dissolved solids in water, which in the Ozarks is usually diluted by precipitation-driven storm runoff, although the first-flush may sometimes increase conductivity (McNeil and Cox, 2000). Turbidity, however, can be increased by material delivered by storm runoff and is therefore strongly related to discharge. Generally, conductivity trends and turbidity trends were similar at each site. Turbidity tended to strongly increase with discharge while conductivity tended to slightly decrease with discharge. Generally, turbidity has more scatter about the trendline than conductivity at all sites due to the discrete and variable manner of material delivery by storm runoff. Among the sites, Middle James turbidity measurements had the steepest regression slope, least amount of scatter, and highest R^2 value; Pearson, Finley, Wilson, and Upper James, respectively, followed. Conductivity measured at the Middle James site also had the steepest slope followed by Wilson, Pearson, Finley, and Upper James. However, trendline slopes of conductivity measured Pearson, Finley, and Upper James were all near zero indicating that there was little relationship between conductivity and discharge at these sites.

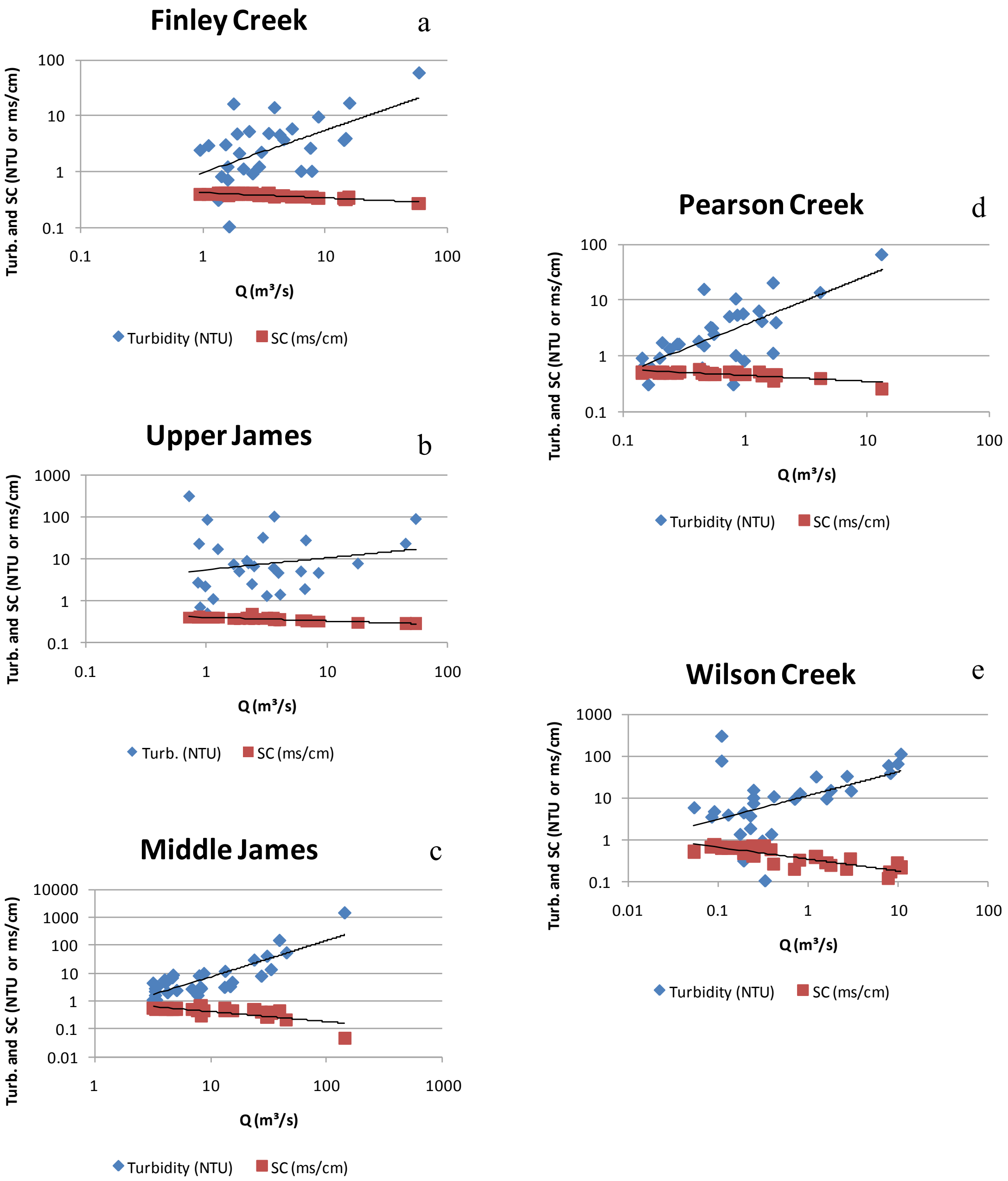


Figure 5.4a-e. Discharge Influences on Specific Conductance and Turbidity

Relationship between TDS and Conductance. Typically there is a positive relationship between TDS and conductance due to the ability of dissolved material to conduct an electrical current (Klein, 1981). Consequently, conductance measurements have been used as a relatively easy and cost-effective method of estimating TDS concentration (Finlayson, 1979; McNeil and Cox, 2000). A calibration curve must be constructed by regression in order to make an estimation of concentration. Figure 5.5a-e shows TDS concentration and conductivity measurements taken from each study site. In general, a positive relationship between TDS and conductance was shown at all sites (even the Upper James if the outlier is ignored). However, only TDS concentration and conductance measurements from Wilson Creek appear to have a clear positive relationship. The trendline of the Wilson data set shows a strong positive slope and the R^2 value is near 0.5 (Table 5.3). Conductance data and TDS concentration data from all other sites have either weak slopes or R^2 values near zero (Table 5.3), indicating a weak relationship between TDS and conductance. TDS for Wilson Creek could be fairly accurately predicted from conductance using the Wilson Creek curve.

Table 5.3.Regression Equation Relating TDS to Conductance

Watershed	X	Y	n	bo	b1	R^2
Finley	Qi	TDS	30	1.85	0.81	0.05
Upper James	Qi	TDS	30	256.12	-0.03	0.00
Middle James	Qi	TDS	30	4.69	0.66	0.14
Pearson	Qi	TDS	30	19.28	0.44	0.05
Wilson	Qi	TDS	30	0.62	0.99	0.42

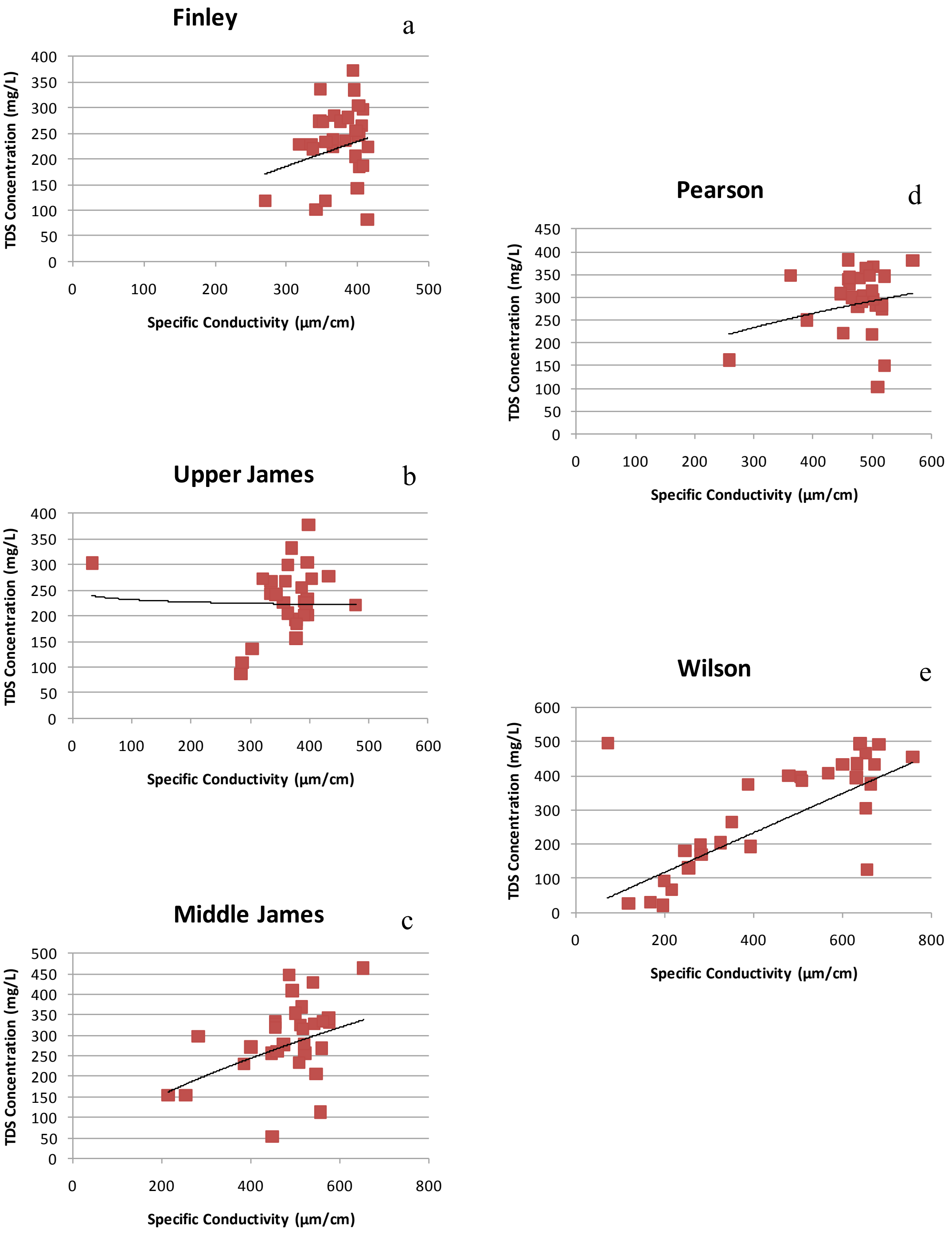


Figure 5.5a-e. Relationship between TDS and Conductance

Conductance and Seasonal Influence. Conductance measurements were expected to remain consistent throughout the study period due to the abundance of soluble rock (limestone) in the study area. Indeed, there is some difference among average seasonal conductance measurements at Wilson, Pearson, and Middle James as conductance did not fluctuate much over the course of the year at any of the sampling sites (Figure 5.6). Conductance varies most at the Wilson site. Conductance is highest during the winter most likely due to increased concentration of dissolved carbonate from groundwater during this time of year (Calcite precipitates out of water as temperatures decrease (Carling, 1983) and application of rock salt to roads during snowfall (Gardner and Royer, 2010). Overall, conductance is highest at Wilson Creek possibly due to the availability of soluble chemicals found in urban areas, as well as springs located in that sub-watershed. Conductance was also high at Pearson Creek due to springs and sinkholes and high at Middle James because of the relatively large sub-watershed, and upstream sewage treatment facilities and tributary inputs.

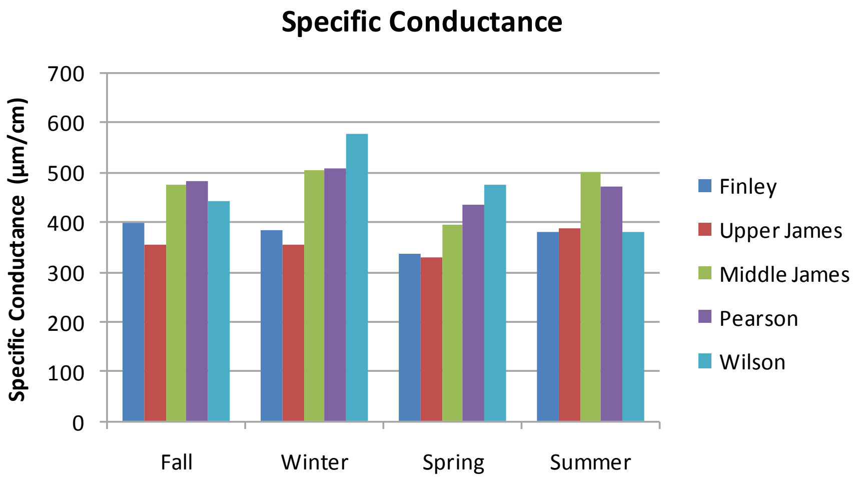


Figure 5.6. Specific Conductance by Site and Season

Relationship Between TSS and Turbidity. Like conductivity and TDS concentration, there may be a strong relationship between turbidity and TSS concentration (Lewis, 1996). Turbidity has been used as a cost-effective way to estimate suspended sediment concentration (Foster, et al., 1992; Lewis, 1996).Total suspended solids and turbidity measurements from each sample site are plotted in Figure 5.7a-e. Total suspended solids are shown to have a positive relationship with turbidity as found in Lewis, 1996. There is a positive to strongly positive trendline slope for each site dataset, which indicates that a rating curve can be constructed to predict TSS (Table 5.4). However, it should be noted that the 1.5 – 0.45 µm size fraction that may also affect turbidity was not measured. The R^2 values from this rating curve are much higher than R^2values when TDS and SC were plotted. The TSS and turbidity data set from the Middle James yielded the strongest rating equation and R^2 value, followed by Pearson Creek and Finley Creek.

Table 5.4. Regression Equation Relating TSS to Turbidity

Watershed	Log Qi	Log Y	n	bo	b1	R^2
Finley		TDS	30	2.725	0.66	0.62
Upper James		TDS	30	3.788	0.37	0.23
Middle James		TDS	30	2.782	0.82	0.64
Pearson		TDS	30	2.226	0.81	0.63
Wilson		TDS	30	3.961	0.42	0.24

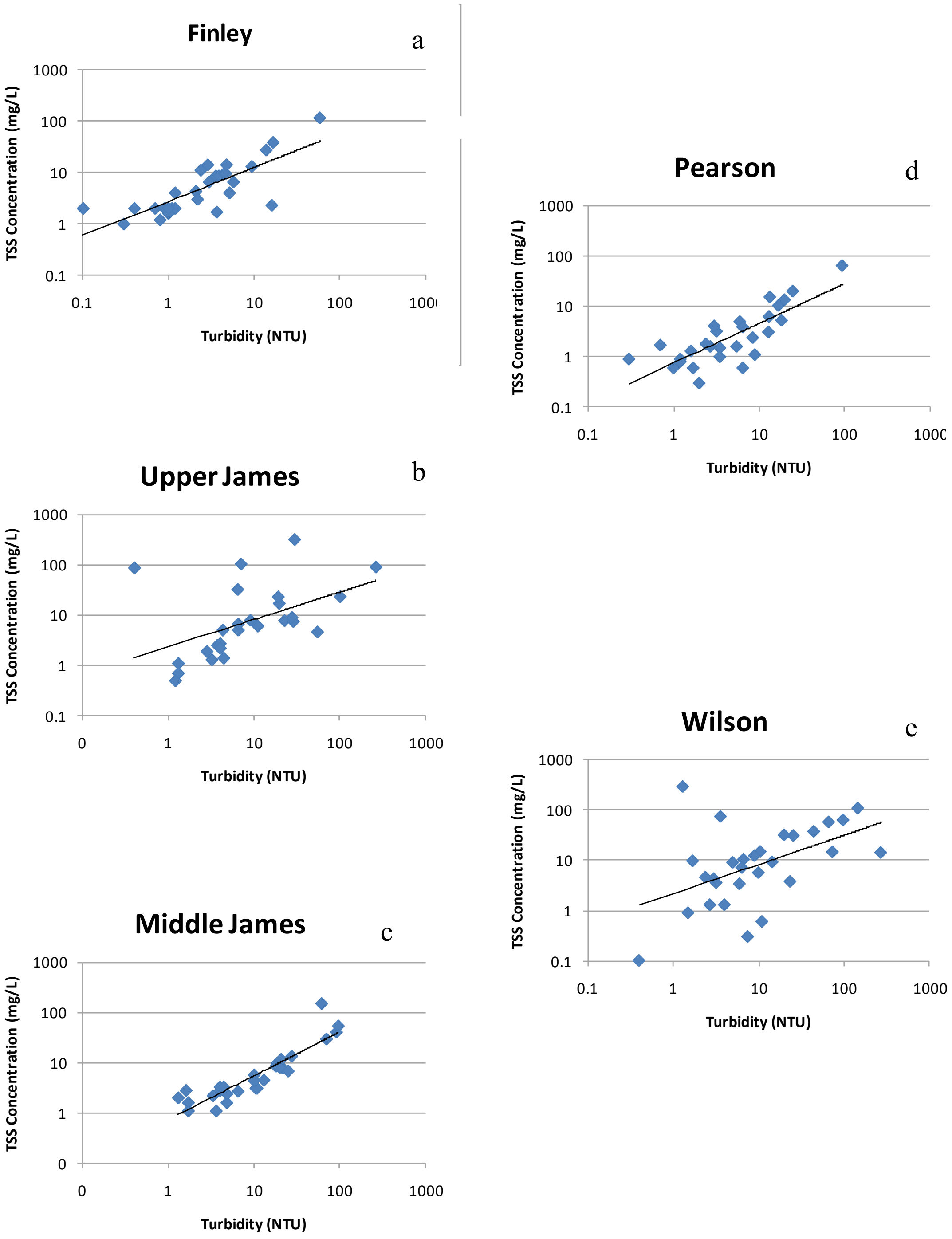


Figure 5.7a-e. Relationship between TSS and Turbidity

Turbidity and Seasonal Influence. Turbidity measurements were expected to vary over the course of the study period because measurements are dependent upon runoff, seasonal conditions, and sediment supply. Indeed, measurements tended to fluctuate by season and vary among sample site due to the variance in storm events (Lewis, 1996) (Figure 5.8).These trends were affected by number of storm samples collected during each season as well as the first flush of storm runoff. The highest turbidity measurement was from the Middle James during spring, which was an order of magnitude higher than any other turbidity measurement due to a large storm event that took place in May 2009. Correspondingly, the highest discharge value for the study was recorded at the Middle James during the spring. The highest turbidity measurements for Finley and Pearson Creeks were recorded during the spring. However, highest turbidity measurements at the Upper James and Wilson Creek were recorded during fall and winter. Lowest turbidity measurements occurred in winter (Finley and Pearson) and summer (Upper James, Middle James, and Wilson).

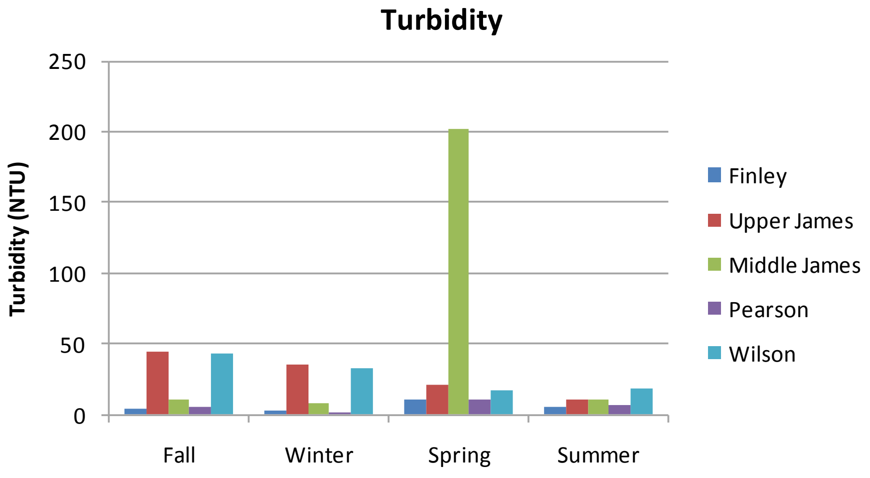


Figure 5.8. Seasonal Changes in Turbidity

Constituent Concentration Trends

Suspended Solids. TSS sources include disturbed soils and urban pollutants which are highly variable in supply (Wolman, 1967; Johnson and East, 1982). Concentrations were expected to increase with discharge due to material delivered from the watershed via storm runoff. Indeed, TSS concentrations increased with discharge at all sites. TSS plots had more scatter about the trendline than TDS, which could indicate that there may be other factors, such as bank erosion, controlling input of suspended material besides storm runoff. The relationship between TSS concentration and discharge appears to be strongest at the Middle James site (highest R^2 value and steepest slope), probably due to the relatively large size of this sub-watershed, as well as upstream inputs of suspended material from tributaries. Wilson Creek also had a fairly high R^2 value and steep slope indicating a strong relationship, but suspended material at this site probably originated from urban sources, such as erosion from construction sites. Finley Creek had quite a few points that plotted relatively high in concentration, but low in discharge. Presence of livestock in the channel just upstream from the sample site may be the source of this suspended material. Additionally, impoundments located on Finley Creek upstream of the sample site may be responsible for several points that had low TSS concentration and high discharge. The impoundments may be preventing some sediment from being transported downstream.

Dissolved Solids. Sources of dissolved materials include soluble rock, ions, and nutrients tend to reflect overall watershed contributions that are less variable (Meybeck, 1976; Groves and Meiman, 2001).Dissolved materials were expected to slightly decrease with discharge, however, the large quantity of TDS supplied from karst and carbonate rock are not easily depleted because of the high degree of contact streamwater has with this rock. Data showed TDS concentrations decreased with discharge, as expected Table 5.5, figures 5.9a-e). However, at many sites the trendline slope was close to zero indicating that there was little relationship between discharge and TDS concentration. Indeed, the p-value of the F statistic (Table 5.5) shows that the relationship between concentration of TDS and discharge at three of the sample sites was either weak or not significant. Concentrations of TDS at the Middle James and Wilson Creek had a statistically significant negative relationship with discharge. It should be noted that ignoring one outlier from the Middle James sample set makes the trendline have a slope close to zero. Total dissolved solids concentrations at Finley Creek and the Upper James had a weak statistically significant negative relationship with discharge. However, TDS concentration had no statistically significant relationship with discharge at the Pearson Creek site, most likely due to delivery of solute from a major spring recharge located near the sampling site on Pearson Creek.

Table 5.5. Instantaneous Concentration Equations (TDS and TSS)

Watershed	Y	n	bo	b1	R^2	F Sig.	se
Finley	TDS	30	255.72	-0.114	0.09	No	0.15
Upper James	TDS	30	247.08	-0.133	0.16	Weak	0.16
Middle James	TDS	30	432.71	-0.211	0.23	Yes	0.17
Pearson	TDS	30	239.04	0.071	0.04	No	0.13
Wilson	TDS	30	171.37	-0.39	0.43	Yes	0.31
Finley	TSS	29	2.230	0.654	0.30	Yes	0.42
Upper James	TSS	29	3.527	0.817	0.43	Yes	0.48
Middle James	TSS	29	0.852	1.184	0.70	Yes	0.35
Pearson	TSS	29	0.452	0.938	0.41	Yes	0.36
Wilson	TSS	29	15.32	0.714	0.53	Yes	0.46

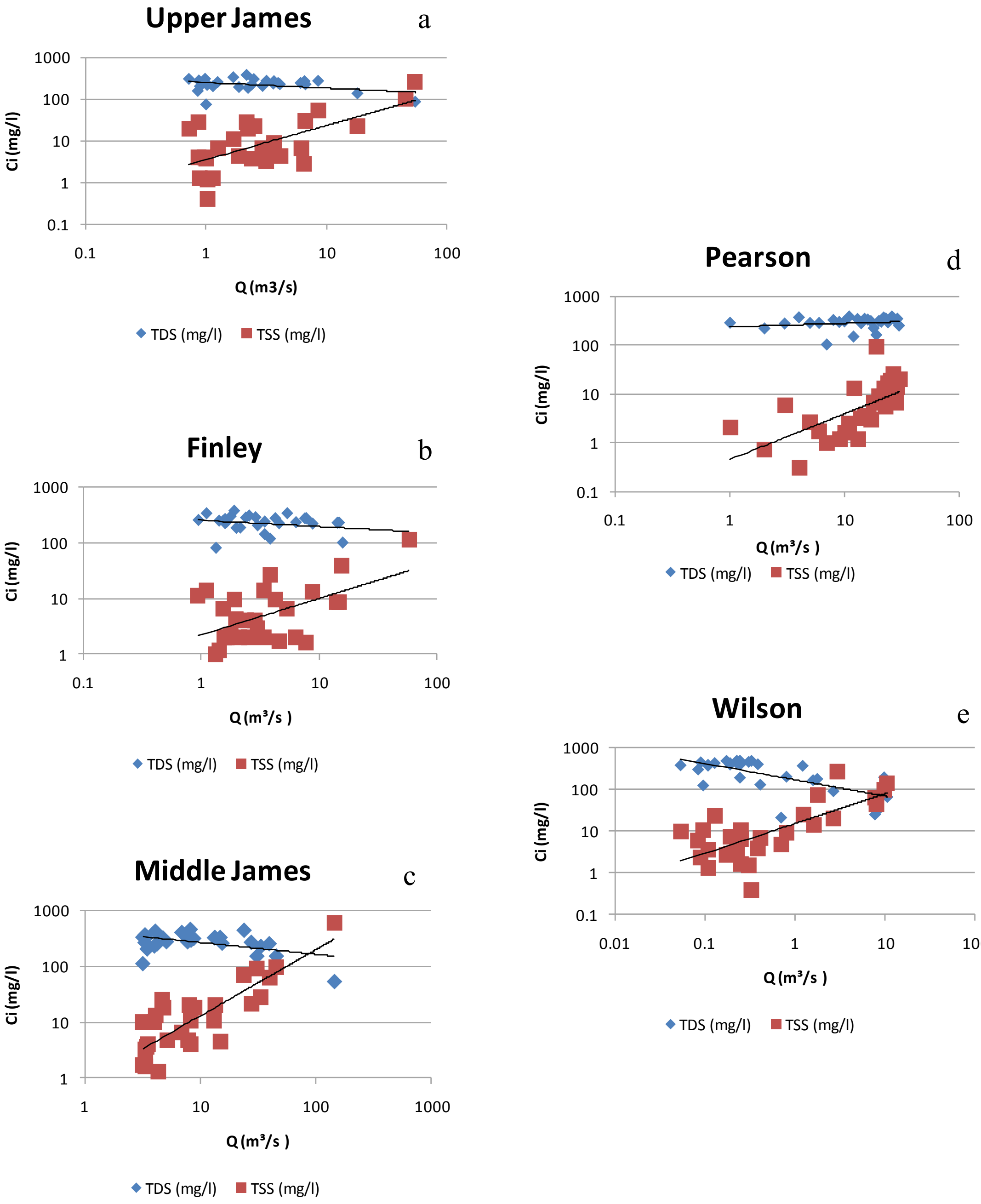


Figure 5.9a-e. Discharge Influence on TDS and TSS Concentrations

Fine Suspended Solids. Midway through the study it was decided that the 0.45 µm filters would be dried and weighed and their mass combined with the 1.5 µm filter masses to obtain fine suspended solids (FSS) concentration (recall that total suspended solids (TSS) was determined using only the 1.5 µm filter). While 0.45 µm data was not used to calculate total suspended solids loads, these data were used to estimate percent total FSS, and to estimate how much suspended material was missed by only using the 1.5 µm filters to determine TSS concentrations. The percent FSS by hydrograph limb and baseflow are displayed in Figure 5.10. Recall that suspended material transported during the rising limb tends to originate near the stream bed, while material transported during the falling limb tends to either originate far from the stream bed or from bank failure that may occur during the latter part of a storm event (Asselman, 1999). Most of the FSS was found to be transported either during the rising or falling limb in the Upper James and Finley, while very little was transported during baseflow, indicating most of the FSS transport occurred during storm flow at these sites as would be expected in a rural setting. Conversely, this material tended to be transported during baseflow or falling limb at Pearson and Wilson Creek. This was possibly due to a constant presence of FSS from urban sources in the channel during baseflow and more FSS being available from sources located far away from these sample sites during falling limb. Transport of FSS at Middle James tended to occur during falling limb over baseflow or rising limb indicating that most of the FSS in this sub-watershed originated from a distant source.

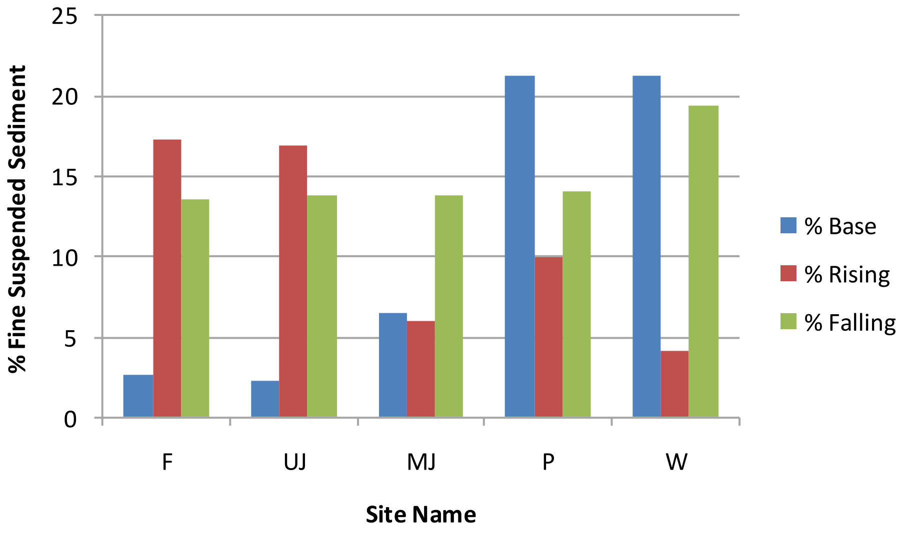
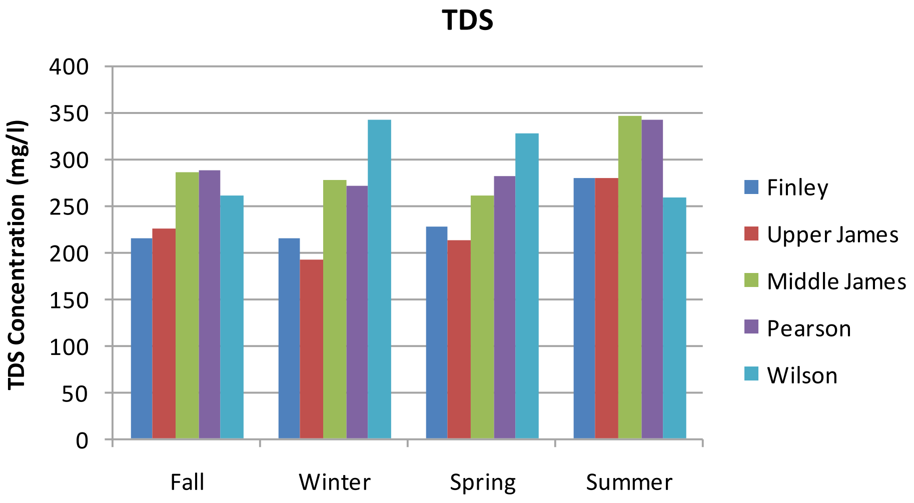


Figure 5.10. Percent Fine Suspended Solids by Site

<u>Seasonal Influence.</u> Seasonal concentrations of total dissolved solids remained fairly constant throughout the year, similar to conductivity, ranging from 200 mg/L to 350 mg/L (Figure 5.11a). TDS concentration is highest at Wilson, Pearson, and Middle James, and lowest at Finley and Upper James. TDS concentrations are highest overall during the summer at all sites, except for Wilson. The highest TDS concentration at Wilson occurred during the winter, which is also when the highest conductivity measurement at that site was taken, possibly due to the application of salts to roads (Gardner and Royer, 2010).

Seasonal total dissolved solids concentrations during baseflow are shown in Figure 5.11b. These graphs show that Wilson Creek, the most urban sub-watershed, had the highest TDS concentration during baseflow of all sub-watersheds throughout the study period. TDS concentrations also tended to fluctuate the most seasonally at Wilson Creek possibly due to the availability of dissolved urban chemicals. TDS concentrations during baseflow at Pearson Creek appear to remain fairly constant throughout the study period. This is probably due to the constant supply of dissolved material supplied by groundwater at this sample site.



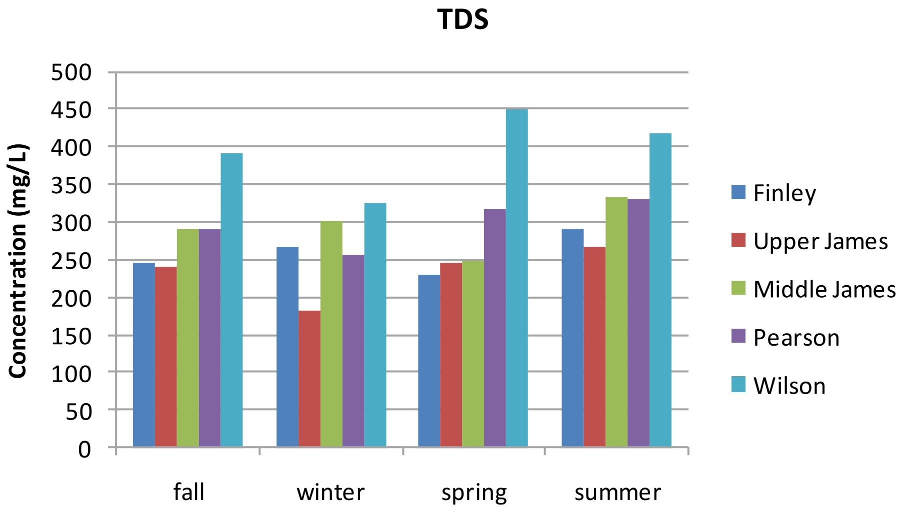


Figure 5.11a-b. Seasonal Influence on TDS Concentrations during all flow types (a) and during baseflow (b)

Average seasonal concentration of TSS varied widely by site and season, similar to seasonal trends of conductance (Figure 5.12a-b). Total suspended solids concentrations at all flow types were highest in the spring months and lowest in the fall months. However, the number of samples taken during each season and during each flow type (rising limb, falling limb, and baseflow) varied at each site and season. Therefore, it is difficult to determine whether seasonality actually had an effect on TSS concentrations. By graphing only baseflow TSS concentrations (Figure 5.12b) it is easier to show seasonal differences in TSS concentration. Overall, the highest TSS concentrations during baseflow occurred during the summer and fall months. Spring showed the lowest baseflow TSS concentrations, which seems unexpected at first, but by looking at Figure 5.12a the effect of discharge on TSS concentration is apparent; TSS concentrations are much higher during the spring when all flow types are considered.

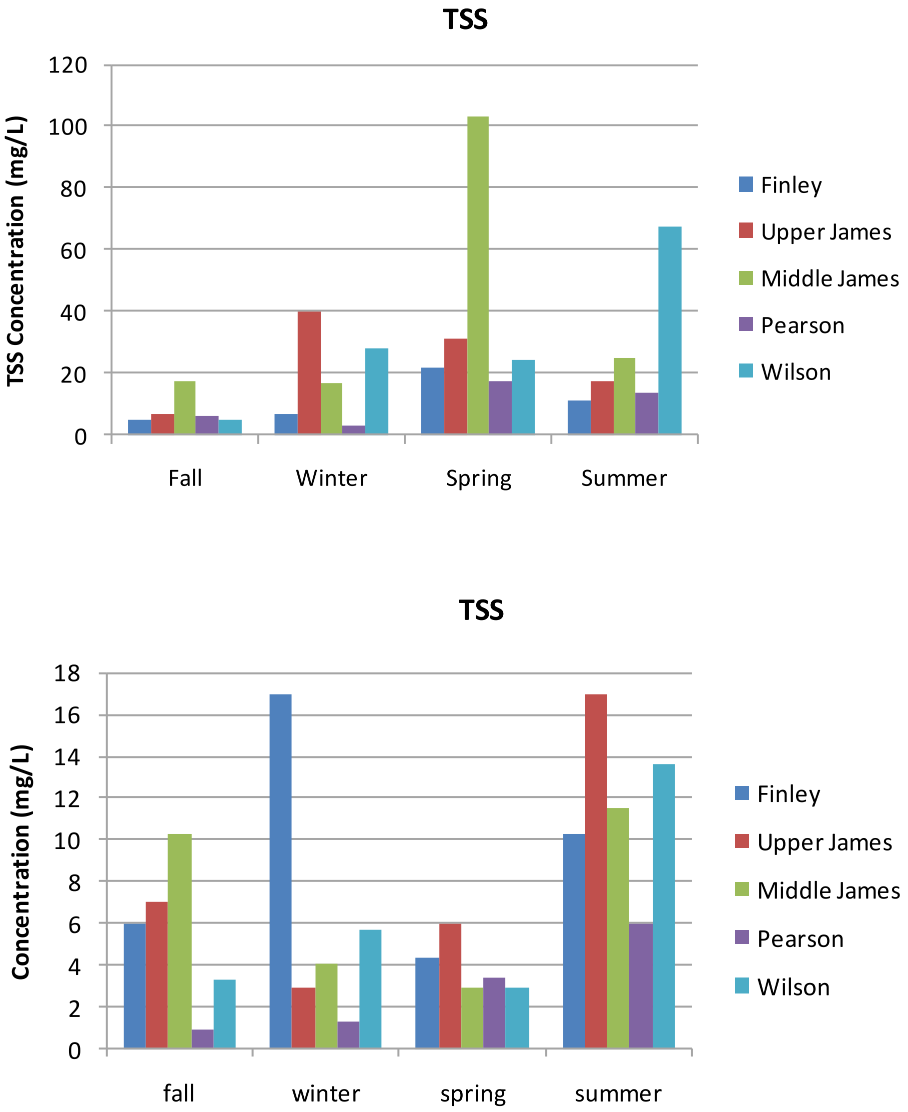


Figure 5.12a-b. Seasonal Influence on TSS concentrations during all flow types (a) and during baseflow (b)

Hysteresis Influence. Recall that a hysteresis is a cyclical relationship between discharge and constituent concentration that may occur during a storm event (Johnson and East, 1982). Hysteresis does not appear to influence total dissolved solids concentration because the rising limb and falling limb trendline equations were similar at all sample sites (Figures 5.13a-e, and Tables 5.6 and 5.7). However, total suspended solids concentrations did appear to be influenced by hysteresis at all sample sites. Total suspended solids concentration increased dramatically during the rising limb at each sample site, while falling limb TSS concentrations trends differed at each site. TSS concentrations sharply dropped during falling limb at Finley Creek indicating exhaustion of suspended material, an effect possibly due to the impoundments upstream from this sample site. However, TSS concentrations during falling limb at Upper James and Pearson Creek continued to increase from rising limb concentrations indicating supply of suspended material has not been exhausted, but may have been coming from a distant source in the watershed. TSS concentrations during falling limb at Middle James and Wilson Creek were lower than during rising limb, which was an indication of exhaustion, but the trendline has a positive slope showing that the supply was not been completely exhausted.

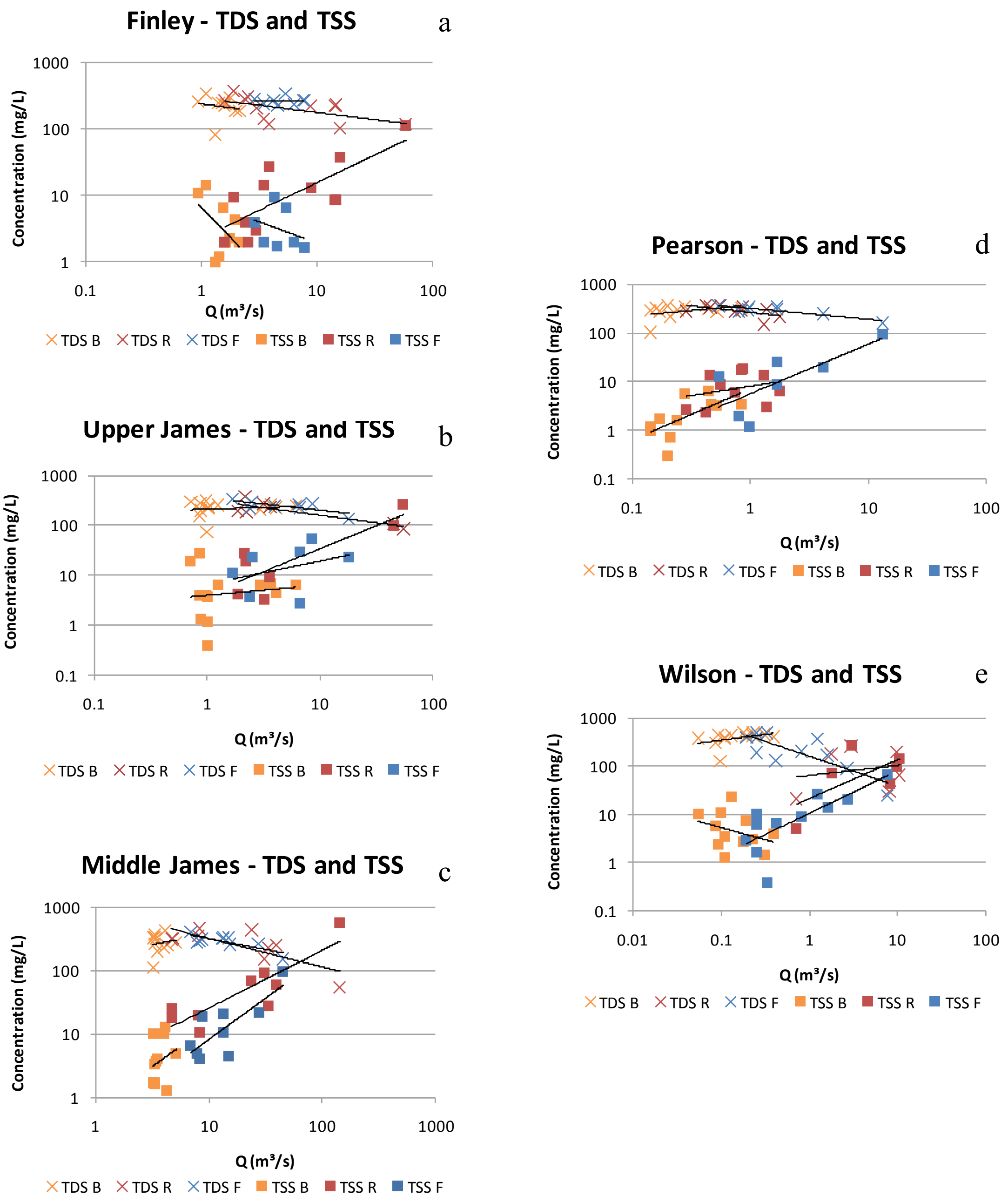


Figure 5.13 a-e. Hysteresis Influence on TDS and TSS Concentrations

Table 5.6. Regression Equation Relating TDS to Hysteresis

Watershed	X	Y	n	bo	b1	R^2
Finley	Qi	TDS – R	12	255.4	0.00	0.00
Finley	Qi	TDS - F	8	292.0	0.33	0.33
Upper James	Qi	TDS – R	7	319.8	-0.30	0.74
Upper James	Qi	TDS - F	8	359.6	-0.25	0.54
Middle James	Qi	TDS – R	9	919.7	-0.45	0.60
Middle James	Qi	TDS - F	10	703.4	-0.34	0.61
Pearson	Qi	TDS – R	8	266.1	-0.27	0.32
Pearson	Qi	TDS - F	10	322.4	-0.22	0.79
Wilson	Qi	TDS – R	6	64.6	0.21	0.05
Wilson	Qi	TDS - F	11	161.9	-0.62	0.67

Table 5.7. Regression Equation Relating TSS to Hysteresis

Watershed	X	Y	n	bo	b1	R^2
Finley	Qi	TSS – R	12	2.27	0.84	0.57
Finley	Qi	TSS - F	8	8.33	-0.64	0.10
Upper James	Qi	TSS – R	7	4.07	0.92	0.70
Upper James	Qi	TSS - F	8	6.57	0.47	0.13
Middle James	Qi	TSS – R	9	0.40	1.30	0.62
Middle James	Qi	TSS - F	10	3.16	0.911	0.76
Pearson	Qi	TSS – R	8	8.04	0.38	0.08
Pearson	Qi	TSS - F	10	5.66		
Wilson	Qi	TSS – R	6	21.5	0.80	0.40
Wilson	Qi	TSS - F	11	10.6	0.88	0.57

Carbon. Inorganic and organic carbon concentrations were expected to have opposite relationships with discharge. Indeed, carbon concentration data plotted over discharge showed that inorganic carbon had a negative relationship and organic carbon had a very weak positive to no relationship with discharge. Total and dissolved inorganic carbon concentration trends are almost identical at all sites, indicating that the vast majority of the inorganic carbon in the streamwater is in the dissolved form (Figures 5.15a-e).The trendline slope (Table 5.8) of inorganic carbon data was a negative value at all sites showing that the concentrations were diluted by storm runoff. Additionally, very little scatter about the TIC and DIC trendlines indicate that a strong relationship between TIC and DIC and discharge exists. The trendline equation from the Wilson Creek TIC and DIC data had the steepest slope of -0.28, while the equation from Upper James data had the highest R^2 (0.84) indicating discharge and inorganic carbon concentration had a strong negative relationship at both of these sites. Upon examining the statistical significance (Table 5.8), both total and dissolved inorganic carbon concentration were found to have a significant negative relationship with discharge at all sites. This relationship was slightly negative at all sites, except Wilson, where the relationship was very negative.

TOC and DOC concentrations tended to increase with discharge. TOC concentrations increased more than DOC due to the presence of suspended organic carbon in that fraction which is associated with the suspended load. Organic carbon concentration plots show more of a difference between total and dissolved forms than were seen between total and dissolved forms of inorganic carbon (Figures 5.14a-e). Organic carbon concentration data from Wilson Creek had the steepest TOC slope (0.4) and also the highest R^2 (0.5) showing that organic carbon concentration is strongly related to discharge at this site. All other sites have much lower R^2 of around 0.1 or lower. According to the p-value of the F stat, TOC concentration at Finley Creek and the Upper James had no significant relationship with discharge. At the Pearson and Middle James sites TOC had a borderline significant relationship with discharge. However, TOC concentration at Wilson Creek exhibited a strongly negative significant relationship with discharge. Unlike inorganic carbon, dissolved organic carbon did not exhibit the same trends as TOC. Concentration of DOC exhibited no relationship with discharge at all sites, except Wilson. However, DOC concentration only had a weak positive significant relationship with discharge at that site.

Table 5.8. Instantaneous Concentration Equations (Carbon)

Watershed	Y	n	bo	b1	R^2	FSig.	se
Finley	TIC	27	36.352	-0.096	0.66	Yes	0.03
Upper James	TIC	27	36.063	-0.124	0.84	Yes	0.03
Middle James	TIC	27	38.865	-0.073	0.20	Yes	0.04
Pearson	TIC	27	37.305	-0.12	0.55	Yes	0.05
Wilson	TIC	27	25.067	-0.276	0.67	Yes	0.13
Finley	TOC	27	1.3924	0.0933	0.03	No	0.2
Upper James	TOC	27	1.6287	0.0781	0.03	No	0.22
Middle James	TOC	27	1.546	0.2058	0.16	Weak	0.21
Pearson	TOC	27	2.2684	0.1892	0.16	Weak	0.21
Wilson	TOC	27	3.6689	0.3686	0.47	Yes	0.26
Finley	DIC	27	36.366	-0.103	0.64	Yes	0.03
Upper James	DIC	27	36.083	-0.125	0.84	Yes	0.03
Middle James	DIC	27	37.337	-0.064	0.13	Yes	0.04
Pearson	DIC	27	36.543	-0.122	0.58	Yes	0.04
Wilson	DIC	27	23.653	-0.284	0.69	Yes	0.13
Finley	DOC	27	1.584	-0.044	0.0	No	0.2
Upper James	DOC	27	1.6734	-0.002	0.0	No	0.19
Middle James	DOC	27	2.3914	-0.066	0.03	No	0.15
Pearson	DOC	27	2.1018	0.1167	0.08	No	0.19
Wilson	DOC	27	2.8315	0.1842	0.22	Weak	0.23

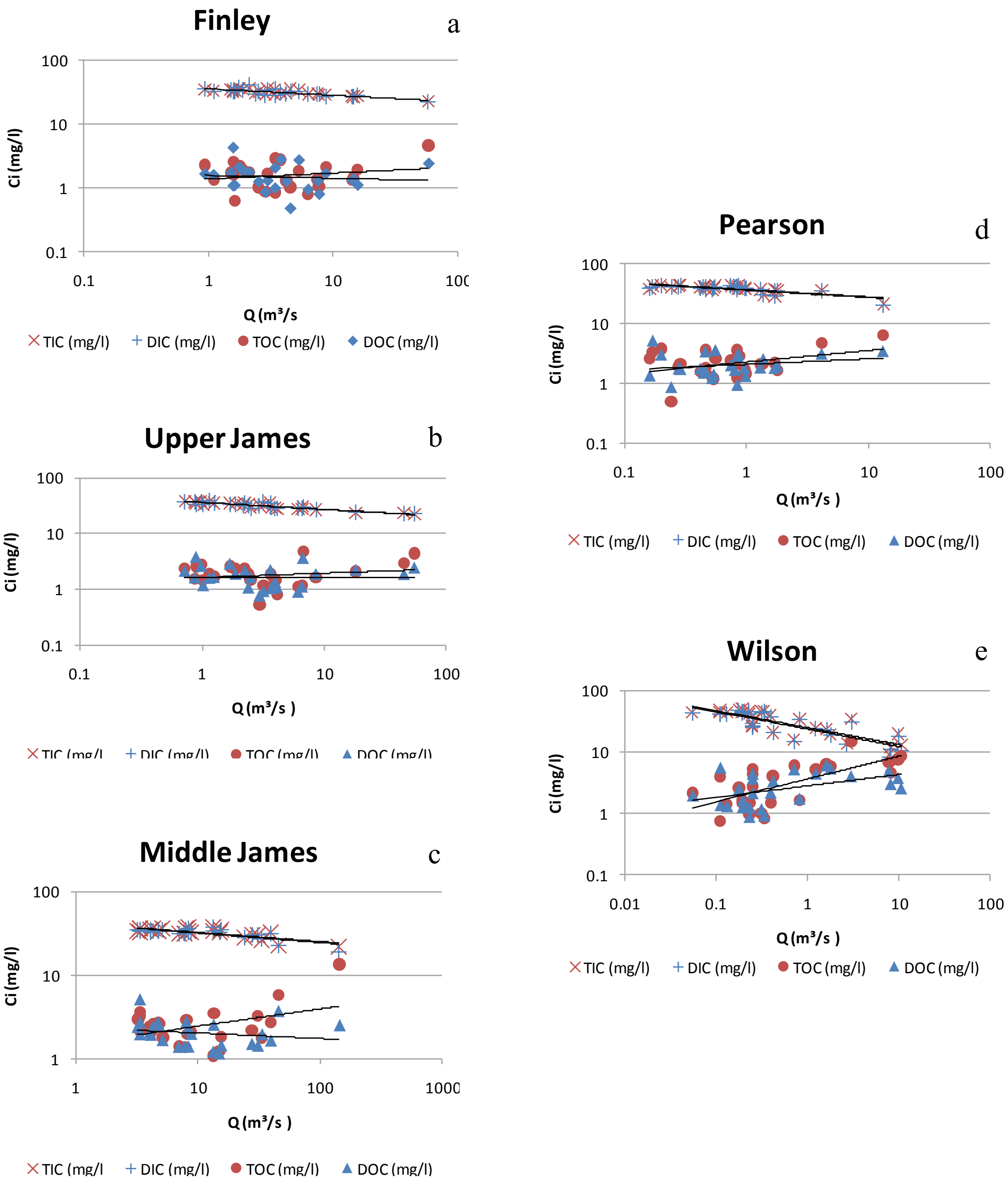


Figure 5.14a – e. Discharge Influence on Carbon Concentrations

Seasonal Influence. Inorganic carbon and organic carbon were not influenced by seasonal changes in the same way. Overall, average TIC and DIC concentrations at all sample sites did not vary much during the course of the study period probably due to the steady supply of soluble carbonate that makes up most of the regional geology. Because inorganic carbon occurs mostly in dissolved form the average TIC and DIC concentrations have almost identical seasonal trends at all sites (Figures 5.15 and 5.16). The highest average TIC and DIC concentrations for each season occurred at Pearson Creek, again probably due to groundwater influence. The greatest difference between concentrations at Pearson and the other sites occurred during the summer and fall. Lowest average concentrations occurred during the spring at all sites, except Wilson; highest average concentration of TIC and DIC at Wilson occurred during spring. Average concentration of TIC and DIC was also highest during the fall at the Upper James and Finley.

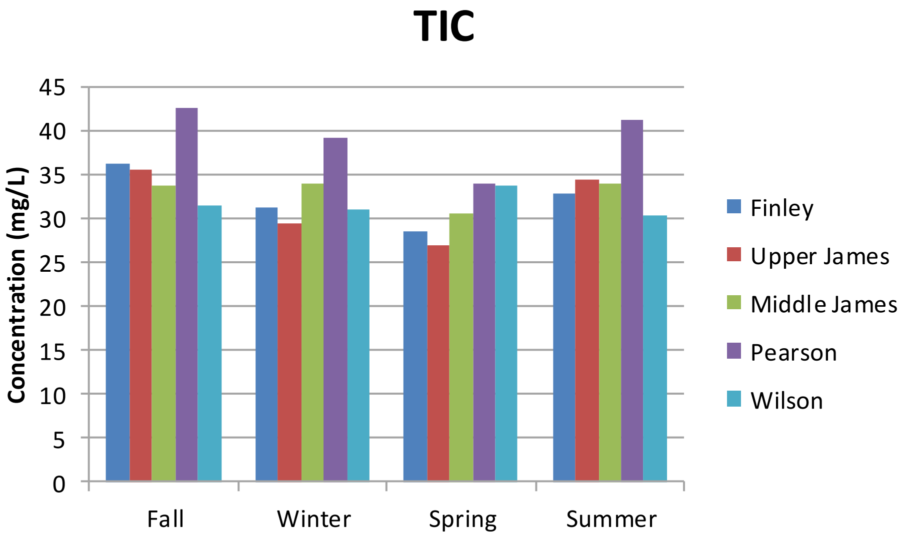


Figure 5.15. Seasonal Influences on TIC Concentrations during all flow types

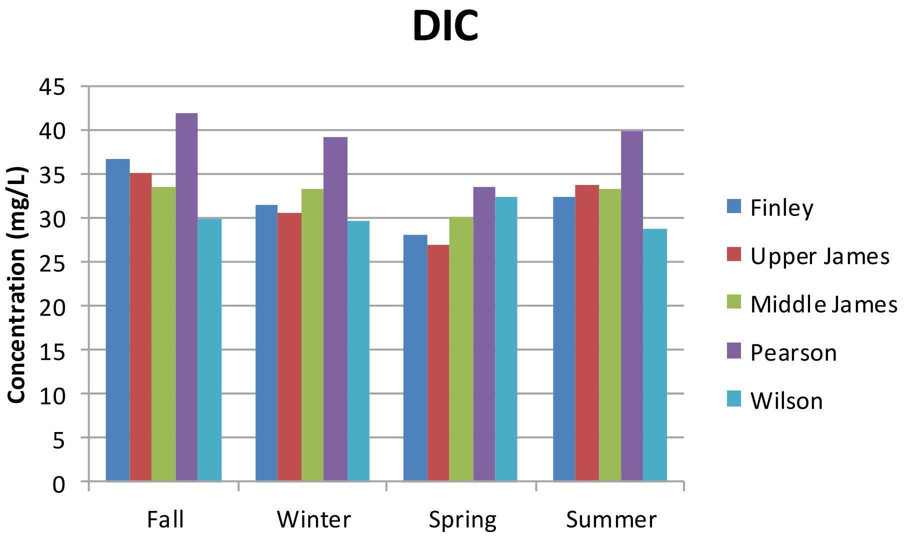


Figure 5.16. Seasonal Influences on DIC Concentrations during all flow types

Seasonal variation of total and dissolved organic carbon concentrations (Figure 5.17) was strong and unlike that of average TIC and DIC concentrations. Organic carbon concentrations were expected to increase during times of algal growth (late spring and summer) and during leaf fall. Out of all sites, average TOC concentration was highest at Wilson Creek during summer, fall and winter. Average TOC concentration was noticeably higher at Wilson than all other sites during summer possibly due to an increase in algae growth that usually occurs during this time. During spring, average TOC concentration was highest at the Middle James, though it was not much higher than concentrations at the other sites. During spring months, organic matter from upstream tributaries and particulate organic matter delivered by spring rain events were likely organic carbon sources.

Average DOC concentrations were highest at Wilson during all seasons; average concentration at this site was high especially during the fall. In fact, DOC concentrations were highest at all sites during the fall, most likely due to the influence of DOC from leaf litter leachate, as well as dissolved chemicals that accumulate on urban impervious surfaces. Average DOC concentrations were much lower in the winter and spring, but increased slightly at all sites during the summer (Wallace, et al., 1982).

Organic material transport may often be transported by storm runoff, similar to TSS. Therefore graphing all flow types may hinder showing seasonality of organic material transport because the effects of discharge may overpower seasonal effects. Dissolved organic carbon concentrations during baseflow were graphed in Figure 5.17b to show how organic carbon was affected by seasonality in the absence of storm events. Overall, slightly more seasonal variability among the sample sites was seen. Highest

DOC concentrations occurred during fall, at the Upper James, Pearson Creek, and Wilson Creek, again most likely due to leachate from decomposing leaves that accumulate during these months.

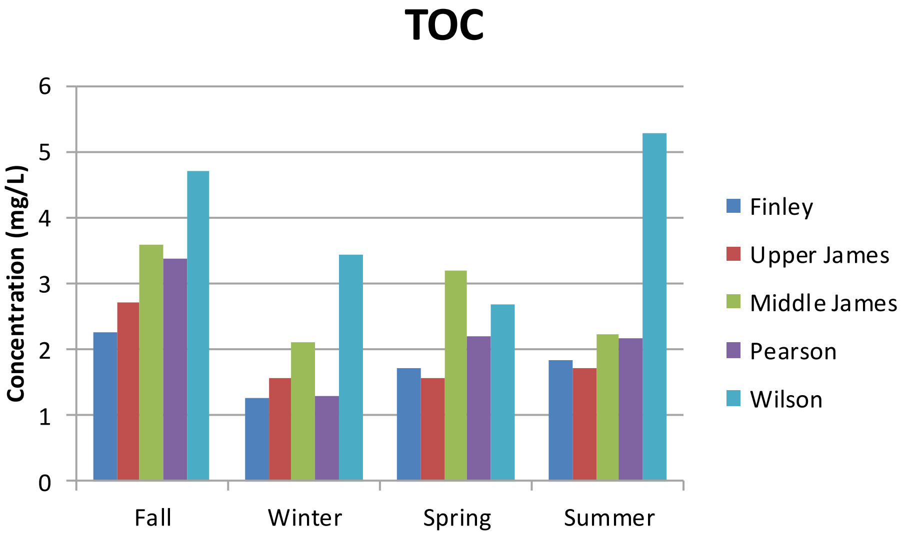
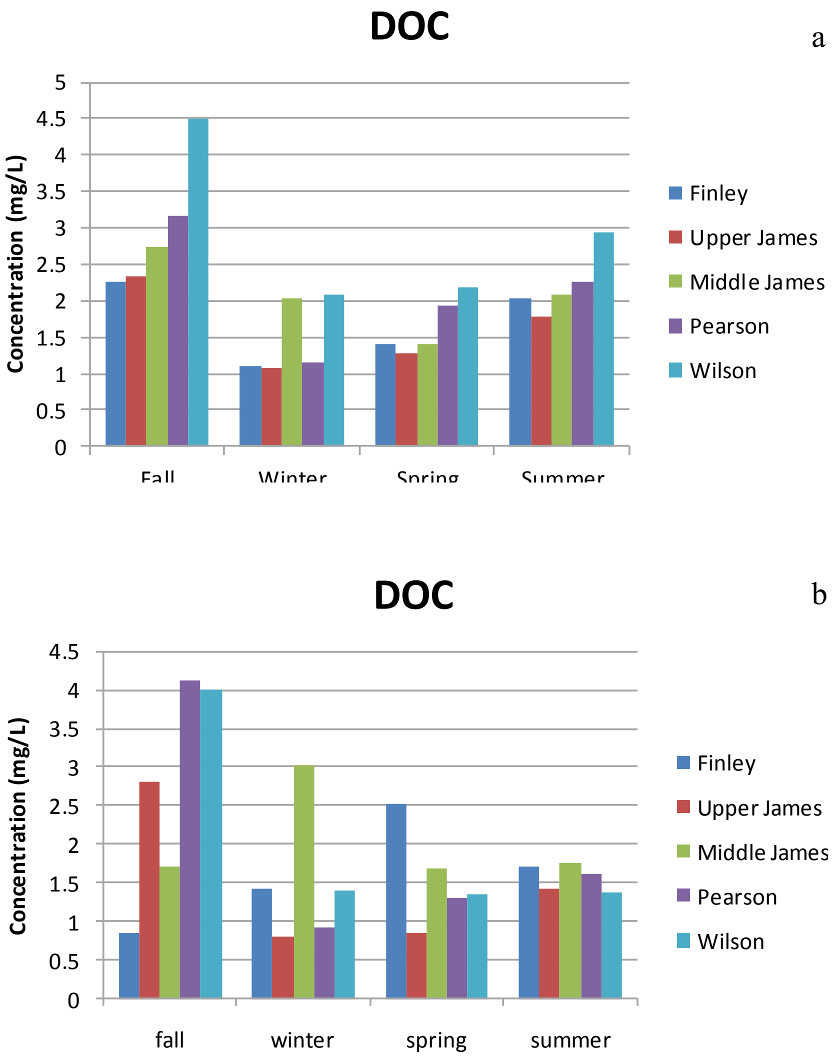


Figure 5.17. Seasonal Influences on TOC Concentrations during all flow types



Figures 5.18a and b. Seasonal Influences on DOC Concentrations during all flow types (a) and baseflow (b)

<u>Hysteresis Influence.</u> Hysteresis was expected to have little effect on inorganic carbon concentration due to the constant presence of inorganic carbon in study area streams from limestone (Holland, 1978). Results showed that hydrograph limb influence on TIC and DIC concentrations at Upper James, Middle James, Finley and Pearson were similar: only a slight negative trendline slope during rising and falling limb were seen at

these sites, indicating little hysteresis influence on TIC and DIC concentration (Figures5.19a-e, 5.20a-e, and Tables 5.9, 5.10, 5.11, and 5.12).

Hysteresis was expected to influence effects on organic carbon concentration. Overall, hysteresis effects were weak, but were apparent at some sample sites. It should be noted that trendline R^2 values for TOC and DOC were quite low for all discharge types at all sites. Little hysteresis effect on TOC and DOC concentration was seen at the Upper James. However, concentrations of TOC and DOC during falling limb at Finley Creek was lower than concentrations during baseflow and rising limb indicating exhaustion of both forms of organic carbon. A slight amount of TOC and DOC exhaustion during falling limb also occurred at the Middle James and Wilson Creek sites. Concentration of TOC and DOC at Pearson Creek is generally slightly lower during falling limb, but hysteresis influence at this site is minimal.

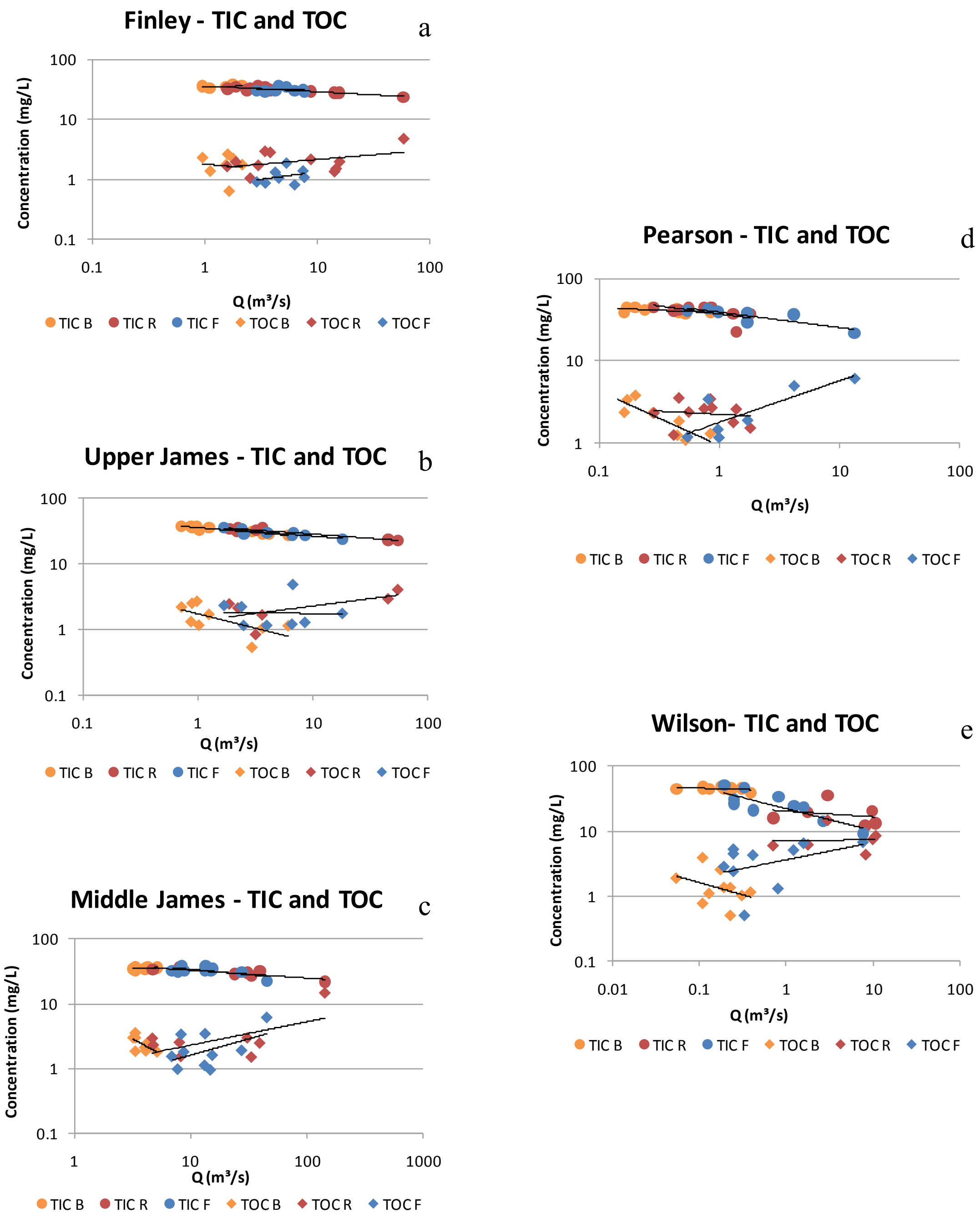


Figure 5.19a – e. Hysteresis Influence on Total Carbon Concentration

Table 5.9. Regression Equation Relating TIC to Hysteresis

Watershed	X	Y	n	bo	b1	R^2
Finley	Qi	TIC – R	12	31.4	0.00	0.00
Finley	Qi	TIC - F	8	36.6	-0.10	0.79
Upper James	Qi	TIC – R	7	38.2	-0.13	0.93
Upper James	Qi	TIC - F	8	36.7	-0.14	0.82
Middle James	Qi	TIC – R	9	43.7	-0.12	0.77
Middle James	Qi	TIC - F	10	50.1	-0.17	0.46
Pearson	Qi	TIC – R	8	36.9	-0.20	0.29
Pearson	Qi	TIC - F	10	38.7	-0.19	0.72
Wilson	Qi	TIC – R	6	20.4	-0.09	0.06
Wilson	Qi	TIC - F	11	22.2	-0.34	0.68

Table 5.10. Regression Equation Relating TOC to Hysteresis

Watershed	X	Y	n	bo	b1	R^2
Finley	Qi	TOC – R	12	1.50	0.16	0.18
Finley	Qi	TOC - F	8	0.744	0.24	0.10
Upper James	Qi	TOC – R	7	1.35	0.23	0.40
Upper James	Qi	TOC - F	8	1.81	-0.02	0.00
Middle James	Qi	TOC – R	9	0.99	0.37	0.38
Middle James	Qi	TOC - F	10	0.50	0.50	0.24
Pearson	Qi	TOC – R	8	2.21	-0.08	0.02
Pearson	Qi	TOC - F	10	1.77	0.50	0.67
Wilson	Qi	TOC – R	6	7.2	0.01	0.00
Wilson	Qi	TOC - F	11	3.6	027	0.15

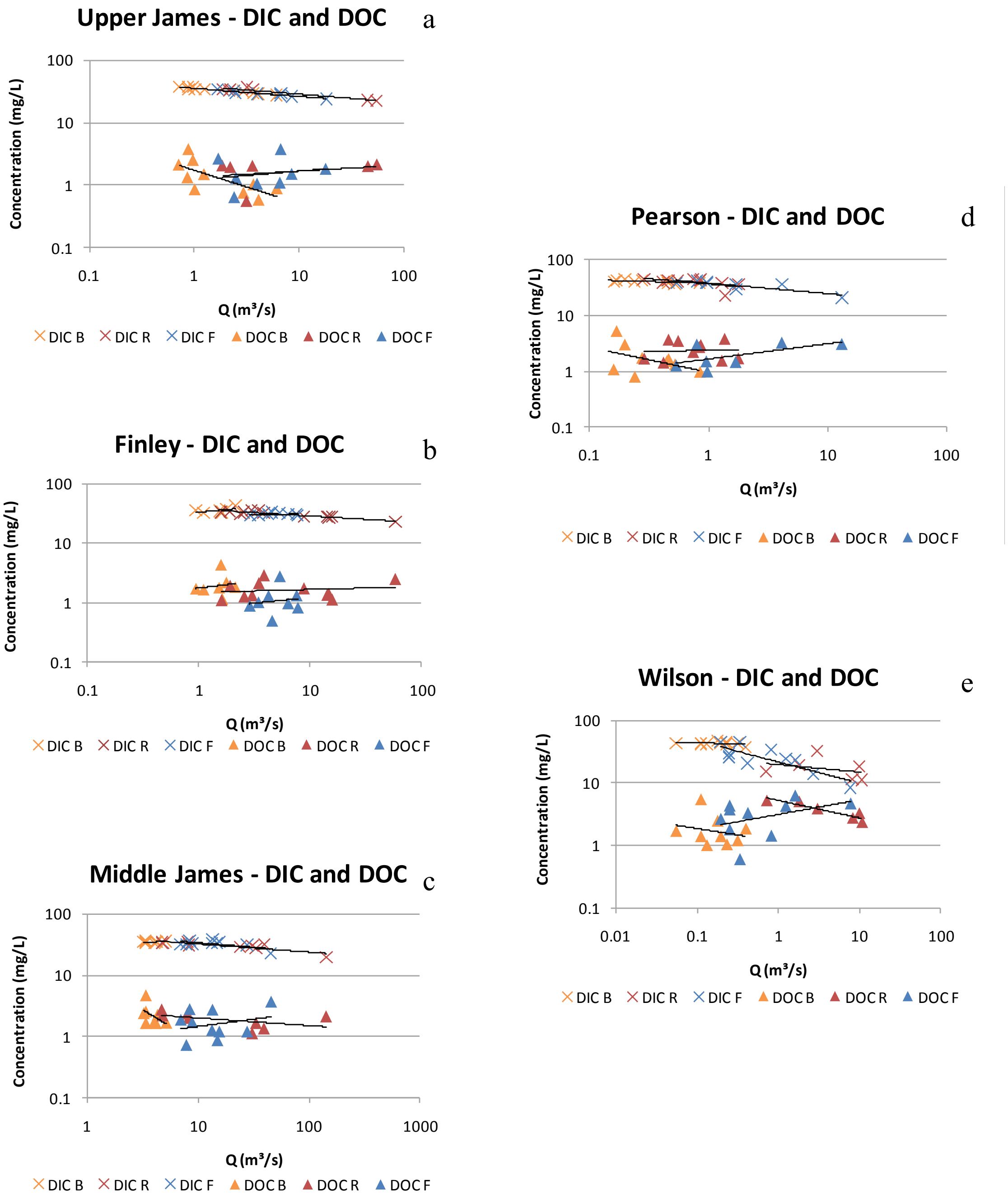


Figure 5.20a – e. Hysteresis Influence on Dissolved Carbon Concentration

Table 5.11. Regression Equation Relating DIC to Hysteresis

Watershed	X	Y	n	bo	b1	R^2
Finley	Qi	DIC – R	12	36.9	-0.11	0.84
Finley	Qi	DIC - F	8	29.4	0.02	0.03
Upper James	Qi	DIC – R	7	38.9	-0.14	0.92
Upper James	Qi	DIC - F	8	35.3	-0.13	0.87
Middle James	Qi	DIC – R	9	43.7	-0.13	0.73
Middle James	Qi	DIC - F	10	47.4	-0.15	0.41
Pearson	Qi	DIC – R	8	36.4	-0.19	0.30
Pearson	Qi	DIC - F	10	37.8	-0.19	0.74
Wilson	Qi	DIC – R	6	19.5	-0.12	0.11
Wilson	Qi	DIC - F	11	21.4	-0.34	0.67

Table 5.12. Regression Equation Relating DOC to Hysteresis

Watershed	X	Y	n	bo	b1	R^2
Finley	Qi	DOC – R	12	1.50	0.05	0.03
Finley	Qi	DOC - F	8	0.77	0.20	0.02
Upper James	Qi	DOC – R	7	1.50	0.10	0.08
Upper James	Qi	DOC - F	8	0.78	0.14	0.04
Middle James	Qi	DOC – R	9	2.68	-0.13	0.27
Middle James	Qi	DOC - F	10	0.847	0.24	0.07
Pearson	Qi	DOC – R	8	2.36	0.03	0.00
Pearson	Qi	DOC - F	10	1.65	0.27	0.40
Wilson	Qi	DOC – R	6	5.22	-0.28	0.85
Wilson	Qi	DOC - F	11	3.13	0.23	0.15

Nutrients. In general, nitrogen has been shown to be transported mostly with the dissolved load (Mitsch, et al., 2001). Additionally, most nitrogen transported in streams occurs in the form of nitrate (Rabalais, 2002). Therefore, TN concentration was expected to be poorly or negatively affected by discharge. Indeed, TN concentration trendlines for all sites show slight negative slope or zero slope (Figures 5.21a-e and Table 5.13). Thus, in a similar manner as other dissolved constituents TN was most likely transported by groundwater flow and then diluted by rainfall runoff (Mitsch, et al., 2001).

Total nitrogen concentration was found to have a statistically significant negative relationship with discharge at Finley Creek, Middle James, and Wilson Creek. The expectation was that sites that had significant relationships between TDS and discharge would also have significant relationships with TN concentration because nitrogen species most often occur in dissolved form. However, TDS concentration at Finley Creek did not have a significant relationship with discharge, but TN did have a significant relationship with discharge (although the p-value for the F stat was very close to the α value of 0.05). Likewise, TDS concentration at the Upper James had a significant relationship with discharge, but there was no relationship between TN and discharge (once again, the p-value was close to α).

Total phosphorus concentration, however, is usually associated with the suspended load (Pimentel, et al., 1995) and therefore was expected to show a positive relationship with discharge. Indeed, TP trendline slopes were positive and increased with discharge indicating phosphorus tended to be controlled by storm runoff. Additionally, the TP trendline slopes were steeper than the TN trendline slopes at all sites underscoring the difference in transport between the two nutrients. However, the relatively high degree of scatter about the trendline could indicate variability in delivery mechanisms of phosphorus, such as bank failure or influence of livestock in the stream channel (Pimentel, et al., 1995).

Total phosphorus concentration was expected to have a positive significant relationship at all of the sites that had positive significant relationships with TSS because phosphorus is often transported along with suspended material. Indeed, TP concentration had a positive significant relationship with discharge at all sites, except Finley Creek, indicating that TP transport was affected by the frequency and severity of storm events. The trendline for the Wilson Creek data had the steepest slope (0.5) and highest R^2 value (0.7) and least amount of scatter showing that the relationship between TP and discharge is strong at this site.

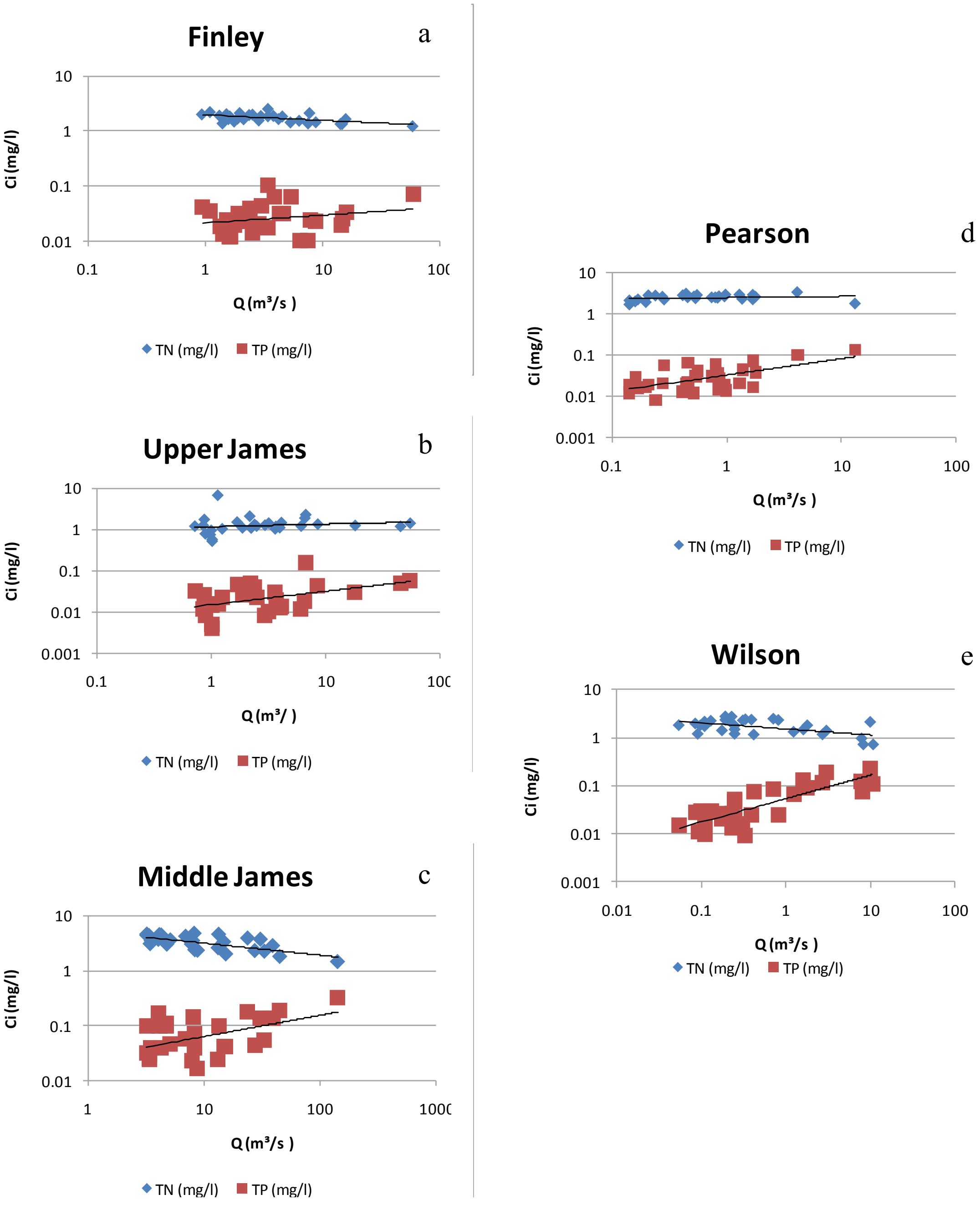


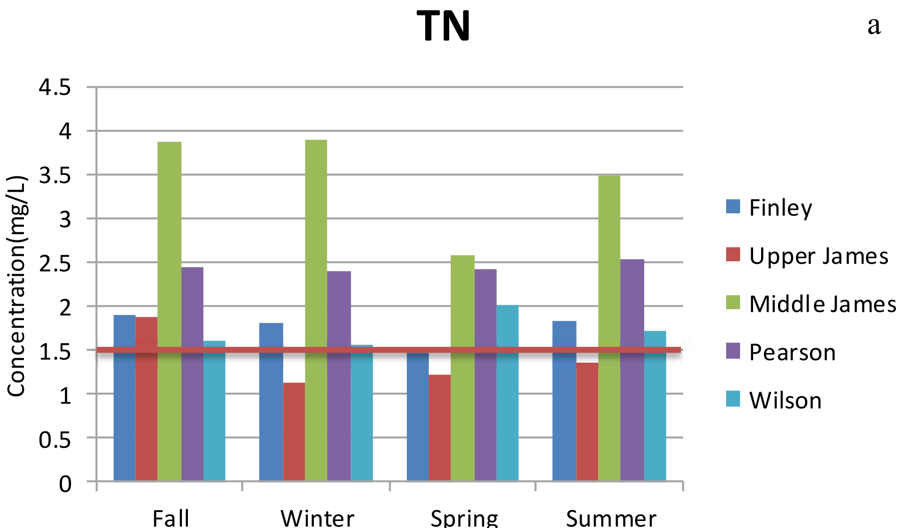
Figure 5.21a – e. Discharge Influence on Nutrient Concentrations

Table 5.13. Instantaneous Concentration Equations (Nutrients)

Watershed	Y	n	bo	b1	R^2	F Sig.	se
Finley	TP	30	0.0211	0.147	0.05	No	0.25
Upper James	TP	30	0.0151	0.3216	0.22	Yes	0.31
Middle James	TP	30	0.0263	0.3857	0.25	Yes	0.29
Pearson	TP	30	0.0327	0.3965	0.37	Yes	0.24
Wilson	TP	30	0.054	0.488	0.67	Yes	0.23
Finley	TN	30	1.9617	-0.102	0.30	Yes	0.06
Upper James	TN	30	1.1571	0.0639	0.03	No	0.20
Middle James	TN	30	5.2627	-0.218	0.50	Yes	0.09
Pearson	TN	30	2.4519	0.032	0.04	No	0.07
Wilson	TN	30	1.5162	-0.124	0.28	Yes	0.14

Seasonal Influence. Total nitrogen concentrations were expected to show some seasonal variation since nitrate levels can peak in winter due to reduced uptake by dormant vegetation (Rabalais, 2002). Average total nitrogen concentration showed the most seasonal variation at the Middle James site possibly due to the relative large size of this sub-watershed, as well as nutrients from livestock and fertilizer present in this sub-watershed. Additionally, the maximum TN concentration occurred at the Middle James site (Figure 5.22a). During fall and winter TN concentration at the Middle James site was nearly twice that of the other sites and during the summer TN concentration was higher than other sites. Average concentration of TN was lowest during spring at all sites probably due to an increase in uptake by algae and plants during these months (Rabalais, 2002). TN concentration did not show much seasonal fluctuation at the Pearson site because it may be more continuously supplied by groundwater from springs and sinkholes in that sub-watershed. The TMDL maximum TN concentration for the James River was set at 1.5 mg/L. The only sample site that had TN concentrations lower than the TMDL was the Upper James River. This is probably due to the lack of mitigation practices to reduce nitrogen levels in the James River Basin because agencies are generally more concerned with TP levels since phosphorus is often the limiting nutrient for algae in streams.

Total nitrogen concentrations for only baseflow conditions were graphed to correct for discharge effects (Figure 5.22b). During baseflow, TN seasonal fluctuations are slightly more apparent. For instance, TN concentrations at the Middle James was lower during fall baseflow than the other seasons possibly due to lack of stormflow to dilute nitrogen and presence of algae to uptake nutrients. Pearson Creek TN baseflow concentrations show how nitrogen levels may diminish in the winter due to a decrease in groundwater flow during these months. However, baseflow TN concentrations all sites, except the Upper James, are still above the TMDL level.



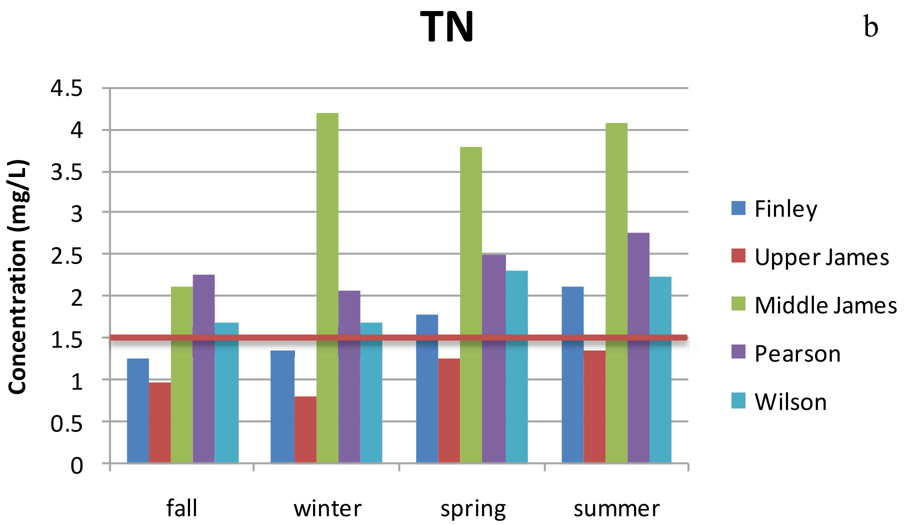
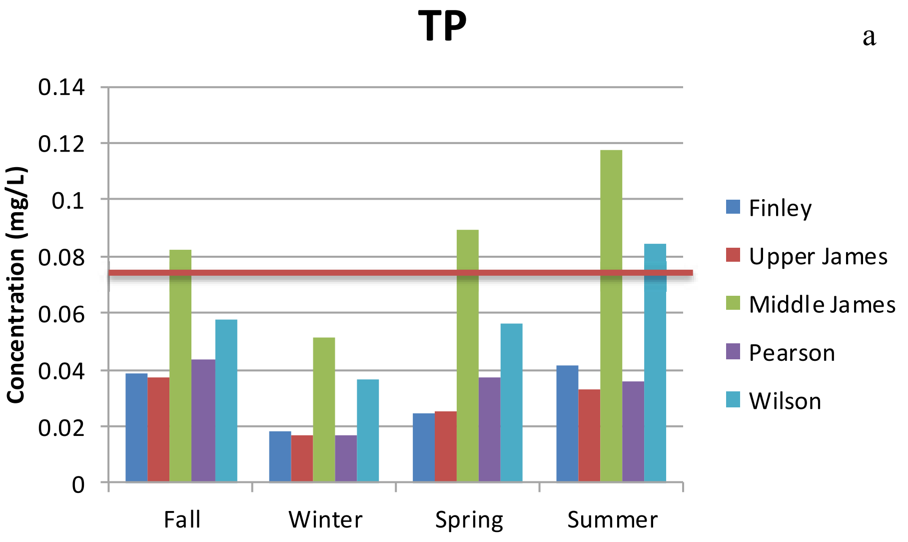


Figure 5.22a-b. Seasonal Influences on Total Nitrogen Concentrations during all flow types (a) and during baseflow (b).

Total phosphorus concentrations were expected to show seasonal variation at all sites because of this nutrient‘s association with TSS, which varies seasonally due to the presence or absence of storm events, as well as other factors. The most seasonal variation of TP concentrations occurred at the Middle James and Wilson Creek (Figure 5.23a-b). At these sites average TP concentration was much higher than at other sites most likely due to wastewater effluent from the SWWWTP, septic tanks, urban runoff, and suspended sediment from urbanization that occur in those sub-watersheds which are all delivered to streams by runoff from rain events. Total phosphorus concentrations at the Middle James and Wilson Creek sites were highest during the summer months when several storm events occurred and lowest during the winter when few storm events occurred. Lowest average concentration occurred during the winter at all other sites, as well. Total phosphorus concentrations may begin to increase during the spring as fertilizer is applied and continues to increase into the summer as fertilizer is reapplied. In the fall and winter, TP concentrations may decrease in the fall and winter as the growing season ends. Total phosphorus concentrations exceeded TMDL levels (0.075 mg/L) at the Middle James during spring, summer, and fall, as well as at Wilson Creek during the summer. Drainage area size and urbanization may be responsible for TP levels that exceed TMDL levels at those sites. However, when TP concentrations at baseflow were graphed, only concentrations at the Middle James site exceeded the TMDL TP levels during the summer months (Figure 5.23b). This figure shows how great an influence stormflow has on TP concentrations.



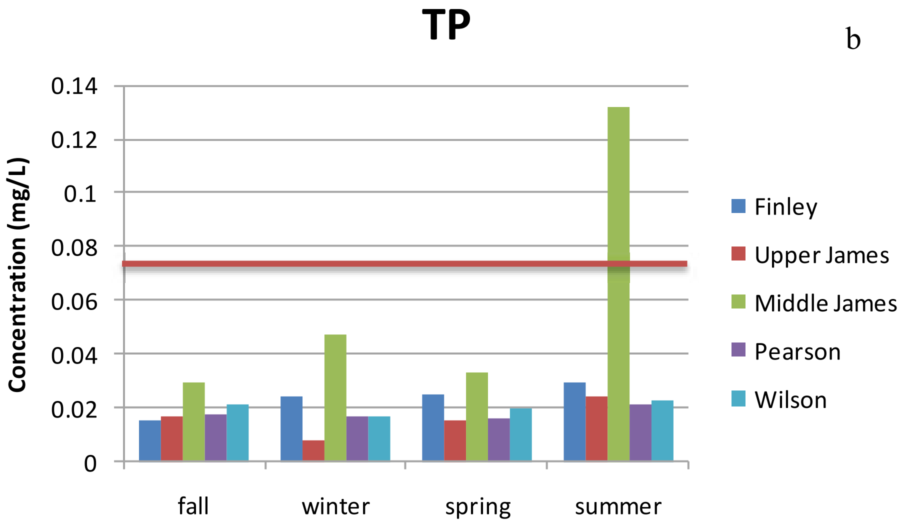


Figure 5.23a-b. Seasonal Influences on Total Phosphorus Concentrations during all flow types (a) and during baseflow (b).

Hysteresis Influence. Hysteresis was not expected to influence TN concentrations because nitrogen concentrations did not increase with discharge. Accordingly, little hysteresis influence on total nitrogen concentration was apparent. TN concentration was very similar during all flow types, indicating no influence of hysteresis (Figure 5.24a-e; table 5.14).

Total phosphorus concentrations were expected to be influenced by hysteresis since it is transported within the suspended load. Indeed, hysteresis effects on total phosphorus were more apparent (Figure 5.24a-e; table 5.15). Generally, TP concentration was lower during baseflow than stormflow. Total phosphorus was slightly higher during rising limb than falling limb at Finley, Middle James, and Wilson, indicating that TP increases with discharge during rising limb, but the supply becomes exhausted during falling limb. Hysteresis had little effect on TP concentration at Pearson and Upper James because concentration was not much different during rising limb than during falling limb.

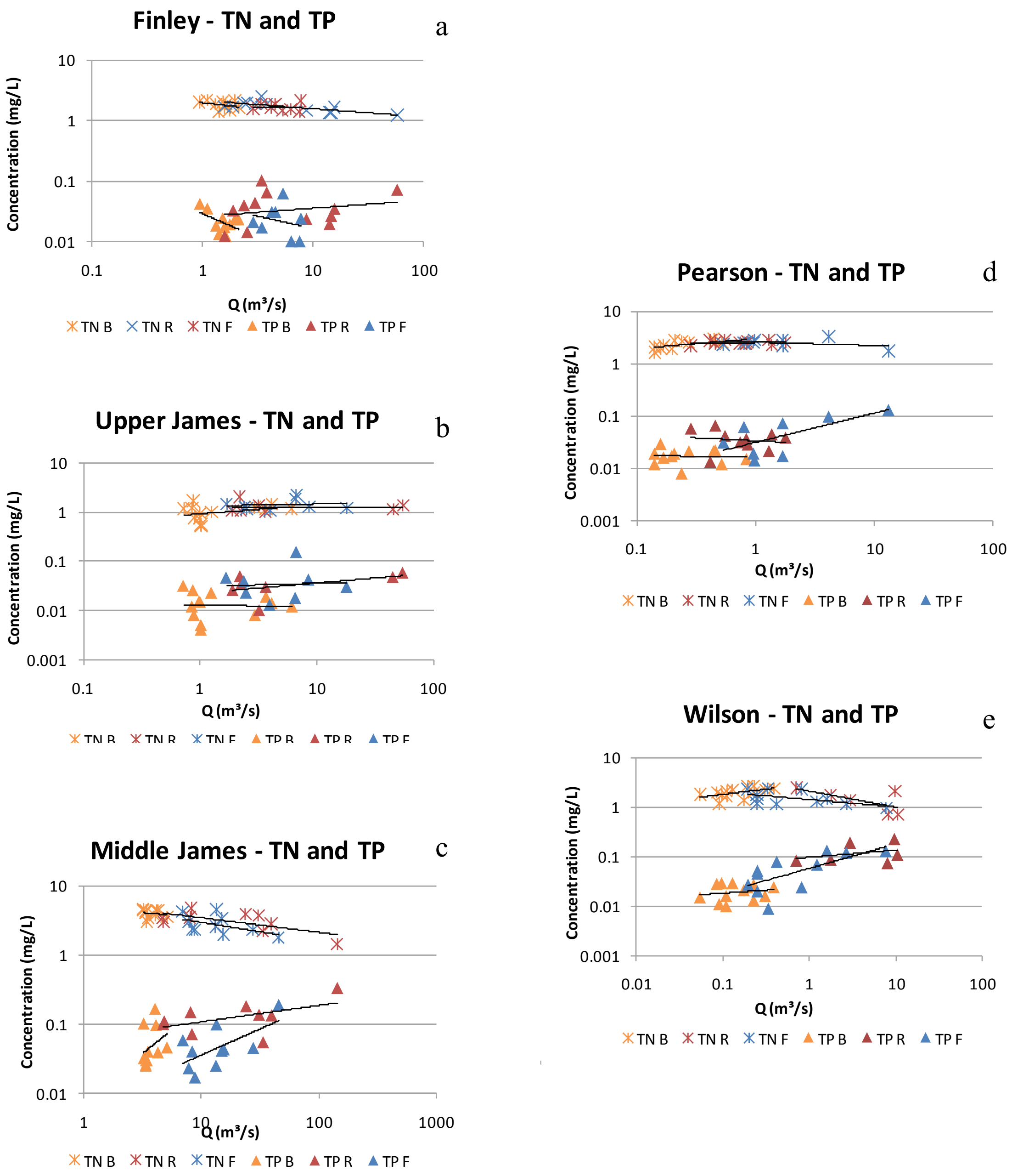


Figure 5.24a-e. Hysteresis Influence on Nutrient Concentration

Table 5.14. Regression Equation Relating TN to Hysteresis

Watershed	X	Y	n	bo	b1	R^2
Finley	Qi	TN – R	12	2.14	-0.13	0.55
Finley	Qi	TN - F	8	1.70	-0.01	0.00
Upper James	Qi	TN – R	7	1.27	0.00	0.00
Upper James	Qi	TN - F	8	1.32	0.04	0.02
Middle James	Qi	TN – R	9	5.61	-0.24	0.48
Middle James	Qi	TN - F	10	5.53	-0.27	0.28
Pearson	Qi	TN – R	8	2.51	0.02	0.03
Pearson	Qi	TN - F	10	2.56	-0.07	0.13
Wilson	Qi	TN – R	6	2.10	-0.33	0.44
Wilson	Qi	TN - F	11	1.42	-0.15	0.31

Table 5.15. Regression Equation Relating TP to Hysteresis

Watershed	X	Y	n	bo	b1	R^2
Finley	Qi	TP – R	12	0.03	0.13	0.05
Finley	Qi	TP - F	8	0.04	-0.41	0.06
Upper James	Qi	TP – R	7	0.02	0.20	0.25
Upper James	Qi	TP - F	8	0.03	0.06	0.00
Middle James	Qi	TP – R	9	0.06	0.24	0.27
Middle James	Qi	TP - F	10	0.006	0.75	0.40
Pearson	Qi	TP – R	8	0.03	-0.11	0.02
Pearson	Qi	TP - F	10	0.03	0.56	0.45
Wilson	Qi	TP – R	6	0.10	0.15	0.12
Wilson	Qi	TP - F	11	0.06	0.50	0.47

Anions. Anion concentrations were expected to be diluted by runoff due to their presence in soluble form. Anion concentrations tended to decrease slightly with discharge (Table 5.16 and Figures 5.25a-e). Some anions decreased in slope more markedly than others. For instance, chloride tended to have the highest negative slope of all anions measured possibly due to dilution or source depletion, while sulfate and nitrate tended to have slopes closest to zero. Fluoride concentrations had the most scatter about the trendline at all sites suggesting that discharge effects on fluoride varies and sources may be limited or erratic in supply.

Chloride concentrations at all sites were found to have a statistically significant negative relationship with discharge. Similarly, sulfate concentration at all sites, except the Upper James, showed a statistically negative relationship with discharge. At the Upper James, sulfate concentration showed no significant relationship with discharge. Nitrate concentration at Finley Creek, Upper James, and Middle James had a statistically significant negative relationship with discharge. However, nitrate concentration at Pearson Creek and Wilson Creek had a borderline statistically significant relationship with discharge. Fluoride concentration had a borderline statistically significant negative relationship with discharge at Finley Creek, Upper James, and Middle James. There was no significant relationship between fluoride concentration and discharge at Pearson Creek and Wilson Creek. Only a very small concentration of fluoride was measured in samples – orders of magnitude smaller than other anions because it is not as naturally abundant in the Ozarks as the other anions.

Table 5.16. Instantaneous Anion Concentration Equations

Watershed	Y	n	bo	b1	R^2	F Sig.	se
Finley	F^-	28	0.1251	-0.375	0.14	Weak	0.40
Upper James	F^-	28	0.0903	-0.234	0.11	Weak	0.35
Middle James	F^-	28	0.372	-0.334	0.17	Weak	0.33
Pearson	F^-	28	0.0891	-0.182	0.04	No	0.41
Wilson	F^-	28	0.158	-0.072	0.04	No	0.24
Finley	NO_3^-	28	1.5864	-0.111	0.27	Yes	0.08
Upper James	NO_3^-	28	0.8333	0.0993	0.31	Yes	0.07
Middle James	NO_3^-	28	5.8959	-0.326	0.50	Yes	0.15
Pearson	NO_3^-	28	1.9416	-0.084	0.10	Weak	0.04
Wilson	NO_3^-	28	1.2251	-0.181	0.20	Weak	0.24
Finley	SO_4^{2-}	28	8.4061	-0.098	0.04	Yes	0.05
Upper James	SO_4^{2-}	28	8.9333	-0.019	0.02	No	0.05
Middle James	SO_4^{2-}	28	30.559	-0.271	0.64	Yes	0.09
Pearson	SO_4^{2-}	28	9.6229	-0.073	0.40	Yes	0.11
Wilson	SO_4^{2-}	28	12.679	-0.298	0.66	Yes	0.15
Finley	Cl^-	28	16.699	-0.2	0.64	Yes	0.06
Upper James	Cl^-	28	14.721	-0.103	0.40	Yes	0.06
Middle James	Cl^-	28	69.609	-0.331	0.45	Yes	0.17
Pearson	Cl^-	28	18.725	-0.215	0.47	Yes	0.11
Wilson	Cl^-	28	22.746	-0.365	0.52	Yes	0.24

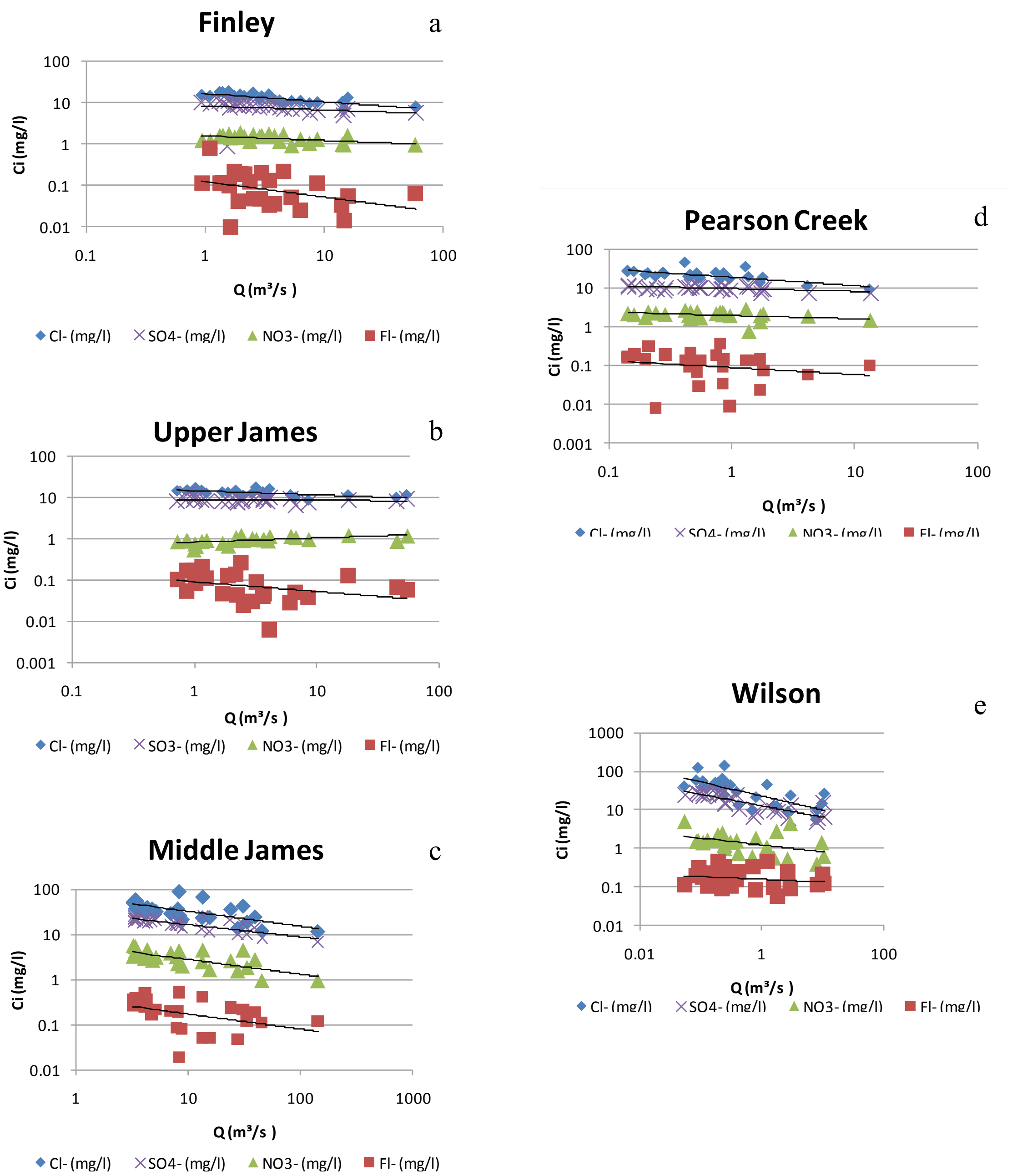


Figure 5.25a – e. Discharge Influence on Anion Concentrations

Seasonal Influence. Anion concentration was expected to vary by season at all sample sites. Chloride was especially thought to show seasonal variation because of application of road salts during winter (Gardner and Royer, 2010). Generally, concentration of all anions did show seasonal variation. Chloride and fluoride concentrations appeared to vary the most by season, while sulfate concentration remained fairly constant at all sites throughout the year.

Chloride concentrations during all flow types were highest at the Middle James and Wilson sites probably due to the influence of wastewater effluent and urban runoff. Chloride concentration remained steady throughout the year and was much lower at the Finley Creek, Upper James, and Pearson Creek sites. Chloride concentration during all flows was highest during winter at all sites (Figure 5.26a), possibly due to application of salts to roads during snow and ice conditions. Chloride concentration at the Wilson Creek site during the winter may be especially high because of road salt application in the City of Springfield. Baseflow chloride concentrations are presented in Figure 5.26b and show that stormflow had only a slight effect on chloride concentrations. Pearson Creek, Finley Creek, and Upper James all show constant chloride concentrations throughout all seasons. However, chloride concentrations during baseflow at Middle James and Wilson Creek are different during each season. Wilson had high baseflow chloride concentrations in winter; about the same concentration as during all flow types. Again, the high chloride concentrations during these months were likely due to the use of road salts in this sub-watershed.

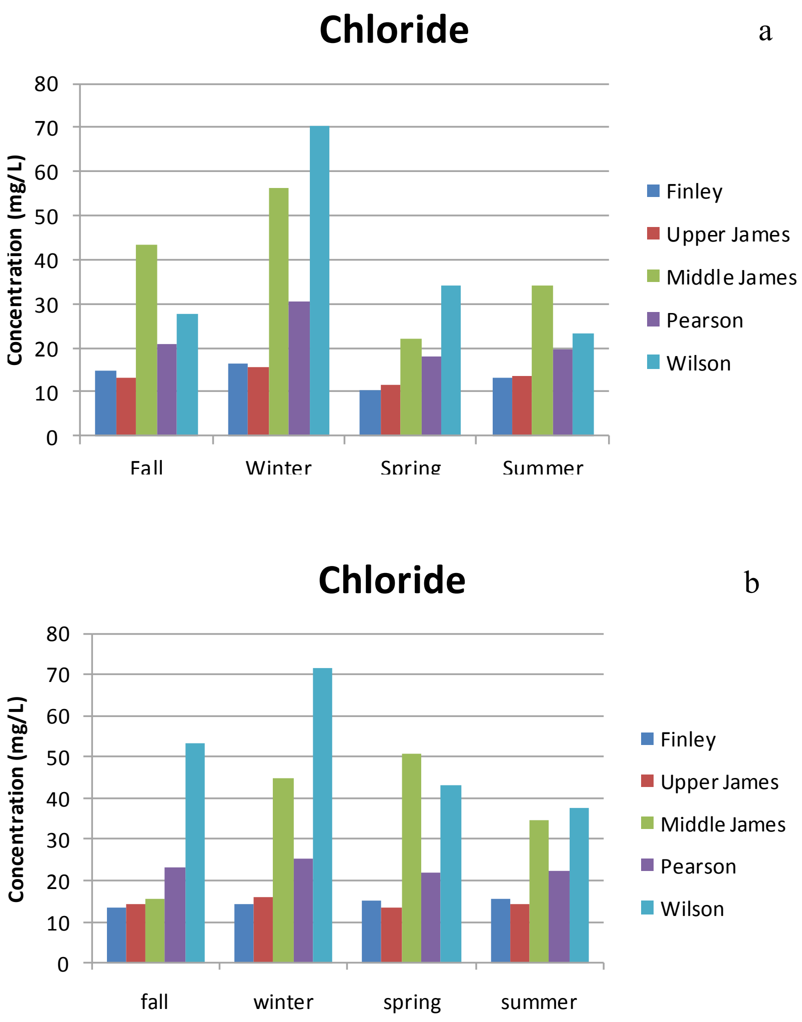


Figure 5.26a-b. Seasonal Influences on Chloride Concentrations during all flow types (a) and during baseflow (b).

Sulfate concentrations during all flow types were fairly constant at all sites throughout the year (Figure 5.27a). Sulfate concentrations were highest at the Middle James and Wilson Creek sites possibly due to wastewater effluent, septic tanks, and urban runoff from both sub-watersheds. While concentrations were highest at the Middle James site during summer, fall and winter concentrations were much higher at the Wilson Creek site during the spring. Sulfate concentrations during baseflow also appear to be fairly constant throughout the seasons (Figure 5.27b). However, baseflow sulfate concentrations at Wilson Creek are higher than concentrations during all flows showing that stormflow tends to dilute sulfate at this site.

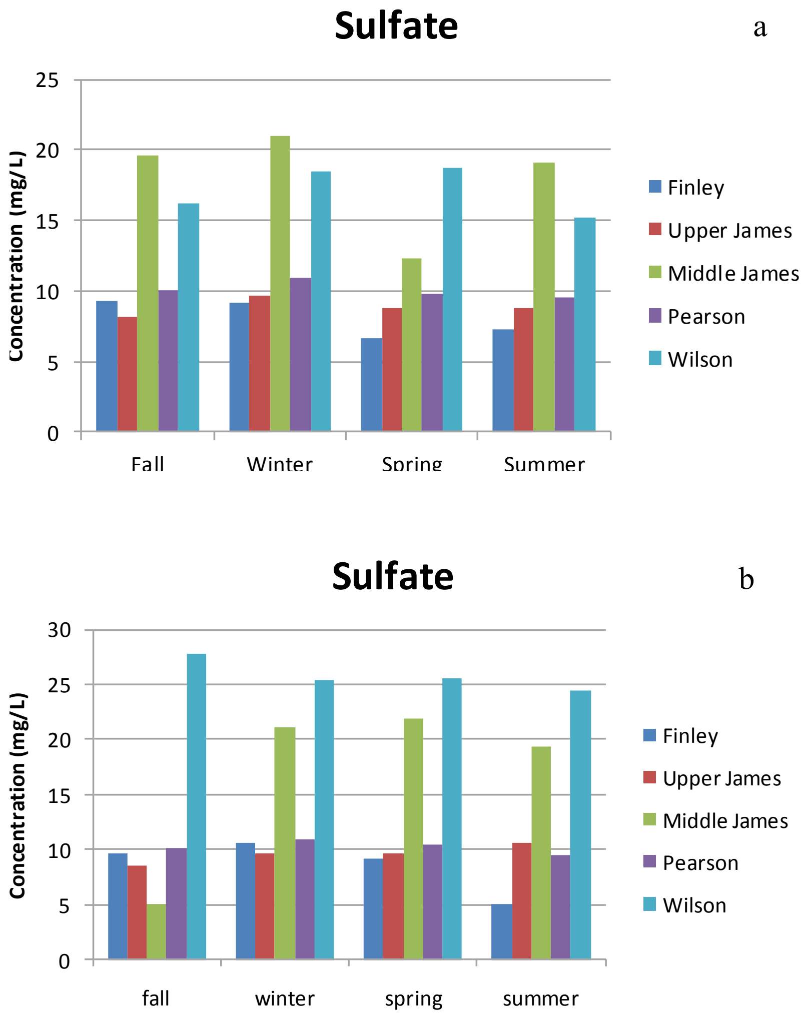


Figure 5.27a-b. Seasonal Influences on Sulfate Concentrations during all flow types (a) and during baseflow (b).

Average nitrate concentrations during all flow types were expected to be similar to that of average TN concentration because nitrate is the most common form of nitrogen found in streamwater (Rabalais, 2002). Like TN, nitrate concentrations during all flow types varied seasonally at all sites (Figure 5.28a). Concentrations were much higher at the

Middle James site than other sites during fall and winter due to the lack of uptake by vegetation. However, during spring and summer average nitrate concentrations at the Middle James were lower probably due to the increase in uptake of this nutrient by vegetation. Nitrate concentrations were lower than TN during all seasons, which was expected because the nitrate ion is included in the total nitrogen analysis; however, average nitrate concentrations were actually slightly higher than average TN concentration in some instances, possibly due to differences in analytical methods and/or analytical error.

Nitrate concentrations during baseflow were similar to those during all flows, except at the Middle James site (Figure 5.28b). Baseflow nitrate concentrations were much lower indicating nitrate was dependent on stormflow during these months. Additionally, baseflow concentrations were much higher during spring suggesting that most nitrate transport during the spring was not stormflow dependent.

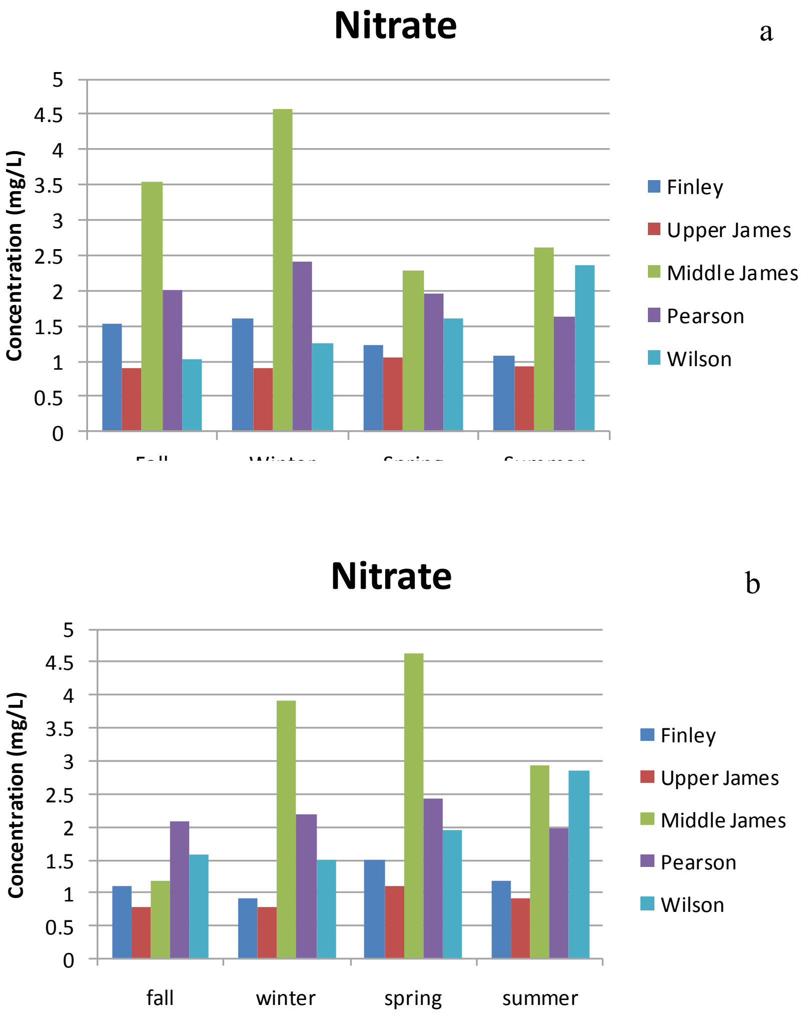


Figure 5.28a-b. Seasonal Influences on Nitrate Concentrations during all flow types (a) and during baseflow (b).

Fluoride concentrations during all flow types varied quite a lot seasonally among sample sites (Figure 5.29a). Concentrations at all sites were highest during the fall and lowest during either spring or summer. Concentrations during all flows were highest at Middle James and Wilson during fall, winter, and spring. Fluoride concentrations during baseflow were similar to those during all flow types, except for two very high concentration values during the fall at Middle James and during summer at Finley Creek.

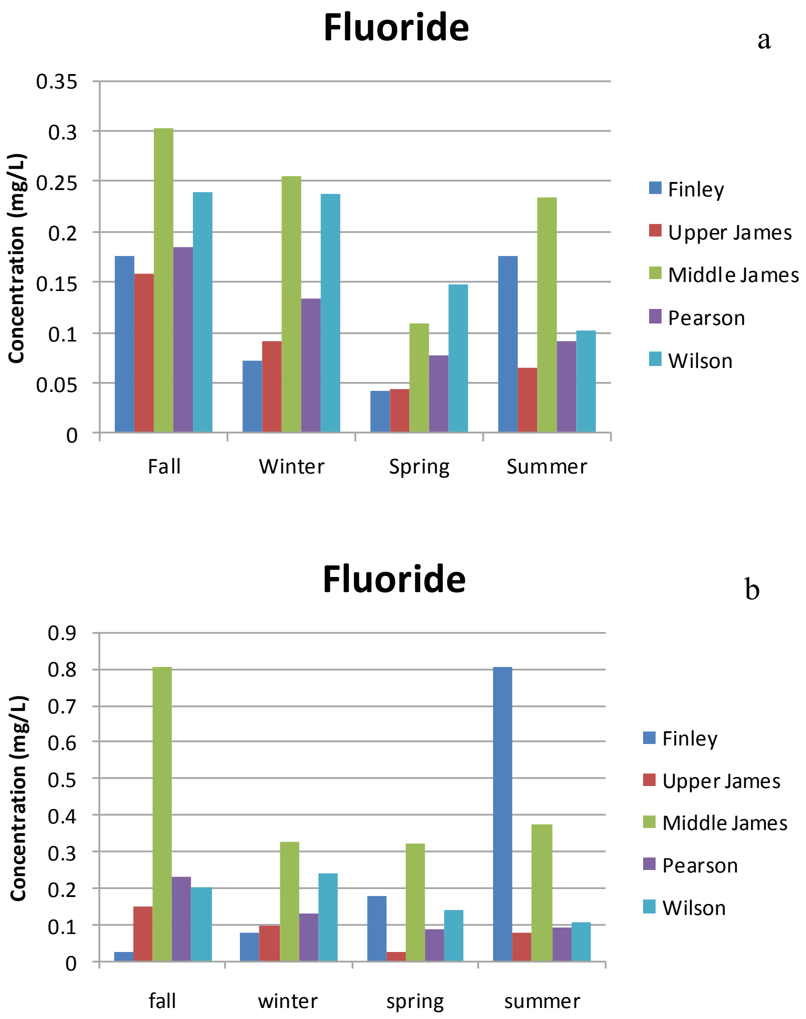


Figure 5.29a-b. Seasonal Influences on Fluoride Concentrations during all flow types (a) and during baseflow (b).

<u>Hysteresis Influence.</u> Hysteresis effects were weak at best for chloride, sulfate, and nitrate concentrations (Figures 5.30a-e and tables 5.17 – 18). Chloride concentration was higher during rising limb than falling limb at Middle James and Pearson, while sulfate concentration was slightly higher during rising limb at Middle James indicating some exhaustion during falling limb. Additionally, concentration of nitrate is higher on the rising limb than falling limb at Wilson (Figures 5.31a-e and tables 5.19 - 20). Chloride and sulfate concentration at Wilson Creek during falling limb were higher than

concentrations during rising limb, indicating that these anions were delivered to this stream from a distant source. Fluoride concentration varied more than the other anions. While little relationship between fluoride and discharge was observed, some slight hysteresis effects were seen. Fluoride concentrations were higher on the rising limb at Finley Creek and Pearson Creek. Some slight exhaustion may have occurred during falling limb. However, at Wilson Creek, fluoride concentration was higher on the falling limb.

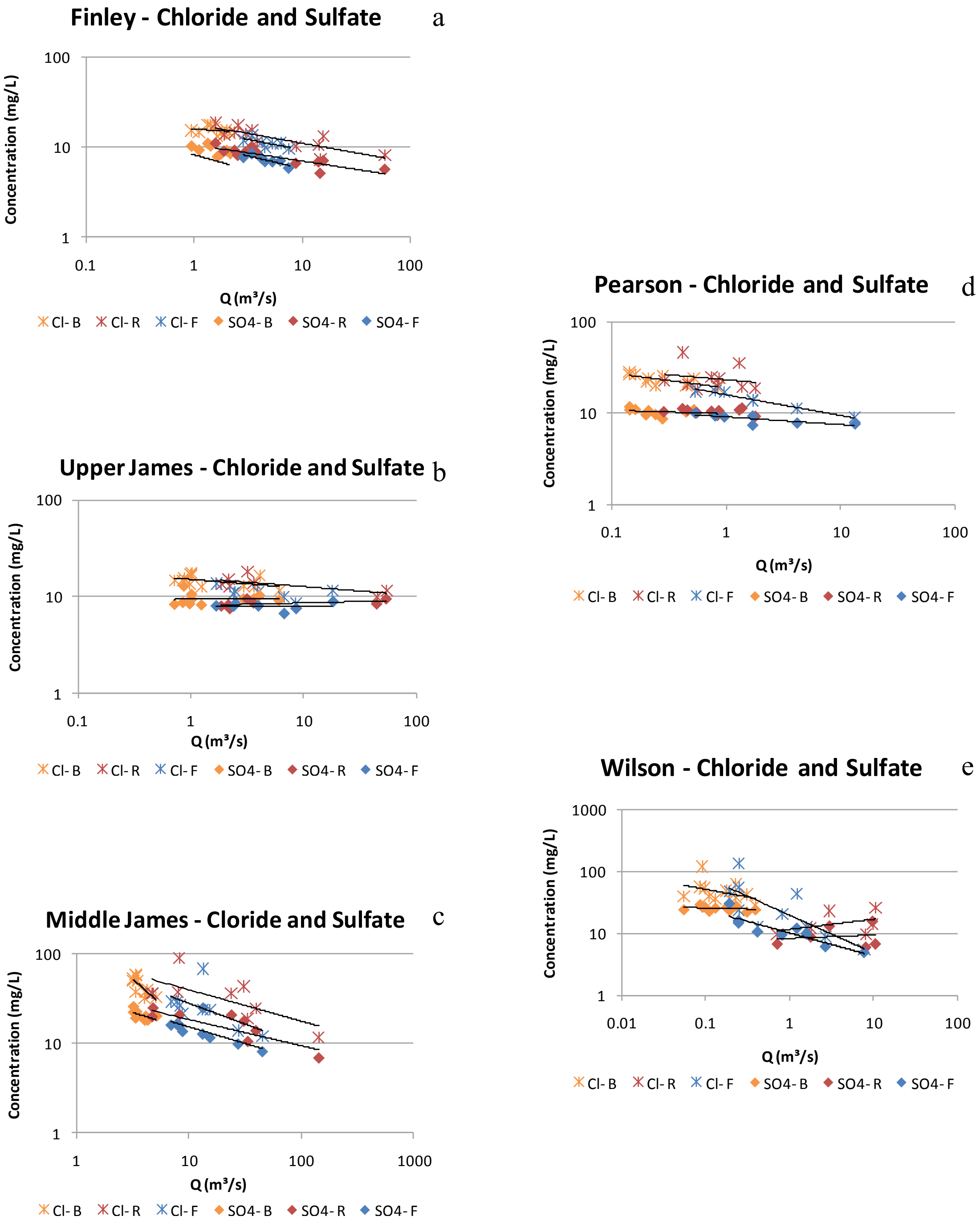


Figure 5.30a – e. Hysteresis Influence on Chloride and Sulfate

Table 5.17. Regression Equation Relating Cl- to Hysteresis

Watershed	X	Y	n	bo	b1	R^2
Finley	Qi	Cl – R	12	18.1	-0.21	0.66
Finley	Qi	Cl - F	8	15.9	-0.23	0.50
Upper James	Qi	Cl – R	7	15.7	-0.09	0.51
Upper James	Qi	Cl - F	8	12.3	-0.08	0.23
Middle James	Qi	Cl – R	9	89.9	-0.35	0.50
Middle James	Qi	Cl - F	10	82.3	-0.47	0.35
Pearson	Qi	Cl – R	8	23.2	-0.11	0.04
Pearson	Qi	Cl - F	10	15.9	-0.23	0.97
Wilson	Qi	Cl – R	6	11.7	0.16	0.17
Wilson	Qi	Cl - F	11	19.7	-0.61	0.59

Table 5.18. Regression Equation Relating SO_4 -to Hysteresis

Watershed	X	Y	n	bo	b1	R^2
Finley	Qi	SO_4 – R	12	10.7	-0.18	0.75
Finley	Qi	SO_4 - F	8	11.0	-0.28	0.72
Upper James	Qi	SO_4 – R	7	8.08	0.03	0.23
Upper James	Qi	SO_4 - F	8	7.88	0.00	0.00
Middle James	Qi	SO_4 – R	9	36.6	-0.30	0.69
Middle James	Qi	SO_4 - F	10	36.2	-0.37	0.51
Pearson	Qi	SO_4 – R	8	10.4	-0.03	0.06
Pearson	Qi	SO_4 - F	10	9.10	-0.08	0.59
Wilson	Qi	SO_4 – R	6	8.33	0.05	0.02
Wilson	Qi	SO_4 - F	11	10.2	-0.37	0.80

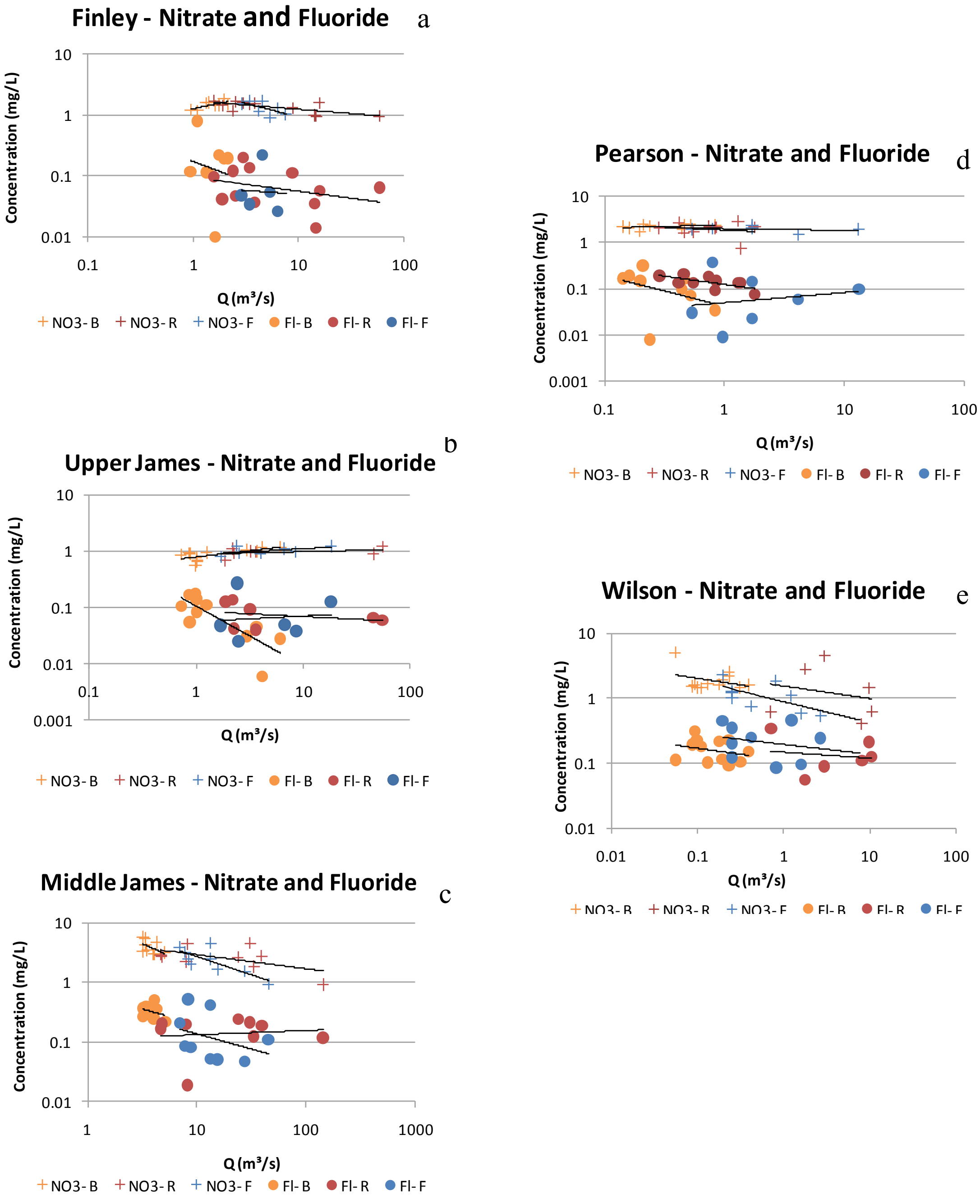


Figure 5.31a – e. Hysteresis Influence on Nitrate and Fluoride

Table 5.19. Regression Equation Relating NO_3^- to Hysteresis

Watershed	X	Y	n	bo	b1	R^2
Finley	Qi	NO_3 – R	12	1.72	-0.14	0.50
Finley	Qi	NO_3 - F	8	2.63	-0.45	0.40
Upper James	Qi	NO_3 – R	7	0.88	0.05	0.15
Upper James	Qi	NO_3 - F	8	0.86	0.11	0.30
Middle James	Qi	NO_3 – R	9	5.02	-0.24	0.32
Middle James	Qi	NO_3 - F	10	11.1	-0.61	0.60
Pearson	Qi	NO_3 – R	8	1.87	-0.12	0.04
Pearson	Qi	NO_3 - F	10	2.01	-0.04	0.08
Wilson	Qi	NO_3 – R	6	1.54	-0.19	0.05
Wilson	Qi	NO_3 - F	11	0.88	-0.32	0.41

Table 5.20. Regression Equation Relating Fl^- to Hysteresis

Watershed	X	Y	n	bo	b1	R^2
Finley	Qi	Fl – R	12	0.09	-0.23	0.12
Finley	Qi	Fl - F	8	0.07	-0.12	0.00
Upper James	Qi	Fl – R	7	0.09	-0.09	0.08
Upper James	Qi	Fl - F	8	0.06	0.10	0.01
Middle James	Qi	Fl – R	9	0.11	0.07	0.01
Middle James	Qi	Fl - F	10	0.44	-0.51	0.12
Pearson	Qi	Fl – R	8	0.124	-0.36	0.43
Pearson	Qi	Fl - F	10	0.05	0.22	0.04
Wilson	Qi	Fl – R	6	0.15	-0.10	0.02
Wilson	Qi	Fl - F	11	0.19	-0.15	0.05

Comparison to Long Term Data

The United States Geological Survey also collects water quality samples at the gaging stations used for this study. A comparison between instantaneous constituent concentrations collected by the USGS and from this study was made to determine if sample collection and analyses were similar. The range of instantaneous discharges for the USGS data and for this study were similar indicating that water samples were collected by the USGS during a wide variety of flow types. It should be noted that there were some discrepancies between sample collection protocol for the USGS and this study. For instance, the USGS has a sample collection schedule that is created in advance, without regard to changes in flow conditions. This study also sampled baseflow at scheduled times, but used flexible storm chasing to get runoff samples. Additionally, the USGS does not analyze for the same constituents at each site that is sampled; likewise, each sample site has a different period of sample record. Some sites are sampled more regularly than others. Additionally, the USGS collection and analytical methods may differ from the methods used in this study, which may affect the concentration data. USGS data had many gaps in data, as well.

TDS Comparison. Concentration regression equations for TDS as measured by the USGS were generally similar to that of this study at Finley Creek and Middle James sites (Figure 5.32a-b). The expectation was that trendline slopes from both data sets would both be slightly negative. Both data sets showed Middle James having the steepest slope (~-0.2), followed by Finley Creek (~-0.1). There appeared to be more scatter about the trendline for this study at both sites. The R^2 value and slope were relatively high for both Finley Creek and Middle James data sets, indicating that there is a good relationship between discharge and TDS concentration at these sites. Even though the USGS R^2 value for Finley Creek and Middle James were much higher than that of this study, which could be due to larger sample size, the trend that TDS concentration decreases with discharge is still apparent.

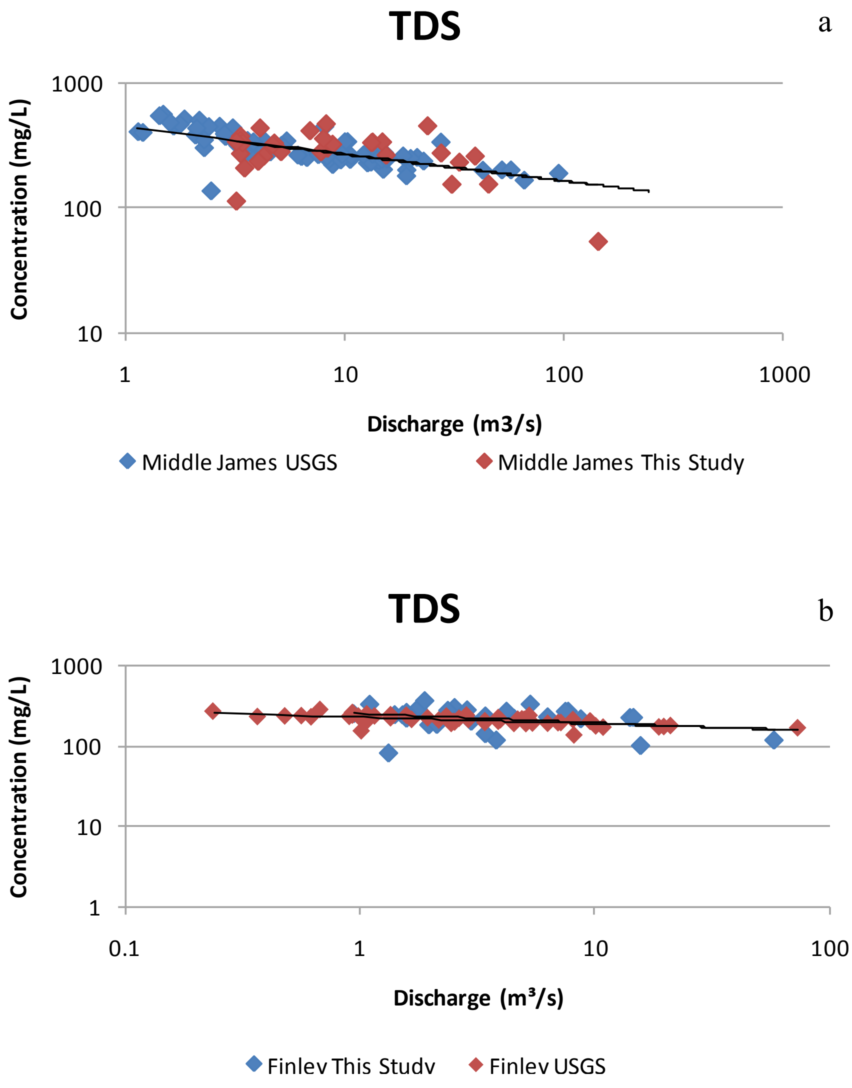


Figure 5.32a-b. Comparison of Total Dissolved Solids Concentrations

TSS Comparison. Data from both USGS and this study collected at the Middle James sites were compared (Figure 5.33). The trendline from this study had a strong positive slope, relatively high R^2 values, and relatively little scatter. However, the USGS equation had a much lower slope compared to the slope from this study and lower R^2 values. It should be noted that USGS data is anchored by low flow events because they do not storm chase and collect samples on a set interval schedule. However, data from this study shows that there is a strong positive relationship between TSS and discharge. Data from the Middle James site had a positive slope near 1.0 and R^2 value above 0.5 indicating that there is an especially strong relationship between TSS and discharge.

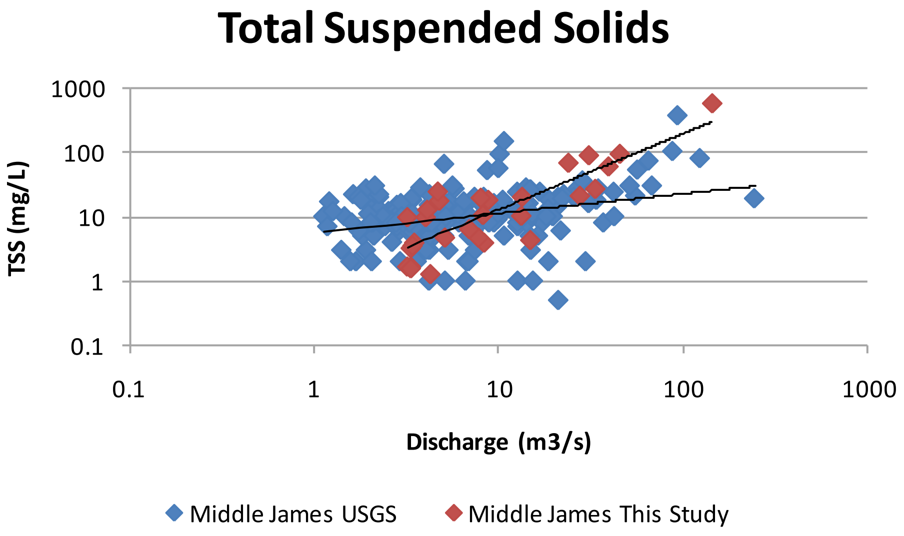


Figure 5.33. Comparison of Total Suspended Solids Concentrations

Total Nitrogen Comparison. Data from Finley Creek and Middle James sites were compared to TN data from USGS (Figure 5.34a-b). Due to the soluble nature of TN, it was expected to slightly decrease with discharge, which was what was exhibited at Middle James with both data sets (slopes of about -0.3 and R^2 values near 0.5). The equation from the USGS data at Finley Creek had a slope of near zero, R^2 value near zero, and quite a bit of scatter compared to the slightly negative slope, R^2 value of about 0.3 of data from this study.

Middle James TN data from both USGS and this study showed a strong negative relationship with discharge, which could be due to an influx of nitrogen from upstream sources (e.g. wastewater effluent and septic tanks) and surrounding agricultural land. Equations from both USGS data and data from this study show there is little relationship between TN concentration and discharge at the Finley Creek Site.

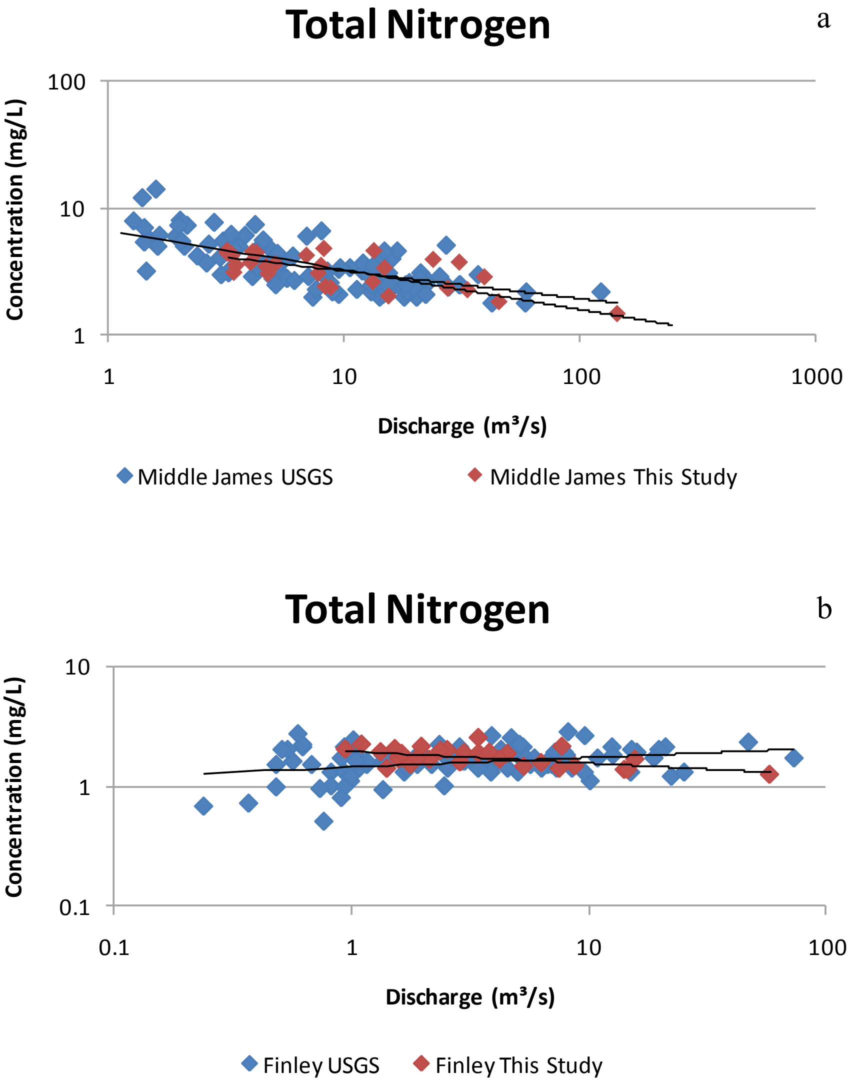


Figure 5.34a-b. Comparison of Total Nitrogen Concentrations

Total Phosphorus Comparison. Middle James site data from this study were compared to two USGS data sets: pre-phosphorus removal upgrade and post-phosphorus removal upgrade in order to address the reduction of phosphorus concentration in the SWWWTP effluent (Figure 5.35). Behavior of TP was expected to parallel that of TSS and increase with discharge because phosphorus tends to adsorb onto fine sediment particles. The TP concentration comparisons between USGS data and this study were interesting because the USGS trendline equations had negative slopes while the trendline from this study had a positive slope.

The pre-upgrade USGS data set had a strong negative slope (-0.65) and a high R^2 value indicating a strong negative relationship with discharge, which was contrary to what would be expected for TP concentrations. Post-upgrade trendline showed a slightly negative slope which shows that improvements to the SWWWTP have successfully removed phosphorus from the wastewater effluent because the concentration values were much lower than data points from before improvements were implemented.

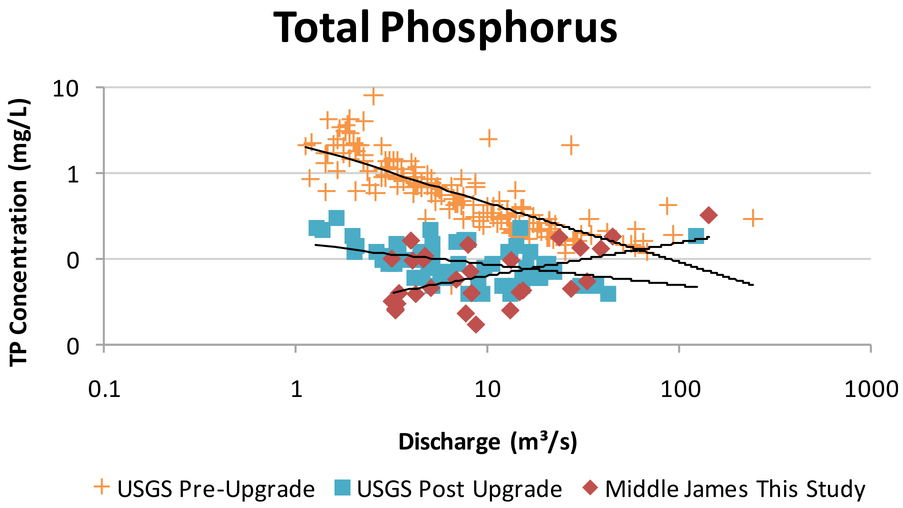
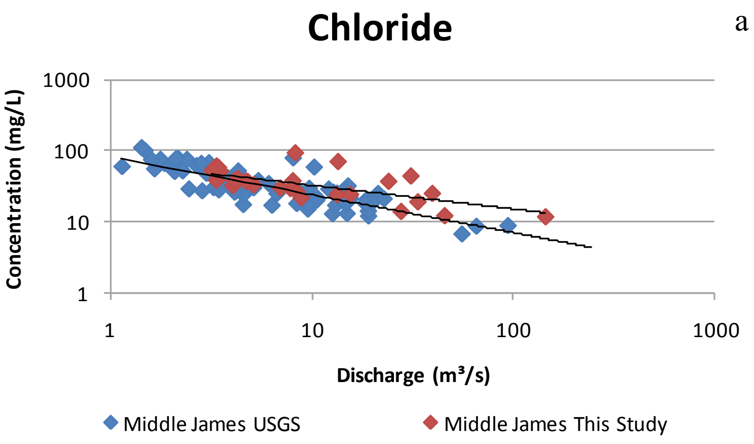


Figure 5.35. Comparison of Total Phosphorus Concentrations

Anion Comparison. Anion data were collected by the USGS at most sites used in this study, however, only chloride and sulfate data are compared to data from this thesis study (Figures 5.35a-b and 5.36a-b). Overall, most of the anion trends found in this study are comparable to USGS concentration trends. The expected trend, a general negative relationship with discharge, was demonstrated, though some anions have a stronger negative relationship than others. Anions behaved differently among sites, as well. The strongest relationship between anion concentration and discharge was always at the Middle James site.

The chloride data trends for both this study and USGS data are negative slopes, however, there is a large range among slope values (Figure 5.35). Most of the R^2 values are relatively high (~0.5). The slopes from Finley Creek site data are similar for both USGS and this study. The slopes at Middle James site are the steepest indicating the relationship between discharge and chloride concentrations from both data sets is stronger at this site.



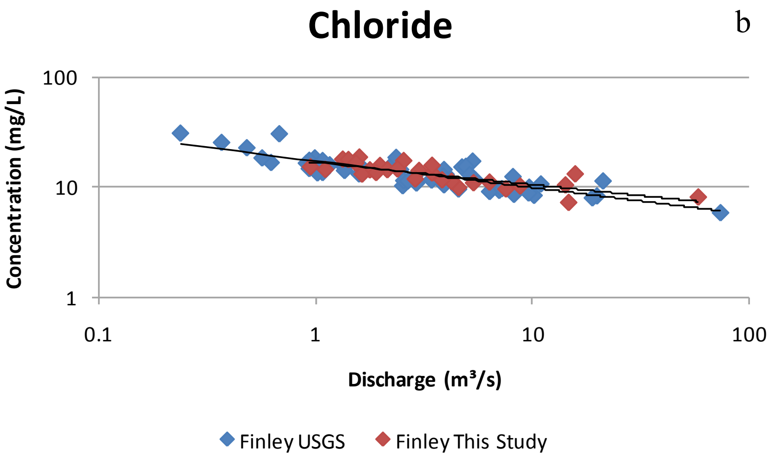


Figure 5.36a-b. Comparison of Chloride Concentrations

Sulfate concentration data from both USGS and this study had similar trends, as well (Figure 5.37). Data from this thesis study and from the USGS at the Middle James site both had steep negative slopes (~-0.3). Additionally, both data sets yielded relatively high R^2 values indicating a strong negative relationship between sulfate concentration and discharge at the Middle James site. Data collected during this study and by the USGS at the Finley Creek site had little slope and a low R^2 value indicating little relationship between discharge and sulfate concentration at this sites.

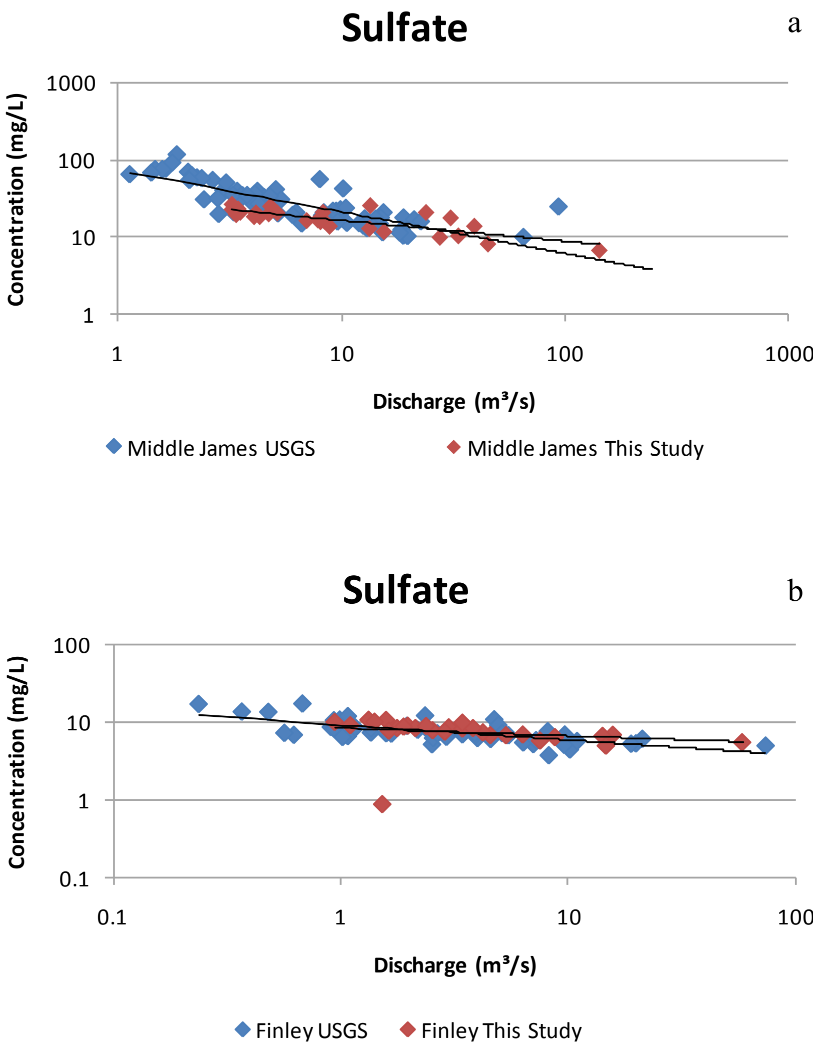


Figure 5.37a-b. Comparison of Sulfate Concentrations

Table 5.21. Equation Comparisons for Finley Creek

Constituent	Agency	Collection Period	n	bo	b1	R^2
TDS	USGS	6/01-3/10	54	230.78	-0.084	0.48
	OEWRI			255.72	-0.114	0.09
TSS	USGS	6/01-3/10	17	21.022	0.0524	0.01
	OEWRI			2.2302	0.654	0.30
TN	USGS	6/01-3/10	96	1.4438	0.0749	0.09
	OEWRI			1.9548	-0.099	0.30
TP	USGS	6/01-3/10	58	0.1368	-0.074	0.02
	OEWRI			0.0213	0.1414	0.05
Cl^-	USGS	6/01-3/10	53	17.346	-0.243	0.72
	OEWRI			16.699	-0.2	0.65
SO_4^{2-}	USGS	6/01-3/10	80	5.4582	0.046	0.02
	OEWRI			8.4061	-0.098	0.04

Table 5.23. Equation Comparisons for Middle James

Constituent	Agency	Collection Period	n	bo	b1	R^2
TDS	USGS	7/77-3/10	203	394.12	-0.204	0.54
	OEWRI			432.71	-0.211	0.23
TSS	USGS	7/77-3/10	146	5.6297	0.3456	0.14
	OEWRI			0.8515	1.1839	0.70
TN	USGS	7/77-3/10	152	6.9767	-0.351	0.46
	OEWRI			5.2627	-0.218	0.49
TP	USGS (Post Update)	7/77-3/10	56	0.1523	-0.24	0.19
	OEWRI			0.0263	0.3857	0.25
Cl^-	USGS	7/77-3/10	194	64.715	-0.559	0.68
	OEWRI			69.609	-0.331	0.45
SO_4^{2-}	USGS	7/77-3/10	194	38.656	-0.366	0.40
	OEWRI			30.559	-0.271	0.64

Summary of Water Quality Trends

A summary of major influences on constituent concentration is provided in Table 5.23. The constituents with the strongest positive discharge trends were TSS (Upper James, Middle James, and Pearson), and TP (Upper James, Middle James, Pearson, and Wilson). Because TSS and TP concentrations have strong discharge relationships at most of the sites these two constituents probably have the strongest discharge/concentration relationship of all constituents. Likewise, constituents (followed by sites) with the strongest negative discharge trends were TDS (Middle James and Wilson), DIC (Wilson), TN (Middle James), nitrate (Middle James), sulfate (Wilson), and chloride (Middle James and Wilson).

The constituents with the strongest hysteresis influence are TDS (Wilson), TSS (Finley, Upper James, Middle James, and Wilson), TIC, (Wilson), TOC (Pearson and Wilson), DOC (Wilson), and TP (Finley, Middle James, Pearson). Suspended materials and associated constituents (TOC and TP) are expected to exhibit counter-clockwise hysteresis due to their relationship with storm runoff. Because hysteresis influences on TSS, TOC, and TP are strong at several sites it can be concluded that these constituent concentrations are greatly affected by hysteresis.

Constituents influenced strongly by seasonal changes are TSS (Middle James), TOC (Middle James, Pearson, and Wilson), DOC (Pearson and Wilson), TP, Middle James and Wilson), fluoride (all sites), nitrate (Middle James), sulfate (Middle James and Wilson), and chloride (Middle James and Wilson). Constituents that are expected to exhibit a strong relationship to seasonal changes are those that are related to plant growth (TOC and DOC, nutrients). Concentration of TOC and DOC in streamwater is partially dependent upon allochthonous inputs of organic material. Algae growth, which varies throughout the year, also influences TOC and DOC concentrations. Anion concentration, especially fluoride, appears to be influenced by seasonal change, as well.

Constituent concentrations at the Middle James and Wilson Creek sites tend to show stronger trends than the other sites. The relatively large drainage area of the Middle James and tributary influence are probably major reasons why discharge and hysteresis trends are so apparent at this site. Particulate and dissolved material from the urban area that makes up the Wilson Creek sub-watershed is possibly responsible for the strong trends at this site. The flashy nature of Wilson Creek may magnify discharge and hysteresis effects, as well.

Table 5.23. Influences on Constituent Concentration

	Finley			Upper James			Middle James			Pearson			Wilson		
	Season	**Hyst.**	**Q**	**Season**	**Hyst.**	**Q**	**Season**	**Hyst.**	**Q**	**Season**	**Hyst.**	**Q**	**Season**	**Hyst.**	**Q**
TDS	W	W	-	W	W	-	W	W	- -	W	W	0	W	S	- -
TSS	W	S	+	W	S	+ +	S	S	+ +	W	W	+ +	S	S	+
TIC	0	0	0	0	0	-	0	0	0	0	0	-	0	S	-
DIC	W	W	0	W	W	0	S	W	-	S	S	-	S	S	- -
TOC	0	0	-	0	0	-	0	0	0	0	0	-	0	0	- -
DOC	W	W	0	W	W	0	W	W	0	S	W	-	S	S	-
TN	W	0	-	W	0	0	W	0	- -	0	0	0	0	W	-
TP	W	S	+	W	W	+ +	S	S	+ +	W	S	++	S	W	+ +
Cl^-	0	0	-	0	0	-	S	W	- -	W	W	-	S	W	- -
SO_4^{2-}	0	0	0	0	0	0	S	W	-	0	0	0	S	W	- -
NO_3^-	W	0	-	0	0	0	S	W	- -	W	0	0	W	W	-
Fl^-	S	W	- -	S	0	-	S	W	- -	S	W	-	S	W	0

Key: W – weak, S – strong, 0 – no relationship; - - (very negative), - (negative), 0 (no relationship), + (positive), + + (very positive)

Mass Load Calculation/Mean Annual Yield

Mean annual loads for each constituent were calculated using the flow-duration rating-curve method outlined in Chapter Four. Load value indicates the total mass of a particular constituent being transported out of a watershed via rivers. Yield values are loads normalized by drainage area and indicate the rate of supply per unit area of a watershed.

Dissolved Solids and Suspended Solids Loads. Dissolved solids (DS) loads are expected to be larger than suspended solids (SS) loads due to the continuous input of soluble material from chemical weathering of limestone in the Ozarks (Walling, 1984). Pearson Creek sub-watershed had, by far, the highest DS yield perhaps due to the cluster springs draining to the sample site (Table 5.24 and Figure 5.38). The DS yield for this sub-watershed was about twice that of the next largest yield (Middle James at 92 Mg/km^2/yr). Wilson Creek, Finley Creek, and Upper James sub-watersheds followed, all having yields of about 70 Mg/km^2/yr. The Middle James had the highest mean annual yield of SS (87 Mg/km^2/yr). This yield is approximately twice that of the Upper James. Wilson Creek and Pearson Creek sub-watersheds had SS yields of 35 and 18 Mg/km^2/yr, respectively. Finley Creek sub-watershed had the lowest mean annual yield of SS at 9 Mg/km^2/yr. The annual yields of SS and DS yields are almost equal in the Middle James sub-watershed. The Pearson Creek and Finley Creek sub-watersheds have the most difference between SS and DS yield.

The sub-watershed that had the highest percentage of suspended solids out of the total solids loads (DS and SS loads added together) was the Middle James River (49% suspended solids), followed by the Upper James (39%). This is to be expected because of the cumulative effect upstream tributaries have on the concentration of suspended material in the main stem.

Table 5.24. Solids Loads (Mg/km^2)

Sub-watershed	Ad	TDS	TSS	Total Solids	% TSS
UJ	637	39,167	25,252	64,419	39
F	676	46,570	6,103	52673	12
MJ	1197	109,720	104,520	214,240	49
P	54.4	8,585	977	9,562	10
W	46.1	3,369	1,391	4,760	29

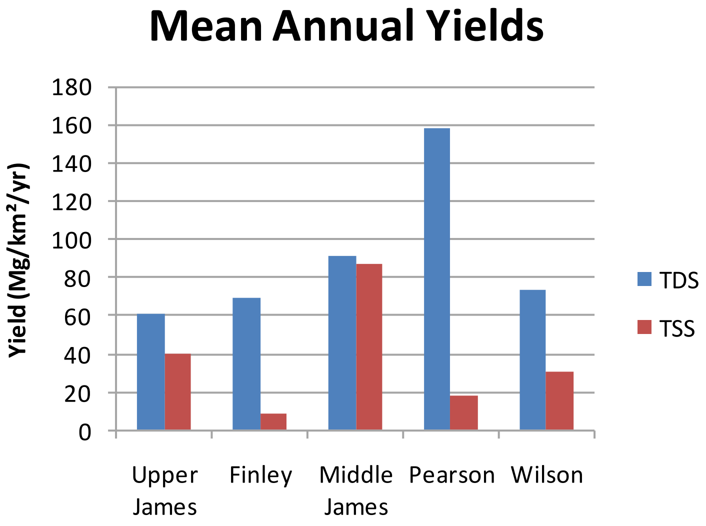


Figure 5.38. Mean Annual Solids Yields by Site

Carbon Loads. Carbon loads, particularly inorganic carbon, were expected to be abundant in the James River and its tributaries due to dissolved carbonate inputs. Total inorganic carbon mean annual yields from all sub-watersheds were much higher than total organic carbon yields most likely due to the abundance of soluble carbonate rock in the Ozarks (Table 5.25 and Figure 5.39). Total inorganic carbon yields were highest at the Pearson Creek sub-watershed (20 Mg/km^2/yr), which was much higher than the next highest yield (from the Wilson Creek and Middle James sub-watersheds). Wilson Creek and Middle James sub-watersheds both had yields of about 13 Mg/km^2/yr followed by Finley Creek and Upper James sub-watersheds, which had similar yields (10 and 9.2 Mg/km^2/yr, respectively).

Wilson Creek sub-watershed had the highest total organic carbon yield (2.7 Mg/km^2/yr) followed by Pearson Creek, Middle James, Upper James, and Finley Creek sub-watersheds. Pearson Creek and Middle James had almost identical total organic carbon yields at 1.5 and 1.6 Mg/km^2/yr, respectively. Upper James and Finley Creek had almost identical total organic carbon yields, as well at 0.8 and 0.7Mg/km^2/yr, respectively. Dissolved inorganic and organic carbon yields exhibited a relationship similar to the total carbon yields with DIC yields at about 10 times those of DOC. Pearson Creek sub-watershed had the most difference between inorganic carbon and organic carbon yields for both total carbon and dissolved fractions.

Table 5.25. Carbon Loads (Mg/yr)

Sub-watershed	TIC	TOC	Total	% TOC	DIC	DOC	Total	% DOC
UJ	5,883	508	6,391	7.9	5,853	398	6,251	6.4
F	6,962	470	7,432	6.3	6,823	351	7,174	4.9
MJ	14,954	1,778	16,732	11	14,911	986	15,897	6.2
P	1,100	87	1,187	7.3	1,077	72	1,149	6.3
W	621	123	744	17	589	77	666	12

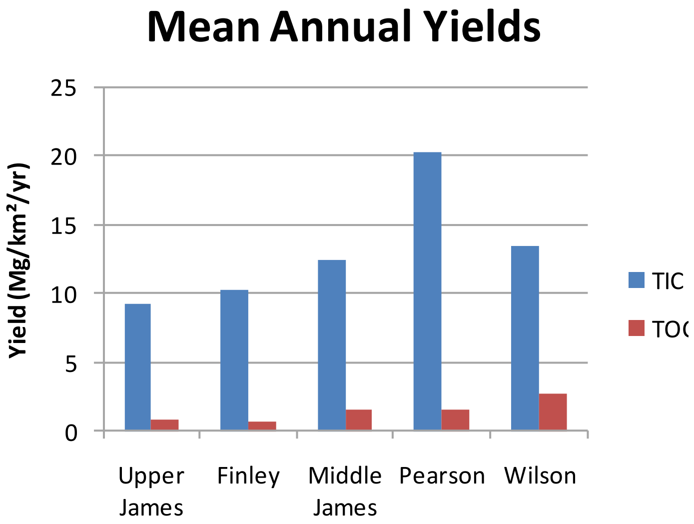


Figure 5.39. Mean Annual Total Carbon Yields by Site

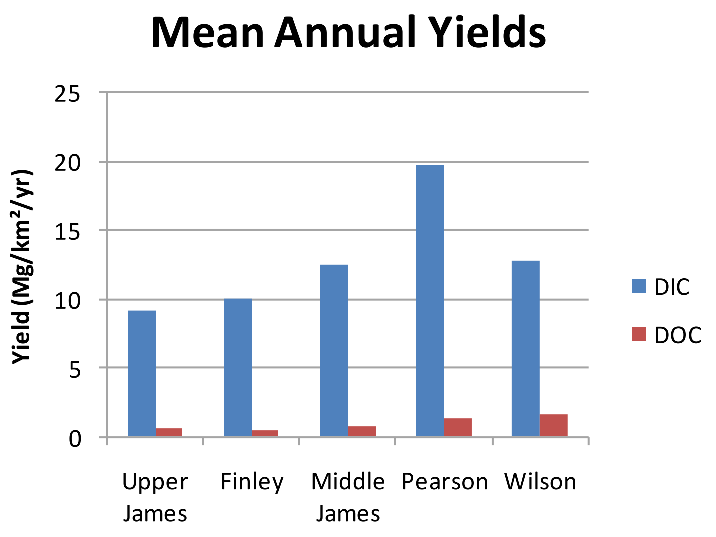


Figure 5.40. Mean Annual Dissolved Carbon Yields by Site

Nutrient Loads. Nitrogen is naturally more abundant in the atmosphere and on the earth than phosphorus (Vézie ,et al., 2002). As expected, TN yields were much higher than TP yields (Table 5.26 and Figure 5.41). Pearson Creek sub-watershed had the highest yield of TN (1.4 Mg/km^2/yr) which is probably due to the soluble nature of nitrogen and the influence of the spring recharge near the sample site. Middle James sub-watershed had the next highest TN yield followed by Wilson Creek sub-watershed. The Upper James and Finley Creek sub-watersheds had nearly identical TN yields.

Sub-watersheds with high TSS yields were also expected to have high TP yields because phosphorus is often transported as part of the suspended load. Middle James and Wilson Creek sub-watersheds had the highest TP yields as well as high TSS yields. However, the Upper James sub-watershed had a higher TSS yield than Wilson Creek indicating that TSS yield may be more related to tributary influence on the mainstem of the James and TP yields may be more influenced by urban influences since Wilson Creek had a higher TP yield. Pearson Creek and Upper James sub-watersheds had the next highest TP yields followed by Finley Creek, which had a very small yield further indicating that TP is more influenced by urban area.

Table 5.26. Nutrient Loads

Sub-watershed	TN (Mg/km^2)	TP (Mg/km^2)
UJ	344	12
F	371	8.0
MJ	1,302	64
P	80	2.0
W	32	3.0

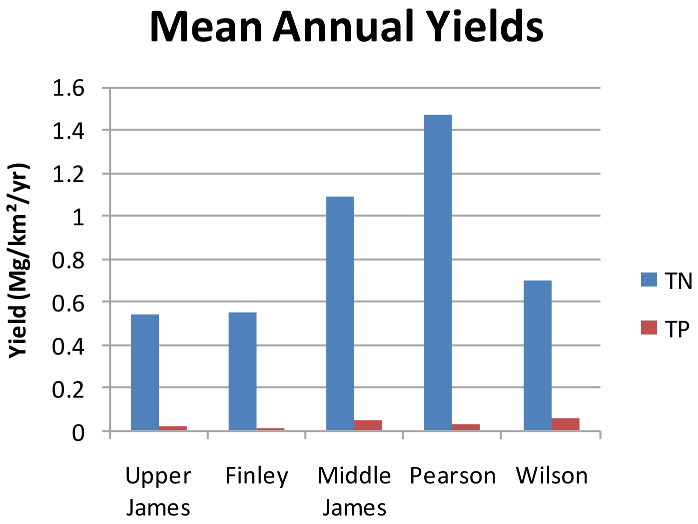


Figure 5.41. Mean Annual Nutrient Yields by Site

Anion Loads. Chloride and sulfate yields were highest from sub-watersheds that have a large amount of urban influence including Middle James, Wilson Creek, and Pearson Creek (Table 5.27 and Figures 5.42 and 5.43). Chloride yields were approximately twice that of sulfate at these sites. Upper James and Finley Creek sub-watersheds, the two most rural areas monitored in this study, had the lowest chloride and sulfate yields. Chloride yields from these sub-watersheds were only slightly higher than sulfate yields.

Nitrate yields were expected to be slightly less than TN yields because nitrate is the dominant form of nitrogen in streamwater. Indeed, nitrate yields from all sub-watersheds were approximately 30% lower than TN yields. Nitrate yields were also about four times less than sulfate yields in all sub-watersheds. Pearson Creek and Middle James sub-watersheds had the highest nitrate yields, followed by Wilson Creek. Upper James and Finley Creek had nearly identical nitrate yields, which were the lowest of all sub-watersheds. In all sub-watersheds the anion with the lowest yield was fluoride, which had yields comparable to TP at less than 0.1 $Mg/km^2/yr$ (Table 5.26). Wilson Creek sub-watershed had the highest fluoride yield, followed by Middle James and Pearson Creek, which had similar yields. Upper James and Finley Creek had the lowest yields, which were about the same.

Table 5.27. Anion Loads (Mg/km^2)

Sub-watershed	F^-	Cl^-	NO_3^-	SO_4^{2-}
UJ	11	2,551	280	2,014
F	12	2,499	302	1,657
MJ	64	12,115	1,043	6,411
P	3.0	529	58	292
W	3.5	447	25	250

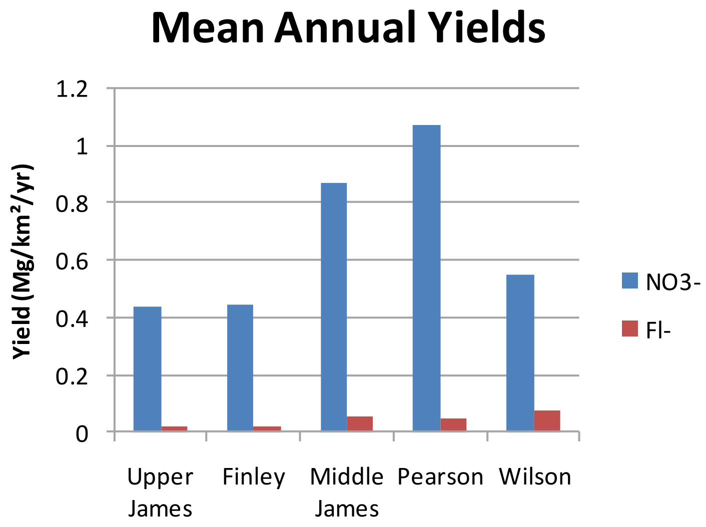


Figure 5.42. Mean Annual Nitrate and Fluoride Yields by Site

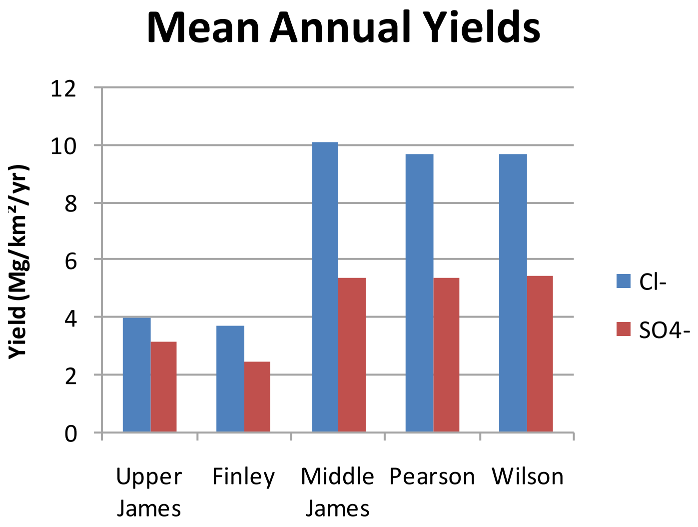


Figure 5.43. Mean Annual Chloride and Sulfate Yields by Site

Land Use Influence

Different land use characteristics among the sub-watersheds may affect constituent yields to varying degrees. For instance, nearly all runoff draining into Wilson Creek is from the City of Springfield. In addition, Wilson Creek is an upstream tributary of the Middle James. Therefore, if a constituent load or yield is higher in both Wilson and Middle James sub-watersheds than in other sub-watersheds, that constituent load is probably higher due to the influence of urban land use. Additionally, if a constituent yield from a sub-watershed that is predominantly agricultural in land use, such as the Finley or Upper James sub-watersheds, is higher than the yield from other sub-watersheds, then that constituent is probably influenced by agricultural land use. However, many constituents present in the study area streams originate from natural sources including bedrock weathering (TDS, TIC, DIC), leaf litter (TOC, DOC), and organisms (TOC, DOC, TP).It should be noted that these constituent yields may still be influenced by urbanization or agricultural practices due to accelerated degradation of soil structure, presence of decaying vegetation and chemicals. Mean annual yield of each constituent was plotted by sample site and arranged from least percent urban area to highest percent urban area (Figures 5.38 – 5.43).

Overall, there was little difference in TSS and TDS yields between urban and non-urban sub-watersheds. TDS yield was highest in the Pearson Creek sub-watershed and much lower in the Middle James and Wilson sub-watersheds indicating little urban influence. Middle James and Upper James sub-watersheds had higher TSS yields than Wilson Creek, Pearson Creek, or Finley Creek sub-watersheds indicating that upstream tributary influence, not urbanization, was more of a contributor of suspended material.

The inorganic carbon yield from Pearson Creek sub-watershed was much higher than that of any other sub-watershed. Because inorganic carbon yields from all other sub-watersheds were similar (9.2 to 13 Mg/km^2/yr), urbanization does not appear to contribute to an increase in inorganic carbon. Organic carbon yield, however, can be ranked highest to lowest using the urban gradient. Dissolved inorganic carbon and organic carbon yields follow the same trend as total carbon yields.

Total nitrogen yields were about two times larger in the Pearson Creek and Middle James sub-watersheds than in the other sub-watersheds. A TN yield/urbanization relationship does not appear to exist because Wilson Creek did not have a large yield. Likewise, agriculture does not appear to increase TN yields because the Upper James and Finley Creek sub-watersheds do not have relatively large yields. Increased nitrogen concentration from springs could possibly be due to anthropogenic sources such as leaky septic systems and. Natural sources of nitrogen include leaching of nitrogen into groundwater and lack of vegetation in caves uptaking nitrogen. However, Pearson Creek sub-watershed may have a large TN load because dissolved nitrogen from east Springfield may be transported from via sinkholes and karst conduits to the Pearson Creek sample site. Mean annual yield of TP, however, does appear to be influenced by urbanization as Middle James and Wilson Creek sub-watersheds have the largest yields in the study area.

Chloride yields were highest of all anions. Yields were highest at Middle James, Wilson Creek and Pearson Creek sub-watersheds (~10 Mg/km^2/yr for all). The sub-watersheds with the least amount of urban area had the lowest yields of chloride. Sulfate yields were less than chloride yields for all sub-watersheds, although yields for this anion followed the same pattern as chloride: largest yields were from the Pearson Creek, Wilson Creek, and Middle James sub-watersheds. The lowest yields were from the Upper James and Finley Creek sub-watersheds. Nitrate yields were the third largest of the anions. Pearson Creek sub-watershed had the highest nitrate yield, followed by Middle James and Wilson Creek. Upper James and Finley Creek sub-watersheds had the lowest nitrate yields. No discernable urban gradient pattern can be found when comparing nitrate yields to percent urban area. Yields for fluoride were the smallest of the anions. Fluoride yields were highest from the Wilson Creek sub-watershed followed by, Middle James, Pearson Creek, and then Upper James and Finley Creek.

Constituent Concentration at Mean Annual Discharge

Similar to mean annual yield data, each constituent‘s concentration at the mean annual discharge for the study period was plotted by sample site and arranged from least percent urban area to highest percent urban area (Figures 5.44a-f).While concentration of TDS at the mean annual discharge was highest at Middle James and Pearson Creek, it was not much higher than concentrations at the other three sites (only about 10% difference). No discernable urban gradient trend was seen with TDS as geological inputs were most likely the main source of TDS in the study area. Concentration of TSS at mean annual discharge was highest at the Upper James and Middle James and lowest at Pearson Creek. However, Finley Creek and Wilson Creek have lower TSS concentration, as well, indicating that urbanization was not responsible for the higher TSS concentration at the main stem sites. Upstream tributaries were more likely the cause of higher concentration on the main stem of the James.

Concentrations of TIC and DIC at mean annual discharge show trends similar to that of TDS. Concentrations were highest at Pearson and lowest at Wilson, indicating a lack of urban influence. In addition, many tributaries of the Wilson Creek drain areas that have a high percentage of impervious surfaces and as a result have a flashy response to storm runoff. Further, channels of some Wilson tributaries have been encased in concrete, which not only increases flashiness, but reduces groundwater inputs and geologic inputs of inorganic carbon. Most likely this is why TIC and DIC concentrations were lower at Wilson Creek than the other sites.

TOC and DOC concentrations at mean annual flow appear to be similar at all sites. TOC concentrations at mean annual flow were highest at Wilson and Middle James and only slightly lower at the other sites. Because no drastic difference in TOC concentration at all sites exists, urban area does not appear to influence organic carbon concentration. Concentration of DOC at mean annual flow (Figure 5.44c) was similar to that of TOC.

TN and TP concentration at mean annual flow was highest at Middle James and lowest at Upper James, Finley, and Wilson Creek. Pearson Creek had a relatively high concentration of TN at mean annual flow compared to Wilson Creek, which has a similar drainage area. TP concentrations were highest at Middle James and Wilson, indicating a slight influence from urban areas.

Chloride and sulfate concentrations at mean annual flow were highest at Wilson and Middle James. Chloride and sulfate are commonly found in urban runoff and wastewater effluent, which are both delivered to the James River via Wilson Creek and other upstream sources. These anion concentrations show the most urban influence of all constituents discussed in this study. Nitrate concentration at mean annual flow was similar to that of TN at all sites. Agriculture, upstream inputs, and groundwater appear to influence the concentration of nitrate and TN (mostly soluble) instead of urban influence. Fluoride concentration at mean annual discharge was highest at Wilson and Middle James, indicating this anion may be delivered to the James River from urban sources.

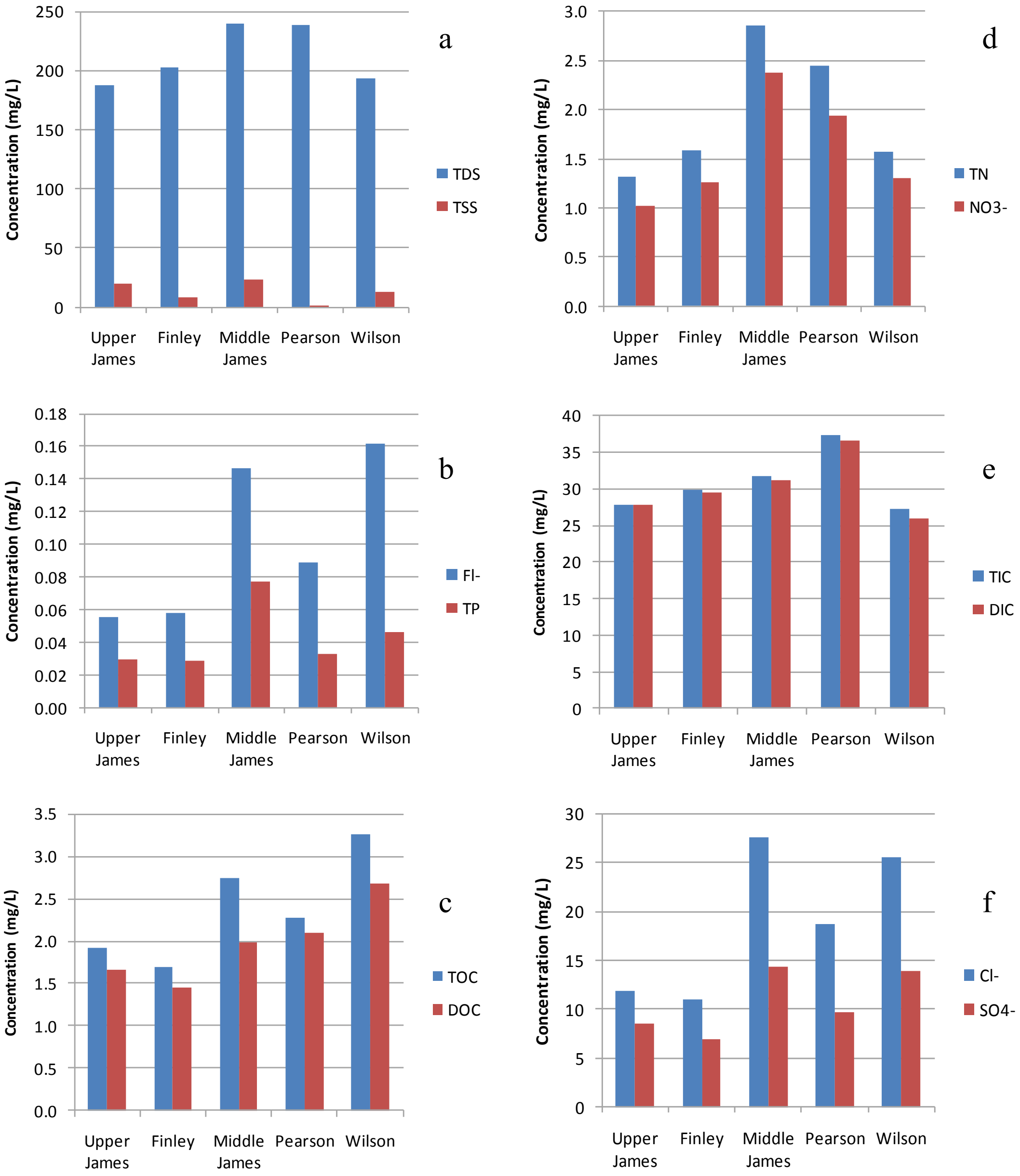


Figure 5.44 a-f. Concentrations at Mean Annual Discharge

Hysteresis and Upper Limit Yields

Recall that several constituent concentrations exhibited hysteresis patterns during stormflow conditions. The most common pattern was an increase in concentration during rising limb, followed by a decline in concentration during falling limb (exhaustion). In order to determine the amount of material being transported during rising limb, yields of constituents exhibiting hysteresis were calculated using the rising limb trendline equation. Yields calculated using the rising limb trendline equation act as the upper limit of each yield because the maximum concentration of these constituents was transported during this flow type. Upper limit yields of TSS, TOC, DOC, TP, and the anions were compared to yields calculated using all flow types (Figure 5.45a-h).

Suspended material was expected to be transported mostly during the rising limb at most of the sample sites. Indeed, rising limb TSS yields for Finley, Middle James, and Wilson were much larger than the all discharge yields indicating that most of the TSS was transported during this part of the hydrograph. Further, most of the TSS supply was probably in close proximity to the stream channel. TP was expected to be transported with TSS; however, TP yields were only slightly higher during rising limb at Finley and Middle James. This may indicate that most of the TP supply does not originate near the stream channel.

Urban runoff containing organic chemicals was probably the main source of total and dissolved organic carbon in the study area. TOC rising limb yields for Middle James and Wilson were slightly larger than all discharge yield at Middle James, but much larger at Wilson. Urban pollutants are most likely the cause for the higher rising limb TOC yield at Wilson. Similarly, DOC rising limb yields were much higher than the all discharge yield at the Wilson, again, possibly due to the presence of urban pollutants in this sub-watershed.

Likewise, most of the anions in the streams probably originated from accumulated urban chemicals delivered to streams via runoff. Chloride, sulfate, and fluoride rising limb yields were higher than all discharge yields at Middle James and Pearson. Chloride and fluoride yields were slightly higher during rising limb, but sulfate rising limb yields were much higher than all discharge yields for these sub-watersheds. The high rising limb yields for sulfate indicate that large quantities were being delivered during the first flush of storms in these sub-watersheds. Possible sulfate sources include wastewater effluent and coal fired power plants.

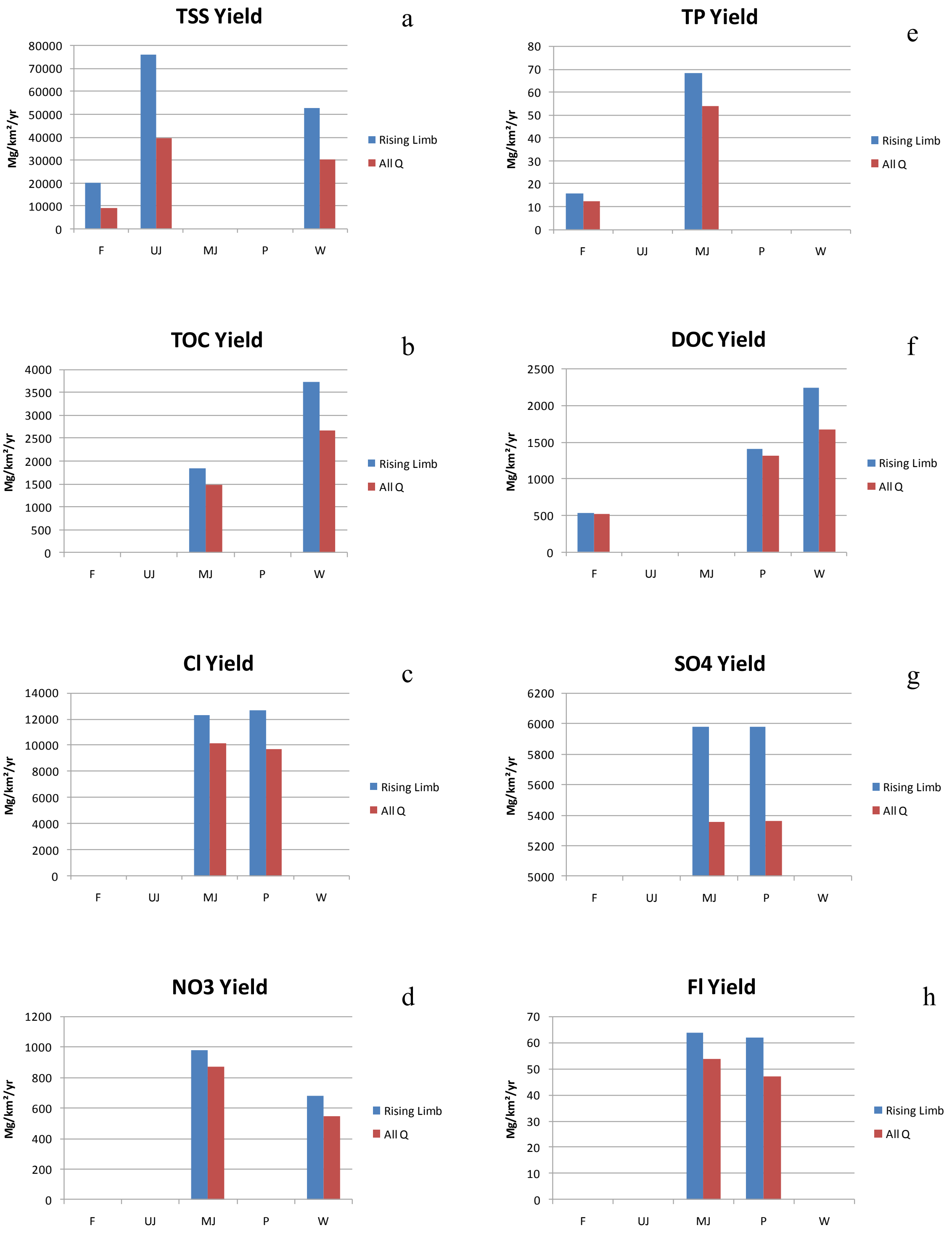


Figure 5.45a-h. Upper Limit Yields

Comparison to Yields from Other Regions

Many water quality studies have been conducted to determine suspended and dissolved loads in the United States and other countries. By comparing nutrient yields from the Middle James River to those from differing river systems, effects of climate, elevation and slope, and agricultural practices on yield become apparent.

Nutrient Yield Comparison. Agricultural practices are among the greatest contributors to nutrient loads (Royer, et al., 2006). Row crop methods, planting one or two crops in the same area year after year, has been especially problematic in the release of nitrogen and phosphorus into streams. Nutrient yields from the Embarras and Kaskaskia Rivers in Illinois drain land that is used to grow mostly corn and soybean row crops, consequently these rivers tend to have very large nutrient loads Royer, et al. (2006). Additionally, estimated annual TN and TP yields from the White River, Arkansas are reported. The section of the White River studied in Haggard, et al. (2003) receives large amounts of poultry litter from nearby farms which account for relatively large nutrient loads. Unsurprisingly, the rivers with the highest annual TN and TP loads in Table 5.28 (Embarras, and Kaskaskia) drain land that is heavily used for agriculture and these yields are higher than nutrient yields from the Middle James River, which though 55% agriculture land, supports few, if any row crops or poultry farms.

Table 5.28. Cumulative Annual Nutrient Loads from Different River Systems

River	Ad (km^2)	TN Yield ($Mg/km^2/yr$)	TP Yield ($Mg/km^2/yr$)	Source
Embarras, IL	481	2.9	0.08	Royer, et al.
Kaskaskia, IL	368	3.4	0.08	Royer, et al.
White, AR	1064	0.5	0.04	Haggard, et al.
Middle James	1197	1.1	0.05	Current study

Comparison to Yields from the Ozarks. Nutrient yields for the South Dry Sac River in Northeast Greene County were calculated in the Marc Bowen thesis (Bowen, 2004). Additionally, nutrient yields were also calculated for the Jordan, Fassnight, and Upper Wilson Creek basin using the flow duration rating curve method in Ronald Miller‘s 2006 thesis. Yield results were comparable to those estimated for Wilson Creek in this thesis study demonstrating consistency in sampling, analytical, and computational methods (Table 5.29).

Table 5.29. Nutrient Loads from Urban Ozarks Streams

Location	Ad (km^2)	TN ($Mg/km^2/yr$)	TP ($Mg/km^2/yr$)	Source
South Dry Sac	13.7	0.9	0.01	Bowen Thesis
Upper Wilson	46.1	0.5	0.03	Miller Thesis
Wilson	46.1	0.7	0.06	Present Study

CHAPTER 6

SUMMARY AND CONCLUSION

The major goal of this study was to quantify suspended and dissolved solids, determine the controls of solids transport, and calculate solids loads in the Upper and Middle James River Basin. Little data on solids transport and loads previously existed so it is important to provide a baseline survey of constituent concentration, loads, yields, and transport mechanisms as a reference point for future studies. In addition, the transport and source of nutrients, carbon, and anions were also investigated in relation to dissolved and solids mass transport in the James River.

Water samples were collected during baseflow and stormflow over a one year period. Samples were analyzed using a variety of methods to determine total suspended solids, total dissolved solids, inorganic and organic carbon, nutrient, and anion concentrations. Effects of discharge, seasonal variation, and hysteresis were determined for constituent concentrations. Data from this study were then compared to long-term data to determine consistency in sample collection and analysis methods. Additionally, nonlinear regression was used to calculate constituent loads and yields. In summary, several factors determined how materials were transported in the James River Basin. As expected, different materials were shown to be transported in different ways; further, the same materials were shown to be transported differently among the sub-watersheds in the study area.

The results of this study show:

1. Water chemistry parameters were controlled by seasonal variations. Temperature, pH, and DO measurements were largely unaffected by the influence of stormflow at all sites, but measurements varied seasonally. DO concentrations and pH were largely negatively related to water temperature. Turbidity, which was positively related to total suspended solids, varied by site and season and was mostly related to storm runoff as suggested by Lewis (1996). Turbidity measurements were highest at the Middle James in the spring. However, conductivity measurements, which were positively related to total dissolved solids and negatively related to discharge as suggested by Klein (1981), did not vary by site or season indicating that seasonal changes did not control conductivity.

2. Suspended solids, organic carbon, and total phosphorus concentrations were positively related to discharge. The variability of sediment supply and rain events were found contribute to TSS concentration, similar to the findings of Johnson and East (1982). Trendline slopes for Wilson Creek and Middle James sites were the steepest (positive) slopes for TSS. Similar to Smith et al. (2007), TP concentration trends were found to be related to TSS concentration trends most likely due to the tendency of phosphorus to be transported with the suspended load. Organic carbon (TOC and DOC) concentrations increased with discharge at all sites, except TOC and DOC at Finley Creek and Upper James and DOC at Middle James. Organic carbon concentrations were mostly related to autumn leaf fall and urban pollutants as found by McGlynn and McDonnell (2003).

3. Dissolved solids, inorganic carbon, total nitrogen, and anion concentrations were negatively related to discharge. Dissolved solids concentrations were not found to

vary with discharge due to the near constant supply of these materials from groundwater and soluble bed material. These findings were similar to those of Peters (1984) and Groves and Meiman (2001). Dissolved solids concentrations at Pearson Creek were the most constant (trendline slope was near zero) of all sample sites possibly due to the influence of groundwater from near-by springs. Wilson Creek TDS concentrations had the strongest negative slope, possibly due to inputs of urban chemicals accumulated on impervious surfaces. Inorganic carbon concentrations, a large component of TDS concentrations, were continuously available to streams from bed material, and did not appear to be influenced much by discharge. Total nitrogen concentrations also remained constant across discharge measurements similar to findings by Mitsch, et al. (2001). Concentrations at Upper James and Pearson Creek showed zero slope, indicating groundwater may have been supplying nitrogen. However, TN concentrations at Finley Creek, Middle James, and Wilson Creek all had a slight negative slope. Finally, anion concentrations were found to be somewhat diluted by discharge. However, chloride, sulfate, and nitrate concentrations had zero slope at Upper James, suggesting that a constant supply of these anions was available to this study site.

4. Seasonal changes affected TSS, total phosphorus, organic carbon, chloride, and fluoride concentrations. Total suspended solids concentrations were found to be highest in the spring and summer months due to the increase in frequency of storm events during this time. These results are similar to those found by Wallace et al. (1982). Total phosphorus concentrations were highest during the summer and fall and lowest during winter, most likely due to storm event patterns, also similar to the findings of Wallace, et al. (1982). Total organic carbon concentrations at all sites were found to be largely

dependent on availability of leaf litter during the fall months as found by Meyer and Tate (1983). Dissolved organic carbon concentrations were also found to be relatively high in the fall however, concentrations were also high in the summer probably due to increased algae growth during this time. Some of the anions were found to be affected by seasonality, as well. Chloride concentrations appeared to be affected during the winter most likely due to the application of road salt at this time. Fluoride concentrations were found to be highest during fall months.

5. Hysteresis affected TSS, TOC, TP, chloride, and nitrate concentrations. Suspended material concentrations were found to be greatly affected by hysteresis, similar to the findings of Wood (1977) and Assleman (2000). Total suspended solids concentrations at the Finley, Middle James, and Wilson Creek sites were found to peak during the rising limb and then become exhausted during the falling limb. Additionally, total phosphorus and total organic carbon concentrations showed a similar trend at these same sample sites. Chloride concentrations also peaked during rising limb and were exhausted during falling limb at the Middle James and Pearson Creek sites. Likewise, nitrate concentrations peaked during rising limb and were exhausted during falling limb at the Wilson Creek site. The occurrence of concentrations peaking during rising limb and becoming exhausted during falling limb was found to be related to near channel constituent supplies becoming exhausted by Seeger (2004). Those water quality indicators affected by hysteresis or first flush needs to be monitored by storm chasing or auto sampling using storm hydrographs.

6. Concentration data were comparable to long-term concentration data from USGS. Constituent concentration data and associated discharge from this study were

compared to that collected by the USGS over a period of several years. Data collected from both Finley Creek and Middle James sites were compared. Total dissolved solids, TSS, TN, chloride, and sulfate concentrations trends from both USGS and this study data at both sites were very similar indicating that data from this study was collected and analyzed in an acceptable manner. TP data from the USGS had a negative slope while data from this study had a positive slope. However, when USGS data collected pre-SWWWTP improvements were discarded the trend was closer to that of this study. In general, after considering differences in sample schedule, sample site, and source effect on trend, concentration – discharge relationships were similar between this study and USGS.

Additionally, average seasonal TN and TP concentrations measured at each site were compared to TMDL levels put in place by the Missouri DNR in 2001. Total nitrogen concentrations were found to exceed the TMDL level of 1.5 mg/L during each season and at all sample sites, except the Upper James. Total phosphorus concentrations, however, were found to be lower than the TMDL level of 0.075 mg/L during all seasons at the Finley Creek, Upper James, and Pearson Creek sites. Levels were exceeded during spring, summer, and fall at the Middle James site and during the summer at the Wilson Creek site. While few management plans exist solely to lower total nitrogen levels, many plans have been implemented to lower TP levels most likely because phosphorus has been found to be the limiting nutrient in algae growth (Turner and Rabalais, 2004)

7. Mean annual yields of dissolved solids were higher than mean annual yields of suspended solids. Dissolved material is often found in greater abundance than suspended material due to the continuous delivery of dissolved material from groundwater, karst,

and soluble bed material as found by Peters (1984). Indeed, TDS yields were found to be higher than TSS yields in all sub-watersheds of the Upper and Middle James River Basin. Pearson Creek sub-watershed had the highest TDS yield of 159 $Mg/km^2/yr$, which was probably due to groundwater supply and karst effects in that sub-watershed. Upper James sub-watershed had the lowest TDS yield of 61 $Mg/km^2/yr$, possibly due to a lack of groundwater and urban influences.

The Middle James sub-watershed had the highest TSS yield of 87 $Mg/km^2/yr$, most likely due to its relatively large drainage area. Montgomery (1999) also determined drainage area size was an important factor affecting solids yields. Conversely, Finley Creek sub-watershed had the smallest TSS yield at 9 $Mg/km^2/yr$. Impoundments are most likely trapping suspended solids upstream of the sample site. This has been found to reduce the amount of TSS transported downstream by Ward and Trimble (2004). Additionally, inorganic carbon yields, about 90% in dissolved form, were much larger than organic carbon yields. Pearson Creek sub-watershed had the largest inorganic carbon yield at 20 $Mg/km^2/yr$, while Upper James sub-watershed had the lowest at 9$Mg/km^2/yr$. The presence of karst and groundwater in the Pearson Creek sub-watershed was likely responsible for the large yield. Wilson Creek sub-watershed had the highest TOC and DOC yields at 2.7 $Mg/km^2/yr$ and 1.7 $Mg/km^2/yr$, respectively. Finley Creek sub-watershed had the lowest organic carbon yields at 0.8 $Mg/km^2/yr$ and 0.6 $Mg/km^2/yr$, respectively. This demonstrates that urban chemicals may play a large role in the organic carbon yield of drainage area.

Nutrient yields also showed a dissolved/suspended separation. Total nitrogen yields were over an order of magnitude higher than TP yields at all sites. This was probably related to nitrogen naturally occurring in greater abundance than phosphorus and because nitrogen is associated with groundwater that constantly feeds many streams in the study area (Vezie, et al., 2002). Pearson Creek sub-watershed had the highest TN yield at 1.4 Mg/km^2/yr, while the Upper James sub-watershed had the lowest at 0.6 Mg/km^2/yr. Wilson Creek had the highest TP yield at 0.06 Mg/km^2/yr and Finley Creek had the lowest at 0.01 Mg/km^2/yr. Total phosphorus yields were highest in the more urban sub-watersheds compared to the rural sub-watersheds, indicating that TP yield is related to urbanization.

8. Urbanization was found to also influence anion yields in the Upper and Middle James River Basin. The Middle James, Pearson Creek, and Wilson Creek sub-watersheds all had the highest yields of chloride and sulfate (10 Mg/km^2/yr, 9.7 Mg/km^2/yr, and 9.7 Mg/km^2/yr, respectively for chloride and 5.4 Mg/km^2/yr at all three sites for sulfate). Fluoride was also found to be highest in the urban sub-watersheds. Wilson Creek sub-watershed had the highest fluoride yield of 0.08 Mg/km^2/yr.

Urban land use affected organic carbon, chloride, sulfate, and fluoride yields. Differing land uses in the study area were predicted to have an effect on some constituent yields. Indeed, dissolved organic carbon, TP, chloride, sulfate, and fluoride yields were highest in the sub-watersheds with the most urban area (Wilson Creek, Pearson Creek, and Middle James). Additionally, organic carbon yields were highest in the urban sub-watersheds. This was most likely due to accumulation of chemicals containing organic carbon on impervious surfaces being delivered to streams by runoff (Gurtz, et al., 1988; Finlay, 2001). Total phosphorus yields from the Middle James and Wilson Creek sub-watersheds were highest. Use of lawn fertilizer and accumulated phosphorus on urban surfaces possibly contributed to the higher urban yield (Prowse, 1987). Chloride, sulfate, and fluoride yields were all highest in the Wilson Creek, Pearson Creek, and Middle James sub-watersheds. Landfill leachate, wastewater effluent, rock salt, fossil fuel emissions, and drinking water all may have contributed to the relatively high yields of these (ATSDR, 1993; Christensen, 2001; Shanley, et al., 2005; Gardner and Royer, 2010).

Future Work

Now that a baseline description of solids transport in the James River Basin exists many more in-depth studies can be done either in this basin or another river basin in the Ozarks. The following are some examples of topics that need to be better understood:

1. Sources of suspended sediment in the James River Basin are not clear. Some soil series present in the study area have relatively high levels of erodibility and may be more likely to be found in the suspended load. Additionally, bank erosion may also contribute to the suspended load. What role do bank erosion and soil distribution play in sediment transport?

2. Many different sized impoundments are located in the James River Basin. How do these impoundments affect sediment and sediment-associated pollutant transport?

3. Similar to TP, high levels of TN may cause excess algal growth. Sources of TN and nitrate in the James River Basin need to be better understood to determine an appropriate TN exceedence level.

4. Geologic formations appear to influence levels of some solids found in the James River Basin. The role of karst hydrology on water chemistry in the Ozarks needs to be studied more in depth to find how pollution transport is linked to natural influences.

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APPENDIX

Pearson Creek Instantaneous Concentration Data

Date	Time	Season	Q m3/s	Hydrograph Limb	Temp °C	SC us/cm	pH	DO mg/l	Turbidity NTU	TSS mg/l	SS1.5-0.45 mg/l	SS0.45 mg/l	TSS %>0.45	TDS mg/l
9/26/08	9:52:00	Fall	0.80	Falling	24.68	ND	8.83	5.34	0.3	2.0	ND	ND	ND	285
10/14/08	9:30	Fall	0.21	Base	16.69	0.499	9.47	7.88	1.7	0.7	ND	ND	ND	219
10/23/08	10:21:16	Fall	0.74	Rising	14.04	0.517	9.52	8.28	5	6.0	ND	ND	ND	275
11/5/08	10:11:05	Fall	0.20	Base	14.31	0.502	9.72	7.26	0.9	0.3	ND	ND	ND	367
11/11/08	9:18:25	Fall	0.29	Peak	11.14	0.507	9.65	8.36	1.6	2.7	ND	ND	ND	283
11/25/08	8:43:34	Fall	0.17	Base	7.52	0.515	9.94	9.07	0.6	1.7	ND	ND	ND	283
12/4/08	8:45	Winter	0.14	Base	5.11	0.509	8.26	12.79	0.6	1.0	ND	ND	ND	104
12/9/08	8:51	Winter	0.16	Base	12.55	ND	9.48	12.11	0.3	0.0	ND	ND	ND	324
12/18/08	13:53	Winter	0.14	Base	7.39	0.502	10.01	14.96	0.9	1.2	ND	ND	ND	296
1/23/09	8:01	Winter	0.24	Base	6.13	0.484	9.9	13.4	1.3	1.6	ND	ND	ND	304
2/2/09	8.36	Winter	0.42	Rising	6.65	0.568	10.31	12.96	1.8	2.4	ND	ND	ND	381
2/11/09	8:15	Winter	1.30	Rising	11.79	0.521	9.92	8.54	6.3	13.2	ND	ND	ND	150
2/20/09	8:32	Winter	0.98	Falling	8.56	0.46	10.18	11.85	0.8	1.2	ND	ND	ND	339
3/4/09	8:10	Spring	0.52	Base	7.26	0.475	10.04	12.11	3.2	3.2	ND	ND	ND	279
3/11/09	8:27	Spring	0.46	Base	9.34	0.478	10.02	9.23	1.5	3.5	ND	ND	ND	342
4/8/09	9:10	Spring	0.84	Base	10.6	0.462	9.97	12.33	1	3.5	0.0	3.5	0	330
4/13/09	8:59	Spring	1.37	Rising	11.87	0.447	10.06	10.65	4.1	3.0	3.0	6.0	50	308
4/19/09	10:48	Spring	1.79	Rising	13.82	0.451	9.98	10.15	3.9	6.5	0.0	6.5	100	222
5/1/09	9:08	Spring	13.24	Falling	14.22	0.258	9.91	10.33	64.7	95.0	22.0	117.0	81	162
5/15/09	10:13	Spring	1.70	Falling	15.09	0.446	9.9	10.88	1.1	9.0	2.5	11.5	78	310
5/22/09	12:49	Spring	0.96	Falling	16.02	0.466	9.96	10.49	5.6	ND	5.5	0.0	ND	300
6/22/09	9:54	Summer	0.54	Falling	18.61	0.49	9.99	9.29	3.1	13.0	2.5	15.5	84	364
7/8/09	9:29	Summer	0.28	Base	18.51	0.495	10.19	9.05	1.6	5.5	4.5	10.0	55	347
7/14/09	9:12	Summer	0.84	Rising	19.39	0.482	10.13	7.93	10.4	17.0	0.5	17.5	97	290
7/21/09	11:45	Summer	0.86	Rising	18.81	0.52	10.23	8.61	5.3	18.5	0.0	18.5	100	346
7/30/09	14:08	Summer	0.55	Rising	18.07	0.459	8.25	7.61	2.4	8.5	0.0	8.5	100	382
8/20/09	11.23	Summer	1.70	Falling	18.01	0.362	7.85	8.49	20.1	25.0	4.0	29.0	86	348
8/26/09	11:27	Summer	0.44	Base	18.75	0.499	7.9	9.38	0.6	6.5	1.5	8.0	81	314
9/9/09	11:38	Fall	0.46	Rising	18.24	0.461	7.72	10.31	15.4	13.5	1.0	14.5	93	344
9/22/09	11:54	Fall	4.14	Falling	17.00	0.39	7.45	10.46	13.5	20.0	0.0	20.0	100	250

Pearson Creek Instantaneous Concentration Data, continued

Date	TN mg/l	TP mg/l	TIC mg/l	TOC mg/l	DIC mg/l	DOC mg/l	SIC mg/l <0.45 um	SOC mg/l	Organic Carbon %	Fl- mg/l	Cl- mg/l	NO3- mg/l	SO4- mg/l
9/26/08	2.43	0.062	43.27	3.36	41.04	3.03	2.23	0.33	90	0.366	17.494	2.421	9.396
10/14/08	2.72	0.019	ND	ND	ND	ND	ND	ND	ND	0.317	24.343	2.445	10.685
10/23/08	2.43	0.031	43.94	2.58	44.38	2.18	-0.44	0.40	85	0.183	25.068	2.212	10.562
11/5/08	1.87	0.017	44.64	3.75	43.80	2.99	0.84	0.76	80	0.147	21.913	1.744	9.613
11/11/08	2.16	0.057	44.28	2.29	43.90	1.67	0.38	0.61	73	0.193	22.877	2.090	10.428
11/25/08	2.17	0.016	44.16	3.32	41.78	5.23	2.39	-1.92	158	ND	ND	ND	ND
12/4/08	2.05	0.019	ND	ND	ND	ND	ND	ND	ND	0.162	26.603	2.193	10.903
12/9/08	1.94	0.029	38.00	2.32	39.58	1.06	-1.59	1.26	46	0.193	26.714	2.068	11.010
12/18/08	1.64	0.012	ND	ND	ND	ND	ND	ND	ND	0.168	28.210	2.260	11.788
1/23/09	2.69	0.008	41.14	0.00	40.73	0.78	0.41	-0.78	ND	0.008	19.803	2.297	9.715
2/2/09	2.73	0.013	40.60	1.23	39.19	1.42	1.40	-0.18	115	0.135	46.496	2.714	11.269
2/11/09	2.83	0.021	37.45	1.75	37.77	1.53	-0.33	0.22	87	0.135	35.801	2.897	10.908
2/20/09	2.83	0.014	38.62	1.14	38.65	1.01	-0.03	0.13	89	ND	ND	ND	ND
3/4/09	2.55	0.012	37.15	1.06	37.07	1.31	0.08	-0.25	124	0.071	24.032	2.478	10.947
3/11/09	2.58	0.022	38.86	1.82	37.98	1.64	0.88	0.18	90	0.164	22.024	2.452	10.709
4/8/09	2.4	0.015	38.19	1.27	38.20	0.96	-0.01	0.32	75	0.034	19.111	2.402	9.820
4/13/09	2.24	0.044	22.06	2.54	22.54	3.75	-0.48	-1.20	147	0.136	19.400	0.754	11.448
4/19/09	2.51	0.038	36.73	1.50	35.77	1.69	0.96	-0.19	113	0.075	18.601	2.187	9.308
5/1/09	1.73	0.132	21.56	6.00	20.68	3.10	0.88	2.90	52	0.100	8.996	1.491	7.669
5/15/09	2.80	0.017	37.65	1.85	36.47	1.49	1.18	0.37	80	0.023	13.612	1.953	9.368
5/22/09	2.56	0.019	39.77	1.43	39.00	1.53	0.77	-0.10	107	0.009	17.086	1.953	9.147
6/22/09	2.31	0.031	40.31	1.16	38.60	1.29	1.71	-0.13	111	0.030	17.399	2.066	10.094
7/8/09	2.52	0.021	43.98	2.30	42.92	1.71	1.06	0.58	75	0.000	25.290	0.000	8.699
7/14/09	2.39	0.036	43.42	3.38	41.75	2.68	1.67	0.70	79	0.091	20.138	2.062	9.542
7/21/09	2.57	0.028	44.47	2.65	43.01	2.91	1.45	-0.26	110	0.149	24.206	2.167	10.718
7/30/09	2.77	0.041	43.61	2.34	41.22	3.44	2.39	-1.09	147	0.135	18.297	1.701	10.188
8/20/09	2.18	0.073	29.21	ND	29.57	ND	-0.36	ND	ND	0.142	13.834	1.356	7.436
8/26/09	2.99	0.021	42.86	1.22	41.72	1.51	1.14	-0.29	124	0.096	19.779	1.978	10.328
9/9/09	2.44	0.065	41.15	3.48	41.75	3.63	-0.60	-0.15	104	0.210	20.666	1.635	10.872
9/22/09	3.24	0.098	36.49	4.88	35.71	3.27	0.78	1.62	67	0.060	11.261	1.914	7.844

Upper James Instantaneous Concentration Data

Date	Time	Season	Q m3/s	Hydrograph Limb	Temp °C	SC us/cm	pH	DO mg/l	Turbidity NTU	TSS mg/l >1.5 um	SS1.5-0.45 mg/l 1.5-0.45 um	SS0.45 mg/l >0.45 um	TSS %>0.45	TDS mg/l <0.45 um
9/26/2008	10:45:43	Fall	2.39	Falling	16.62	0.478	9.38	8.17	2.5	3.7	ND	ND	ND	221
10/14/2008	10:21	Fall	0.85	Base	18.96	0.388	9.51	7.44	2.7	4.0	ND	ND	ND	156
10/23/2008	10:43:30	Fall	1.88	Rising	14.49	0.377	9.69	8.3	5	4.3	ND	ND	ND	193
11/5/2008	10:27:56	Fall	0.98	Base	14.46	0.396	9.67	7.17	2.2	4.0	ND	ND	ND	305
11/11/2008	9:46:49	Fall	1.14	Peak	9.86	0.397	9.78	8.19	1.1	1.3	ND	ND	ND	202
11/25/2008	9:03:04	Fall	0.89	Base	6.8	0.391	9.95	12.33	0.7	1.3	ND	ND	ND	202
12/4/2008	9:20	Winter	1.00	Base	5.19	ND	9.9	22.53	ND	3.7	ND	ND	ND	74
12/9/2008	9:15	Winter	1.02	Base	12.01	ND	11.9	12.46	84.7	0.4	ND	ND	ND	217
12/18/2008	14:26	Winter	1.02	Base	4.18	0.391	10.19	15.58	0.5	1.2	ND	ND	ND	229
1/23/2009	8:32	Winter	2.95	Base	3.93	0.363	10.13	13.61	31.8	6.4	ND	ND	ND	205
2/2/2009	8.59	Winter	3.18	Rising	3.81	0.404	9.86	15.07	1.3	3.2	ND	ND	ND	273
2/11/2009	8:37	Winter	54.84	Rising	9.43	0.284	10.02	10.01	88.3	262.0	ND	ND	ND	86
2/20/2009	8:54	Winter	6.58	Falling	5.33	0.335	10.17	12.72	1.9	2.8	ND	ND	ND	268
3/4/2009	8:41	Spring	4.11	Base	5.05	0.356	10.33	13.39	1.4	4.4	ND	ND	ND	226
3/11/2009	8:52	Spring	3.67	Base	10.56	0.359	10.07	8.41	101.1	7.0	ND	ND	ND	268
4/8/2009	9:30	Spring	6.11	Base	9.28	0.335	6.56	12.00	5	6.5	0.5	7.0	8	243
4/13/2009	9:28	Spring	18.13	Falling	10.22	0.303	10.17	11.02	7.7	22.5	4.5	27.0	20	136
4/19/2009	11:12	Spring	45.16	Rising	13.45	0.286	10.18	9.96	22.9	100.5	0.0	100.5	0	108
5/15/2009	10:35	Spring	8.55	Falling	17.1	0.321	10.08	9.57	4.6	54.5	13.0	67.5	24	272
5/22/2009	12:34	Spring	3.97	Falling	18.12	0.343	10.15	9.74	4.6	ND	11.0	ND	ND	242
6/22/2009	10:21	Summer	2.49	Falling	23.59	0.363	10.05	7.12	6.6	23.0	2.0	25.0	9	300
7/8/2009	9:51	Summer	1.25	Base	22.59	0.387	10.12	7.63	16.9	6.5	0.0	6.5	0	255
7/14/2009	9:38	Summer	2.23	Rising	22.56	0.378	10.09	6.73	7.8	19.5	13.5	33.0	69	184
7/21/2009	11:28	Summer	3.63	Rising	21.52	0.396	10.11	7.43	6	9.0	3.0	12.0	33	234
7/30/2009	13:49	Summer	1.68	Falling	22.11	0.369	8.53	6.33	7.4	11.0	0.0	11.0	0	332
8/20/2009	11.06	Summer	2.17	Rising	20.04	0.398	8.01	7.94	8.9	28.5	0.5	29.0	2	378
8/26/2009	11:52	Summer	0.87	Base	20.93	0.432	7.99	7.42	22.7	27.5	0.5	28.0	2	278
9/9/2009	11:19	Fall	0.72	Base	20.86	0.394	7.9	9.45	307.9	19.0	0.0	19.0	0	303
9/22/2009	11:38	Fall	6.71	Falling	18.24	0.33	7.66	9.89	27.4	29.5	10.0	39.5	34	225

Upper James Instantaneous Concentration Data, continued

Date	TN	TP	TIC	TOC	DIC	DOC	SIC	SOC	Organic Carbon	Fl-	Cl-	NO3-	SO4-
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	%	mg/l	mg/l	mg/l	mg/l
						<0.45 um	<0.45 um						
9/26/2008	1.29	0.039	34.07	2.24	32.36	0.65	1.71	1.59	29	0.271	10.784	1.24	7.944
10/14/2008	1.22	0.012	ND	ND	ND	ND	ND	ND	ND	0.169	14.625	0.924	8.704
10/23/2008	1.07	0.026	34.57	2.45	34.36	2.03	0.21	0.41	83	0.126	13.406	0.678	7.979
11/5/2008	0.73	0.015	37.78	2.70	37.76	2.52	0.02	0.18	93	0.175	13.574	0.545	8.423
11/11/2008	6.55	0.016	38.15	1.84	39.70	1.52	-1.55	0.32	83	0.218	15.187	0.883	8.858
11/25/2008	0.77	0.008	35.80	2.52	34.37	3.76	1.43	-1.24	149	ND	ND	ND	ND
12/4/2008	0.93	0.015	ND	ND	ND	ND	ND	ND	ND	0.143	16.831	0.770	9.288
12/9/2008	0.51	0.004	32.17	1.16	33.69	0.86	-1.52	0.30	74	0.083	16.456	0.659	9.374
12/18/2008	0.56	0.005	ND	ND	ND	ND	ND	ND	ND	0.139	17.555	0.687	10.620
1/23/2009	1.24	0.008	31.55	0.53	32.02	0.76	-0.48	-0.23	144	0.031	12.800	1.041	9.510
2/2/2009	1.39	0.01	32.77	0.82	36.85	0.55	-4.08	0.27	67	0.092	18.170	0.984	9.510
2/11/2009	1.38	0.059	22.58	4.07	22.50	2.11	0.08	1.96	52	0.059	11.62	1.201	9.483
2/20/2009	1.84	0.018	27.50	1.21	27.76	1.10	-0.26	0.11	91	ND	ND	ND	ND
3/4/2009	1.43	0.014	28.13	ND	28.93	0.59	-0.80	ND	ND	0.006	16.462	1.158	10.373
3/11/2009	1.15	0.019	29.04	1.05	29.18	1.03	-0.14	0.01	99	0.046	12.674	0.985	9.559
4/8/2009	1.18	0.012	27.31	1.14	27.78	0.90	-0.47	0.24	79	0.028	11.646	1.179	9.171
4/13/2009	1.22	0.030	24.07	1.76	24.00	1.82	0.06	-0.06	103	0.126	11.547	1.228	8.829
4/19/2009	1.16	0.048	23.29	2.94	22.95	1.99	0.34	0.95	68	0.066	9.980	0.890	8.387
5/15/2009	1.31	0.042	26.89	1.28	26.46	1.51	0.43	-0.23	118	0.038	8.562	0.979	7.508
5/22/2009	1.08	0.013	29.66	1.15	28.89	1.06	0.77	0.10	92	-0.001	11.048	0.907	7.987
6/22/2009	1.18	0.023	29.27	1.15	29.23	1.31	0.04	-0.15	113	0.025	11.286	0.931	8.442
7/8/2009	1.01	0.023	35.47	1.70	34.03	1.50	1.44	0.20	88	0.109	12.777	0.937	8.214
7/14/2009	1.06	0.035	35.17	2.12	34.46	1.92	0.71	0.20	91	0.042	12.823	0.933	7.493
7/21/2009	1.01	0.030	35.63	1.66	34.52	2.01	1.11	-0.35	121	0.040	13.734	0.969	8.605
7/30/2009	1.47	0.046	35.21	2.34	33.98	2.64	1.24	-0.30	113	0.048	13.700	0.795	7.986
8/20/2009	2.04	0.050	32.06	ND	32.46	ND	-0.40	ND	ND	0.137	15.109	1.101	8.248
8/26/2009	1.7	0.026	37.64	1.31	36.95	1.34	0.69	-0.02	102	0.055	15.402	0.899	12.910
9/9/2009	1.17	0.032	37.36	2.21	37.41	2.13	-0.05	0.08	96	0.104	14.699	0.864	8.322
9/22/2009	2.23	0.151	30.26	4.93	29.38	3.73	0.89	1.19	76	0.049	10.032	1.093	6.686

Finley Creek Instantaneous Concentration Data

Date	Time	Season	Q m3/s	Hydrograph Limb	Temp °C	SC us/cm	pH	DO mg/l	Turbidity NTU	TSS mg/l >1.5 um	SS1.5-0.45 mg/l 1.5-0.45 um	SS0.45 mg/l >0.45 um	TSS %>0.45	TDS mg/l <0.45 um
9/26/08	11:41	Fall	4.55	Falling	18.6	366	9.5	7.5	3.7	1.7	ND	ND	ND	223
10/14/08	11:30	Fall	1.97	Base	18.6	403	9.7	8.3	2.1	4.3	ND	ND	ND	185
10/23/08	11:41	Fall	2.99	Peak	14.6	397	9.7	8.4	2.2	3.0	ND	ND	ND	205
11/5/08	11:17	Fall	1.77	Base	14.7	408	9.7	7.6	16.3	2.3	ND	ND	ND	297
11/11/08	10:24	Fall	2.13	Base	11.0	408	9.8	9.9	1.1	2.0	ND	ND	ND	187
11/25/08	9:44	Fall	1.58	Base	7.2	415	10.3	12.7	0.7	2.0	ND	ND	ND	224
12/4/08	10:15	Winter	1.33	Base	5.0	414	10.2	13.7	0.3	1.0	ND	ND	ND	82
12/9/08	9:59	Winter	1.58	Rising	8.8	406	9.9	10.3	1.2	2.0	ND	ND	ND	265
12/18/08	15:19	Winter	1.41	Base	5.9	401	10.2	15.7	0.8	1.2	ND	ND	ND	248
1/23/09	9:15	Winter	1.63	Base	4.8	383	10.1	12.7	0.1	2.0	ND	ND	ND	235
2/2/09	9.52	Winter	2.54	Rising	5.2	402	10.3	14.5	0.9	2.0	ND	ND	ND	305
2/11/09	9:26	Winter	15.75	Rising	10.0	342	10.0	9.6	16.9	38.0	ND	ND	ND	102
2/20/09	9:44	Winter	7.74	Falling	6.7	347	10.0	11.6	1	1.6	ND	ND	ND	274
3/4/09	9:23	Spring	3.43	Falling	6.4	366	10.4	12.5	0.4	2.0	ND	ND	ND	239
3/11/09	9:30	Spring	2.87	Falling	10.6	368	10.1	8.2	1.2	4.0	ND	ND	ND	285
4/8/09	10:09	Spring	6.33	Falling	10.3	356	10.5	11.9	1	2.0	0.0	2.0	100	233
4/13/09	10:12	Spring	14.20	Rising	11.1	335	10.0	10.9	3.6	8.5	2.0	10.5	81	228
4/19/09	11:58	Spring	58.37	Rising	13.6	270	10.0	10.2	59.3	113.5	0.5	114.0	100	119
5/1/09	11:22	Spring	8.76	Rising	15.6	337	10.0	9.4	9.5	13.0	4.0	17.0	76	220
5/15/09	11:30	Spring	14.69	Rising	17.4	318	10.2	11.0	3.9	8.5	9.0	17.5	49	229
5/22/09	11:38	Spring	7.53	Falling	18.0	352	10.3	11.2	2.6	ND	1.5	1.5	ND	273
6/22/09	11:08	Summer	4.22	Falling	24.0	376	10.3	8.3	4.5	9.5	5.0	14.5	66	274
7/8/09	10:45	Summer	1.52	Base	22.8	402	10.2	8.5	3	6.5	0.0	6.5	100	247
7/14/09	10:19	Summer	1.89	Rising	22.9	394	10.1	6.8	4.7	9.5	0.5	10.0	95	372
7/21/09	10:45	Summer	3.82	Rising	20.9	355.3	10.1	7.7	14	27.0	0.5	27.5	98	119
7/30/09	13:05	Summer	5.33	Falling	22.1	348	8.6	6.9	5.8	6.5	0.0	6.5	100	336
8/20/09	10.04	Summer	2.37	Peak	22.2	387	8.1	7.5	5.2	4.0	1.0	5.0	80	281
8/26/09	12:38	Summer	1.10	Base	22.5	396	8.1	7.8	2.9	14.0	0.5	14.5	97	335
9/9/09	10:32	Fall	0.94	Base	21.7	398	7.9	9.2	2.4	11.0	0.5	11.5	96	255
9/22/09	10:45	Fall	3.43	Peak	20.1	400	7.9	9.9	4.8	14.0	3.5	17.5	80	143

Finley Creek Instantaneous Concentration Data, continued

Date	TN mg/l	TP mg/l	TIC mg/l	TOC mg/l	DIC mg/l <0.45 um	DOC mg/l <0.45 um	SIC mg/l	SOC mg/l	Organic Carbon %	F- mg/l	Cl- mg/l	NO3- mg/l	SO4- mg/l
9/26/2008	1.85	0.031	36.40	1.04	33.02	0.49	3.38	0.55	47	0.22	9.96	1.70	6.95
10/14/2008	2.12	0.023	ND	ND	ND	ND	ND	ND	ND	0.19	15.70	1.85	9.20
10/23/2008	1.88	0.043	36.48	1.70	35.39	1.33	1.09	0.37	78	0.20	14.16	1.59	8.76
11/5/2008	1.5	0.019	37.39	2.22	37.71	2.17	-0.32	0.05	98	0.22	14.34	1.46	8.58
11/11/2008	1.65	0.023	36.69	1.76	42.06	1.81	-5.37	-0.05	103	0.20	14.40	1.52	8.58
11/25/2008	1.66	0.017	34.77	2.63	32.91	4.38	1.86	-1.75	167	ND	ND	ND	ND
12/4/2008	1.91	0.018	ND	ND	ND	ND	ND	ND	ND	0.12	17.90	1.59	10.99
12/9/2008	1.73	0.012	32.36	1.64	33.09	1.11	-0.73	0.52	68	0.10	18.70	1.74	10.94
12/18/2008	1.39	0.013	ND	ND	ND	ND	ND	ND	ND	0.11	17.76	1.61	10.37
1/23/2009	1.85	0.012	33.83	0.64	33.13	1.13	0.70	-0.49	176	0.01	13.14	1.43	7.92
2/2/2009	1.99	0.014	32.85	1.04	33.04	1.28	-0.19	-0.24	123	0.05	17.39	1.68	8.03
2/11/2009	1.66	0.034	28.00	1.96	28.13	1.14	-0.13	0.82	58	0.06	13.20	1.60	7.02
2/20/2009	2.12	0.024	28.97	1.07	29.39	0.82	-0.42	0.25	77	ND	ND	ND	ND
3/4/2009	1.86	0.017	29.48	0.86	29.32	1.01	0.16	-0.16	118	0.03	13.46	1.73	8.44
3/11/2009	1.57	0.021	29.86	0.89	29.08	0.88	0.78	0.01	99	0.05	11.88	1.53	7.69
4/8/2009	1.55	0.010	30.22	0.80	30.35	0.97	-0.13	-0.17	121	0.03	11.13	1.31	7.07
4/13/2009	1.36	0.019	28.08	1.34	27.76	1.36	0.32	-0.02	101	0.04	10.49	1.00	6.80
4/19/2009	1.24	0.071	23.45	4.70	22.67	2.47	0.78	2.23	53	0.06	8.17	0.96	5.62
5/1/2009	1.46	0.023	29.17	2.14	27.61	1.74	1.55	0.40	81	0.11	10.26	1.31	6.55
5/15/2009	1.36	0.026	27.51	1.50	26.97	1.41	0.54	0.09	94	0.01	7.31	0.97	5.07
5/22/2009	1.39	0.010	30.82	1.38	30.42	1.32	0.40	0.06	96	0.00	9.66	1.05	5.90
6/22/2009	1.66	0.031	30.52	1.31	30.19	1.30	0.33	0.01	99	ND	11.29	1.17	7.53
7/8/2009	2.03	0.024	35.25	1.75	34.91	1.77	0.34	-0.02	101	0.00	16.55	0.00	0.89
7/14/2009	1.69	0.032	34.97	1.94	34.39	1.91	0.59	0.03	99	0.04	13.58	1.45	8.95
7/21/2009	1.89	0.064	30.92	2.79	31.83	2.85	-0.92	-0.05	102	0.04	11.66	1.56	8.57
7/30/2009	1.45	0.063	34.35	1.88	32.31	2.79	2.04	-0.92	149	0.05	10.98	0.92	6.91
8/20/2009	1.96	0.039	30.63	ND	30.73	ND	-0.10	ND	ND	0.12	14.63	1.18	9.13
8/26/2009	2.21	0.035	33.42	1.38	32.67	1.64	0.76	-0.26	119	0.81	14.49	1.19	9.34
9/9/2009	2.01	0.042	35.74	2.31	35.49	1.70	0.25	0.61	74	0.12	15.29	1.23	10.29
9/22/2009	2.51	0.101	35.46	2.91	35.77	2.11	-0.31	0.80	73	0.13	15.77	1.54	10.07

Middle James Instantaneous Concentration Data

Date	Time	Season	Q	Hydrograph	Temp	SC	pH	DO	Turbidity	TSS	SS1.5-0.45	SS0.45	TSS	TDS
			m3/s	Limb	°C	us/cm		mg/l	NTU	mg/l	mg/l	mg/l	%>0.45	mg/l
										>1.5 um	1.5-0.45 um	>0.45 um		<0.45 um
9/26/08	13:03:48	Fall	8.34	Falling	19.19	0.282	9.71	9.45	2.8	4.0	ND	ND	ND	297
10/14/08	13:00	Fall	3.49	Base	20.32	0.547	9.86	9.02	3.3	4.0	ND	ND	ND	207
10/23/08	12:08:00	Fall	13.40	Falling	15.32	0.577	9.79	8.31	11.6	20.7	ND	ND	ND	332
11/5/08	12:30:36	Fall	3.35	Base	16.2	0.515	10.11	9.68	2.2	3.3	ND	ND	ND	370
11/11/08	10:45:21	Fall	4.27	Base	10.64	0.522	10.06	10.55	2	1.3	ND	ND	ND	257
11/25/08	10:00:16	Winter	3.35	Base	7.69	0.575	10.71	11.91	1.6	1.7	ND	ND	ND	342
12/4/08	11:00	Winter	3.21	Base	5.32	0.560	10.37	13.47	1.1	1.7	ND	ND	ND	113
12/9/08	10:40	Winter	3.35	Base	9.07	0.559	10.04	10.32	2.8	1.6	ND	ND	ND	269
12/18/08	15:42	Winter	3.42	Base	6.16	0.543	10.4	14.74	1.1	3.6	ND	ND	ND	328
1/23/09	9:44	Winter	5.12	Base	7.19	0.521	10.17	11.55	2.4	4.8	ND	ND	ND	279
2/2/09	10.16	Winter	8.23	Rising	7.46	0.653	9.91	11.51	3.1	10.8	ND	ND	ND	464
2/11/09	10:03	Winter	30.77	Rising	12.7	0.254	9.87	7.85	40.3	91.6	ND	ND	ND	154
2/20/09	10:11	Winter	14.84	Falling	8.03	0.456	10.16	10.46	3.3	4.4	ND	ND	ND	333
3/4/09	9:49	Spring	7.79	Falling	7.59	0.474	10.46	10.69	1.6	4.8	ND	ND	ND	278
3/11/09	9:55	Spring	6.94	Falling	12.21	0.493	9.81	7.15	2.7	6.5	ND	ND	ND	409
4/8/09	10:44	Spring	13.26	Falling	11.74	0.455	10.21	11.15	3.1	10.5	0.0	10.5	100	329
4/13/09	10:34	Spring	33.32	Rising	12.49	0.385	9.94	10.02	13.4	27.5	4.0	31.5	87	230
4/19/09	12:22	Spring	39.31	Rising	15.43	0.446	9.93	9.5	148.1	61.5	0.0	61.5	100	257
5/1/09	10:45	Spring	143.17	Rising	17.83	0.048	9.89	8.19	1433	590.0	20.0	610.0	97	54
5/15/09	12:05	Spring	27.52	Falling	19.83	0.400	10.05	9.55	7.8	21.5	7.0	28.5	75	272
5/22/09	11:15	Spring	15.44	Falling	19.55	0.460	10.13	9.33	4.7	ND	2.0	ND	ND	262
6/22/09	11:36	Summer	8.79	Falling	25.67	0.455	10.21	7.43	9.7	18.5	5.0	23.5	79	319
7/8/09	11:03	Summer	4.03	Base	23.37	0.509	10.29	7.97	5.7	10	0.0	10.0	100	234
7/14/09	10:53	Summer	4.77	Rising	23.82	0.512	10.17	6.74	8.5	18	3.0	21.0	86	326
7/21/09	10:29	Summer	4.69	Rising	22.51	0.517	10.22	7.42	6.8	25	-0.5	24.5	102	316
7/30/09	12:40	Summer	8.00	Rising	23.89	0.501	8.58	6.32	8	20	1.0	21.0	95	354
8/20/09	9.39	Summer	23.86	Rising	21.88	0.486	8.01	7.89	29.3	70	7.0	77.0	91	447
8/26/09	13:00	Summer	4.11	Base	22.88	0.539	8.13	7.68	4.5	13	1.5	14.5	90	430
9/9/09	10:10	Fall	3.21	Base	22.28	0.563	7.9	9.01	4.4	10	1.0	11.0	91	335
9/22/09	10:16	Fall	45.26	Falling	19.52	0.214	7.58	9.97	53.3	96.5	10.0	106.5	91	154

Middle James Instantaneous Concentration Data, continued

Date	TN mg/l	TP mg/l	TIC mg/l	TOC mg/l	DIC mg/l	DOC mg/l <0.45 um	SIC mg/l <0.45 um	SOC mg/l	Organic Carbon %	F- mg/l	Cl- mg/l	NO3- mg/l	SO4- mg/l
9/26/08	2.38	0.04	38.37	3.31	36.25	2.76	2.12	0.55	83	0.52	26.909	2.416	16.02
10/14/08	3.49	0.04	ND	ND	ND	ND	ND	ND	ND	ND	50.572	3.506	20.736
10/23/08	4.56	0.098	37.83	3.38	38.28	2.71	-0.44	0.67	80	0.416	69.076	4.566	25.255
11/5/08	4.32	0.03	36.83	3.01	36.42	2.60	0.42	0.42	86	0.363	37.937	4.245	19.343
11/11/08	4.41	0.039	37.11	2.54	35.33	2.29	1.78	0.25	90	0.356	40.271	4.657	18.277
11/25/08	4.17	0.026	37.02	3.58	34.78	4.76	2.24	-1.18	133	ND	ND	ND	ND
12/4/08	4.37	0.032	ND	ND	ND	ND	ND	ND	ND	0.364	53.262	5.713	22.569
12/9/08	4.16	0.025	33.01	1.85	33.70	1.69	-0.69	0.17	91	0.320	59.760	5.417	21.846
12/18/08	3.07	0.03	ND	ND	ND	ND	ND	ND	ND	0.391	57.170	4.291	22.871
1/23/09	3.59	0.046	36.19	1.81	35.79	1.71	0.40	0.10	94	0.220	32.885	3.137	20.403
2/2/09	4.75	0.072	34.37	1.50	31.30	2.00	3.07	-0.50	134	0.019	91.208	4.413	20.735
2/11/09	3.7	0.137	30.42	2.93	30.60	1.14	-0.17	1.80	39	0.214	43.545	4.534	17.616
2/20/09	3.33	0.041	32.82	0.93	33.04	0.85	-0.23	0.08	91	ND	ND	ND	ND
3/4/09	3.02	0.023	31.58	0.96	31.51	0.71	0.07	0.24	75	0.086	29.080	3.205	16.609
3/11/09	4.19	0.058	32.24	1.51	31.84	1.85	0.40	-0.35	123	0.207	29.616	3.898	16.261
4/8/09	2.59	0.025	33.38	1.10	33.60	1.25	-0.22	-0.15	114	0.052	23.921	2.459	12.899
4/13/09	2.24	0.055	26.95	1.47	27.68	1.66	-0.73	-0.19	113	0.123	19.054	1.836	10.412
4/19/09	2.83	0.134	32.38	2.43	31.50	1.36	0.89	1.07	56	0.191	24.946	2.781	13.804
5/1/09	1.45	0.333	21.77	14.78	19.36	2.11	2.41	12.67	14	0.118	11.820	0.920	6.808
5/15/09	2.30	0.045	30.86	1.87	31.09	1.18	-0.23	0.68	63	0.047	14.011	1.532	9.967
5/22/09	2.00	0.043	34.95	1.57	34.74	1.19	0.20	0.39	75	0.051	24.190	1.630	11.747
6/22/09	2.33	0.017	32.83	1.77	32.59	1.68	0.24	0.09	95	0.082	21.765	1.977	13.789
7/8/09	3.68	0.167	34.92	2.12	33.49	1.82	1.43	0.30	86	0.248	31.928	2.931	18.248
7/14/09	3.01	0.110	34.13	2.27	33.55	2.20	0.57	0.07	97	0.203	36.555	2.671	24.752
7/21/09	3.43	0.100	34.25	2.89	34.18	2.72	0.07	0.17	94	0.167	36.778	2.9	19.786
7/30/09	3.49	0.149	36.11	2.49	34.60	2.35	1.50	0.14	94	0.197	37.36	2.227	15.754
8/20/09	3.89	0.182	28.98	ND	28.93	ND	0.05	ND	ND	0.238	36.689	2.609	20.651
8/26/09	4.48	0.097	35.70	1.88	35.02	1.68	0.67	0.19	90	0.507	37.524	2.929	20.383
9/9/09	4.59	0.102	34.53	3.01	34.84	2.44	-0.31	0.57	81	0.268	50.927	3.290	26.164
9/22/09	1.80	0.186	22.69	6.03	23.00	3.66	-0.31	2.37	61	0.111	12.226	0.928	8.201

Wilson Creek Instantaneous Concentration Data

Date	Time	Season	Q m3/s	Hydrograph Limb	Temp °C	SC us/cm	pH	DO mg/l	Turbidity NTU	TSS mg/l >1.5 um	SS1.5-0.45 mg/l 1.5-0.45 um	SS0.45 mg/l >0.45 um	TSS %>0.45	TDS mg/l <0.45 um
9/26/08	13:27:40	Fall	0.19	Falling	21.37	0.479	9.77	9.09	4.3	3.0	ND	ND	ND	400
10/14/08	13:54	Fall	0.09	Base	20.18	0.653	9.46	8.82	3.4	6.0	ND	ND	ND	304
10/23/08	13:07:21	Fall	0.42	Falling	12.8	0.254	9.78	9.95	10.5	6.7	ND	ND	ND	131
11/5/08	13:34:42	Fall	0.18	Base	15.41	0.638	9.63	8.58	1.3	2.7	ND	ND	ND	493
11/11/08	11:18:35	Fall	0.25	Falling	10.53	0.393	9.57	9.42	9.8	1.7	ND	ND	ND	193
11/25/08	10:51:45	Fall	0.11	Base	6.85	0.664	9.82	13.19	299.3	1.3	ND	ND	ND	376
12/4/08	11:40	Winter	0.10	Base	3.87	0.656	10.11	15.6	0.6	11.0	ND	ND	ND	125
12/9/08	11:22	Winter	1.23	Falling	9.11	0.388	9.71	9.95	31.4	25.6	ND	ND	ND	374
12/18/08	16:27	Winter	0.09	Base	5.61	0.759	9.85	15.56	4.6	2.4	ND	ND	ND	454
1/23/09	10:22	Winter	0.11	Base	5.82	0.632	9.99	11.85	75.6	3.6	ND	ND	ND	395
2/2/09	11.1	Winter	0.25	Falling	4.45	0.71	9.95	14.68	7.2	6.4	ND	ND	ND	496
2/11/09	10:42	Winter	10.61	Peak	9.79	0.216	10.01	9.56	110.6	146.0	ND	ND	ND	66
2/20/09	10:48	Winter	0.33	Falling	6.67	0.682	10.16	11.97	0.1	0.4	ND	ND	ND	492
3/4/09	10:45	Spring	0.23	Base	6.24	0.672	10.57	12.59	3.6	3.2	ND	ND	ND	434
3/11/09	10:44	Spring	0.25	Falling	7.91	0.506	9.88	7.98	15	10.5	ND	ND	ND	396
4/8/09	11:28	Spring	0.31	Base	11.32	0.653	10.31	11.48	0.9	1.5	0.5	2.0	75	465
4/13/09	11:17	Spring	0.81	Falling	10.07	0.326	9.96	11.16	12.4	9.0	5.0	14.0	64	204
4/19/09	13:03	Spring	8.13	Rising	13.23	0.168	10.06	10.21	38	44.5	0.0	44.5	100	30
5/1/09	10:01	Spring	9.79	Rising	15.57	0.281	9.90	9.46	64.2	98.0	10.5	108.5	90	197
5/15/09	12:47	Spring	0.39	Base	20.03	0.569	9.87	9.86	1.3	4.0	4.5	8.5	47	407
5/22/09	10:30	Spring	0.23	Base	17.98	0.64	9.93	9.57	1.8	ND	3.5	ND	ND	495
6/22/09	12:15	Summer	0.13	Base	24.85	0.633	10.12	9.17	3.8	23.5	5.5	29.0	81	435
7/8/09	11:03	Summer	0.05	Base	23.37	0.509	10.29	7.97	5.7	10.0	1.0	11.0	91	385
7/14/09	8:33	Summer	7.75	Falling	22.74	0.118	10.35	7.22	58.6	66.5	5.5	72.0	92	25
7/21/09	9:29	Summer	2.98	Rising	21.48	0.351	10	6.85	14.4	271.0	1.5	272.5	99	265
7/30/09	11:56	Summer	1.78	Rising	23.06	0.245	8.47	6.44	14.8	73.5	1.0	74.5	99	180
8/20/09	8.41	Summer	2.69	Falling	20.32	0.199	7.95	7.73	32.3	20.0	1.5	21.5	93	91
8/26/09	13:37	Summer	0.19	Base	22.46	0.601	8.04	8.34	0.3	7.5	0.0	7.5	100	433
9/9/09	9:28	Fall	0.71	Rising	21.21	0.195	7.94	9.47	9.1	5.0	0.5	5.5	91	21
9/22/09	9:34	Fall	1.60	Falling	18.73	0.282	7.59	9.93	9.3	14.5	5.5	20.0	73	168

Wilson Creek Instantaneous Concentration Data, continued

Date	TN mg/l	TP mg/l	TIC mg/l	TOC mg/l	DIC mg/l	DOC mg/l <0.45 um	SIC mg/l <0.45 um	SOC mg/l	Organic Carbon %	F- mg/l	Cl- mg/l	NO3- mg/l	SO4- mg/l
9/26/08	2.31	0.027	50.70	2.81	45.40	2.64	5.30	0.17	94	0.449	48.753	2.28	30.261
10/14/08	1.94	0.028	ND	ND	ND	ND	ND	ND	ND	0.192	57.116	1.538	29.363
10/23/08	1.14	0.077	21.08	4.22	20.66	3.28	0.42	0.94	78	0.250	12.886	0.755	10.564
11/5/08	1.39	0.021	49.23	2.55	46.93	2.48	2.30	0.07	97	0.217	49.597	1.618	26.323
11/11/08	1.18	0.051	30.92	5.20	29.75	4.29	1.17	0.91	83	0.348	23.956	1.017	14.703
11/25/08	1.7	0.016	48.38	3.91	43.00	5.52	5.39	-1.61	141	ND	ND	ND	ND
12/4/08	1.76	0.029	ND	ND	ND	ND	ND	ND	ND	0.225	54.137	1.462	26.85
12/9/08	1.3	0.068	24.53	5.04	24.45	4.24	0.08	0.81	84	0.456	44.050	1.097	12.08
12/18/08	1.18	0.011	ND	ND	ND	ND	ND	ND	ND	0.314	120.800	1.617	26.568
1/23/09	2.12	0.01	44.12	0.76	41.92	1.40	2.19	-0.63	183	0.181	39.404	1.434	22.754
2/2/09	1.46	0.02	26.26	2.39	25.49	1.80	0.77	0.59	75	0.122	138.031	1.238	15.517
2/11/09	0.71	0.11	13.22	8.47	11.19	2.32	2.03	6.15	27	0.127	25.75	0.629	6.847
2/20/09	2.37	0.009	46.93	0.50	45.09	0.61	1.84	-0.11	121	ND	ND	ND	ND
3/4/09	1.99	0.013	43.25	0.50	41.97	ND	1.27	ND	ND	0.229	62.719	2.542	27.744
3/11/09	1.75	0.045	27.26	4.43	26.25	3.73	1.01	0.70	84	0.202	55.461	1.276	16.076
4/8/09	2.25	0.016	45.57	1.01	43.26	1.20	2.32	-0.19	119	0.105	42.668	1.468	22.147
4/13/09	2.29	0.024	34.25	1.30	34.34	1.43	-0.10	-0.14	111	0.085	20.765	1.867	9.450
4/19/09	0.71	0.075	12.01	4.35	11.37	2.72	0.64	1.63	63	0.111	9.568	0.402	6.059
5/1/09	2.09	0.225	20.22	7.47	18.25	3.25	1.97	4.21	44	0.211	14.261	1.441	15.690
5/15/09	2.33	0.024	39.48	1.14	37.54	1.86	1.93	-0.72	163	0.150	28.641	1.607	24.129
5/22/09	2.70	0.027	47.18	1.34	45.50	1.03	1.68	0.31	77	0.090	37.829	2.164	28.005
6/22/09	2.21	0.029	44.67	1.09	41.83	1.00	2.84	0.09	92	0.103	36.449	1.656	25.723
7/8/09	1.79	0.015	44.87	1.88	42.98	1.70	1.89	0.18	90	0.112	39.687	5.038	24.184
7/14/09	0.95	0.127	9.20	6.66	8.36	4.65	0.84	2.01	70	0.000	5.477	0.000	4.934
7/21/09	1.38	0.191	34.98	14.62	31.78	3.87	3.20	10.75	26	0.089	23.059	4.509	13.151
7/30/09	1.78	0.088	19.50	6.16	19.21	5.07	0.29	1.09	82	0.055	12.089	2.813	8.861
8/20/09	1.15	0.117	14.02	ND	13.82	ND	0.20	ND	ND	0.241	8.704	0.539	6.116
8/26/09	2.72	0.024	44.39	1.35	43.75	1.40	0.63	-0.05	104	0.113	36.559	1.891	23.353
9/9/09	2.44	0.084	15.91	5.98	15.03	5.26	0.88	0.72	88	0.337	9.564	0.612	6.829
9/22/09	1.45	0.128	23.30	6.42	23.09	6.19	0.21	0.23	96	0.096	12.499	0.582	9.753

Pearson Creek Instantaneous Load Data

Date	TSS	TDS	TN	TP	TIC	TOC	DIC	DOC	F-	Cl-	NO3-	SO4-
	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day
	>1.5 um	<0.45 um						<0.45 um				
9/26/08	138	19690	168	4.28	2980	140	2825	117	25	1209	167	649
10/14/08	13	3938	49	0.34	ND	ND	ND	ND	6	438	44	192
10/23/08	385	17654	156	1.99	2809	156	2838	131	12	1609	142	678
11/5/08	5	6277	32	0.29	762	66	748	53	3	375	30	164
11/11/08	67	6983	53	1.41	1101	53	1090	44	5	564	52	257
11/25/08	25	4132	32	0.23	634	49	599	77	ND	ND	ND	ND
12/4/08	12	1274	25	0.23	ND	ND	ND	ND	2	327	27	134
12/9/08		4474	27	0.40	523	36	545	19	3	369	29	152
12/18/08	15	3636	20	0.15	ND	ND	ND	ND	2	346	28	145
1/23/09	33	6302	56	0.17	850	10	839	18	0	410	48	201
2/2/09	86	13687	98	0.47	1454	58	1404	64	5	1670	97	405
2/11/09	1479	16809	317	2.35	4189	234	4226	209	15	4012	325	1222
2/20/09	102	28732	240	1.19	3265	125	3267	114	ND	ND	ND	ND
3/4/09	144	12542	115	0.54	1678	57	1677	56	3	1080	111	492
3/11/09	139	13570	102	0.87	1542	72	1507	65	7	874	97	425
4/8/09	254	23905	174	1.09	2766	92	2767	69	2	1384	174	711
4/13/09	355	36459	265	5.21	3632	258	3613	307	16	2296	89	1355
4/19/09	1006	34351	388	5.88	5671	255	5523	312	12	2878	338	1440
5/1/09	108702	185365	1980	151	24537	7356	23534	4036	114	10293	1706	8775
5/15/09	1320	45471	411	2.49	5513	324	5341	270	3	1997	286	1374
5/22/09		24929	213	1.58	3300	143	3235	151	1	1420	162	760
6/22/09	603	16884	107	1.44	1877	56	1806	67	1	807	96	468
7/8/09	131	8279	60	0.50	1046	47	993	43	ND	603	ND	208
7/14/09	1229	20967	173	2.60	3129	262	3008	211	7	1456	149	690
7/21/09	1376	25730	191	2.08	3297	213	3188	232	11	1800	161	797
7/30/09	407	18275	133	1.96	2081	123	1966	176	6	875	81	487
8/20/09	3667	51045	320	10.7	4269	ND	4322	ND	21	2029	199	1091
8/26/09	249	12046	115	0.81	1644	58	1600	59	4	759	76	396
9/9/09	535	13629	97	2.58	1651	144	1627	138	8	819	65	431
9/22/09	7162	89529	1160	35.1	13085	1719	12805	1140	21	4033	685	2809

Upper James Instantaneous Load Data

Date	TSS kg/day >1.5 um	TDS kg/day <0.45 um	TN kg/day	TP kg/day	TIC kg/day	TOC kg/day	DIC kg/day	DOC kg/day <0.45 um	F- kg/day	Cl- kg/day	NO3- kg/day	SO4- kg/day
9/26/08	765	45711	267	8.07	7085	389	6650	220	56.1	2230.5	256.5	1643.1
10/14/08	295	11494	90	0.88	ND	ND	ND	ND	12.5	1077.5	68.1	641.3
10/23/08	697	31284	173	4.21	5575	373	5541	306	20.4	2173.0	109.9	1293.3
11/5/08	339	25848	62	1.27	3195	237	3193	222	14.8	1150.4	46.2	713.8
11/11/08	128	19910	646	1.58	3724	188	3877	157	21.5	1496.9	87.0	873.1
11/25/08	100	15503	59	0.61	2692	199	2583	293	ND	ND	ND	ND
12/4/08	320	6394	80	1.30	ND	ND	ND	ND	12.4	1454.3	66.5	802.5
12/9/08	35	19114	45	0.35	2823	130	2958	103	7.3	1449.5	58.0	825.7
12/18/08	106	20171	49	0.44	ND	ND	ND	ND	12.2	1546.3	60.5	935.5
1/23/09	1633	52297	316	2.04	8048	135	8169	195	7.9	3265.4	265.6	2426.1
2/2/09	879	75023	382	2.75	8974	328	10094	253	25.3	4993.3	270.4	2613.4
2/11/09	1241472	407506	6539	279.57	106668	20858	106306	11588	279.6	55060.7	5690.9	44934.7
2/20/09	1593	152447	1047	10.24	15600	659	15788	631	ND	ND	ND	ND
3/4/09	1561	80180	507	4.97	9928	284	10211	385	2.1	5840.4	410.8	3680.1
3/11/09	2218	84929	364	6.02	9204	332	9248	328	14.6	4016.4	312.1	3029.2
4/8/09	3432	128318	623	6.34	14422	601	14669	473	14.8	6149.7	622.6	4842.8
4/13/09	35250	213067	1911	47.00	37443	3259	37177	3509	197.4	18090.4	1923.5	13832.1
4/19/09	392098	421359	4526	187.27	90942	11402	89124	7283	257.5	38936.7	3472.6	32721.6
5/15/09	40244	200853	967	31.01	19811	1210	19495	1381	28.1	6322.4	722.9	5544.1
5/22/09		83041	371	4.46	10156	496	9892	463		3791.1	311.4	2740.7
6/22/09	4955	64627	254	4.95	6252	322	6242	355	5.4	2431.3	200.6	1818.6
7/8/09	701	27501	109	2.48	3783	181	3710	179	11.8	1378.0	101.1	885.9
7/14/09	3763	35510	205	6.75	6759	456	6622	418	8.1	2474.7	180.1	1446.1
7/21/09	2819	73301	316	9.40	11118	585	10772	695	12.5	4302.2	303.5	2695.5
7/30/09	1601	48323	214	6.70	5109	376	4929	419	7.0	1994.1	115.7	1162.4
8/20/09	5347	70917	383	9.38	5996	ND	6070	ND	25.7	2834.6	206.6	1547.4
8/26/09	2068	20906	128	1.96	2816	117	2778	122	4.1	1158.3	67.6	970.9
9/9/09	1181	18833	73	1.99	2338	147	2344	133	6.5	913.6	53.7	517.3
9/22/09	17090	130346	1289	87.67	17558	2805	17045	2114	28.4	5811.7	633.2	3873.3

Finley Creek Instantaneous Load Data

Date	TSS kg/day >1.5 um	TDS kg/day <0.45 um	TN kg/day	TP kg/day	TIC kg/day	TOC kg/day	DIC kg/day <0.45 um	DOC kg/day <0.45 um	F- kg/day	Cl- kg/day	NO3- kg/day	SO4- kg/day
9/26/08	668	87671	727	12.2	14310	409	12982	193	87.7	3916	666	2730
10/14/08	732	31509	361	3.9	ND	ND	ND	ND	32.2	2674	315	1566
10/23/08	774	52919	485	11.1	9416	439	9135	344	51.6	3655	410	2262
11/5/08	352	45423	229	2.9	5718	340	5767	332	34.0	2193	223	1313
11/11/08	368	34435	304	4.2	6756	324	7745	333	36.1	2651	280	1580
11/25/08	273	30629	227	2.3	4754	360	4500	599	ND	ND	ND	ND
12/4/08	115	9394	219	2.1	ND	ND	ND	ND	13.2	2051	182	1259
12/9/08	273	36235	237	1.6	4425	224	4524	152	13.1	2557	238	1496
12/18/08	146	30176	169	1.6	ND	ND	ND	ND	13.5	2161	196	1261
1/23/09	281	33059	260	1.7	4759	90	4661	158	1.4	1849	202	1115
2/2/09	438	66841	436	3.1	7198	229	7240	281	10.3	3812	367	1760
2/11/09	51710	138255	2259	46.3	38104	2663	38284	1548	76.2	17961	2177	9558
2/20/09	1070	183217	1418	16.0	19372	715	19652	548	ND	ND	ND	ND
3/4/09	593	70867	552	5.0	8740	254	8693	300	10.1	3990	514	2502
3/11/09	992	70659	389	5.2	7402	222	7210	219	11.9	2945	379	1907
4/8/09	1093	127351	847	5.5	16518	436	16590	528	14.2	6082	717	3864
4/13/09	10426	279666	1668	23.3	34439	1647	34050	1667	42.9	12870	1222	8338
4/19/09	572413	600151	6254	358.1	118261	23710	114351	12473	322.8	41219	4859	28328
5/1/09	9840	166525	1105	17.4	22076	1618	20901	1314	84.0	7762	995	4956
5/15/09	10785	290565	1726	33.0	34910	1902	34223	1790	17.8	9271	1231	6436
5/22/09		177694	905	6.5	20061	898	19800	859	ND	6284	684	3840
6/22/09	3467	99988	606	11.3	11137	478	11017	474	ND	4121	427	2749
7/8/09	855	32500	267	3.2	4638	230	4593	233	ND	2177	ND	117
7/14/09	1552	60785	276	5.2	5715	316	5619	312	6.7	2218	236	1462
7/21/09	8910	39270	624	21.1	10203	922	10505	939	11.9	3847	514	2828
7/30/09	2996	154861	668	29.0	15830	865	14891	1288	24.9	5060	425	3186
8/20/09	821	57641	402	8.0	6282	ND	6303	ND	24.6	3000	241	1873
8/26/09	1333	31887	210	3.3	3181	131	3109	156	76.6	1379	114	889
9/9/09	893	20711	163	3.4	2902	187	2882	138	9.6	1241	99	836
9/22/09	4151	42401	744	29.9	10514	863	10606	626	39.7	4675	456	2987

Middle James Instantaneous Load Data

Date	TSS	TDS	TN	TP	TIC	TOC	DIC	DOC	F-	Cl-	NO3-	SO4-
	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day
	>1.5 um	<0.45 um						<0.45 um				
9/26/08	2882	213953	1715	29	27537	1426	26014	1032	375	19385	1740	11540
10/14/08	1208	62505	1054	12	ND	ND	ND	ND		15270	1059	6261
10/23/08	23966	384380	5279	113	43137	4105	43186	2989	482	79974	5286	29240
11/5/08	955	107047	1250	9	10589	940	10340	801	105	10976	1228	5596
11/11/08	480	94838	1627	14	13559	966	12757	906	131	14861	1719	6745
11/25/08	492	98947	1206	8	10522	1062	9754	1487	ND	ND	ND	ND
12/4/08	471	31294	1210	9	ND	ND	ND	ND	101	14750	1582	6250
12/9/08	463	77826	1204	7	9517	626	9718	578	93	17290	1567	6320
12/18/08	1064	96958	908	9	ND	ND	ND	ND	116	16900	1268	6761
1/23/09	2124	123461	1589	20	16013	801	15837	755	97	14552	1388	9029
2/2/09	7676	329774	3376	51	24250	1399	23043	1640	14	64823	3136	14737
2/11/09	243546	408392	9838	364	80717	8675	81175	3901	569	115778	12055	46837
2/20/09	5643	427088	4271	53	41955	1616	42245	1524	ND	ND	ND	ND
3/4/09	3229	187013	2032	15	21291	928	21379	962	58	19562	2156	11173
3/11/09	3898	245276	2513	35	19255	852	19016	853	124	17761	2338	9752
4/8/09	12029	376913	2967	29	38241	1256	38492	1428	60	27405	2817	14777
4/13/09	79162	662080	6448	158	77337	5195	79441	5743	354	54849	5284	29972
4/19/09	208856	872782	9611	455	109695	9373	106685	5724	649	84718	9444	46879
5/1/09	7298112	667963	17936	4119	269475	168220	234247	31519	1460	146210	11384	84213
5/15/09	51113	646645	5468	107	73221	5285	73765	3658	112	33309	3642	23695
5/22/09		349553	2668	57	46535	2490	46262	1972	68	32274	2175	15673
6/22/09	14053	242326	1770	13	24745	1605	24564	1536	62	16534	1502	10475
7/8/09	3482	81484	1281	58	12108	839	11610	735	86	11118	1021	6354
7/14/09	7422	134425	1241	45	13884	1105	13805	1064	84	15073	1101	10206
7/21/09	10124	127969	1389	40	13785	1118	13688	1117	68	14894	1174	8013
7/30/09	13832	244822	2414	103	24890	2019	24150	1936	136	25838	1540	10895
8/20/09	144305	921488	8019	375	59206		59412		491	75634	5378	42572
8/26/09	4616	152689	1591	34	12636	768	12397	700	180	13324	1040	7238
9/9/09	2769	92775	1270	28	9539	833	9625	676	74	14104	911	7246
9/22/09	377397	602270	7045	728	88899	22814	88848	14628	434	47814	3631	32073

Wilson Creek Instantaneous Load Data

Date	TSS kg/day >1.5 um	TDS kg/day <0.45 um	TN kg/day	TP kg/day	TIC kg/day	TOC kg/day	DIC kg/day <0.45 um	DOC kg/day <0.45 um	Fl- kg/day	Cl- kg/day	NO3- kg/day	SO4- kg/day
9/26/08	50	6662	38.5	0.450	2474	72	2214	64	7	812	38	504
10/14/08	44	2242	14.3	0.207	ND	ND	ND	ND	1	421	11	217
10/23/08	241	4709	41.0	2.768	1886	369	1858	308	9	463	27	380
11/5/08	41	7494	21.1	0.319	2164	116	2063	113	3	754	25	400
11/11/08	36	4133	25.3	1.092	1645	284	1560	240	7	513	22	315
11/25/08	12	3566	16.1	0.152	1516	127	1345	178	2	513	14	255
12/4/08	92	1052	14.8	0.243	ND	ND	ND	ND	ND	ND	ND	ND
12/9/08	2711	39602	137.7	7.200	2692	573	2686	495	48	4664	116	1279
12/18/08	19	3576	9.3	0.087	ND	ND	ND	ND	2	952	13	209
1/23/09	34	3746	20.1	0.095	259	4	246	8	2	374	14	216
2/2/09	137	10622	31.3	0.428	563	59	546	47	3	2956	27	332
2/11/09	133813	60491	650.7	101	12951	8660	10682	2576	116	23601	576	6275
2/20/09	11.5	14120	68.0	0.258	813	15	782	16	ND	ND	ND	ND
3/4/09	63	8577	39.3	0.257	453	10	440	9	5	1239	50	548
3/11/09	225	8481	37.5	0.964	320	52	308	44	4	1188	27	344
4/8/09	40	12452	60.3	0.428	725	16	688	19	3	1143	39	593
4/13/09	631	14292	160.4	1.681	1839	88	1844	95	6	1455	131	662
4/19/09	31277	21085	499.0	53	8431	3305	7981	2155	78	6725	283	4259
5/1/09	82878	166602	1767.5	190	16956	6484	15314	3234	178	12060	1219	13269
5/15/09	135	13754	78.7	0.811	8391	318	7979	471	5	968	54	815
5/22/09		9782	53.4	0.534	1148	37	1110	31	2	748	43	553
6/22/09	264	4889	24.8	0.326	0	4	4	4	1	410	19	289
7/8/09	47	1813	8.4	0.071	15534	756	14879	693	1	187	24	114
7/14/09	44502	16730	635.7	85.0	6073	4628	5508	3279	ND	3665	ND	3302
7/21/09	69888	68340	355.9	49.3	8951	3810	8129	1048	23	5947	1163	3391
7/30/09	11292	27654	273.5	13.5	2957	915	2877	838	8	1857	432	1361
8/20/09	4642	21119	266.9	27.2	2963	ND	2919	ND	56	2020	125	1419
8/26/09	125	7212	45.3	0.400	498	18	491	19	2	609	31	389
9/9/09	306	1285	149.3	5.139	813	307	768	270	21	585	37	418
9/22/09	2003	23211	200.3	17.7	3312	899	3282	867	13	1727	80	1347

Upper James Triplicate Data

Date	TDS	TSS	TN	TP	TIC	TOC	DIC	DOC	Fl-	Cl-	NO3-	SO4-
9/26/2008	235	15.7	1.38	0.034	33.76	1.55	32.39	1.31	0.252	11.158	1.22	8.033
	221	3.7	1.29	0.039	34.07	2.24	32.36	0.65	0.271	10.784	1.24	7.944
	216	4.0	1.33	0.06	34.93	1.84	31.70	1.24	0.33	10.688	1.207	7.959
Mean	224	7.80	1.33	0.04	34.25	1.88	32.15	1.07	0.28	10.88	1.22	7.98
Stdev	9.85	6.84	0.05	0.01	0.61	0.35	0.39	0.36	0.041	0.248	0.017	0.048
CV	0.044	0.877	0.034	0.311	0.018	0.184	0.012	0.341	0.143	0.023	0.014	0.006
12/4/2008	84	2.7	1.00	0.013	ND	ND	ND	ND	0.087	16.496	0.672	9.418
	74	3.7	0.93	0.015	ND	ND	ND	ND	0.143	16.831	0.770	9.288
	76	1.0	0.89	0.013	ND	ND	ND	ND	0.209	16.832	0.833	9.489
Mean	78	2.47	0.94	0.01					0.15	16.72	0.76	9.40
Stdev	5.29	1.37	0.06	0.00					0.06	0.19	0.08	0.10
CV	0.068	0.553	0.059	0.084					0.417	0.012	0.107	0.011
2/20/2009	286	2.0	1.82	0.017	27.43	1.23	27.89	1.05	ND	ND	ND	ND
	268	2.8	1.84	0.018	27.50	1.21	27.76	1.10	ND	ND	ND	ND
	270	3.6	1.79	0.016	27.34	1.04	27.61	1.18	ND	ND	ND	ND
Mean	275	2.80	1.82	0.02	27.42	1.16	27.75	1.11				
Stdev	9.87	0.80	0.03	0.00	0.08	0.10	0.14	0.06				
CV	0.036	0.286	0.014	0.059	0.003	0.089	0.005	0.057				
4/19/2009	106	75.0	1.17	0.038	23.48	3.17	23.03	1.95	0.073	10.027	0.906	8.677
	108	100.5	1.16	0.048	23.29	2.94	22.95	1.99	0.066	9.980	0.890	8.387
	87	107.5	1.02	0.048	23.16	2.66	22.55	1.67	0.064	9.914	0.898	8.607
Mean	100	94.33	1.12	0.04	23.31	2.92	22.84	1.87	0.07	9.97	0.90	8.56
Stdev	11.59	17.11	0.08	0.01	0.16	0.25	0.26	0.17	0.00	0.06	0.01	0.15
CV	0.116	0.181	0.075	0.129	0.007	0.087	0.011	0.093	0.070	0.006	0.009	0.018
7/8/2009	256	5.5	1.12	0.024	34.67	1.74	34.68	1.87	0.042	12.697	0.825	7.970
	255	6.5	1.01	0.023	35.47	1.70	34.03	1.50	0.109	12.777	0.937	8.214
	281	14.0	1.02	0.026	35.10	1.60	34.48	1.59	0.032	12.751	0.795	7.997
Mean	264	8.67	1.05	0.02	35.08	1.68	34.40	1.66	0.06	12.74	0.85	8.06
Stdev	14.73	4.65	0.06	0.00	0.40	0.07	0.34	0.19	0.04	0.04	0.07	0.13
CV	0.056	0.536	0.058	0.063	0.011	0.043	0.010	0.116	0.686	0.003	0.088	0.017
9/9/2009	281	15.0	1.20	0.034	37.75	2.78	37.94	2.38	0.181	15.624	1.111	8.906
	303	19.0	1.17	0.032	37.36	2.21	37.41	2.13	0.104	14.699	0.864	8.322
	281	21.5	1.18	0.039	37.74	2.10	37.78	1.90	0.113	14.569	0.653	7.899
Mean	288	18.50	1.18	0.04	37.62	2.36	37.71	2.14	0.13	14.96	0.88	8.38
Stdev	12.70	3.28	0.02	0.00	0.22	0.37	0.27	0.24	0.04	0.58	0.23	0.51
CV	0.044	0.177	0.013	0.103	0.006	0.155	0.007	0.112	0.317	0.038	0.262	0.060

Upper James Field Duplicate Data

Date	TDS	TSS	TN	TP	TIC	TOC	DIC	DOC	Fl-	Cl-	NO3-	SO4-
10/14/2008	183	4.7	1.17	0.016	ND	ND	ND	ND	0.169	14.625	0.771	8.704
	156	4.0	1.22	0.012	ND	ND	ND	ND	0.115	14.038	0.924	8.723
Mean	169.50	4.35	1.20	0.01					0.14	14.33	0.85	8.71
Stdev	19.09	0.49	0.04	0.00					0.04	0.42	0.11	0.01
CV	0.113	0.114	0.030	0.202					0.269	0.029	0.128	0.002
12/18/2008	208	2.8	0.5	0.008	ND	ND	ND	ND	0.139	17.555	0.687	10.62
	229	1.2	0.56	0.005	ND	ND	ND	ND	0.121	17.494	0.713	10.546
Mean	218.50	2.00	0.53	0.01					0.13	17.52	0.70	10.58
Stdev	14.85	1.13	0.04	0.00					0.01	0.04	0.02	0.05
CV	0.068	0.566	0.080	0.326					0.098	0.002	0.026	0.005
2/2/2009	271	3.6	1.34	0.012	32.2	0.75	32.2	0.75	0.092	18.17	0.984	9.51
	273	3.2	1.39	0.1	36.7	0.92	36.7	0.92	0.06	18.656	1.002	9.742
Mean	272.00	3.40	1.37	0.06	34.45	0.84	34.45	0.84	0.08	18.41	0.99	9.63
Stdev	1.41	0.28	0.04	0.06	3.18	0.12	3.18	0.12	0.02	0.34	0.01	0.16
CV	0.005	0.083	0.026	1.111	0.092	0.144	0.092	0.144	0.298	0.019	0.013	0.017
4/13/2009	184	22.0	1.4	0.041	23.5	2.3	23.5	2.3	0.126	11.547	1.228	8.829
	136	16.0	1.22	0.03	23.9	2.2	23.9	2.2	0.071	11.137	0.935	8.853
Mean	160.00	19.00	1.31	0.04	23.70	2.25	23.70	2.25	0.10	11.34	1.08	8.84
Stdev	33.94	4.24	0.13	0.01	0.28	0.07	0.28	0.07	0.04	0.29	0.21	0.02
CV	0.212	0.223	0.097	0.219	0.012	0.031	0.012	0.031	0.395	0.026	0.192	0.002
8/26/2009	229	9.0	1.77	0.037	37.3	1.6	37	1.6	0.055	15.402	0.899	12.91
	278	27.5	1.7	0.025	37.5	1.6	36.8	1.6	0.96	15.811	1.1	8.892
Mean	253.50	18.25	1.74	0.03	37.40	1.60	36.90	1.60	0.51	15.61	1.00	10.90
Stdev	34.65	13.08	0.05	0.01	0.14	0.00	0.14	0.00	0.64	0.29	0.14	2.84
CV	0.137	0.717	0.029	0.274	0.004	0.000	0.004	0.000	1.261	0.019	0.142	0.261

Finley Creek Triplicate Data

Date	TDS	TSS	TN	TP	TIC	TOC	DIC	DOC	Fl-	Cl-	NO3-	SO4-
11/5/2008	325	7.0	1.57	0.019	37.57	2.33	38.33	2.22	0.17	14.12	1.44	8.69
	297	2.3	1.5	0.019	37.02	2.10	38.32	2.11	0.22	14.34	1.46	8.58
	308	2.3	1.58	0.02	37.57	2.23	36.48	2.17	0.13	13.94	1.40	8.50
Mean	310.00	3.87	1.55	0.02	37.39	2.22	37.71	2.17	0.17	14.13	1.43	8.59
Stdev	14.11	2.71	0.04	0.00	0.32	0.12	1.06	0.06	0.05	0.20	0.03	0.09
CV	0.05	0.70	0.03	0.03	0.01	0.05	0.03	0.03	0.27	0.01	0.02	0.01
12/9/2008	254	1.2	1.61	0.013	32.03	2.07	32.23	0.71	0.09	18.96	1.76	10.9
	265	2.0	1.73	0.012	32.50	1.50	33.67	1.12	0.10	18.70	1.74	10.9
	279	2.0	1.81	0.015	32.55	1.34	33.35	1.50	0.09	18.39	1.66	10.7
Mean	266.00	1.73	1.72	0.01	32.36	1.64	33.09	1.11	0.09	18.68	1.72	10.9
Stdev	12.53	0.46	0.10	0.00	0.29	0.39	0.75	0.40	0.00	0.29	0.05	0.10
CV	0.05	0.27	0.06	0.11	0.01	0.24	0.02	0.36	0.04	0.02	0.03	0.01
2/11/2009	98	36.4	1.63	0.024	28.20	2.02	27.83	1.20	0.07	13.16	1.65	7.44
	102	38.0	1.66	0.034	28.16	1.82	28.17	1.03	0.06	13.20	1.60	7.02
	126	41.2	1.65	0.047	27.64	2.03	28.40	1.18	0.06	13.19	1.84	7.05
Mean	108.27	38.53	1.65	0.04	28.00	1.96	28.13	1.14	0.06	13.18	1.70	7.17
Stdev	15.14	2.44	0.02	0.01	0.31	0.12	0.29	0.09	0.01	0.02	0.13	0.23
CV	0.14	0.06	0.01	0.33	0.01	0.06	0.01	0.08	0.09	0.00	0.08	0.03
4/8/2009	250	1.0	1.63	0.011	30.22	0.95	30.29	0.82	0.02	11.17	1.33	7.28
	233	2.0	1.55	0.010	30.28	0.83	30.55	1.17	0.03	11.13	1.31	7.07
	234	3.5	1.61	0.011	30.16	0.62	30.22	0.91	0.03	10.85	1.25	7.18
Mean	239.00	2.17	1.60	0.01	30.22	0.80	30.35	0.97	0.02	11.05	1.30	7.18
Stdev	9.54	1.26	0.04	0.00	0.06	0.16	0.17	0.18	0.00	0.18	0.04	0.10
CV	0.04	0.58	0.03	0.05	0.00	0.21	0.01	0.18	0.19	0.02	0.03	0.01
5/15/2009	275	16.0	1.36	0.019	27.54	1.72	26.97	1.59	0.02	7.39	0.99	5.33
	229	8.5	1.36	0.026	27.59	1.43	27.03	1.32	0.01	7.31	0.97	5.07
	228	15.5	1.49	0.021	27.41	1.35	26.92	1.32	0.01	7.01	0.90	5.16
Mean	244.00	13.33	1.40	0.02	27.51	1.50	26.97	1.41	0.01	7.23	0.95	5.19
Stdev	26.85	4.19	0.08	0.00	0.09	0.20	0.06	0.16	0.00	0.20	0.05	0.13
CV	0.11	0.31	0.05	0.16	0.00	0.13	0.00	0.11	0.28	0.03	0.05	0.03
7/14/2009	215	6.0	1.84	0.033	35.21	1.94	34.30	1.90	0.05	13.69	1.49	9.41
	372	9.5	1.69	0.032	34.59	1.93	34.42	2.09	0.04	13.58	1.45	8.95
	233	11.5	1.76	0.032	35.12	1.93	34.44	1.74	0.05	13.81	1.50	9.31
Mean	273.33	9.00	1.76	0.03	34.97	1.94	34.39	1.91	0.04	13.69	1.48	9.22
Stdev	85.92	2.78	0.08	0.00	0.33	0.00	0.08	0.18	0.00	0.12	0.03	0.24
CV	0.31	0.31	0.04	0.02	0.01	0.00	0.00	0.09	0.07	0.01	0.02	0.03
8/20/2009	386	4.5	1.85	0.043	30.60	ND	30.67	ND	0.12	14.47	1.17	9.24
	281	4.0	1.96	0.039	30.88	ND	30.46	ND	0.12	14.63	1.18	9.13
	231	11.5	1.86	0.036	30.40	ND	31.05	ND	0.17	14.41	1.07	9.11
Mean	299.33	6.67	1.89	0.04	30.63		30.73		0.13	14.50	1.14	9.16
Stdev	79.11	4.19	0.06	0.00	0.24		0.30		0.03	0.11	0.06	0.07
CV	0.26	0.63	0.03	0.09	0.01		0.01		0.21	0.01	0.05	0.01

Finley Creek Field Duplicate Data

Date	TDS	TSS	TN	TP	TIC	TOC	DIC	DOC	Fl-	Cl-	NO3-	SO4-
11/11/2008	191	2	1.67	0.025	37	1.8	44	1.8	0.196	14.396	1.519	8.582
	187	2	1.65	0.023	36.4	1.7	40.1	1.8	0.191	14.477	1.496	8.453
Mean	189.00	2.00	1.66	0.02	36.70	1.75	42.05	1.80	0.19	14.44	1.51	8.52
Stdev	2.83	0.00	0.01	0.00	0.42	0.07	2.76	0.00	0.00	0.06	0.02	0.09
CV	0.01	0.00	0.01	0.06	0.01	0.04	0.07	0.00	0.02	0.00	0.01	0.01
12/4/2008	81.3	0.3	2.1	0.025	12.2	24.5	15.8	21.4	0.115	17.9	1.592	10.99
	82	1	1.9	0.018	21.7	15	13.8	22.8	0.084	17.596	1.534	10.80
Mean	81.65	0.65	2.00	0.02	16.95	19.75	14.80	22.10	0.10	17.75	1.56	10.90
Stdev	0.49	0.49	0.14	0.00	6.72	6.72	1.41	0.99	0.02	0.21	0.04	0.13
CV	0.01	0.76	0.07	0.23	0.40	0.34	0.10	0.04	0.22	0.01	0.03	0.01
1/23/2009	222	1.2	1.81	0.014	ND	ND	ND	ND	0.01	13.141	1.434	7.924
	235	2	1.85	0.012	ND	ND	ND	ND	-0.003	12.774	1.495	8.25
Mean	228.50	1.60	1.83	0.01					0.00	12.96	1.46	8.09
Stdev	9.19	0.57	0.03	0.00					0.01	0.26	0.04	0.23
CV	0.04	0.35	0.02	0.11					2.63	0.02	0.03	0.03
2/20/2009	280	1.6	2.13	0.018	28.6	1.1	29.5	0.99	ND	ND	ND	ND
	274	1.6	2.12	0.024	29.3	1	29.3	0.65	ND	ND	ND	ND
Mean	277.00	1.60	2.13	0.02	28.95	1.05	29.40	0.82				
Stdev	4.24	0.00	0.01	0.00	0.49	0.07	0.14	0.24				
CV	0.02	0.00	0.00	0.20	0.02	0.07	0.00	0.29				
5/22/2009	270		1.47	0.01	30.6	1.4	30.4	1.3	0	9.655	1.051	5.9
	273		1.39	0.011	30.9	1.3	30.4	1.3	0	10.048	1.102	6.158
Mean	271.50		1.43	0.01	30.75	1.35	30.40	1.30	0.00	9.85	1.08	6.03
Stdev	2.12		0.06	0.00	0.21	0.07	0.00	0.00	0.00	0.28	0.04	0.18
CV	0.01		0.04	0.07	0.01	0.05	0.00	0.00		0.03	0.03	0.03
6/22/2009	310	6.5	1.68	0.031	30.2	1.4	30.8	1.3	-0.037	11.293	1.17	7.534
	274	9	1.66	0.031	30.9	1.2	29.6	1.3	0.021	11.359	1.21	7.624
Mean	292.00	7.75	1.67	0.03	30.55	1.30	30.20	1.30	-0.01	11.33	1.19	7.58
Stdev	25.46	1.77	0.01	0.00	0.49	0.14	0.85	0.00	0.04	0.05	0.03	0.06
CV	0.09	0.23	0.01	0.00	0.02	0.11	0.03	0.00	-5.13	0.00	0.02	0.01
9/22/2009	164	10.5	2.51	0.063	35.3	2.6	35.6	2.2	0.134	15.767	1.537	10.07
	143	14	2.51	0.139	35.7	3.2	35.9	1.9	0.066	15.46	1.504	10.17
Mean	153.50	12.25	2.51	0.10	35.50	2.90	35.75	2.05	0.10	15.61	1.52	10.13
Stdev	14.85	2.47	0.00	0.05	0.28	0.42	0.21	0.21	0.05	0.22	0.02	0.07
CV	0.10	0.20	0.00	0.53	0.01	0.15	0.01	0.10	0.48	0.01	0.02	0.01

Middle James Triplicate Data

Date	TDS	TSS	TN	TP	TIC	TOC	DIC	DOC	Fl-	Cl-	NO3-	SO4
10/23/2008	302	14.7	4.34	0.085	36.73	3.37	36.57	2.53	0.38	61.9	4.14	23.3
	332	20.7	4.56	0.098	37.83	3.38	38.28	2.71	0.42	69.1	4.57	25.3
	341	26.7	4.6	0.097	37.74	4.33	37.59	2.95	0.42	70.0	4.61	25.3
Mean	325.0	20.7	4.5	0.1	37.4	3.7	37.5	2.7	0.4	67.0	4.4	24.6
Stdev	20.42	6	0.14	0.01	0.61	0.55	0.86	0.21	0.02	4.45	0.26	1.17
CV	0.06	0.29	0.03	0.08	0.02	0.15	0.02	0.08	0.06	0.07	0.06	0.05
11/25/2008	321	2.7	4.1	0.025	37.08	3.59	34.41	4.99	ND	ND	ND	ND
	342	1.7	4.17	0.026	37.02	3.58	34.78	4.76	ND	ND	ND	ND
	325	4.3	4.02	0.025	37.18	3.64	34.12	5.48	ND	ND	ND	ND
Mean	329.3	2.9	4.1	0.0	37.1	3.6	34.4	5.1				
Stdev	11.15	1.3	0.08	0.001	0.08	0.03	0.33	0.37				
CV	0.03	0.45	0.02	0.02	0.00	0.01	0.01	0.07				
2/2/2009	452	10.8	4.7	0.074	34.58	1.65	33.92	1.51	0.18	78.1	4.04	17.2
	464	10.8	4.75	0.072	34.37	1.50	31.30	2.00	0.02	91.2	4.41	20.7
	452	8.8	4.61	0.069	33.77	1.65	32.40	2.29	0.00	98.8	4.88	6.0
Mean	456.0	10.1	4.7	0.1	34.2	1.6	32.5	1.9	0.1	89.4	4.4	14.7
Stdev	6.9	1.15	0.07	0.00	0.4	0.1	1.3	0.4	0.10	10.47	0.42	7.69
CV	0.02	0.11	0.02	0.04	0.01	0.05	0.04	0.20	1.49	0.12	0.10	0.52
3/11/2009	371	7.5	4.07	0.055	31.92	1.54	31.57	1.38	0.18	29.5	3.91	16.5
	409	6.5	4.19	0.058	32.24	1.51	31.84	1.85	0.21	29.6	3.90	16.3
	408	5.0	4.12	0.058	32.16	1.21	31.72	1.03	0.19	29.6	3.91	16.4
Mean	396.0	6.3	4.1	0.1	32.1	1.4	31.7	1.4	0.2	29.6	3.9	16.4
Stdev	21.66	1.26	0.06	0.00	0.16	0.18	0.13	0.41	0.02	0.09	0.01	0.12
CV	0.05	0.20	0.01	0.03	0.01	0.13	0.00	0.29	0.08	0.00	0.00	0.01
5/1/2009	32	758.0	1.18	0.347	22.16	13.88	18.63	2.18	0.13	12.1	0.95	6.7
	54	590.0	1.45	0.333	21.77	14.78	19.36	2.11	0.12	11.8	0.92	6.8
	64	604.0	0.98	0.314	21.76	10.86	19.17	2.08	0.11	11.6	0.89	6.6
Mean	50.0	650.7	1.2	0.3	21.9	13.2	19.1	2.1	0.1	11.8	0.9	6.7
Stdev	16.37	93.2	0.24	0.02	0.23	2.05	0.38	0.05	0.01	0.23	0.03	0.09
CV	0.33	0.14	0.20	0.05	0.01	0.16	0.02	0.02	0.08	0.02	0.03	0.01
7/21/2009	290	13	3.3	0.094	34.03	2.54	33.39	2.53	0.17	35.9	2.72	19.0
	316	25	3.43	0.100	34.25	2.89	34.18	2.72	0.17	36.8	2.90	19.8
	339	14.5	3.48	0.095	34.25	2.23	34.24	2.40	0.16	36.5	2.84	19.9
Mean	315.0	17.5	3.4	0.1	34.2	2.6	33.9	2.5	0.2	36.4	2.8	19.5
Stdev	24.52	6.5	0.09	0.003	0.13	0.33	0.47	0.16	0.003	0.44	0.09	0.50
CV	0.08	0.37	0.03	0.03	0.00	0.13	0.01	0.06	0.02	0.01	0.03	0.03
9/22/2009	65	96.5	1.98	0.176	22.63	5.41	22.30	3.76	0.20	12.4	0.92	8.1
	154	96.5	1.80	0.186	22.69	6.03	23.00	3.66	0.11	12.2	0.93	8.2
	126	96.5	1.91	0.180	22.74	6.31	22.72	4.05	0.10	12.1	0.88	8.1
Mean	115.0	96.5	1.9	0.2	22.7	5.9	22.7	3.8	0.1	12.3	0.9	8.1
Stdev	45.51	0.00	0.09	0.01	0.05	0.46	0.35	0.21	0.06	0.13	0.02	0.05
CV	0.40	0.00	0.05	0.03	0.00	0.08	0.02	0.05	0.41	0.01	0.03	0.01

Middle James Field Duplicate Data

Date	TDS	TSS	TN	TP	TIC	TOC	DIC	DOC	Fl-	Cl-	NO3-	SO4-
11/5/2008	385	3.0	3.77	0.027	36.4	3.4	35.1	2.8	0.363	37.937	4.245	19.34
	370	3.3	4.32	0.03	36.7	3.1	36.3	2.7	0.347	38.139	4.149	19.18
Mean	377.5	3.2	4.0	0.0	36.6	3.3	35.7	2.8	0.4	38.0	4.2	19.3
Stdev	10.6	0.2	0.4	0.0	0.2	0.2	0.8	0.1	0.0	0.1	0.1	0.1
CV	0.03	0.07	0.10	0.07	0.01	0.07	0.02	0.03	0.03	0.00	0.02	0.01
3/4/2009	278	3.2	3.06	0.022	31.8	1.3	32.2	1.7	0.086	29.08	3.205	16.60
	310	4.8	3.02	0.023	31.4	1.5	31.4	1.2	0.186	30.597	3.519	17.62
Mean	294.0	4.0	3.0	0.0	31.6	1.4	31.8	1.5	0.1	29.8	3.4	17.1
Stdev	22.6	1.1	0.0	0.0	0.3	0.1	0.6	0.4	0.1	1.1	0.2	0.7
CV	0.08	0.28	0.01	0.03	0.01	0.10	0.02	0.24	0.52	0.04	0.07	0.04
4/8/2009	305	6.0	2.54	0.025	ND	ND	ND	ND	0.052	23.921	2.459	12.89
	329	10.5	2.59	0.025	ND	ND	ND	ND	0.07	24.161	2.667	13.30
Mean	317.0	8.3	2.6	0.0					0.1	24.0	2.6	13.1
Stdev	17.0	3.2	0.0	0.0					0.0	0.2	0.1	0.3
CV	0.05	0.39	0.01	0.00					0.21	0.01	0.06	0.02
7/14/2009	319	21.0	3.07	0.112	33.4	2.1	33.5	2.7	0.203	36.555	2.671	24.75
	326	18.0	3.01	0.11	34	2.9	33.4	2.4	0.284	36.982	3.015	29.19
Mean	322.5	19.5	3.0	0.1	33.7	2.5	33.5	2.6	0.2	36.8	2.8	27.0
Stdev	4.9	2.1	0.0	0.0	0.4	0.6	0.1	0.2	0.1	0.3	0.2	3.1
CV	0.02	0.11	0.01	0.01	0.01	0.23	0.00	0.08	0.24	0.01	0.09	0.12
7/30/2009	370	23.5	4	0.155	36	3.1	35.3	3	0.197	37.36	2.227	15.75
	354	20.0	3.49	0.149	36	2.7	34.5	2.6	0.174	38.568	2.136	17.07
Mean	362.0	21.8	3.7	0.2	36.0	2.9	34.9	2.8	0.2	38.0	2.2	16.4
Stdev	11.3	2.5	0.4	0.0	0.0	0.3	0.6	0.3	0.0	0.9	0.1	0.9
CV	0.03	0.11	0.10	0.03	0.00	0.10	0.02	0.10	0.09	0.02	0.03	0.06
8/20/2009	404	71.5	3.89	0.206	28.6	4	28.2	2.1	0.238	36.689	2.609	20.65
	417	70.0	3.89	0.182	28.9	3.6	28.8	2.2	0.296	36.639	2.603	20.98
Mean	410.5	70.8	3.9	0.2	28.8	3.8	28.5	2.2	0.3	36.7	2.6	20.8
Stdev	9.2	1.1	0.0	0.0	0.2	0.3	0.4	0.1	0.0	0.0	0.0	0.2
CV	0.02	0.01	0.00	0.09	0.01	0.07	0.01	0.03	0.15	0.00	0.00	0.01

Pearson Creek Triplicate Data

Date	TDS	TSS	TN	TP	TIC	TOC	DIC	DOC	Fl-	Cl-	NO3-	SO4-
10/14/2008	198	0.7	2.67	0.045	ND	ND	ND	ND	0.110	23.2	2.3	10.9
	219	0.7	2.72	0.019	ND	ND	ND	ND	0.317	24.3	2.4	10.7
	219	2.7	2.6	0.044	ND	ND	ND	ND	0.120	23.5	2.3	10.6
Mean	212.0	1.4	2.7	0.0					0.2	23.7	2.3	10.7
Stdev	12.1	1.2	0.1	0.0					0.1	0.6	0.1	0.2
CV	0.1	0.8	0.0	0.4					0.6	0.02	0.04	0.02
11/11/2008	268	0.7	2.11	0.023	45.34	2.34	43.37	1.66	0.152	21.9	2.0	10.5
	283	2.7	2.16	0.057	44.28	2.29	43.90	1.67	0.193	22.9	2.1	10.4
	261	1.7	2.12	0.021	44.22	1.83	45.22	1.96	0.234	22.8	2.1	10.4
Mean	270.7	1.7	2.1	0.0	44.6	2.2	44.2	1.8	0.2	22.5	2.1	10.4
Stdev	11.2	1.0	0.0	0.0	0.6	0.3	1.0	0.2	0.0	0.5	0.1	0.0
CV	0.0	0.6	0.0	0.6	0.0	0.1	0.0	0.1	0.2	0.0	0.0	0.0
12/18/2008	324	2.4	1.64	0.012	ND	ND	ND	ND	0.165	28.0	2.2	11.5
	296	1.2	1.64	0.012	ND	ND	ND	ND	0.168	28.2	2.3	11.8
	223	2.0	1.87	0.021	ND	ND	ND	ND	0.220	27.5	2.2	13.2
Mean	281.0	1.9	1.7	0.0					0.2	27.9	2.2	12.1
Stdev	52.1	0.6	0.1	0.0					0.03	0.3	0.05	0.9
CV	0.2	0.3	0.1	0.3					0.2	0.01	0.02	0.08
1/23/2009	305	2.4	2.73	0.008	40.95	0.86	41.20	1.21	0.121	19.5	2.2	10.0
	304	1.6	2.69	0.008	41.14	0.00	40.73	0.78	0.008	19.8	2.3	9.7
	381	2.0	2.65	0.007	40.99	0.63	39.51	0.64	0.106	20.0	2.4	10.1
Mean	330.0	2.0	2.7	0.0	41.0	0.5	40.5	0.9	0.1	19.8	2.3	9.9
Stdev	44.2	0.4	0.0	0.0	0.1	0.4	0.9	0.3	0.1	0.2	0.1	0.2
CV	0.1	0.2	0.0	0.1	0.0	0.9	0.0	0.3	0.8	0.01	0.04	0.02
3/4/2009	294	7.2	2.52	0.017	37.76	1.61	37.57	1.58	0.044	22.3	3.0	11.1
	279	3.2	2.55	0.012	37.15	1.06	37.07	1.31	0.071	24.0	2.5	10.9
	312	3.2	2.58	0.012	37.05	1.15	37.24	0.84	0.052	22.9	2.9	11.0
Mean	295.0	4.5	2.6	0.0	37.3	1.3	37.3	1.2	0.1	23.1	2.8	11.0
Stdev	16.5	2.3	0.0	0.0	0.4	0.3	0.3	0.4	0.0	0.9	0.3	0.1
CV	0.1	0.5	0.0	0.2	0.0	0.2	0.0	0.3	0.2	0.04	0.1	0.01
4/13/2009	301	6.0	2.32	0.027	35.24	2.61	34.89	2.34	0.086	20.6	1.8	9.0
	308	3.0	2.24	0.044	22.06	2.54	22.54	3.75	0.136	19.4	0.8	11.4
	267	4.5	2.22	0.025	34.74	1.37	34.15	1.70	0.105	23.5	0.3	9.1
Mean	292.0	4.5	2.3	0.0	30.7	2.2	30.5	2.6	0.1	21.1	1.0	9.8
Stdev	21.9	1.5	0.1	0.0	7.5	0.7	6.9	1.0	0.0	2.1	0.8	1.4
CV	0.1	0.3	0.0	0.3	0.2	0.3	0.2	0.4	0.2	0.1	0.8	0.1
6/22/2009	347	10.0	2.54	0.029	41.19	1.43	39.38	1.70	0.044	17.6	2.1	9.8
	364	13.0	2.31	0.031	40.31	1.16	38.60	1.29	0.030	17.4	2.1	10.1
	382	7.5	2.39	0.022	39.90	1.04	38.83	1.33	0.046	17.8	2.1	9.9
Mean	364.3	10.2	2.4	0.0	40.5	1.2	38.9	1.4	0.0	17.6	2.1	9.9
Stdev	17.5	2.8	0.1	0.0	0.7	0.2	0.4	0.2	0.0	0.2	0.01	0.1
CV	0.0	0.3	0.0	0.2	0.0	0.2	0.0	0.2	0.2	0.01	0.01	0.01
8/26/2009	282	6.0	3.1	0.026	44.03	2.00	43.09	1.68	0.114	18.9	2.0	10.1
	314	6.5	2.99	0.021	42.86	1.22	41.72	1.51	0.096	19.8	2.0	10.3
	271	9.0	3.06	0.022	41.66	1.29	40.35	1.40	0.045	19.2	1.8	10.1
Mean	289.0	7.2	3.1	0.0	42.9	1.5	41.7	1.5	0.1	19.3	1.9	10.2
Stdev	22.3	1.6	0.1	0.0	1.2	0.4	1.4	0.1	0.0	0.5	0.1	0.1
CV	0.1	0.2	0.0	0.1	0.0	0.3	0.0	0.1	0.4	0.02	0.04	0.01

Pearson Creek Field Duplicate Data

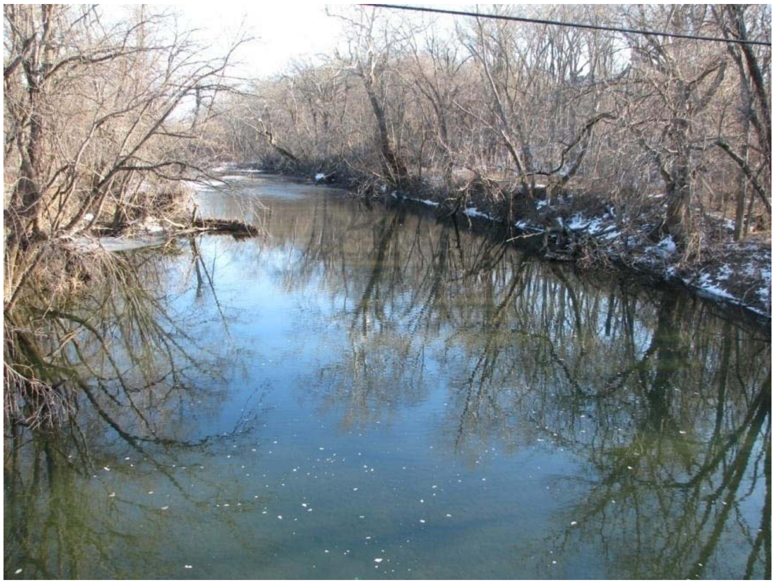
Date	TDS	TSS	TN	TP	TIC	TOC	DIC	DOC	Fl-	Cl-	NO3-	SO4-
9/26/2008	276	2.0	2.14	0.025	43.2	0	40.7	0.59	0.366	17.494	2.421	9.396
	285	2.0	2.43	0.062	43.1	2.03	40.9	1.7	0.188	18.087	2.508	9.513
Mean	280.5	2.0	2.3	0.0	43.2	1.0	40.8	1.1	0.3	17.8	2.5	9.5
Stdev	6.4	0.0	0.2	0.0	0.1	1.4	0.1	0.8	0.1	0.4	0.1	0.1
CV	0.0	0.0	0.1	0.6	0.0	1.4	0.0	0.7	0.5	0.0	0.0	0.0
11/25/2008	278	2.0	2.12	0.014	42.9	3.2	40.4	4.2	0.152	26.106	2.169	10.855
	283	1.7	2.17	0.016	43.4	3.4	41.1	5.3	0.236	26.466	2.149	10.857
Mean	280.5	1.9	2.1	0.0	43.2	3.3	40.8	4.8	0.2	26.3	2.2	10.9
Stdev	3.5	0.2	0.0	0.0	0.4	0.1	0.5	0.8	0.1	0.25	0.01	0.00
CV	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.2	0.3	0.01	0.01	0.00
3/11/2009	366	2.5	2.46	0.022	38.2	1.03	38.5	0.9	0.141	22.024	2.452	10.709
	342	3.5	2.58	0.024	38.9	1.8	37.9	1.6	0.164	22.094	2.283	10.223
Mean	354.0	3.0	2.5	0.0	38.6	1.4	38.2	1.3	0.2	22.1	2.4	10.5
Stdev	17.0	0.7	0.1	0.0	0.5	0.5	0.4	0.5	0.0	0.05	0.1	0.3
CV	0.0	0.2	0.0	0.1	0.0	0.4	0.0	0.4	0.1	0.00	0.1	0.0
4/19/2009	264	3.5	2.54	0.042	36.6	1.5	35.7	1.4	0.075	18.601	2.187	9.308
	222	6.5	2.51	0.038	36.7	1.8	35.7	2	0.071	18.293	1.926	9.13
Mean	243.0	5.0	2.5	0.0	36.7	1.7	35.7	1.7	0.1	18.4	2.1	9.2
Stdev	29.7	2.1	0.0	0.0	0.1	0.2	0.0	0.4	0.0	0.2	0.2	0.1
CV	0.1	0.4	0.0	0.1	0.0	0.1	0.0	0.2	0.0	0.01	0.09	0.01
5/15/2009	314	93.0	2.55	0.01	37.2	0.8	36	1.1	0.023	13.612	1.953	9.368
	310	98.0	2.8	0.017	37.6	2.2	36.4	1.8	0.022	13.676	1.96	9.263
Mean	312.0	95.5	2.7	0.0	37.4	1.5	36.2	1.5	0.0	13.6	2.0	9.3
Stdev	2.8	3.5	0.2	0.0	0.3	1.0	0.3	0.5	0.0	0.05	0.00	0.07
CV	0.0	0.0	0.1	0.4	0.0	0.7	0.0	0.3	0.0	0.00	0.00	0.01
7/8/2009	358	3.5	2.47	0.021	43.6	1.4	40.5	1.6	0	25.29	0	8.699
	347	5.5	2.52	0.022	43.8	2.6	42.8	2	0.21	21.195	0.017	9.479
Mean	352.5	4.5	2.5	0.02	43.70	2.00	41.65	1.80	0.11	23.24	0.01	9.09
Stdev	7.8	1.4	0.035	0.001	0.141	0.849	1.626	0.283	0.148	2.896	0.012	0.552
CV	0.0	0.3	0.01	0.03	0.00	0.42	0.04	0.16	1.41	0.12	1.41	0.06
7/21/2009	326	14.0	2.63	0.03	44.8	2.2	43.2	22.4	0.149	24.206	2.167	10.718
	346	18.5	2.57	0.28	44.3	2.9	43	3.1	0.096	24.147	2.198	11.209
Mean	336.0	16.3	2.6	0.2	44.6	2.6	43.1	12.8	0.1	24.2	2.2	11.0
Stdev	14.1	3.2	0.0	0.2	0.4	0.5	0.1	13.6	0.0	0.04	0.02	0.35
CV	0.0	0.2	0.02	1.1	0.0	0.2	0.0	1.1	0.3	0.00	0.01	0.03
9/9/2009	366	18.0	2.41	0.075	41.3	2.6	40.9	2.6	0.21	20.666	1.635	10.872
	344	13.5	2.46	0.065	41.1	3.5	41.7	3.6	0.14	20.297	1.495	9.421
Mean	355.0	15.8	2.4	0.1	41.2	3.1	41.3	3.1	0.2	20.5	1.6	10.1
Stdev	15.6	3.2	0.0	0.0	0.1	0.6	0.6	0.7	0.0	0.3	0.1	1.0
CV	0.0	0.2	0.0	0.1	0.0	0.2	0.0	0.2	0.3	0.01	0.1	0.1

Wilson Creek Triplicate Data

Triplicate Data	TDS	TSS	TN	TP	TIC	TOC	DIC	DOC	Fl-	Cl-	NO3-	SO4-
5/22/2009	422	ND	2.89	0.015	46.91	0.99	46.00	0.79	0.170	37.821	2.174	27.948
	495	ND	2.70	0.027	47.18	1.34	45.50	1.03	0.090	37.829	2.164	28.005
	408	ND	2.71	0.029	46.90	1.35	44.75	1.14	0.067	37.570	2.149	27.956
Mean	442		2.8	0.0	47.0	1.2	45.4	1.0	0.1	37.7	2.2	28.0
Stdev	46.72		0.11	0.01	0.16	0.21	0.63	0.18	0.05	0.15	0.01	0.03
CV	0.11		0.04	0.32	0.00	0.17	0.01	0.18	0.50	0.00	0.01	0.00
7/30/2009	202	26.0	1.52	0.08	19.20	5.58	18.58	5.46	ND	ND	ND	ND
	180	73.5	1.78	0.088	19.50	6.16	19.21	5.07	ND	ND	ND	ND
	211	27.5	1.65	0.131	19.19	5.37	18.55	5.06	ND	ND	ND	ND
Mean	198	42.3	1.7	0.1	19.3	5.7	18.8	5.2				
Stdev	15.95	27.00	0.13	0.03	0.17	0.41	0.37	0.23				
CV	0.08	0.64	0.08	0.28	0.01	0.07	0.02	0.04				

Wilson Creek Field Duplicate Data

Date	TDS	TSS	TN	TP	TIC	TOC	DIC	DOC	Fl-	Cl-	NO3-	SO4-
10/23/2009	139	7	1.15	0.071	20.7	4.1	20.5	3.6	0.25	12.886	0.76	10.564
	131	6.7	1.14	0.077	20.9	4.1	20.5	3.1	0.238	13.19	0.755	10.649
Mean	135	6.9	1.1	0.1	20.8	4.1	20.5	3.4	0.2	13.0	0.8	10.6
Stdev	5.66	0.21	0.01	0.004	0.141	0.000	0.000	0.354	0.008	0.215	0.004	0.060
CV	0.04	0.03	0.01	0.06	0.01	0.00	0.00	0.11	0.03	0.02	0.00	0.01
12/9/2009	266	23.2	1.29	0.06	24.5	5	24.6	4.4	0.456	44.05	10.097	12.08
	374	25.6	1.3	0.068	24.4	5.4	24.3	4.5	0.363	43.488	1.09	12.058
Mean	320	24.4	1.3	0.1	24.5	5.2	24.5	4.5	0.4	43.8	5.6	12.1
Stdev	76.37	1.70	0.01	0.01	0.07	0.28	0.21	0.07	0.07	0.40	6.37	0.02
CV	0.24	0.07	0.01	0.09	0.00	0.05	0.01	0.02	0.16	0.01	1.14	0.001
2/11/2009	70	152.8	0.71	0.107	13	8.7	10.4	2.6	0.127	25.75	0.629	6.847
	66	146	0.64	0.11	13.2	8.8	11.1	2.6	0.588	26.665	0.416	6.712
Mean	68	149.4	0.7	0.1	13.1	8.8	10.8	2.6	0.4	26.2	0.5	6.8
Stdev	2.83	4.81	0.05	0.002	0.141	0.071	0.495	0.000	0.326	0.647	0.151	0.095
CV	0.04	0.03	0.07	0.02	0.01	0.01	0.05	0.00	0.91	0.02	0.29	0.01
5/1/2009	238	93	1.99	0.225	19.9	7.4	18	3.9	0.211	14.261	1.441	15.69
	197	98	2.09	0.17	20.1	7.9	18.1	3.7	0.154	15.098	1.426	15.512
Mean	217.5	95.5	2.0	0.2	20.0	7.7	18.1	3.8	0.2	14.7	1.4	15.6
Stdev	28.99	3.54	0.07	0.04	0.14	0.35	0.07	0.14	0.04	0.59	0.01	0.13
CV	0.13	0.04	0.03	0.20	0.01	0.05	0.00	0.04	0.22	0.04	0.01	0.01



Upper James Sample Site

Near Upper James Sample Site During Flood (5/1/2009)

Finley Creek Sample Site

Finley Creek Sample Site During Flood (5/1/2009)

Middle James Sample Site

Middle James Sample Site During Flood (5/1/2009)

Pearson Creek Sample Site

Pearson Creek Sample Site During Flood (5/1/2009)

Wilson Creek Sample Site

Wilson Creek Sample Site During Flood (5/1/2009)

95% Confidence Intervals

Site		TDS	TSS	TIC	TOC	DIC	DOC
Finley	U 95%	316	4.1	38	1.9	38	2.2
	L 95%	200	1.2	35	1.0	35	1.1
Upper J	U 95%	316	6.2	37	2.2	37	2.2
	L 95%	200	1.9	35	1.2	35	1.3
Middle J	U 95%	631	1.8	46	2.5	46	3.5
	L 95%	316	0.4	38	1.0	38	1.7
Pearson	U 95%	316	10	39	2.8	38	2.5
	L 95%	251	4.9	35	1.9	35	1.7
Wilson	U 95%	229	23	29	4.8	27	3.5
	L 95%	126	10	22	2.8	21	2.2

95% Confidence Intervals

Site		TN	TP	Cl^-	SO_4^{2-}	NO_3^-	F^-
Finley	U 95%	2.1	0.03	18	11	1.8	0.3
	L 95%	1.8	0.02	15	9.3	1.4	0.1
Upper J	U 95%	1.5	0.02	16	10	0.9	0.1
	L 95%	0.9	0.01	13	8.3	0.8	0.1
Middle J	U 95%	6.5	0.05	100	38	8.3	0.8
	L 95%	4.3	0.01	40	25	4.2	0.2
Pearson	U 95%	2.6	0.04	20	2.1	10	0.1
	L 95%	2.3	0.03	17	1.7	9.3	0.1
Wilson	U 95%	1.7	0.07	30	15	1.6	0.2
	L 95%	1.3	0.04	19	11	1.0	0.1

Flow Exceedance Probability Discharge Values (m^3/s)

Flow Exceedance Probability	Upper James	Finley	Middle James	Pearson	Wilson
0	441	242	495	24	26
1	93	112	193	10	16
2	69	41	103	6.9	5.6
3	39	34	64	4.0	4.2
4	29	28	57	3.4	3.9
5	21	25	49	3.0	2.8
6	19	22	43	2.6	1.9
7	17	20	42	2.3	1.7
8	15	18	39	2.2	1.5
9	13	17	35	2.0	1.3
10	13	16	33	1.9	1.08
11	11	16	30	1.7	1.02
12	10	14	28	1.7	0.93
13	10	14	27	1.6	0.82
14	9.4	13	25	1.5	0.76
15	8.9	12	24	1.5	0.68
16	8.6	11	23	1.4	0.65
17	8.4	11	22	1.4	0.59
18	8.2	10	20	1.3	0.58
19	7.7	9.8	20	1.3	0.57
20	7.5	9.2	19	1.3	0.55
21	6.9	8.8	19	1.2	0.54
22	6.7	8.5	18	1.2	0.52
23	6.4	8.0	17	1.1	0.48
24	6.2	7.5	16	1.1	0.45
25	5.9	7.3	15	1.1	0.43
26	5.7	6.9	15	1.05	0.42
27	5.3	6.5	14	0.99	0.41
28	4.9	6.3	13	0.93	0.4
29	4.9	6.0	13	0.91	0.39
30	4.4	5.7	12	0.85	0.38
31	4.3	5.6	11	0.82	0.37
32	4.2	5.4	10	0.79	0.35
33	4.0	5.1	10	0.76	0.34
34	3.9	5.0	10	0.71	0.33
35	3.7	4.7	9.6	0.68	0.32
36	3.6	4.5	9.5	0.65	0.31
37	3.6	4.3	9.2	0.62	0.30
38	3.5	4.1	9.0	0.59	0.29
39	3.4	4.0	8.8	0.58	0.28
40	3.4	3.8	8.6	0.57	0.28
41	3.3	3.7	8.1	0.54	0.27
42	3.3	3.6	8.0	0.53	0.26
43	3.2	3.5	7.7	0.52	0.25
44	3.1	3.4	7.6	0.51	0.24
45	3.0	3.3	7.5	0.50	0.24
46	2.9	3.2	7.4	0.5	0.23
47	2.8	3.1	7.2	0.49	0.22

Flow Exceedance Probability Discharge Values (m^3/s), continued

Flow Exceedance Probability	Upper James	Finley	Middle James	Pearson	Wilson
48	2.7	3.1	7.0	0.48	0.22
49	2.6	3.0	6.9	0.47	0.22
50	2.5	2.9	6.8	0.46	0.21
51	2.3	2.8	6.6	0.45	0.21
52	2.3	2.7	6.6	0.44	0.20
53	2.2	2.7	6.4	0.44	0.20
54	2.2	2.6	6.3	0.43	0.19
55	2.0	2.5	6.1	0.42	0.19
56	1.9	2.5	6.0	0.41	0.19
57	1.7	2.4	5.9	0.41	0.18
58	1.7	2.4	5.8	0.40	0.18
59	1.6	2.3	5.7	0.4	0.18
60	1.5	2.2	5.6	0.39	0.17
61	1.4	2.2	5.5	0.38	0.17
62	1.4	2.2	5.4	0.37	0.17
63	1.3	2.1	5.3	0.36	0.17
64	1.3	2.1	5.2	0.36	0.16
65	1.2	2.1	5.1	0.35	0.16
66	1.2	2.1	5.0	0.34	0.15
67	1.2	2.0	4.8	0.33	0.15
68	1.1	2.0	4.7	0.32	0.15
69	1.1	1.9	4.7	0.31	0.14
70	1.1	1.9	4.6	0.30	0.14
71	1.1	1.9	4.5	0.29	0.14
72	1.08	1.9	4.5	0.29	0.13
73	1.06	1.8	4.4	0.28	0.13
74	1.05	1.8	4.3	0.28	0.13
75	1.04	1.8	4.3	0.28	0.13
76	1.02	1.7	4.2	0.28	0.13
77	1.01	1.7	4.1	0.27	0.12
78	1.01	1.7	4.1	0.27	0.12
79	1.00	1.6	4.1	0.26	0.12
80	0.99	1.6	3.9	0.26	0.11
81	0.98	1.5	3.9	0.25	0.11
82	0.96	1.5	3.8	0.25	0.11
83	0.95	1.5	3.8	0.24	0.10
84	0.94	1.5	3.7	0.24	0.10
85	0.93	1.4	3.6	0.23	0.10
86	0.92	1.4	3.6	0.22	0.10
87	0.91	1.4	3.6	0.22	0.09
88	0.90	1.4	3.6	0.21	0.09
89	0.89	1.4	3.4	0.20	0.09
90	0.88	1.3	3.4	0.19	0.09
91	0.85	1.3	3.3	0.19	0.09
92	0.82	1.2	3.2	0.18	0.08
93	0.79	1.1	3.2	0.17	0.08
94	0.76	1.1	3.1	0.16	0.08
95	0.74	1.1	3.1	0.15	0.07
96	0.71	1.05	3.1	0.15	0.07
97	0.68	1.02	3.0	0.14	0.06
98	0.65	0.99	2.9	0.14	0.05
99	0.31	0.96	2.8	0.13	0.04
100	0.25	0.91	1.9	0.05	0.04

Instantaneous Load Rating Curves

Watershed	Y	n	R^2	bo	b1
Finley	TDS	30	0.85601	22094	0.8861
Upper James	TDS	30	0.88901	21348	0.8666
Middle James	TDS	30	0.8058	37387	0.789
Pearson	TDS	30	0.9214	24066	0.954
Wilson	TDS	30	0.6481	14806	0.6098
Finley	TSS	29	0.73571	192.69	1.654
Upper James	TSS	29	0.79186	304.7	1.8167
Middle James	TSS	29	0.8863	73.574	2.1839
Pearson	TSS	29	0.8549	611.79	1.9261
Wilson	TSS	29	0.868	1323.5	1.7136

Instantaneous Load Rating Curves

Watershed	Y	n	R^2	bo	b1
Finley	TP	30	0.78097	1.837	1.1414
Upper James	TP	30	0.82293	1.3016	1.3216
Middle James	TP	30	0.8113	2.2725	1.3857
Pearson	TP	30	0.8789	2.8284	1.3965
Wilson	TP	30	0.9506	4.6666	1.488
Finley	TN	30	0.97323	168.9	0.9011
Upper James	TN	30	0.87684	99.978	1.0639
Middle James	TN	30	0.9242	454.7	0.7815
Pearson	TN	30	0.9795	211.85	1.032
Wilson	TN	30	0.9503	130.69	0.8761

Instantaneous Load Rating Curves

Watershed	Y	n	R^2	bo	b1
Upper James	F^-	28	0.56086	7.8062	0.7658
Finley	F^-	28	0.31415	10.641	0.6406
Middle James	F^-	28	0.4475	32.138	0.6664
Pearson	F^-	28	0.4559	7.699	0.8182
Wilson	F^-	28	0.8695	13.65	0.9284
Upper James	NO_3^-	28	0.98229	71.998	1.0993
Finley	NO_3^-	28	0.95146	132.71	0.9135
Middle James	NO_3^-	28	0.8035	509.4	0.674
Pearson	NO_3^-	28	0.9382	167.75	0.9159
Wilson	NO_3^-	28	0.8371	105.85	0.8195
Finley	SO_4^{2-}	28	0.78562	696.74	0.929
Upper James	SO_4^{2-}	28	0.9875	771.84	0.9812
Middle James	SO_4^{2-}	28	0.9276	2640.3	0.7294
Pearson	SO_4^{2-}	28	0.9911	831.42	0.9273
Wilson	SO_4^{2-}	28	0.9166	1095.3	0.7024
Upper James	Cl^-	28	0.97999	1271.9	0.8967
Finley	Cl^-	28	0.96408	1402.3	0.8239
Middle James	Cl^-	28	0.772	6014.2	0.6686
Pearson	Cl^-	28	0.9216	1617.8	0.7846
Wilson	Cl^-	28	0.7662	1965.3	0.6348

Instantaneous Load Rating Curves

Watershed	Y	n	b1	bo	R^2
Finley	Bulk-IC	27	3140.8	0.9042	0.99
Upper James	Bulk-IC	27	3115.8	0.8764	0.99
Middle James	Bulk-IC	27	3629.7	0.891	0.99
Pearson	Bulk-IC	27	3223.20	0.8796	0.98
Wilson	Bulk-IC	27	2632.2	0.4766	0.35
Finley	Bulk-OC	27	120.3	1.0933	0.84
Upper James	Bulk-OC	27	140.72	1.0781	0.86
Middle James	Bulk-OC	27	133.58	1.2058	0.87
Pearson	Bulk-OC	27	198.57	1.1921	0.85
Wilson	Bulk-OC	27	388.01	1.1164	0.62
Finley	Bulk-TC	27	3245.8	0.9199	0.99
Upper James	Bulk-TC	27	3249.4	0.8946	0.99
Middle James	Bulk-TC	27	3501	0.9453	0.99
Pearson	Bulk-TC	27	3470.80	0.9102	0.98
Wilson	Bulk-TC	27	3248	0.5666	0.43
Finley	DS-IC	27	3142.1	0.8968	0.99
Upper James	DS-IC	27	3117.5	0.8745	0.99
Middle James	DS-IC	27	3533.4	0.898	0.99
Pearson	DS-IC	27	3157.3	0.8783	0.98
Wilson	DS-IC	27	2485.4	0.4673	0.35
Finley	DS-OC	27	136.86	0.9557	0.80
Upper James	DS-OC	27	144.58	0.9977	0.87
Middle James	DS-OC	27	206.61	0.9336	0.88
Pearson	DS-OC	27	181.29	1.0924	0.86
Wilson	DS-OC	27	300.83	0.9271	0.56
Finley	DS-TC	27	3289.7	0.9005	0.99
Upper James	DS-TC	27	3274.2	0.8823	0.99
Middle James	DS-TC	27	3801.6	0.892	0.99
Pearson	DS-TC	27	3397.60	0.9017	0.99
Wilson	DS-TC	27	2907.2	0.5195	0.40

Solids Yields (Mg/km²/yr)

Sub-watershed	Ad (km²)	TDS	TSS	TIC	TOC	DIC	DOC
UJ	637	61	39	9.2	0.80	9.2	0.63
F	676	69	9.0	10	0.69	10	0.52
MJ	1,197	92	87	12	1.5	12	0.82
P	54.4	158	18	20	1.6	20	1.3
W	46.1	73	30	13	2.7	13	1.7

Solids Yields (Mg/km²/yr)

Sub-watershed	Ad (km²)	TN	TP	F^-	Cl^-	NO_3^-	SO_4^{2-}
UJ	637	0.54	0.02	0.02	4.0	0.44	3.2
F	676	0.55	0.01	0.02	3.7	0.45	2.5
MJ	1,197	1.1	0.05	0.05	10	0.87	5.4
P	54.4	1.4	0.03	0.05	9.7	1.1	5.4
W	46.1	0.70	0.06	0.08	9.7	0.55	5.4