12-2008

Atrazine Contamination and Suspended Sediment Transport within Logsdon River, Mammoth Cave, Kentucky

Julie Eileen Schenck Brown
Western Kentucky University, julie.brown228@wku.edu

ATRAZINE CONTAMINATION AND SUSPENDED SEDIMENT TRANSPORT WITHIN LOGSDON RIVER, MAMMOTH CAVE, KENTUCKY

A Thesis
Presented to
The Faculty of the Department of Geography and Geology
Western Kentucky University
Bowling Green, Kentucky

In Partial Fulfillment
Of the Requirements for the Degree
Master of Science

By

Julie Eileen Schenck Brown

December 2008

ATRAZINE CONTAMINATION AND SUSPENDED SEDIMENT TRANSPORT WITHIN LOGSDON RIVER, MAMMOTH CAVE, KENTUCKY

Date Recommended ____________________

____
Director of Thesis

____

____

____

____
Dean, Graduate Studies and Research Date

ACKNOWLEDGEMENTS

This thesis would not have been possible without the dedicated guidance and support of Dr. Stephen Kenworthy, who served as the Director of my Thesis, as well as a mentor and a friend. In addition, I thank the other members of my committee, including Dr. Chris Groves, Dr. C. Warren Campbell, and Dr. L. Michael Trapasso.

I also wish to thank the students and staff of Western Kentucky University who provided support with this project. In particular, Leigh Anne Bledsoe, Brian Ham, Johanna Kovarik, Dan Nolfi and Mark Tracy provided continual assistance with data collection from the Pete Strange Falls Instrument Site in Logsdon River. While Ted Baker, Jeremy Goldsmith, Chrissie Hollon, Erin Lynch and James Otoo provided assistance with data collection from the field.

Throughout the course of my studies at Western Kentucky University, I have also been fortunate to interact with individuals who have shared personal and professional experiences, as well as comments and feedback about my research at Logsdon River that have contributed to my knowledge of karst hydrology and geology. These individuals include Don Coons, Jim Currens, Dr. Percy H. Dougherty, Joe Meiman, Dr. Art Palmer, Peggy Palmer, Geary Schindel, Dr. Chris Smart, Dr. Bette White and Dr. Will White.

I dedicate this work to my family and friends who have always supported me in the pursuit of my dream, in particular my husband Jonathan, who has provided the greatest level of support.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ATRAZINE CONTAMINATION AND SUSPENDED SEDIMENT TRANSPORT WITHIN LOGSDON RIVER, MAMMOTH CAVE, KENTUCKY

Julie Eileen Schenck Brown December 2008 161 Pages

Directed by: Dr. Stephen T. Kenworthy
Dr. C. Warren Campbell
Dr. Christopher G. Groves
Dr. L. Michael Trapasso

Department of Geography and Geology Western Kentucky University

ABSTRACT

Understanding the potential for karst aquifer contamination by sediment-sorbed pesticides is important for cave conservation efforts in agricultural landscapes. Flow rate, water quality parameters and suspended sediment concentrations were measured in Logsdon River, a ~10km karst conduit within the Turnhole Spring Groundwater Basin of Mammoth Cave National Park to determine characteristics of storm-period transport of sediment-sorbed atrazine through a conduit-flow karst aquifer.

Analysis of two independent precipitation events occurring in the Spring of 2008 from May 2-4 and May 27-29 demonstrated the rapid response of the Logsdon River to precipitation events with detections of atrazine increasing during the initial turbidity peak and decline in spC, indicating that the atrazine arrives with the initial flush of surface waters that enters the conduit. Distinct peaks of atrazine did not coincide with fine grained (silt and clay-sized) sediment peaks and concentrations of atrazine remained elevated on the falling limb of the hydrograph as turbidity declined. In addition, no systematic relation between filtered and unfiltered samples was evident. There was also

exceedingly weak correlation between the concentration of atrazine and suspended sediment, suggesting that if atrazine is sorbed to fine sediment particles this sorption involves only the fractions finer than 0.22 μm.

CHAPTER 1

INTRODUCTION AND BACKGROUND

1.1 Statement of Problem

Groundwater in karst terrain is susceptible to pollution from the land surface because karst aquifers are particularly effective at transmitting rather than treating pollutants (Ford and Williams, 1989). The natural treatment of water-borne contaminants in karst groundwater basins is identified by Ford and Williams (1989) as being relatively ineffective because:

- The opportunity for evaporation, an important element in the elimination of highly volatile organic compounds such as solvents and pesticides, is greatly reduced by the rapid infiltration of water through karst.
- Karst soils are typically thin, thus providing less physical filtration for sediment and microorganisms that are readily transported into karst aquifers.
- The turbulent flow regime commonly associated with conduit aquifers assists the transmission of particulate matter through karst systems.
- Rapid flow rates of water in conduits curtail the effectiveness of time-dependent elimination mechanisms.
- Fractured karst has less surface area available for colonization of natural microorganisms.

Pollutants are introduced by human activities into karst groundwater basins and are generally dangerous to aquatic life and the continued use of water by humans and animals (White, 1988). Pollutants can originate from chronic point sources, acute point sources and non-point sources, with land use influencing the types of pollutants that enter karst aquifers via surface runoff or through direct subsurface contamination. Chronic point sources of pollutants include hydrocarbons and brines from fossil fuel exploration and production as well as discharge from septic tanks. Acute point sources of pollutants include hazardous materials spilled during incidents on railway and roadway transportation routes. Non-point source pollutants include runoff from parking lots and roads, including oil, gasoline, road salt and related de-icers, animal waste from residential areas and farms, as well as pesticides and fertilizers used in agricultural areas.

The primary causes of contamination of karst groundwater basins and other aquifers in the United States are non-point source pollutants from agriculture in the forms of fertilizers and pesticides (United States Geological Survey, 1999). Atrazine is one of the most frequently detected pesticides in groundwater basins with agricultural use (United States Geological Survey, 2006). Characteristics of karst aquifers which make them highly vulnerable to surface–derived pesticide contamination are identified by Barbesh and Resek (1996):

- Open conduits such as sinkholes, fractures, and swallow holes provide direct entry routes of surface-derived contaminants into the subsurface.
- The transport of pesticides through solution channels in karst is similar to transport of contaminants through soil macropores, implying that rates of contaminant transport exceed those predicted by common porous medium transport models.

- Pesticides bond to soil particulates through the process of adsorption, facilitating their transport as water-borne pollutants through the karst groundwater basin.

Research on groundwater contamination by pesticides has been extensive; however there has been limited research on sediment-borne atrazine contamination in karst aquifers. Understanding the mechanisms that control how agricultural pesticides such as atrazine are transported through karstic aquifers is necessary to estimate the magnitude and likely patterns of contamination resulting from agricultural land use. This research evaluated the hypotheses that: 1) storm-period transport of atrazine through conduit-flow karst aquifers depends on the magnitude and characteristics (particularly grain size) of surface-derived fine sediment inputs and that 2) a commonly measured water quality parameter (turbidity) could be correlated with these characteristics of the suspended sediment load and thus provide an indication of probable atrazine contamination during the pesticide application season.

1.2 Karst Hydrology

1.2.1 *Characteristics of Karst Aquifers*

For over 40 years, karst hydrologists have accepted the notion that porosity and permeability are the most fundamental properties of an aquifer and therefore influence the flow of water on the surface and subsurface (White, 2007). The porosity of a rock is the fraction of the void filled by air or water, whereas the permeability of a rock indicates the ability to transmit fluid. A rock must be porous to be permeable, but the pores also need to be interconnected to allow fluid to move between them (White, 1988). The permeability (or porosity) of karst aquifers have three components known as the triple permeability model: the permeability of the bedrock; permeability produced by fractures such as joints, bedding-plane partings, and faults; and permeability due to conduits (Worthington, 1991; White, 2007). In karstic aquifers the presence of large solution cavities and integrated channels create the conduit porosity (White, 1988).

Drainage divides or boundaries between groundwater basins can be difficult to determine in cavernous rock, even with extensive dye tracing and data collection from wells (Palmer, 2007). Because groundwater flow is three dimensional, drainage divides can overlap and shift as flow rate changes (Palmer, 2007). To further understand the concept of water flow on the surface and subsurface, White (2007) proposes a framework for analysis of surface water and groundwater in karst regions, where both are completely entangled or dependent on each other. The framework for discussion of surface water is the drainage basin, whereas the framework for discussion of groundwater is the aquifer.

The concentration of water flow from the drainage basin to the aquifer can be considered the most characteristic feature of a well-developed karst terrain (White, 1989). As meteoric water in the form of precipitation and snowmelt infiltrates from the surface, it is carried downward by the force of gravity through porous sub-surface material until it reaches the boundary (water table) between the unsaturated and water-saturated zones of the subsurface. The unsaturated zone above the water table is the vadose zone, whereas the saturated or phreatic zone is the volume below the water table. In an unconfined karst aquifer the saturated zone interacts freely with the land surface, allowing the position of the water table to rise and fall with changes in the volume of infiltrating water caused by storms and seasonal changes in precipitation (White, 1989) and convergence capacity of the cavernous aquifer.

Typically, both surface water and groundwater flow paths are convergent, with trunk paths fed by tributaries and diffuse flow through surrounding bedrock or sediment (Gale, 1984). Surface water can enter the karst aquifer through concentrated runoff into sinking streams and sinkholes and through diffuse infiltration of the soil and subcutaneous zone known as the epikarst (Hess and White, 1989). Water in caves can arrive from precipitation that falls on the karst area (autogenic recharge) or it can accumulate on adjoining regions of relatively insoluble rocks and then drain into the karst aquifer as sinking streams (allogenic recharge) (Ford and Williams, 1989; Palmer, 2007). Autogenic recharge is quite diffuse, but allogenic recharge occurs at concentrated inputs such as sinking steams (Ford and Williams, 1989). Within caves, allogenic recharge often causes more variability in flow rate and tends to be more solutionally aggressive than autogenic recharge (Palmer, 2007).

The most useful parameters to characterize karstic groundwater flow are velocity and discharge (Worthington, 1991; Palmer, 2007). The velocity of water is the distance of flow per time, while the discharge (Q) is the volumetric water flow rate (volume per time), equivalent to the product of the mean velocity and the cross sectional area of flow. In karstic aquifers with open-channel cave streams, velocity will vary as the channel slope and dimensions change (White, 1988). As the slope of the hydraulic head and flow velocity increase, fluctuating eddies develop and the flow becomes turbulent (Ford and Williams, 1989; Palmer, 2007). It is possible to infer the hydraulic conditions associated with conduit flow from analysis of solutionally-developed bedforms (scallops) found on the walls of the conduits, or through study of hydraulically-transported sediments found within them (Gale, 1984), using empirical relationships between flow hydraulics and sediment size or bedform dimensions.

Much like surface drainage networks, the conduit drainage trunks in karst aquifers respond to rapid changes in recharge (White, 1988). As water levels in the upstream portion of a karst aquifer begin to rise, the increase in the hydraulic head drives water from deeper storage causing the discharge to rise abruptly above base flow (White, 1988). After the peak in discharge, the water drains from the temporary storage at a lower rate if additional storms do not increase the discharge. Aquifer response can be measured by the time it takes for water levels to return to base flow. In a well-developed conduit system dominated by allogenic recharge the response to storms will often be very flashy, while a karst aquifer with diffuse flow from poorly developed conduits will have a much more subdued response (White, 1988).

1.2.2 *Sediments in Karst Aquifers*

Sediments are solid fragments of inorganic or organic material that derive from the weathering of rock and are transported by water and wind flow. Bosch and White (2004) identify sources for clastic sediments within karst aquifers:

- Clastic loads from allogenic surface basins carried by sinking streams.
- Soils and regolith from the surface flushed into sinkholes.
- Soils carried through open fractures at the base of the epikarst.
- The residue of weathered subsurface material.
- Material from back-flooding at base-level.

Allochtonous sediments originate from sources outside the cave, which can increase contaminant transport; autochthonous sediments are derived from sources within the cave. Fluvial sediments transported through water-filled conduits and open channels usually consist of coarse stream-rounded rock fragments, as well as sand, silt and clay-sized particles.

Karst aquifers require the fluvial transport of sediments for the conduit system to stay open (White, 1988; Bosch and White, 2004). Fluvial sediment transport increases with turbulent intensity and depending on the physical and geometrical characteristics of the particles. Sediment is transported downstream as suspended load when the shear velocity (a measure of shear stress) is greater than the settling velocity of the particles. As distance above the bed increases, the concentration of suspended sediment falls rapidly (White, 1988). Sediment that has intermittent contact with the bottom of the conduit but moves downstream by rolling, sliding or saltation is bed load transport. The transport of most clastic sediments tends to be episodic, with sediment held in storage until infrequent flood events move the materials (Bosch and White, 2004).

1.2.3 *Karst Aquifer Behavior in the Mammoth Cave System*

Although scientists have studied the area around Mammoth Cave for nearly two hundred years, there has been limited evaluation of water quality within subsurface drainage basins in the Mammoth Cave area until the past three decades (Meiman et al., 2001; Meiman, 2006). Beginning in 1973, park hydrologist Dr. James Quinlan and his associates began a systematic evaluation of the relationship of surface water to groundwater basins through dye-tracing, cave mapping, potentiometric surface mapping, and continuous monitoring of water quality parameters and flow levels in the Mammoth Cave area. From 1975 through 1987 more than 500 dye-traces were conducted north and south of the Green River that delineated 27 major groundwater basins, plus additional subbasins, all of which were traced to discharge points on the Green River, Barren River, and Little Barren River (Quinlan and Ewers, 1989). A groundwater hydrology map (Quinlan and Ray, 1989; Ray and Currens, 1998a, 1998b) was produced as a final product (Figure 1).

The results of Quinlan's work at Mammoth Cave National Park provided a systematic understanding of physical hydrology in surface drainage basins and aquifers throughout the south-central Kentucky karst region. Distributaries (cave river branches flowing away from the main stream) in the aquifer were attributed to one or more of several processes including:

- The enlargement of pre-existing anastamostic channels by water flow that can fill an entire conduit during storm events.
- Collapse and subsequent blockage of spring orifices that result in the development of alternative discharge routes.
- Diversion of cave streams, through piracy, to subordinate routes in relation to the lowering of base level and river stage.
- Enlargement of vadose conduits intersecting anastomostic channels and other passages at the water table that rise and fall in response to river levels (Quinlan and Ewers, 1989).

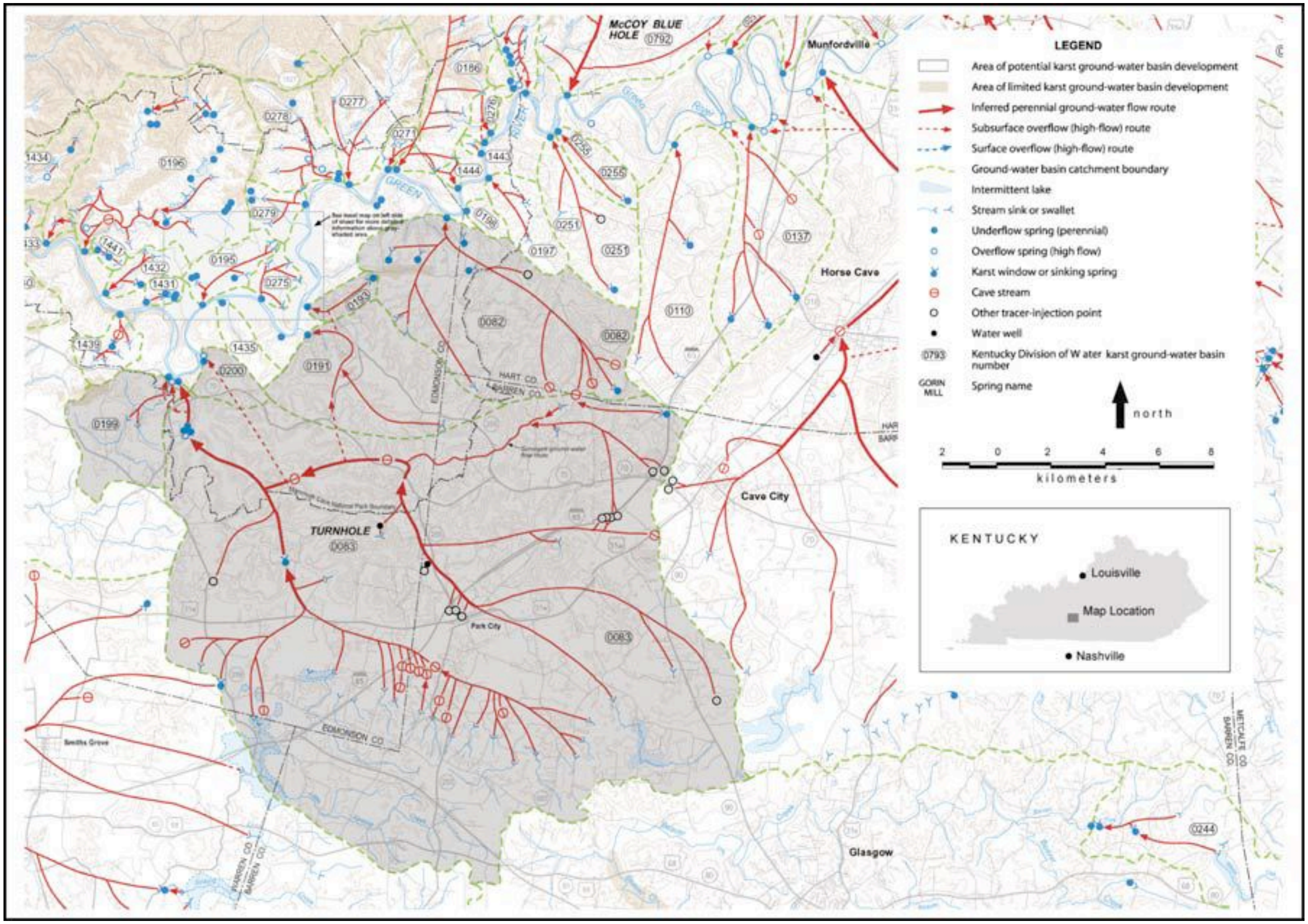

Figure 1. Karst hydrology of the Mammoth Cave area (Ray and Currens, 1998a, 1998b; Glennon and Groves, 2002).

These concepts created the foundation for understanding the relation of drainage basins to karst aquifers within the Mammoth Cave area.

Hess and White (1988) used data on spring discharge and river-flow, as well as data from a rain gage network to understand the storm response of a karst aquifer within Mammoth Cave National Park and to assess the role of conduits in the overall balance of groundwater. Analyzing a time series of specific conductance and water temperature measurements at Owl Cave, located in the downstream drainage of the Turnhole Spring Basin, sharp peaks and dips in the conductivity levels were attributed to well-defined drainage tributaries responding to high intensity storms (Hess and White, 1988). Much of the discharge was through open conduits that carried allogenic water from sinking stream catchments. The Turnhole Spring drainage system exemplified a classic conduit flow aquifer (Hess and White, 1988).

In a study by Raeisi et al., (2007), changes in hydraulic flow of a conduit within the Mammoth Cave System were compared between partially-full pipe and full pipe conditions of the Logsdon River. Analysis of temperature, specific conductance, stage and velocity demonstrated relationships to the geometry of the conduit and fluid transport behavior (Raeisi et al., 2007). During full pipe conditions, initial minimums in specific conductance represented the early movement of storm water through the conduit, while the second minimum was interpreted as storm water temporarily stored in adjacent areas that drained back into the conduit; changes in specific conductance during partially-full pipe conditions were mainly controlled by external recharge conditions, such as the behavior of sinking streams (Raeisi et al., 2007).

1.3 Pollutants in Karst Aquifers

1.3.1 *Transport of Contaminants*

Several environmental initiatives evolved from Quinlan's study of the relationship of drainage basins and aquifers in the Mammoth Cave area (Quinlan and Ewers, 1989). For example, continuous monitoring for high output levels of heavy metals in the Hidden River Cave complex served as the major impetus towards the design of a $13 million regional sewage-treatment system in the 1980s that services the towns of Horse Cave, Cave City, Park City and Mammoth Cave National Park. Dye traces to evaluate the transport of non-point and acute point source pollutants from runoff in parking lots, residential, and urban areas, as well as hazardous material spills along Interstate Highway 65, led to the development of strategies to monitor pollutants in karst terrains and aquifers, with official response plans and instructions for remediation and containment of the hazardous spills. This work also motivated the passage of environmental legislation that provides protection for Mammoth Cave National Park, including federally endangered species such as the Kentucky cave shrimp, *Palaemonias ganteri* as well as other aquatic biota present in surface and cave streams (Quinlan and Ewers, 1989). Quinlan's pioneering work on the drainage basins and karst aquifers in the Mammoth Cave area demonstrated that land use practices outside the Park boundaries directly impact the quality of groundwater within the Park.

To assess the water quality variations generated during runoff producing precipitation events, Hall (1996) tagged specific groundwater inputs with fluorescent dye to determine contaminant flow paths for fecal coliform bacteria and nitrates into the

Mammoth Cave System. Hall selected the Turnhole Spring Basin, which constitutes the largest karst aquifer in the Mammoth Cave System (Quinlan and Ewers, 1989). The Turnhole Spring Basin includes three major groundwater subbasins: Cave City, Pakota Creek, and Mill Hole (Quinlan and Ewers, 1989). Because these subbasins not only had different land uses, but also represented different types of conduit flow conditions within the aquifer, each had its own characteristic flood response. The left fork of the Hawkins River (also known as the Logsdon River in the literature), which drains the 25 km^2 Cave City basin, is a vadose stream with a base flow rate of ≤ 100 liters/second. The right fork of the Hawkins River, which drains the 75 km^2 Pakota Creek basin, is a combination of flow types (vadose and phreatic), with a flow rate nearly six times greater than the left fork. Mill Hole stream, which drains the 112 km^2 Mill Hole Sub basin, is a phreatic stream exposed at the surface for approximately 100 m (Hall, 1996).

At sampling sites within each of the three sub basins, instrumentation in the active stream channel recorded water quality parameters including specific conductance, temperature, and turbidity. Based on dye tracing on the left fork of the Hawkins River (Logsdon River) and observed decreases in the specific conductivity (representing runoff from the vertical shafts mixing with long term residence waters), Hall (1996) inferred one major phreatic tributary at the distal reaches of the basin and documented the contribution of fecal coliform from agricultural land use and septic tanks within the Cave City subbasin. Chemical parameters sampled within this basin, such as nitrates, were diluted during flood pulses.

Temperature and conductivity variations on the right fork of the Hawkins River suggested four major phreatic tributaries which responded more dramatically than the left fork to rainfall events, with the tributary waters not remaining in the trunk passage very long (Hall, 1996). Major increases in fecal coliform counts during runoff producing rain events were noted; however there was no apparent evidence of leaking oil wells due to low base flow concentrations of both chloride and sulphate (Hall, 1996).

The largest of the subbasins, Mill Hole, contained five major phreatic tributaries detected by the conductivity data. This subbasin was more extensively farmed than the other basins, thus the fecal coliform counts and nitrate levels were considerably higher (Hall, 1996). Varying degrees of chloride and sulphate contamination were noted in the Mill Hole subbasin, with greater fluctuation in specific conductivity rates among stores with higher chloride levels (Hall, 1996). In addition, dye tracing and water quality measurements from Parker Cave, a very contaminated cave located in the Mill Hole subbasin, was also found to contribute elevated levels of nitrates (Hall, 1996). Despite the inter-site differences in water quality parameters and pollutant levels, the results were consistent with conduit flow aquifer behavior, in terms of rapid groundwater throughput and fluctuations in the water chemistry.

Another study of water quality variations during and after two storm events that produced surface runoff was conducted by Ryan and Meiman (1996) at the Big Springs groundwater basin within Mammoth Cave National Park. The land use of this groundwater basin is a mix of old growth forest and agriculture. Quantitative dye traces were used with water sample analysis to interpret the rate and amplitude of changes in water quality parameters. Delays between the initial discharge response and changes in the specific conductance suggested the presence of a water filled phreatic conduit that was evacuated once enough hydraulic head was created to discharge the water. Increased suspended sediment and fecal coliform bacteria levels were noted about 12-30 hours after the initial drop in specific conductance. The dye injected into the aquifer via the surface demonstrated similar response times. Thus, the nonpoint source pollutants appeared to be transported while the conduit received runoff from the agricultural subbasins (Ryan and Meiman, 1996).

Continuous monitoring of water and contaminants transported through the vadose zone of Postojnska Jama (Cave) in Slovenia was conducted by Kogovsek and Sebela (2003) to evaluate the mode and rate of groundwater pollution. Analysis of discharge, pH, conductivity, carbonates, calcium, magnesium, chloride, nitrate, sulphate and phosphates has been conducted since 1988 and continues to the present. Contamination was detected in water samples taken from the cave with the source being a septic tank for an army bunkhouse, 100 m above the cave (Kogovsek and Sebela, 2003). The bunkhouse has not been used since 1991 when the army left the area and no new effluent has been generated, but transport of contaminants through a conduit network into Postojnska Jama has continued (Kogovsek and Sebela, 2003). Evidence of contaminant transport from the epikarst to the vadose zone exhibits the potential for long term contamination even after the source of the pollutants are removed.

Mahler et al., (1999) investigated geochemical characteristics of sediments in the Edwards Aquifer of central Texas to demonstrate the wide range of properties affecting contaminant transport. Samples were collected from surface streams, sinkholes, caves, wells and springs to analyze the mineralogy, grain-size distribution, organic carbon content and surface area. The sediment samples were classified into three distinct groups: (1) streambeds, sinkholes, and small springs; (2) wells; and (3) caves with sediments from the primary discharge area (Mahler et al., 1999). Results from this study indicated that high organic carbon and clay content of the sediments correlated to specific land use with a high potential for contaminant transport via a mobile solid phase in the karst aquifer; analysis of mobile sediments in a karst aquifer can therefore reveal a wide range of properties that affect contaminant transport potential (Mahler et al., 1999). New sources of contamination and increases in the amount of sediment entering the aquifer can be expected as urbanization continues in the groundwater basin (Mahler et al., 1999).

In a study conducted in Switzerland by Pronk et al., (2007) continuous monitoring of discharge, turbidity, water temperature, electrical conductivity, particle-size distribution (PSD), and total organic carbon (TOC) were combined with sampling of fecal indicator bacteria to understand the processes of pathogen transport in karst groundwater and to establish PSD as an indicator for possible microbial contamination of drinking water from karst springs. Pronk et al., (2007) demonstrated that suspended particles originated either from remobilization of sediments inside the aquifer (autochthonous) or from a sinking stream draining an agricultural area (allochthonous). The PSD made it possible to distinguish between these two types of turbidity with a relative increase of finer particles on a second, allochtonous turbidity pulse that indicates fecal bacteria contamination through an increase of *E. coli* levels in the water samples (Pronk et al., 2007). The linkage between particle size and bacterial transport identified by Pronk et al., (2007) may also have implications for the transport of sediment-associated pesticides within karst aquifers.

1.3.2 *Pesticides as Contaminants in Karst*

Agriculture within karst areas is important to the economy of the state of Kentucky. The 2002 Census of Agriculture reported 13,843,706 acres of farmland in Kentucky which produced corn, soybeans, tobacco, and wheat (National Agricultural Statistics Service, 2008). This total output ranked Kentucky 14th in total agricultural production in the United States (National Agricultural Statistics Service, 2008). Closely related to high agricultural outputs is the application of pesticides on crops such as corn, tobacco and soybeans. Crain (2006) estimates almost eighty percent of pesticide use being related to agricultural practices, with the remainder coming from industrial, commercial, and residential practice.

The United States Environmental Protection Agency (USEPA) classifies pesticides within a Common Mechanism Group based on cumulative risk assessments that indicate common toxic effects. One such Common Mechanism Group is triazine based pesticides and herbicides which include atrazine, simazine, propazine, and their chlorinated degradates desethyl-s-atrazine (DEA), desisopropyl-s-atrazine (DIA), and diaminochlorotriazine (DACT). Laboratory studies of rats exposed to triazine levels higher than what is commonly found in the environment suggest that these pesticides have the potential to cause neuroendocrine, developmental and reproductive effects which may be relevant to humans (United States Environmental Protection Agency, 2006). The USEPA also thought initially that triazine pesticides shared a common mechanism of toxicity based on the carcinogenic effects in rats that created malignant growths; however, the mode of action which causes tumors in rats depends on a reproductive aging process which does not occur in humans (United States

Environmental Protection Agency, 2006). The USEPA has found triazine pesticides to potentially cause congestion of the heart, lungs and kidneys; low blood pressure; muscle spasms; weight loss and some muscular degeneration in persons exposed at levels above the maximum contaminant level of 3.0 ppb or 3.0 μg/ L (United States Environmental Protection Agency, 2006; Kentucky Department of Agriculture, 2007).

Atrazine (CAS chemical name: 2-chloro-4-ethylamine-6-isopropylamine-S-triazine) is one of the most commonly used pesticides in Kentucky based agriculture because it is highly effective and less expensive than other applications that are available (Kentucky Department of Agriculture, 2007). Atrazine, a selective herbicide, is the active ingredient in several pesticide products used to control a wide spectrum of broadleaf weeds and annual grasses (Kentucky Department of Agriculture, 2007). In Kentucky, atrazine is most commonly used on field corn, but it has also been used on popcorn and sorghum crops; it cannot be used on right-of-ways, roadsides, turf grass or lawns (Kentucky Department of Agriculture, 2007). Applications of atrazine are made with water dispersible granules, powder or as a liquid that is applied directly to the soil as a pre-emergent treatment (United States Environmental Protection Agency, 2006; Kentucky Department of Agriculture, 2007). State regulations in Kentucky prohibit the application of atrazine in the fall, but allow pre-emergent application 45 days prior to planting as well as post-emergent application until the corn reaches twelve inches in height (Kentucky Department of Agriculture, 2007).

Atrazine tends to bond to soil particles through adsorption during movement through soil and water. The moderate to high mobility and adsorption of atrazine to soil particles can result in contamination of both surface and ground water (World Health

Organization, 1990; United States Environmental Protection Agency, 2006). Because atrazine is relatively mobile through soil and water, from runoff and leeching, it is classified as a restricted use pesticide (Kentucky Department of Agriculture, 2007). Atrazine can be introduced into karst aquifers through surface runoff into sinkholes, karst windows, or sinking streams, as well as by penetration through the epikarst layer into vadose and phreatic networks. Best management practices for the state of Kentucky prohibit mixing and loading of atrazine products within 50 feet of sinkholes, drinking water wells, livestock wells, irrigation wells, abandoned wells, intermittent streams, perennial streams, rivers, lakes or reservoirs; atrazine cannot be applied within 50 feet of any well, including drinking water wells, irrigation wells, agricultural drainage wells, livestock water wells and abandoned wells and within 200 feet of a lake or reservoir and within a 66-foot arc measured from points where surface water runoff enters intermittent streams, perennial streams, or rivers (Kentucky Department of Agriculture, 2007).

The degradation of atrazine occurs by either microbial or chemical means (Wehtje et al., 1983). Both methods destroy the herbicidal properties of the atrazine molecule predisposing it to further microbial and/ or chemical degradation and eventual mineralization (Wehtje et al., 1983). Although atrazine breaks down rapidly in sunlight, it is stable to breakdown in water at pH levels ranging from 5 to 10 (United States Environmental Protection Agency, 2006). The breakdown of atrazine in soils depends on soil pH, microbial action, organic material and moisture; breakdown occurs much slower in acidic soils (United States Environmental Protection Agency, 2006). Under cold or dry conditions, atrazine can persist for longer than a year with half-life estimates ranging from 42 to >365 days (United States Environmental Protection Agency, 2006). Since most groundwater has pH levels between 5 to 10 and relatively stable levels of colder temperatures, the potential for atrazine contamination in karst aquifers can be substantial.

The study of groundwater quality in karst regions within agricultural areas has received attention from the United States Geological Survey (USGS) in the 1990s as part of the National Water-Quality Assessment Program (NAWQA). The USGS implemented the NAWQA to examine the quality of the Nation's streams and groundwater basins, and to document changes over time from the impact of humans and natural variation, including the detection of nonpoint source pollutants, particularly pesticides (Kingsbury, 2003). Interdisciplinary assessments have been conducted in more than 50 of the nation's most important river basins and aquifers since the implementation of the NAWQA in 1991. The areas studied account for more than 60 percent of the overall water use of the national population, represent major hydrologic landscapes and ecological resources, and demonstrate the impact of nonpoint source pollutants from agricultural practices within these regions (Kingsbury, 2003).

Within the Green River basin of Kentucky, nine different pesticides were detected in eight karst springs sampled in the drainage basin for NAWQA (United States Geological Survey, 2002). After five months of sampling during May to September 2001, the USGS determined that the herbicide atrazine was present in 100 percent of the karst springs sampled. Samples from the Green River basin karst springs contained atrazine at levels that exceeded the maximum contaminant levels (3.0 ppb), as well as the aquatic-life criterion (1.8 μg/L) assigned by the USEPA. The aquatic-life criterion is designed to prevent unacceptable long-term (years to decades) and short-term (days and weeks) effects on aquatic organisms in groundwater basins and aquifers (United States Geological Survey, 2002).

Similar results were discovered by Crain (2006) in her study of four springs, two streams and one karst window within the Sinking Creek Basin of Kentucky. Crain (2006) discovered atrazine detection levels to be 100 percent in samples collected from April through November 2004, but did not make reference to a seasonal pattern of increased atrazine levels. The samples with atrazine exceeded the aquatic-life criterion established by the USEPA. Pesticide transformation compounds were also present in 98 percent of the samples. Pesticide transformation compounds are more water soluble than their parent compounds, but their toxicity is not known (Crain, 2006). In addition, for 2 of the 48 detections, the levels of atrazine exceeded the USEPA's Maximum Contaminant Level of 3 ppb for drinking water (Crain, 2006). Thus, the study by Crain has implications for the toxicity of pesticides in groundwater, and the potential for persistence of pesticide transformation compounds.

Groundwater sensitivity mapping in Kentucky (Figure 2) indicates the likelihood of groundwater contamination by surface application of agricultural chemicals, based on geological, hydrological and soil properties (Kentucky Department of Agriculture, 2007). Water sampling by the Kentucky Division of Water shows evidence of higher levels of atrazine contamination in karstic areas than non-karstic areas (Goodmann et al., 2002). Atrazine was detected in 509 of 1900 samples collected from more than 300 sites throughout the state (Goodmann et al., 2002). Approximately 41 percent of samples from karst aquifers contained detections of atrazine compared to 2 percent of samples from non-karstic areas with detections of atrazine. Detections of atrazine above the USEPA's

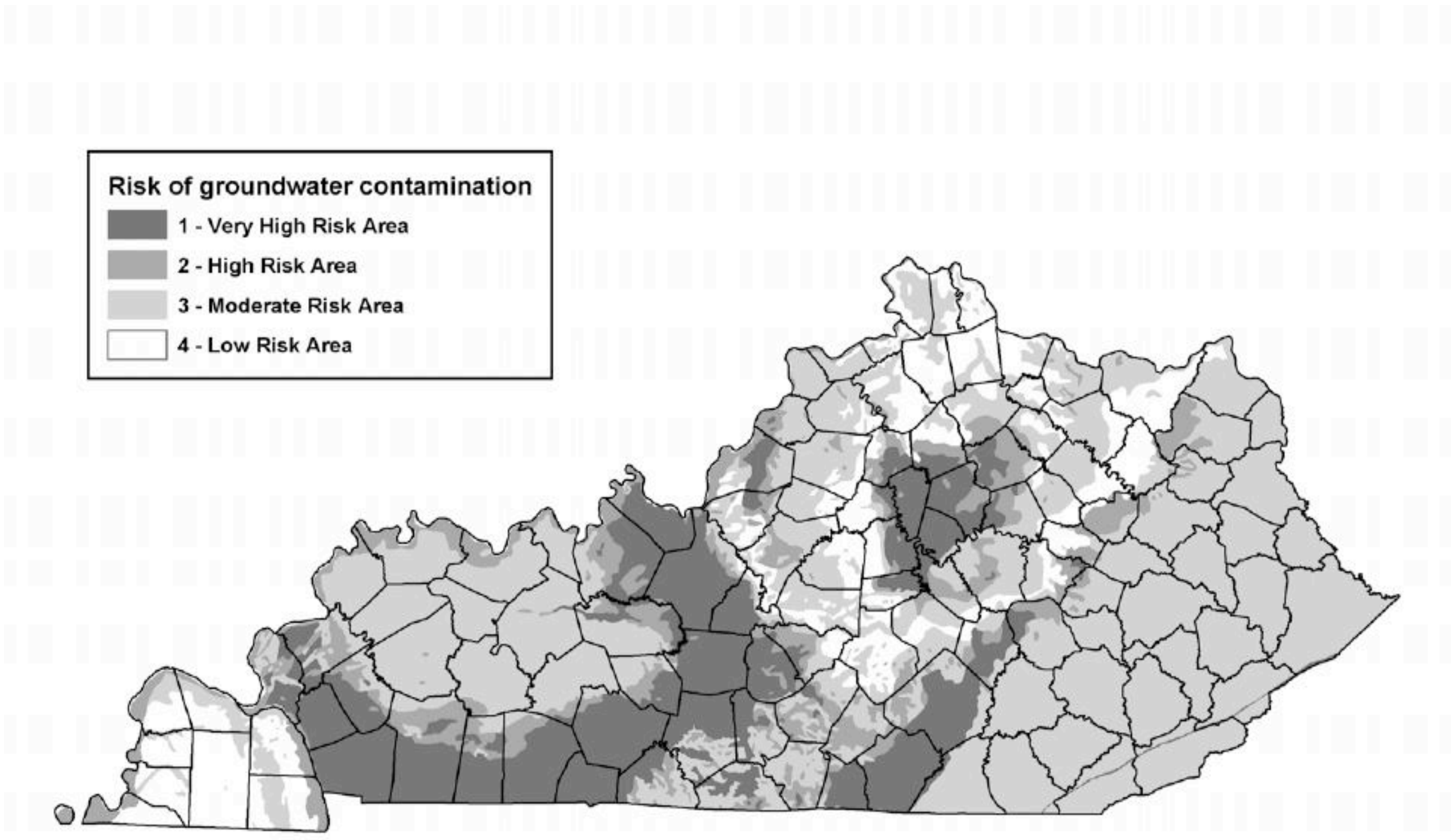

Figure 2. Groundwater sensitivity map of Kentucky (Kentucky Department of Agriculture, 2007).

Maximum Contaminant Level of 3 ppb was only found in karst aquifers (Goodmann et al., 2002). The majority of the landscape within Kentucky's karst regions where groundwater is relatively shallow is used for growing grain or row crops, making these areas more vulnerable to contamination from pesticides (Kentucky Department of Agriculture, 2007). In addition, areas of high groundwater sensitivity are more easily contaminated with atrazine than other chemicals because of fractured and porous bedrock, which are predominant features of karst terrain (Kentucky Department of Agriculture, 2007).

Water quality monitoring by Lerch et al., (2001) within Boone County, Missouri demonstrated the presence of atrazine in karstic areas. During a yearlong period, samples were collected from Hunters Cave and Devils Icebox Cave. Although the caves are located within separate groundwater basins, they have similar land use patterns of agriculture, forest and urbanized areas. Atrazine and other pesticides were detected in 94.5 percent of the samples collected at Hunters Cave and 99.6 percent of the samples collected at Devils Icebox Cave. Of particular note was the increase of atrazine during the spring season from April to June. The increase in atrazine and pesticide levels was attributed to the proximity of the May-June pesticide application season; an increase in seasonal precipitation from intense thunderstorms; insufficient time for the process of pesticide degradation and the formation of mobile metabolites which are susceptible to surface transport (Lerch et al., 2001).

Another study by Kambesis (2007) examined the source and movement of agricultural contaminants in a fluvio-karst groundwater basin that intersects a portion of northeast Iowa and southeast Minnesota. Using dye tracing to discern groundwater flow within the Coldwater Cave groundwater basin, as well as the investigation of basin and aquifer characteristics and analysis of cave survey data, the relationship between surface and subsurface hydrogeology was established (Kambesis, 2007). Through analysis of cave and surface water, the agricultural contamination of the surface and groundwater were found to be related to the seasonal application of pesticides (Kambesis, 2007).

Despite the research on atrazine as a water-borne contaminant in karst basins, very little work has been conducted to examine the presence of sediment-borne atrazine in subsurface basins, particularly within the Mammoth Cave area. Anderson (2002) collected suspended sediment and water samples from the 145 m drilled well site that intersects the Hawkins River in Mammoth Cave. Of the four storm events that were sampled, only the fourth one, which occurred on June 4, 2001, produced sufficient runoff to create turbid flows in the cave stream. The stage of the Hawkins River began a dramatic rise following the surface precipitation, but receded within 24 hours after the initial increase. The temperatures recorded during Anderson's sampling, ranging from 14.4 to 16.4° Celsius, were warmer, compared to the range of 12° Celsius that was recorded during Hall's 1996 study. Reduced water temperature can be attributed to a longer residence time in the cave, but may hinder the adsorption process of atrazine to sediments (Anderson, 2002).

Measurements of water quality parameters in Anderson's study indicated an increase in stage and decrease in specific conductivity with two surface water pulses suggested by the conductivity data occurring from a single storm. The pattern of two distinct pulses can be attributed to water entering the conduit via vertical shafts or nearby sinks to produce the initial pulse, while the second pulse came from distal sources outside the park boundary such as sinkholes, sinking streams and penetration through the epikarst (Anderson, 2002). A small peak in turbidity occurred two hours after the stage peaked. A larger second turbidity peak occurred approximately 8 hours after the stage peaked. For the first three hours of sampling the first turbidity peak coincided with the partial recovery (increase of the specific conductivity) following the first pulse of surface water in which the specific conductivity decreased; as the turbidity levels began to rise rapidly on the falling limb of the hydrograph, the specific conductivity continued to decline (Anderson, 2002). The rise in turbidity and drop in conductivity levels suggest the arrival of water from the distal sources, and were associated with an increase in atrazine concentrations. Atrazine in samples collected by Anderson (2002) was primarily associated with suspended sediments, thus indicating that adsorption to sediments can be a major mechanism for atrazine transport in karst conduit aquifers.

One intriguing aspect of the co-variation of atrazine and suspended sediment concentrations was that although the turbidity declined rapidly following the peak associated with the distal water pulse, atrazine levels remained elevated through the remainder of the sampling period. This pattern of decreasing turbidity, and presumably suspended sediment concentration, is difficult to reconcile with the observations that atrazine levels remained high and that atrazine was associated primarily with suspended sediments. One explanation offered by Anderson was that atrazine may have been preferentially associated with particular mineral or grain size fractions of the sediment, and thus atrazine levels were affected by both total suspended sediment concentration and the changing characteristics of the sediments in transport. Anderson’s study was limited by the fact that only one storm event was sampled, and thus the relation between atrazine levels, suspended sediment concentrations, and the characteristics of sediments in transport through karst conduits remains uncertain.

Additional study is needed to ascertain whether the patterns of atrazine transport in relation to other water quality parameters observed by Anderson (2002) are broadly representative of the storm response of Mammoth Cave karst conduits. In addition, variations in storm period atrazine transport may be affected by spatial patterns of rainfall, land use and pesticide application, as well as by differences in the hydrological responses of aquifers due to variations in antecedent rainfall, soil moisture, and baseflow levels. Thus issues of the hydrologic context and land use patterns will ultimately impact the nature of contamination problems due to sediment-borne transport of agricultural contaminants within karst conduit aquifers.

CHAPTER 2

STUDY AREA AND RESEARCH METHODS

2.1 Introduction

Hydrologic and water quality data were collected from study sites in Logsdon River, a cave stream within the Mammoth Cave System, in order to evaluate the hypotheses that: 1) storm-period transport of atrazine through conduit-flow karst aquifers depends on the magnitude and characteristics (particularly grain size) of surface-derived fine sediment inputs and that 2) a commonly measured water quality parameter (turbidity) can be correlated with these characteristics of the suspended sediment load and thus provide an indication of likely atrazine contamination during the pesticide application season. Observed patterns of suspended sediment flux and pesticide concentrations during storm events were related to the distribution of agricultural land use and to inter-storm differences in spatial and temporal patterns of precipitation.

2.2 Study Area

2.2.1 *The Geology of Kentucky*

The bedrock geology of Kentucky is dominated by sedimentary rock initially deposited as sediments in inland seas and ancient oceans. These sediments were compressed and cemented into a variety of limestones, sandstones, conglomerates, shales and coals which constitute the visible layers of rock today. Deposits from the Pennsylvanian, Cretaceous and Tertiary periods show evidence that water levels fluctuated greatly, including a variety of near shore coastal plain, deltaic and beach deposits (Dougherty, 1985). The rocks of Ordovician Period were deposited in deep seas, but towards the end of this period, the seas became shallower as evidenced by the amount of mud that was deposited and subsequently hardened into shale (Dougherty, 1985). During this period there was widespread warping of the strata that resulted in the Cincinnati Arch, a long gentle arching of the earth's surface that runs from Cincinnati, Ohio to Nashville, Tennessee. The Cincinnati Arch divides the state of Kentucky into independent eastern (Appalachian) and western (Illinois) basins. Mississippian rocks are exposed within a central gap in the anticline and along the flanks of the structure where younger deposits have been stripped off by erosion.

The Mississippian Plateau is the most noted karst area in the United States and is located at the southeastern edge of the Illinois Basin (Dougherty, 1985). Mississippian rocks in this area contain the largest karst groundwater basins in the state of Kentucky, with eight of the state's ten largest volume springs occurring in this region. The topography of the area is characterized by low cuestas which developed on erosion-resistant strata near the perimeter of the Illinois Basin. The Chester upland is one of the most prominent cuestas and is capped by Upper Mississippian and Lower Pennsylvanian sandstones and conglomerates. The limestone in this area forms the largest expanse of cavernous rock in North America although the total thickness of the limestone in this region is rather thin compared to other karst regions of the world (Palmer, 1985).

2.2.2 *The Geology of Mammoth Cave*

Located at the southeastern edge of the Chester upland in Kentucky (Figure 3), approximately 160 km south of Louisville and 160 km north of Nashville, the karst basins of Mammoth Cave and related areas have been described as a world class example of a shallow, intensely karsted, carbonate aquifer unit (Palmer, 1985; White, 1989). Mammoth Cave National Park is primarily positioned on the Chester Cuesta, and is dissected by expansive karst valleys adjacent to the Sinkhole Plain of the southern Pennyroyal Plateau (Meiman, 2006). The Big Clifty Formation, an overlying layer of sandstone from the Mississippian Period erodes much slower than limestone, thus providing a caprock layer for the existing karst that is only a few hundred meters in depth (Palmer, 1985).

Comprising more than 590 km of traversable passages, Mammoth Cave is the longest known cave in the world. Several other extensive cave systems are located in the region: Fisher Ridge Cave (177 km), the Martin Ridge Cave System (52 km) and the Hidden River System (34 km) (Bob Gulden, 2008). The caves passages are formed by the dissolution of limestone when groundwater enters from the surface through sinkholes and vertical shafts, as well as diffuse infiltration.

The Mammoth Cave System intersects the Girkin, Ste. Genevieve, and the St. Louis limestone layers (Figure 4). Stratigraphic descriptions of the Mammoth Cave area are provided by Palmer (1981) and Meiman (2006):

Girkin Formation: Ranging from 30-60 m in thickness, this limestone marks the uppermost strata of cave bearing rock. This layer contains numerous fossil

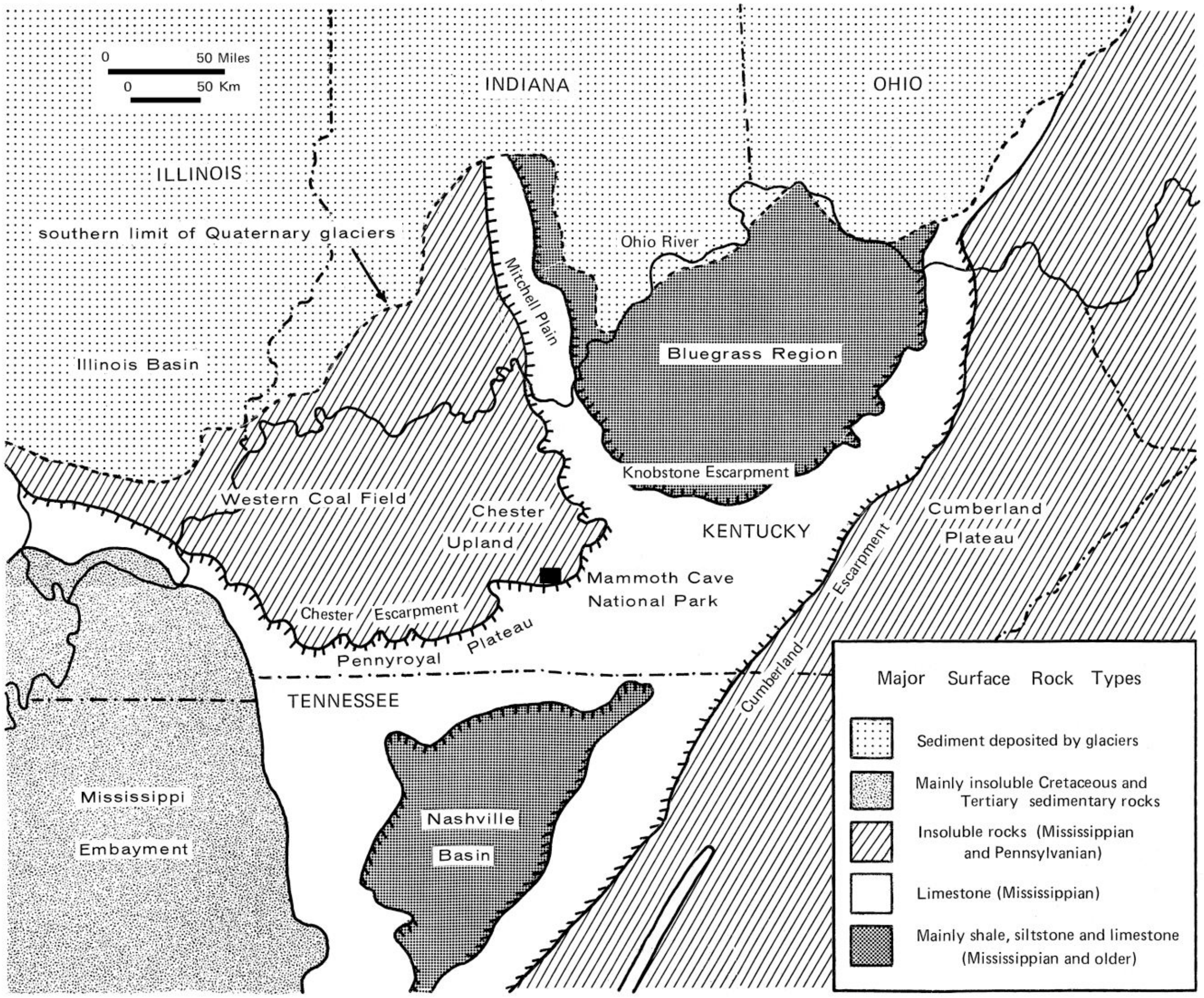

Figure 3. Geological boundaries of the central United States (Palmer, 1981).

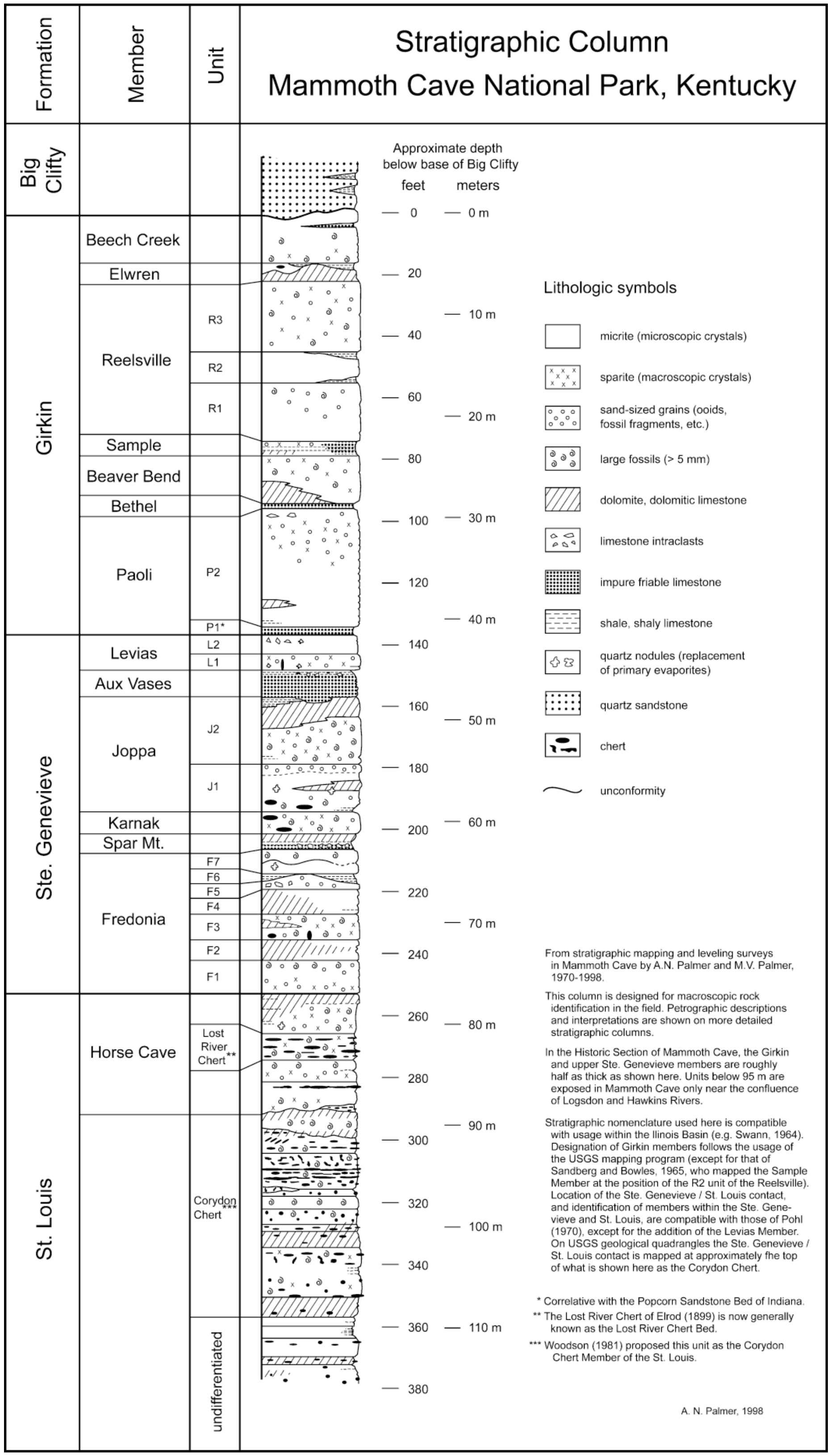

Figure 4. Stratigraphy of Mammoth Cave and surrounding area (Palmer, 2007).

fragments in the upper portion and is interbedded with thin, greenish shales. Near the base of this formation is an abundance of chert. There is no overland flow and all water sinks into dolines and ponors.

Ste. Genevieve Limestone: Approximately 55 m thick, it is difficult to distinguish this limestone from the overlying Girkin Formation and underlying St. Louis limestone as there is no unconformity between these layers. The majority of Mammoth Cave is developed in this layer.

St. Louis Limestone: The St. Louis layer can be as thick as 90 m, and is the lower layer of cave bearing rock. Although this layer is not exposed on the surface within the National Park, it is found throughout the lower levels of Mammoth Cave. Approximately half way through the St. Louis Limestone, the thick-bedded soluble limestones suddenly grade into thinly-bedded limestones consisting of shaley, silty and cherty limestone. These layers do not promote karst development and act as an aquiclude that defines the lower limits of the karst aquifer.

These limestone layers in which Mammoth Cave is located have a small angle of dip, one to one and a half degrees to the northwest, allowing exposure over a large area, creating extensive karst drainage basins of up to 500 km^2 (Palmer, 1985).

The development of Mammoth Cave is closely related to the history of fluvial entrenchment of the Green River. The Green River became deeply entrenched following the Pleistocene formation of the Ohio River at the southern margin of the Laurentide ice sheet (Miotke and Palmer, 1972, Granger et al., 2001). Incision of the Green River through the clastic caprocks of the Chester Upland and into the underlying limestones accelerated the development of the karst groundwater flow system. Alternating river incision and aggradation of the Green River was promoted by climate fluctuations and Pleistocene glacial advances. During periods of river profile stability, lateral erosion and deposition led to floodplain development, while solution processes in the subsurface created the extensive cave networks of the Mammoth Cave System. Cave passages within Mammoth Cave formed at progressively lower levels as the Green River incised episodically. Major levels of the cave passage network correlate with terraces in the Green River valley which are remnants of floodplain surfaces formed during periods of base level stability (Miotke and Palmer, 1972). Many of the lowest cave passages are filled with clastic sediment carried by underground streams since the most recent aggradation of the Green River flooded the lower cave passages (Miotke and Palmer, 1972; Granger et al., 2001).

2.2.3 *The Karst Drainage of Mammoth Cave*

The entire karst drainage system for Mammoth Cave flows to the Green River, which flows east to west in a meandering channel (Figure 1). Both the Nolin River and the Barren River intersect the Green River downstream of Mammoth Cave. The Nolin River flows from the north and east, primarily on clastic rocks above the limestone. The Barren River drains most of the southern portion of the region as it flows from the south and east (Hess et al., 1989). Groundwater basins within the Mammoth Cave area discharge primarily at a spring or group of springs at or near a base-level stream (Quinlan and Ewers, 1989, Figure 1). A dendritic or trellised network of conduits that typically increase in size and order as they decrease in number in the downstream direction, feeds the springs (Quinlan and Ewers, 1989). In some karst basins, distributary flow paths discharge at several springs.

2.2.4 *The Turnhole Spring Groundwater Basin of Mammoth Cave*

The Turnhole Spring Groundwater Basin is one of the larger basins of the Mammoth Cave area, within a drainage area of approximately 245 km^2 (Quinlan and Ewers, 1989; Meiman, 2006). Much of the basin is occupied by private land (215 km^2), which is predominately agricultural but includes a small proportion of commercial property related to the tourism of the Mammoth Cave area (Meiman, 2006). The basin can be considered a conduit flow system as it has been documented to respond rapidly to precipitation, exhibits great fluctuation in discharge rates, and has large variations in both water temperature and chemistry (Quinlan and Ewers, 1989). The fluctuations in discharge rates, water temperature and chemistry can all be impacted by the surface land use, including agricultural runoff and sources of contamination from homes and businesses, such as septic tanks.

The Logsdon River is a conduit of the Turnhole Spring Groundwater Basin that drains the sinkhole plain within the Cave City groundwater subbasin. The surface tributaries of the Logsdon River travel across the Ste. Genevieve limestone, the Girkin Limestone, the Big Clifty Sandstone Member and the Haney Limestone Member (Figure 5). Logsdon River joins the Hawkins River tributary of the Turnhole Spring Basin inside the Mammoth Cave National Park boundary where it intersects the Ste. Genevieve and St. Louis formation. The single bed of Lost River chert at -86 m on the stratigraphy column (Figure 4) shows up prominently in the ceiling of the Logsdon River. The

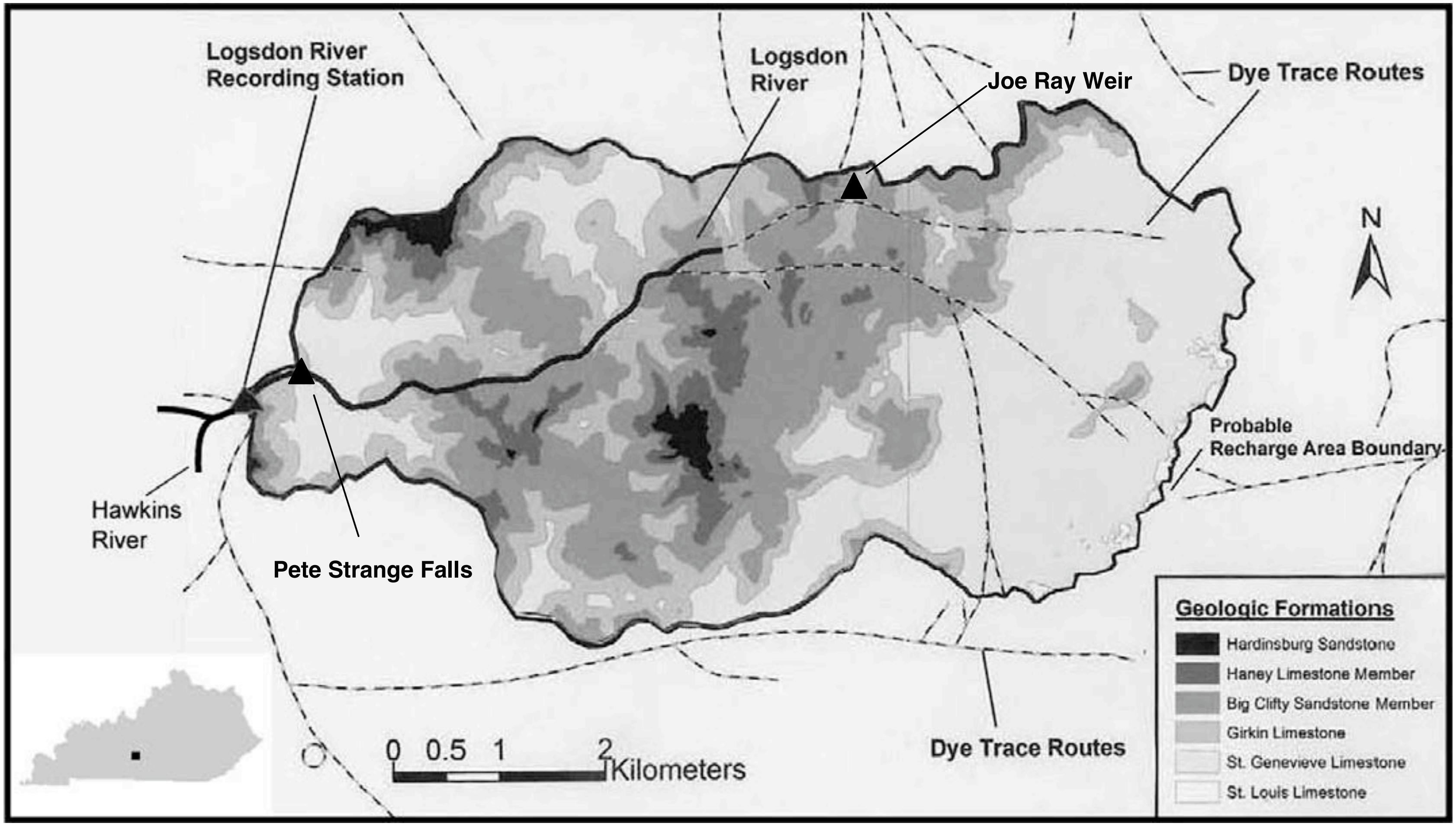

Figure 5. Geology of the study area (Raeisi, et al., 2007).

Corydon Chert is evident in the floor of the River, with silicified shrimp burrows and thin lenses of chert. The lowest part of the stratigraphy column, below -98 m, is exposed only in the downstream section, including the confluence with the Hawkins River (Written communication with Art Palmer, 2008).

Discovered in 1979 by independent parties of cave explorers in the Mammoth Cave System, the river was named the *Hawkins River* by those who had found its downstream end in Proctor Cave, and *Logsdon River* in the upstream reaches where it was found in Morrison Cave, and later in Roppel Cave. It is possible to travel through the Logsdon River conduit for nearly 10 km before ending in a sump at the upstream and downstream sections, making it one of the longest continuously-traversable river passages in the world (Anthony, 1998; Anthony et al., 2003).

Logsdon River can be accessed through several entrances which are privately owned, or the Doyel Valley entrance which is located on National Park property. In Doyel Valley, a 20 m vertical shaft was drilled under the direction of Dr. James Quinlan in the 1980s to facilitate access to study this area of the cave. In addition, wells for water sampling and in-situ instrumentation of both Logsdon River and Hawkins River were drilled near the Doyle Valley entrance, as outlined in the discussion of Anderson (2002) in Chapter One. All cave entrances to the Mammoth Cave system, as well as the Doyel Valley wells, are gated and accessible only with a valid research or survey permit.

Bosch and White (2004) sampled stream sediments upstream from the confluence of the Logsdon and Hawkins Rivers. While samples taken from the same tributary produced very similar distribution functions, comparison of samples from both tributaries showed that the sediments being transported down the two rivers were dramatically different despite the similar hydrogeologic setting (Bosch and White, 2004). Sediments from the Logsdon River were mainly silts and fine sands, while the Hawkins River sediments were uniformly distributed over the range of silt to gravel. Bosch and White (2004) attributed these differences to a contrast in sediment derived from the Plateau and Sinkhole Plain, as well as the Hawkins River being the higher energy stream.

2.2.5 *Land Use and Agricultural Production within the Mammoth Cave Area*

Agricultural land use practice around Mammoth Cave National Park has a major impact on the biology, geology and hydrology of Mammoth Cave. More than 60,000 acres of agricultural land use impact the karst drainage of Mammoth Cave, which is designated as an International Biosphere Preserve based on its geological, biological and historical significance (Meiman, 2006). The Mammoth Cave Water Quality Program has suggested that water quality within Mammoth Cave is correlated to land use within the watersheds and the most significant contamination from non-point source pollutants occurs immediately following precipitation events when surface pollutants are quickly transported into aquifers through numerous sinking streams and dolines (Meiman, 2006).

The Cave City subbasin is approximately 25 km^2, with 2.8 km^2 of the subbasin located within the boundary of Mammoth Cave National Park (Meiman, 2006). The area that is located within the park is predominately forest; the remaining area is a combination of forest (47%); agricultural land use including cultivated crops, grass and pastures (44%); residential development (5%); open space and transitional use (2%); and commercial usage (2%) (Meiman, 2006). Approximately 18% of the land use within the

Cave City subbasin (Figure 6) is classified as row crop with residue (Meiman, 2006). This particular classification of land use includes areas characterized by herbaceous vegetation that has been planted or is intensively managed for the production of food, feed, or fiber including the production of crops, such as corn, soybeans, vegetables, tobacco, and cotton (United States Geological Survey, 2008). This agricultural land use increases the likelihood of transport of atrazine into the karst aquifer following precipitation events.

2.3 Methodology

To document patterns of atrazine transport in relation to suspended sediment flux in Logsdon River, continuous water quality monitoring and automated water sampling were conducted during storm events. Previous monitoring of storm-period hydrochemical variations in Logsdon River have demonstrated that the conduit responds with at least two distinct pulses of turbid, low-conductivity water. This pattern of two distinct pulses may represent inputs from proximal and distal surface sources, or, in the case of the turbidity variations, may reflect the initial mobilization of in-cave sediments followed by the arrival of surface-derived suspended sediment. Analysis of water samples for atrazine concentration and grain size distribution provided an indication of whether the initial pulse of suspended sediment was derived from the land surface or from in-cave sources. Quantitative dye traces were used to establish time of travel from a surface tributary point to the confluence of the Logsdon and Hawkins River, for use in interpreting the observed hydrochemical changes. In addition, storm-period variations in flow and water quality for two different flow events were related to land use and agricultural production patterns

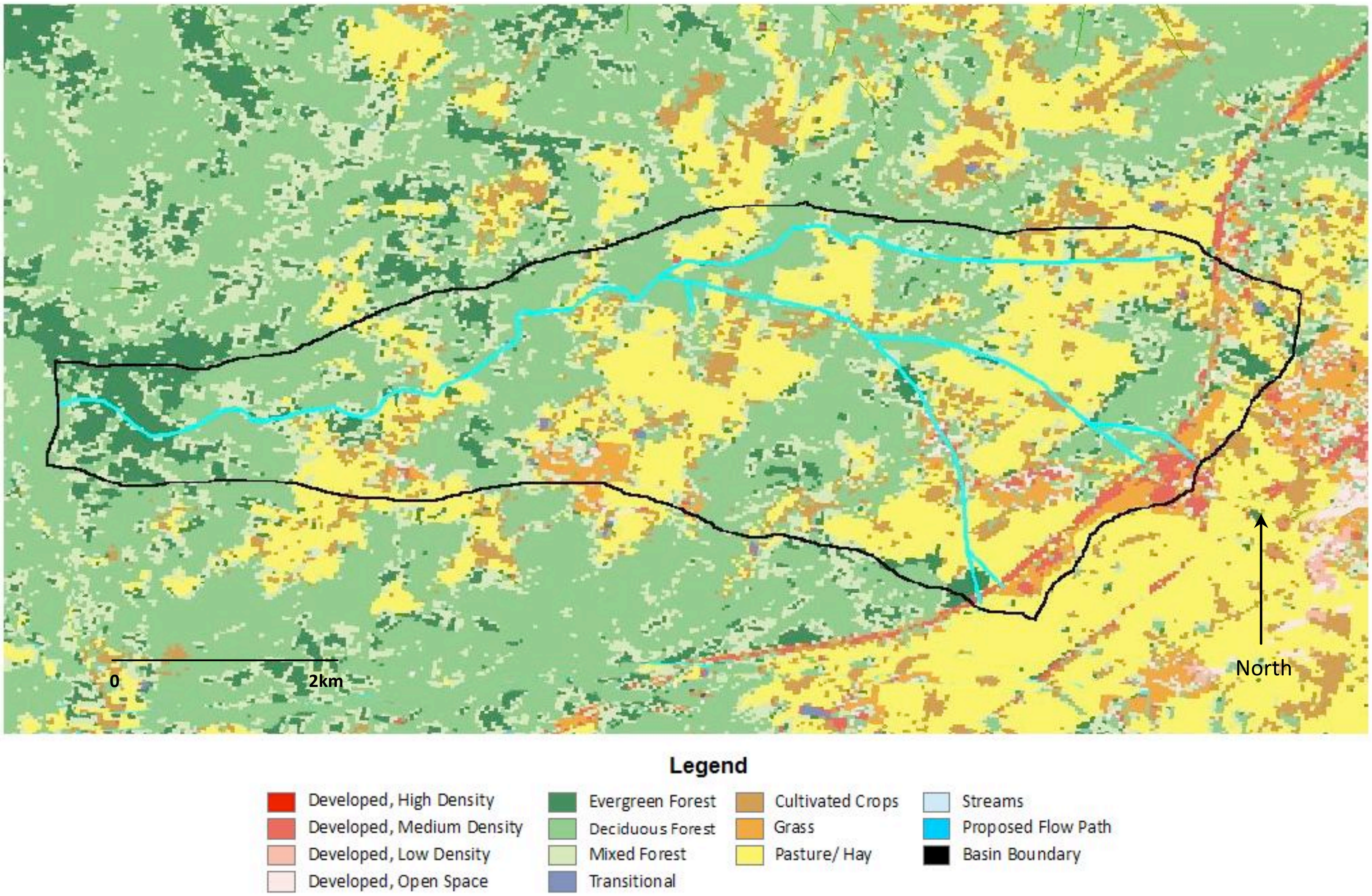

Figure 6. Land use of the Cave City subbasin and surrounding area (Based on NLCD 2001 Data).

and to differences in the timing and spatial pattern of precipitation in the Cave City subbasin.

2.3.1 *Hydrological Observations and Water Quality Parameters*

The primary source of data collected was water quality instrumentation installed in an active flow channel of Logsdon River approximately 100 m upstream from Pete Strange Falls (Figure 7). A Sontek Argonaut acoustic Doppler velocity profiler (aDcp) mounted on the river bed measured flow depth and velocity for estimation of flow rates. Water temperature, pH, specific conductance and turbidity were measured at 10 minute intervals with a Hydrolab MS5 multiparameter water quality sonde; additional sampling for total suspended solids was conducted during a select precipitation event (Table 1). Supplementary information on sediment concentrations and particle size was obtained from a Sequoia LISST 25-X laser diffraction sediment sensor. All instruments operated on battery power and were mounted to the cave passage to prevent movement during high flow conditions.

Data from the instruments was downloaded during site visits which usually occurred every two weeks. Batteries were changed at every visit, while sensors were recalibrated during monthly site visits or following large scale precipitation events that increased the transport of sediment within the conduit. The water level (stage) was recorded from a staff gage during these site visits to compare with the depth recorded by the aDcp. The depth and velocity readings were used in conjunction with measured stream flows to develop discharge estimates using an index velocity approach.

Figure 7. Instrumentation site within Logsdon River. (Photo by: Mark Tracy)

Parameter	Definition
Water Temperature	Measure of internal energy. The solubility of solids expands with increasing temperature.
pH	Indication of alkalinity and acidity in the water by expressing the degree of hydrogen ion activity in an acid or a base. Changes in pH can increase the specific conductance.
Specific Conductance (spC)	Ability of water to conduct an electrical current. Related to the type and concentration of ions in solution and can be used for approximating the dissolved solids concentration in water. Measured in microSiemens/cm (µS/cm), a unit of electrical conductance.
Turbidity	An optical property of the water related to light scattering by suspended particles. Commonly defined in terms of Nephelometric Turbidity Units (NTU). Turbidity in excess of 5 NTU is just noticeable to the average person.
Total Suspended Solids (TSS)	Indicate the amount of un-dissolved solids, including organics, derived from soils (allochtonous sediment), as well as autochthonous sediment within the stream bed.

Table 1.Water quality parameters measured in Logsdon River.

Continuous monitoring data was collected during the Spring 2008 pesticide application season and analyzed for responses to precipitation events in the Cave City sub-basin area. Data collected from rain gages located near the Cave City sub-basin was used to estimate the timing and spatial distribution of precipitation inputs to the groundwater basin. Hydrological and water quality responses to precipitation events were characterized in terms of the covariation of flow, water quality parameters and indicators of suspended sediment concentration and size. Specific characteristics of interest include the magnitude of water quality variations and the timing of peak or minimum values of water quality parameters relative to precipitation inputs and peaks in stage and flow rate. Continuous records of suspended sediment concentration and grain size were estimated from turbidity and laser diffraction data based on correlation with suspended sediment samples collected during flow events. Water quality data that have been collected since the deployment of the instrumentation at the Pete Strange Falls site (August 2005) were analyzed to establish baseline values and typical flood pulse responses for temperature, pH, specific conductance and turbidity.

2.3.2 *Water Sample Analysis*

Water samples for analysis of atrazine and suspended sediment concentration were collected by a Teledyne ISCO sampler (Figure 8) that was programmed to collect samples at 40-60 minute intervals during flow events when turbidity readings exceeded a threshold value (e.g. 100 NTU). Additional data was obtained from a surface tributary sink point near Roppel Cave at the Joe Ray Weir by a Teledyne ISCO sampler and from a pump below the 145 m well shaft that intersects the Logsdon River near the confluence

Figure 8. Retrieving samples from the ISCO Sampler (Photo by: Mark Tracy)

of the Hawkins River (Figure 9). The Teledyne ISCO sampler collected specimens in glass 350 ml bottles that were removed in order, labeled, taped shut to avoid contamination by other sources and stored on ice at 4° Celsius to avoid degradation during transit to the lab at Western Kentucky University. Samples obtained from the Logsdon River Wells were collected manually and followed the same transport protocol. Analysis of atrazine levels within a 50 ml subsample was performed by the WKU WATERS lab using the enzyme linked immunosorbent assay (ELISA) Method. Water samples obtained from the Pete Strange Falls instrument site were filtered in the lab with a .22 μ syringe filter; samples collected at the Logsdon River Wells were filtered in the field, but only values with atrazine detection levels were used; and samples from the Joe Ray Weir were not filtered. Dye trace concentrations for samples obtained from the Logsdon River Wells were analyzed by the Crawford Hydrology Lab at WKU. Sediment analysis for samples collected from the Pete Strange Falls instrument site were analyzed at the WKU Sedimentology lab with a Malvern Mastersizer 2000 optical bench and software with the Malvern Hydro 2000 dispersion unit to calculate the size of the particles within the samples. Average particle size distribution graphs were used to determine sediment characteristics during the sampled event.

2.3.3 *Precipitation Data*

Precipitation data was obtained from the National Park Service who maintains air and soil quality stations within the Mammoth Cave area (Figure 10). Precipitation data includes 5-minute and hourly totals from the Houchins Meadow gage, and hourly data from the Hamilton Valley gage. The 5-minute data were collected by a Campbell datalogger, while the hourly data were collected by an ESC, Inc. datalogger.

Figure 9. Pump intersecting the Logsdon River near the confluence of Hawkins River.
(Photo By: Dr. C. Warren Campbell)

2.3.4 *Data Analysis*

Data collected from the instrument site was analyzed to determine the factors that influence the flux of suspended sediment and atrazine during storm events. Variations in flow and water quality for two different storm events were analyzed and related to precipitation inputs and land use patterns. Rainfall inputs to the Cave City subbasin were used to evaluate the timing of the hydrologic and hydrochemical responses of the Logsdon River conduit to surface precipitation events. Results from a quantitative dye trace for one event were also used to interpret the timing of water quality variations relative to flow variations. By plotting the monitoring data on hydrographs/chemographs for each sampled storm event, the covariation among various parameters such as temperature, pH, specific conductance and turbidity are described qualitatively and related to the data from laboratory analyses of water samples for suspended sediment concentrations, grain size distributions, and atrazine levels. In addition, quantitative measures of the timing and correlation among peaks and minima of measured values (e.g. specific conductance minima are typically correlated with turbidity peaks) were developed and used to compare the responses among different storm events. These qualitative and quantitative relationships were interpreted in terms of the hydrological dynamics of the karst aquifer and conduit system and in relation to spatial patterns of rainfall and land use within the Cave City subbasin. In particular, patterns of atrazine concentration were correlated with peaks in sediment concentration and variation in sediment grain size in order to evaluate the contributions of in-cave versus surface-derived sources of sediment to the observed flux of atrazine.

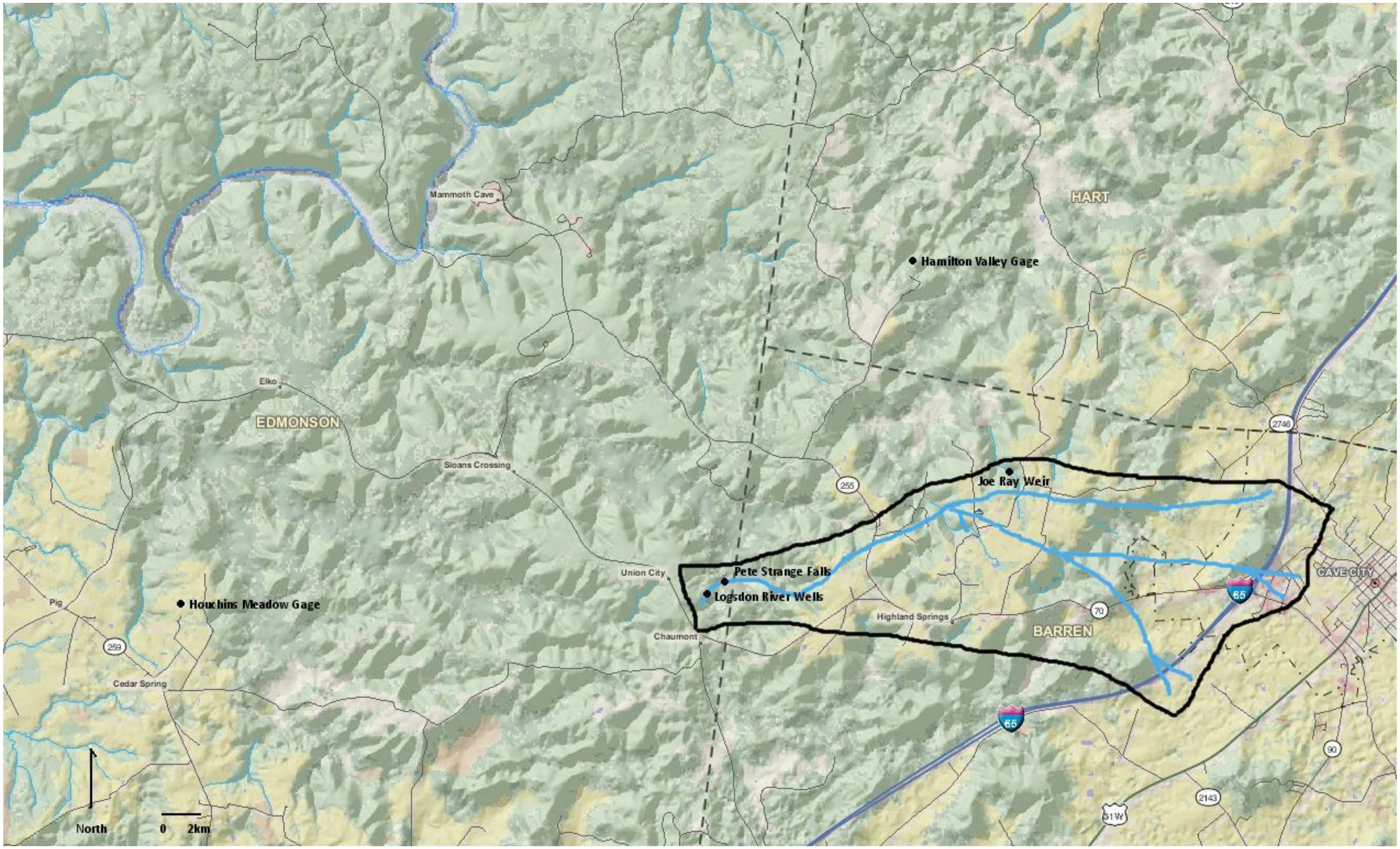

Figure 10. Location of Rain Gages, Logsdon River Wells, Pete Strange Falls Instrument Site, Joe Ray Weir and Cave City subbasin (Based on NLCD 2001 data).

CHAPTER 3

RESULTS AND DISCUSSION

3.1 Introduction

Data were acquired from two independent precipitation events occurring in the Spring of 2008 from May 2-4 (Table 2) and May 27-29 (Table 3). Data for the May 2-4 event was obtained from a surface tributary sink point near Roppel Cave at the Joe Ray Weir, from the instrument site within Logsdon River near Pete Strange Falls, and from the Logsdon River Wells near the confluence with the Hawkins River. Data obtained at the surface monitoring sites was limited to a 72 hour sampling period, while the data from the in-cave site was part of the ongoing water quality monitoring described earlier in the methodology section. Water samples were collected by a Teledyne ISCO sampler at the Joe Ray Weir sampling site (120° V-notch weir), while samples were collected manually with the pump below the 145 m Logsdon River Well. Water samples were not collected from the instrument site near Pete Strange Falls due to a wiring malfunction with the sampler. Water quality data and samples were collected during the May 27-29 event from the instrument site near Pete Strange Falls. Precipitation data for both runoff producing events was obtained from rain gages monitored by the National Park Service. Data plotted on the hydrographs, as well as the parameters of temperature, pH, specific conductance and turbidity on the chemographs represents 10 minute collection intervals, while data plotted for the dye concentrations, total suspended solids and atrazine concentrations on the chemographs represent hourly sampling intervals.

Category	Analysis	Collection Site	Raw Data
Precipitation	Input	Houchins Meadow Hamilton Valley	Appendix A
Hydrologic Response	Stage	Joe Ray Weir	Appendix B
	Stage and Flow Rate	Logsdon River: Pete Strange Falls	
	Fluorescein and Rhodamine WT Dye Trace	Logsdon River Wells	
Water Quality	Water Temperature Specific Conductance (spC) pH	Logsdon River: Pete Strange Falls	Appendix C
Sediment Analysis	Atrazine	Joe Ray Weir	Appendix D
	Atrazine and Total Suspended Solids (TSS)	Logsdon River Wells	
	Turbidity and Grain Size	Logsdon River: Pete Strange Falls	

Table 2-Data obtained during the May 2-4, 2008 precipitation event.

Category	Analysis	Collection Site	Raw Data
Precipitation	Input	Houchins Meadow Hamilton Valley	Appendix E
Hydrologic Response	Stage, Flow Rate	Logsdon River: Pete Strange Falls	Appendix F
Water Quality	Water Temperature Specific Conductance (spC) pH	Logsdon River: Pete Strange Falls	Appendix G
Sediment Analysis	Atrazine, Turbidity, Grain Size, Suspended Sediment	Logsdon River: Pete Strange Falls	Appendix H

Table 3-Data obtained during the May 27-29, 2008 precipitation event.

3.2 Joe Ray Weir and the Logsdon River: May 2-4, 2008

3.2.1 *Hydrologic Response*

Beginning on May 2, 2008 the first of three closely spaced, discrete periods of precipitation began in the Mammoth Cave area. The National Park Service recorded 59.1 mm of precipitation at the Houchins Meadow station and 59 mm of precipitation at the Hamilton Valley station from 0:00 hours on May 2 to 0:00 hours on May 4. The collective totals for each individual period of precipitation reflect a slight variation between the two stations (Figure 11). The first period of precipitation occurred on May 2 from 10:00 hours to 13:00 hours with a total of 14.9 mm recorded at the Houchins Meadow station. As the precipitation moved across the area in an easterly motion, the Hamilton Valley station recorded 7.4 mm of precipitation from 12:00 to 15:00 hours reflecting a two hour time difference in the arrival of the storm front. The second period of precipitation occurred on May 2 from 16:00 hours to 18:00 hours with 5.5 mm recorded at the Houchins Meadow station. An hour later, the Hamilton Valley station recorded 4.3 mm of precipitation from 17:00 hours to 19:00 hours. The third period of precipitation reflected greater variability between the sites related to the movement of the storm front. The Houchins Meadow station recorded 38.4 mm of precipitation from 16:00 hours on May 2 to 7:00 hours on May 3, while the Hamilton Valley station recorded 47.3 mm of precipitation from 22:00 hours on May 2 to 8:00 hours on May 3. While this third period of precipitation was more extensive at the Houchins Meadow station, the Hamilton Valley station recorded a more concentrated total.

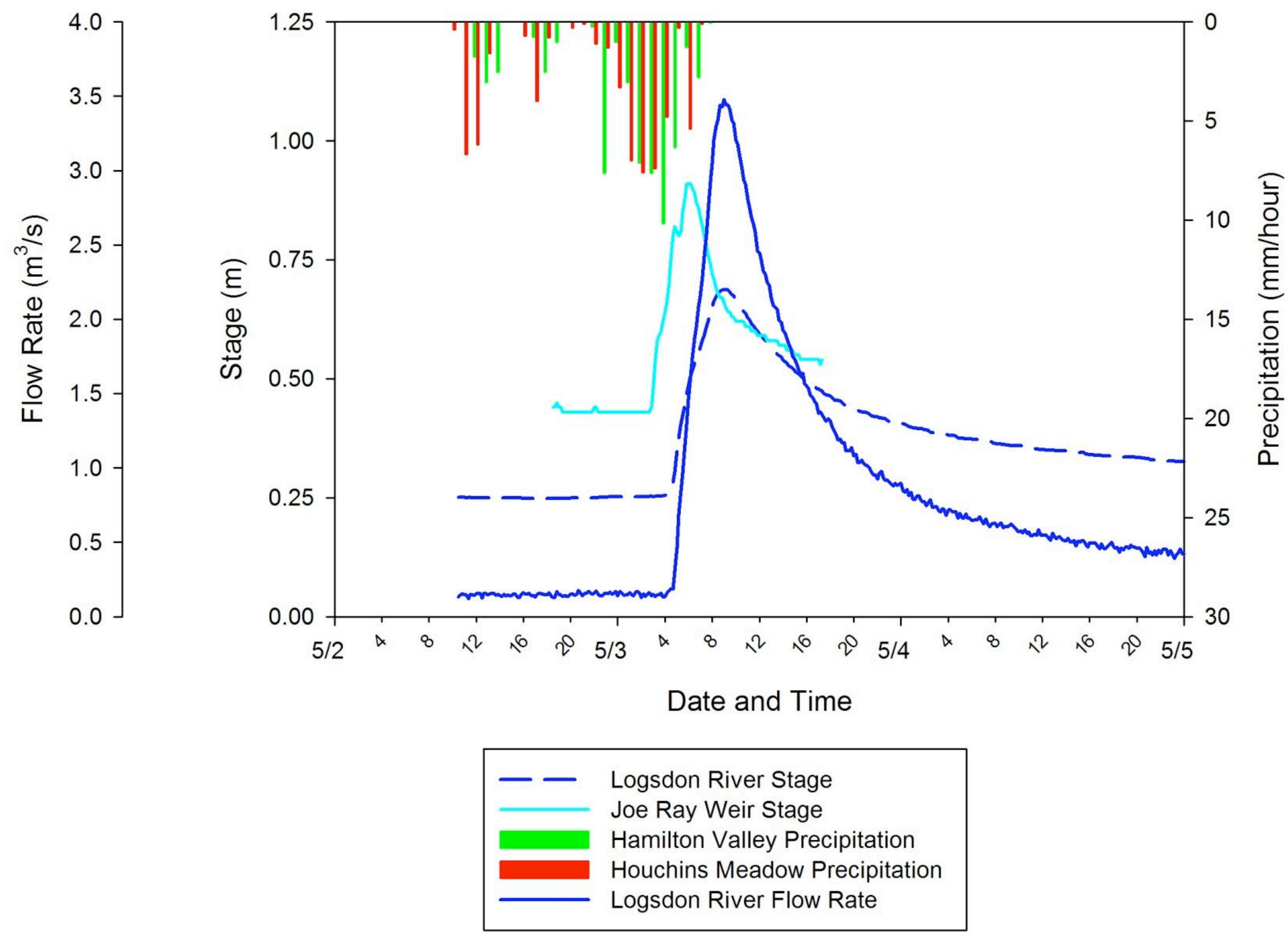

Figure 11. Precipitation, stage response and flow rate in Logsdon River and surface tributary: May 2-5, 2008.

Beginning at 3:00 hours on May 3, one hour after the centroid of the third period of precipitation, the Joe Ray Weir stage began to increase (Figure 11). The stage peaked at 0.91 m at 6:00 hours, reflecting a centroid lag-to-peak of four hours. This peak in stage at the Joe Ray Weir occurred twenty hours after the initial precipitation began; at which point the cumulative precipitation totals were 38.4 mm at the Houchins Meadow station and 56.1 mm at the Hamilton Valley station. The Logsdon River stage at the Pete Strange Falls instrument site began to rise sharply at around 4:00 hours, only an hour after the Joe Ray Weir stage increased. The Logsdon River stage peaked at 0.687 m at 9:00 hours on May 3, approximately three hours after the peak flow at the Joe Ray Weir stage and seven hours after the centroid of precipitation. A final spike of 2.8 mm of precipitation occurred at 7:00 hours on May 3, during the falling limb of the weir hydrograph. Neither stage hydrograph appears to indicate distinct increases that correspond to individual rainfall pulses, other than the rising limbs occurring during the largest discreet rainfall pulse between 0:00 and 5:00 hours on May 3. However, the stage at the Joe Ray Weir and the Logsdon River instrument site reflect the transfer of precipitation from the surface, in particular the rapid response of the Logsdon River as a conduit-flow aquifer.

The flow rate recorded at the instrument site in Logsdon River also reflects the rapid movement of precipitation through the karst aquifer. Flow rate is proportional to the product of stage and velocity; an increase in stage results in an increase in flow rate. Prior to the precipitation events, the flow rate was 0.126 m^3/s. At 3:00 hours on May 3 the stage and flow rate began to rise in unison (Figure 11). The stage peaked at 0.687 m and the flow rate peaked at 3.8 m^3/s at 9:00 hours. Both the stage and flow rate peaked seven hours after the centroid of precipitation. The hydrograph of the Logsdon River represented a rapid increase in the rising limb of the stage and flow, with a gradual falling limb for both parameters indicating the return to pre-storm conditions. As water levels in the upstream portion of Logsdon River began to rise, the increase in the hydraulic head drove water from adjacent storage causing the discharge to rise abruptly above base flow. After the peak in discharge, the water drained from the conduit at a slower rate. This rapid response and gradual recovery is consistent with other studies conducted in the Turnhole Basin including work by Hess and White (1988), Anderson (2002) as well as Raeisi et al., (2007).

Results from the dye trace also reflect the response of the Logsdon River as a conduit aquifer (Figure 12). Fluorescein dye was injected at 19:30 hours on May 2 at the Joe Ray Weir; Rhodamine WT was injected at 3:30 hours on May 3, thirty minutes after the initial stage increase at the Joe Ray Weir. Background levels of both dyes less than .01 ppb were detected in water samples obtained from the Logsdon River Wells prior to the dye injections. The first significant detection of Rhodamine WT was .036 ppb recorded at 7:00 hours on May 3, while the first Fluorescein detection was .048 ppb at 8:00 hours. Both dyes peaked strongly at 11:00 hours, with Rhodamine WT levels at 28.9 ppb and Fluorescein dye levels of 20.4 ppb. The Rhodamine WT peaked 7.5 hours after the injection while the Fluorescein peaked 15.5 hours after injection. Dye concentrations declined quickly to values near 1 ppb by 15:00 hours, with Rhodamine WT levels remaining higher than Fluorescein, except for samples with similar concentrations collected at 12:00 hours (Figure 12). Dye concentrations decreased more gradually after 15:00 hours, with Rhodamine WT values falling below Fluorescein levels and decreasing more rapidly. By the end of sampling on May 5, Rhodamine WT had decreased to 0.081

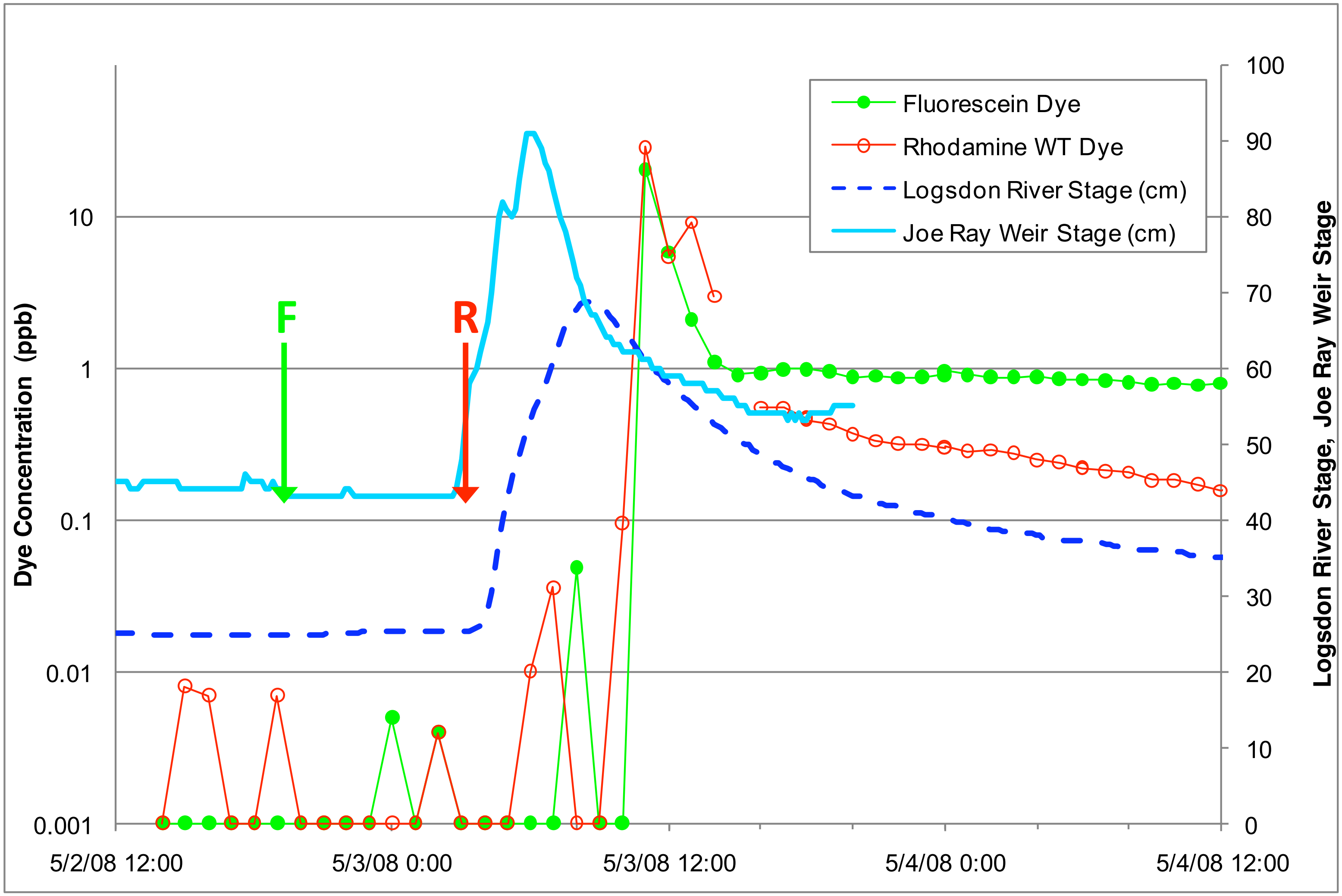

Figure 12. Results of Logsdon River dye trace: May 2-4, 2008.

ppb, whereas Fluorescein concentration was more than 7 times higher at 0.607 ppb. The differences in travel time are related to the different injection times relative to the storm runoff, but may also be affected by flow hydraulics and the passage morphology such as rimstone dams that retain pools of water under normal flow conditions and mobilize the water under high flow events. Thus, the Fluorescein dye may have been caught in the rimstone pools until the discharge rose above base flow.

3.2.2 *Water Quality*

Prior to the precipitation event, the water temperature in Logsdon River was 13.35° Celsius (Figure 13). As relatively cold water passed through the conduit the water temperature began to decline at 5:40 hours on May 3, approximately 2.5 hours after the stage began increasing at the instrument site. Over the next hour, the water temperature decreased to 13.01° Celsius as the stage rose. The water temperature began to increase at 6:50 hours on May 3 however this increase lasted less than an hour before the water temperature began to decline again at 7:40 hours. This secondary decline was larger and more persistent than the initial temperature drop, reaching a low value of 12.78° Celsius at 8:30 hours, just before the peak in stage. Water temperature then increased, with minor fluctuations, over the next six hours before stabilizing around 13.3° Celsius as the flow receded toward base flow conditions. The various changes in water temperature reflect the arrival of the cold meteoric precipitation from the surface, and are closely correlated with similar variations in other water quality parameters.

At 5:30 on May 3, 1.5 hours after the Logsdon River stage began to rise, the specific conductance (spC) began to decrease (Figure 13). SpC decreased from 308 μS to

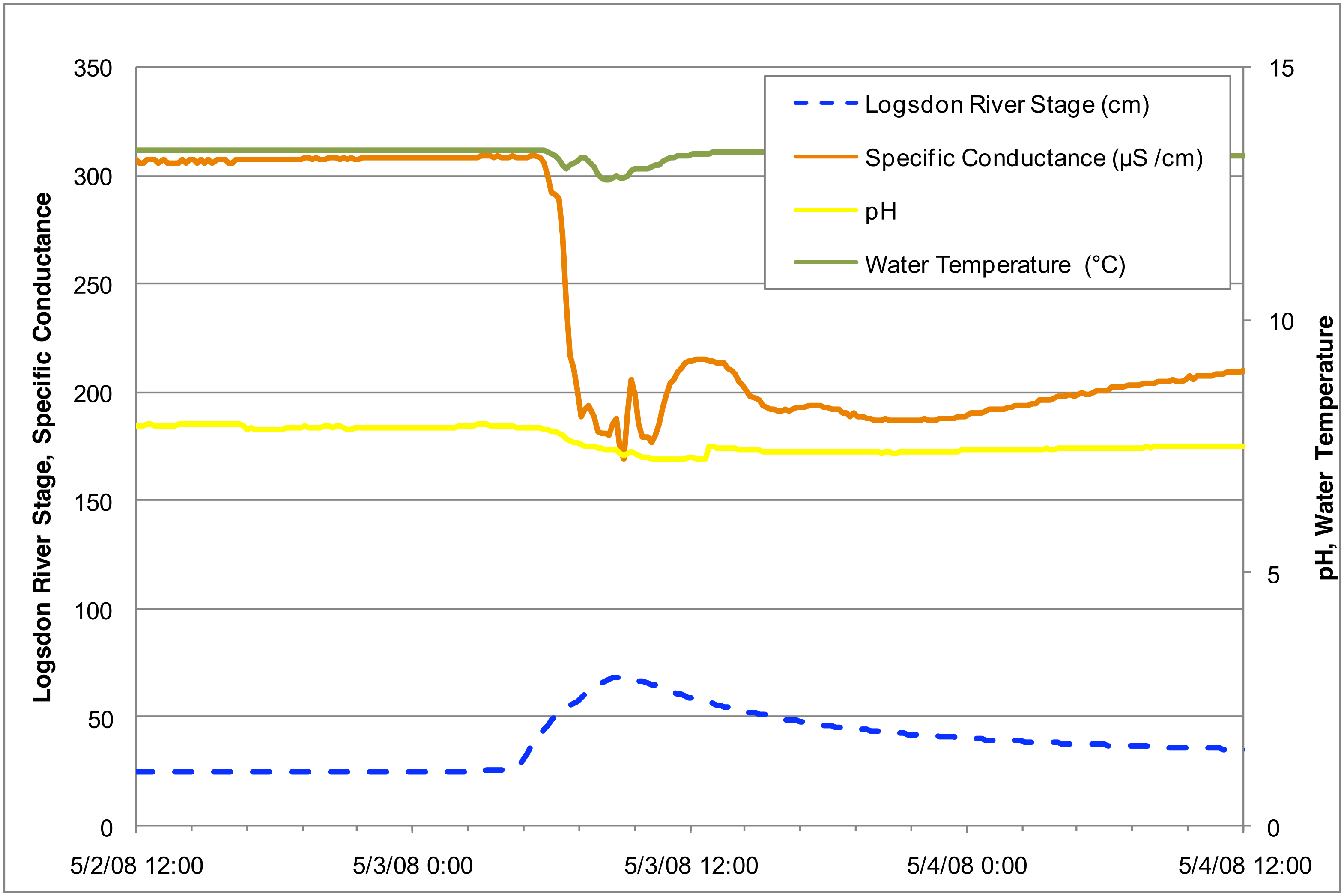

Figure 13. Stage, specific conductance, pH and water temperature in Logsdon River: May 2-4, 2008.

189 µS at 7:20 hours, followed by a more gradual and variable decrease to a low of 169 µS at 9:10 hours. This spC minimum was essentially coincident with the peak of the flow hydrograph. During the early part of the falling limb, spC rose above 200 µS briefly and then quickly dropped back below 180 µS before recovering to values between 210 and 215 µS. SpC remained in this narrow range from 11:40 to 13:40 before beginning a gradual decline over six hours to values of 187 µS, which remained steady from 20:00 to 22:40 hours. Following this broad minimum, spC increased very slowly over a period of several days. Thus the generalized storm-period spC response consists of a rapid decrease of over 100 µS associated with the ~6 hour period of highest flows and a ~2 hour period of somewhat higher, relatively stable values, followed by a second, much more gradual decrease and recovery in spC to levels near pre-storm values. Both the initial drop in spC associated with the discharge peak, and the more gentle secondary dip occurring on the falling limb exhibit lower magnitude, higher frequency fluctuations in spC. These variations in spC are strongly correlated with similar fluctuations in turbidity and suspended sediment concentration, and reflect the flushing of distinct pulses of storm water through the karst drainage system, similar to the models proposed by Hess and White (1988), Anderson (2002) and Raeisi et al., (2007).

Although more gradual, changes in the pH were mostly concurrent with changes in spC (Figure 13). The pH declined in sync with the spC from 7.85 at 5:30 hours to 7.24 at 10:30 hours on May 3. The pH values remained in this low pattern until 12:50 hours on May 3, when the pH had a sudden increase and the spC began the secondary decline and gradual recovery. Following this abrupt pH increase from 7.25 to 7.48 over 10 minutes, the pH levels decreased again in concert with the falling spC values. After leveling off at around 7.37, pH began to recover toward higher pre-event values at 21:00 hours, mirroring the recovery of spC values that began around the same time. The general pH response is thus very similar to the pattern of spC changes, with the exception of the rapid increase in pH at 12:50 hours. Although this rapid change could be attributed to a sensor malfunction in the Hydrolab, the general correspondence in pH and spC variations is consistent with the movement of storm water that has a higher acidity and lower ionic strength than the existing cave water.

3.2.3 *Sediment Analysis*

Only 1.5 hours after the Logsdon River stage began to rise, the turbidity levels increased with four discrete peaks that occurred earlier in the hydrograph and two smaller peaks on the falling limb (Figure 14). The turbidity increased to 23.7 NTU at 5:30 hours followed by additional rises of 34.4 NTU at 6:00 hours and 172.5 NTU at 6:50 hours. The largest peak of 445 NTU occurred less than an hour later at 7:40 hours preceding the peak in stage by ~1 hour. These turbidity increases correlate with the spC minima, water temperature variations and the rising limb of the hydrograph. The turbidity remained elevated until the initial part of the falling limb in which the values dropped to 182 NTU, before recovering for a peak of 223 NTU at 9:50 hours. The turbidity continued to decline on the falling limb of the hydrograph, with a ~2 hour peak later on the falling limb. Thus the generalized turbidity pattern consists of a rapid increase over the first ~2.5 hours of high flows and decreased spC and a ~2 hour period of decreased turbidity that correlate to increases in the spC, followed by a set of peaks on the falling limb that are much more gradual but correlate with the second spC minimum. The fluctuations in

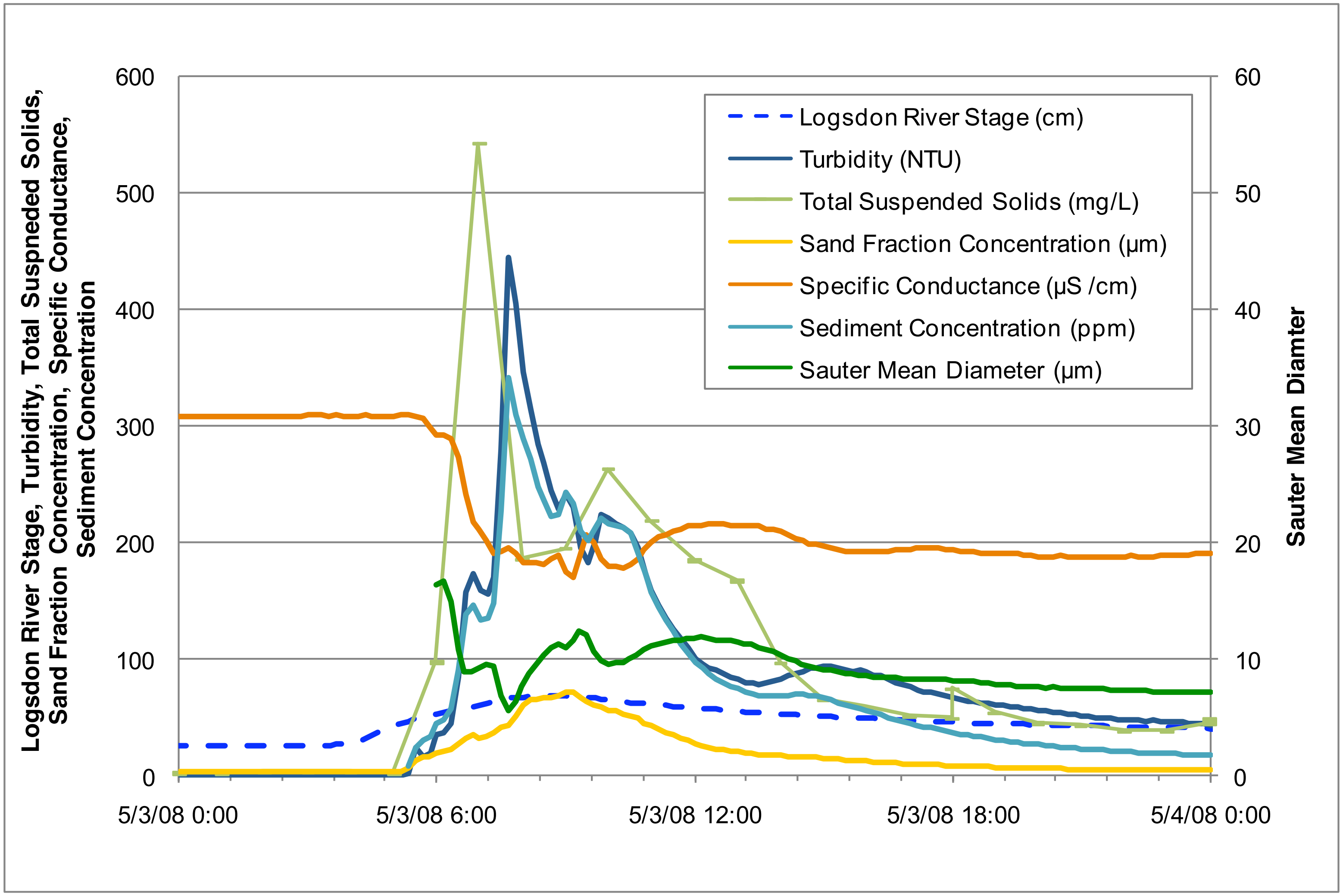

Figure 14. Sediment characteristics in Logsdon River: May 3-4, 2008.

turbidity and spC on the falling limb continue to stay correlated as pulses of storm water pass through the karst drainage system.

The LISST suspended sediment concentration signal essentially mirrors the measured variations in turbidity, although the turbidity sensor is more highly sensitive to the concentration of very fine material. Thus the LISST provides a more reliable estimate of total sediment concentration and also yields information on the proportion of coarse material in suspension. Measurements of the sand fraction (> 63 μm) concentration from the LISST instrument at the Pete Strange Falls site increased on the rising limb of the stage, and peaked during the maximum stage and flow rate (Figure 14). Sauter Mean Diameter (SMD) decreased from 16.3 μm to 5.3 μm at 7:40 hours on the rising limb of the stage as sediment concentrations increased. Grain size increased to 12.44 μm by 9:20 hours, decreased again to 9.6 μm as the sediment concentration peaked at 9:50 hours, and then increased to around 11.75 μm by 12:00 hours. The minima in SMD corresponded to maxima in sediment concentration during this initial period (6:00-12:00 hours) of low spC and high turbidity. After 12:00 hours, SMD decreased progressively to just above 7 μm. SMD values below 20 μm, and the pattern of SMD minima corresponding to peaks in the turbidity and sediment concentration suggests that the sediment in suspension was predominantly in the silt and clay size range (<63 μm), and that the discrete peaks in concentration were associated with pulses of dilute (low spC) water carrying allochthonous sediment washed in from the surface. In contrast, the concentration of coarse particles (> 63 μm) peaked immediately after the stage peaked (1.5 hours after the maximum turbidity peak) and gradually declined thereafter. This strong correlation between flow rate and the concentration of sand in suspension suggests that these coarser sediments were mobilized from within the cave and that concentrations were limited by flow hydraulics and the available supply of sands in the river.

Total suspended solids (TSS) are an indicator of water quality that refers to the suspension of small particles due to the motion of water. TSS was measured in samples collected at the downstream Logsdon River Wells site, while the turbidity values were recorded upstream at the Pete Strange Falls instrument site. Both the TSS and turbidity began to increase on the rising limb of the stage (Figure 14). Within 30 minutes of the first noticeable turbidity reading of 23.7 NTU the TSS began a rapid increase to 97.2 mg/L and reached a maximum of 541.7 mg/ L at 7:00 hours. This major TSS peak occurred just after an upstream turbidity peak at 6:50 hours but preceded the turbidity maximum that occurred at 7:40 hours at Pete Strange Falls. A second TSS peak of 262.5 mg/L occurred at 10:00 hours on May 3, nearly synchronous with an upstream turbidity peak of 223 NTU. Much later, another small TSS increase to 61.6 mg/L occurred at 18:00 hours, three hours after the secondary turbidity peak recorded at the Pete Strange Falls instrument site on the falling limb of the hydrograph. Although the general pattern of TSS variation in samples collected at the Logsdon Wells is consistent with the turbidity and suspended sediment concentration data from the Pete Strange Falls site, the differences in the timing of TSS peaks and similar turbidity peaks could reflect several factors. Because of the distance between the two stations (about 1 km), a delay between corresponding water quality variations is expected. However, the hourly sampling frequency at the Logsdon Wells (versus 10 minute observations at the upstream site), and the associated potential for sampling errors, field contamination of 250 ml TSS samples, or laboratory errors may account for some of the differences between the data records. It is also possible that the large TSS maximum at 7:00 hours that preceded the upstream turbidity maximum reflects a transient input or mobilization of fine sediment downstream of Pete Strange Falls, or possibly the influence of back-flooding from Hawkins River during the rising limb.

3.2.4 *Atrazine and Sediment*

Water sample analysis from the surface tributary at the Joe Ray Weir exhibits multiple peaks in atrazine levels, reflecting the mobilization of atrazine during the runoff producing precipitation event (Figure 15). The first detection of atrazine was 14.4 ppb and correlated with the peak stage at the Joe Ray Weir on May 3; this detection also occurred only two hours after the third and largest period of precipitation at Hamilton Valley. Atrazine levels continued to increase on the falling limb of the stage, with a brief increase to levels >50 ppb, followed by a decrease to 21.2 ppb at 10:00 hours and a return to levels of 50 ppb detected in the next two samples. Levels of atrazine fell to 24.4 ppb at 13:00 hours and then decreased gradually over the rest of the sampling period, with all but one sample >15 ppb. Thus atrazine levels remained consistently elevated, with the lowest detection level of 12.4 ppb occurring near the end of the sampling period. All of the recorded levels of atrazine from this surface tributary exceeded the USEPA's maximum contaminant level of 3 ppb.

Water quality variations between the Pete Strange Falls instrument site and the Logsdon River Wells are offset by a travel time related to the flow rate (Figures 15, 16). During the initial turbidity peak and decline in the spC upstream at the Pete Strange Falls instrument site, the concentration of atrazine in water samples collected at the Logsdon

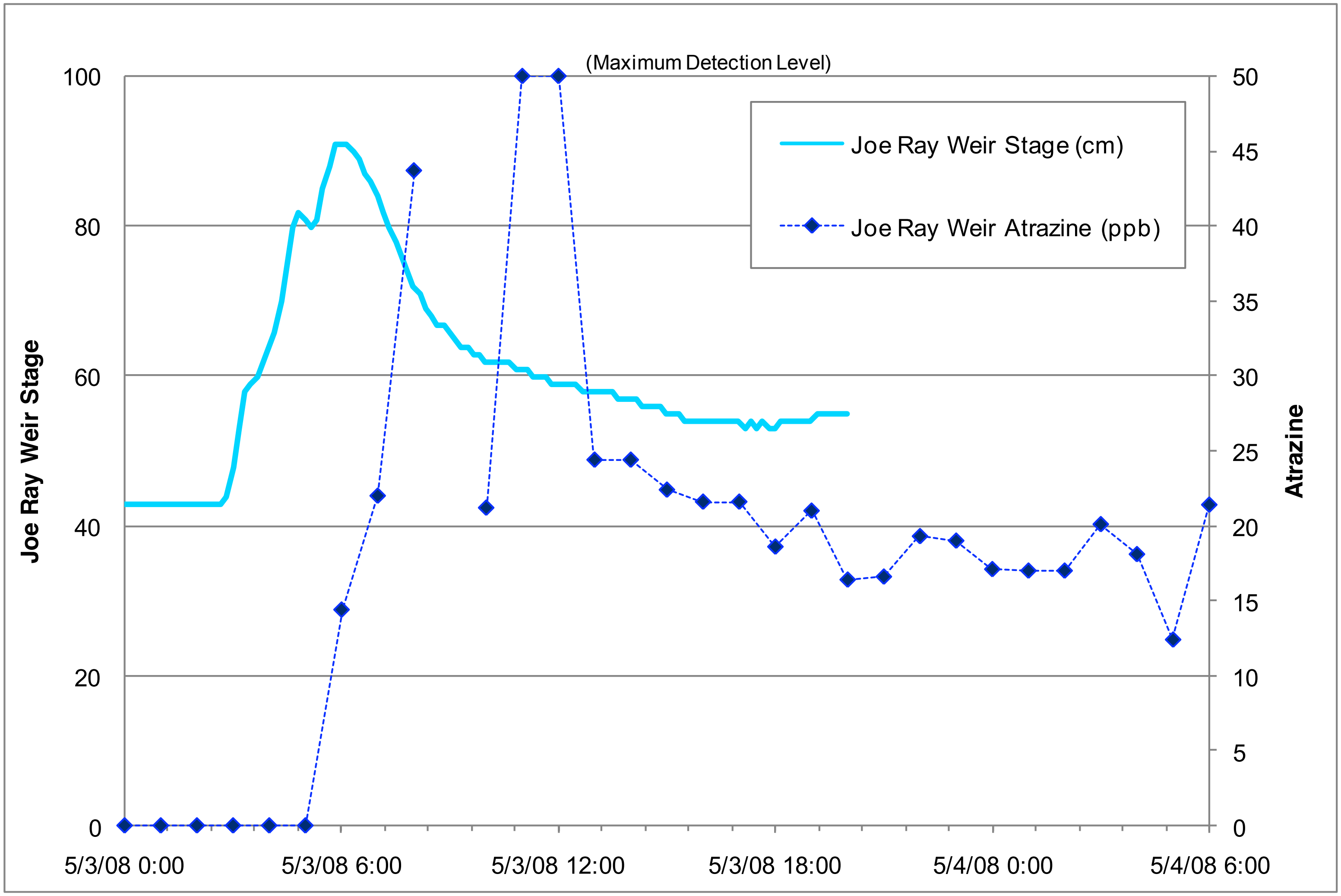

Figure 15. Atrazine levels detected at surface tributary of Logsdon River: May 3-4, 2008.

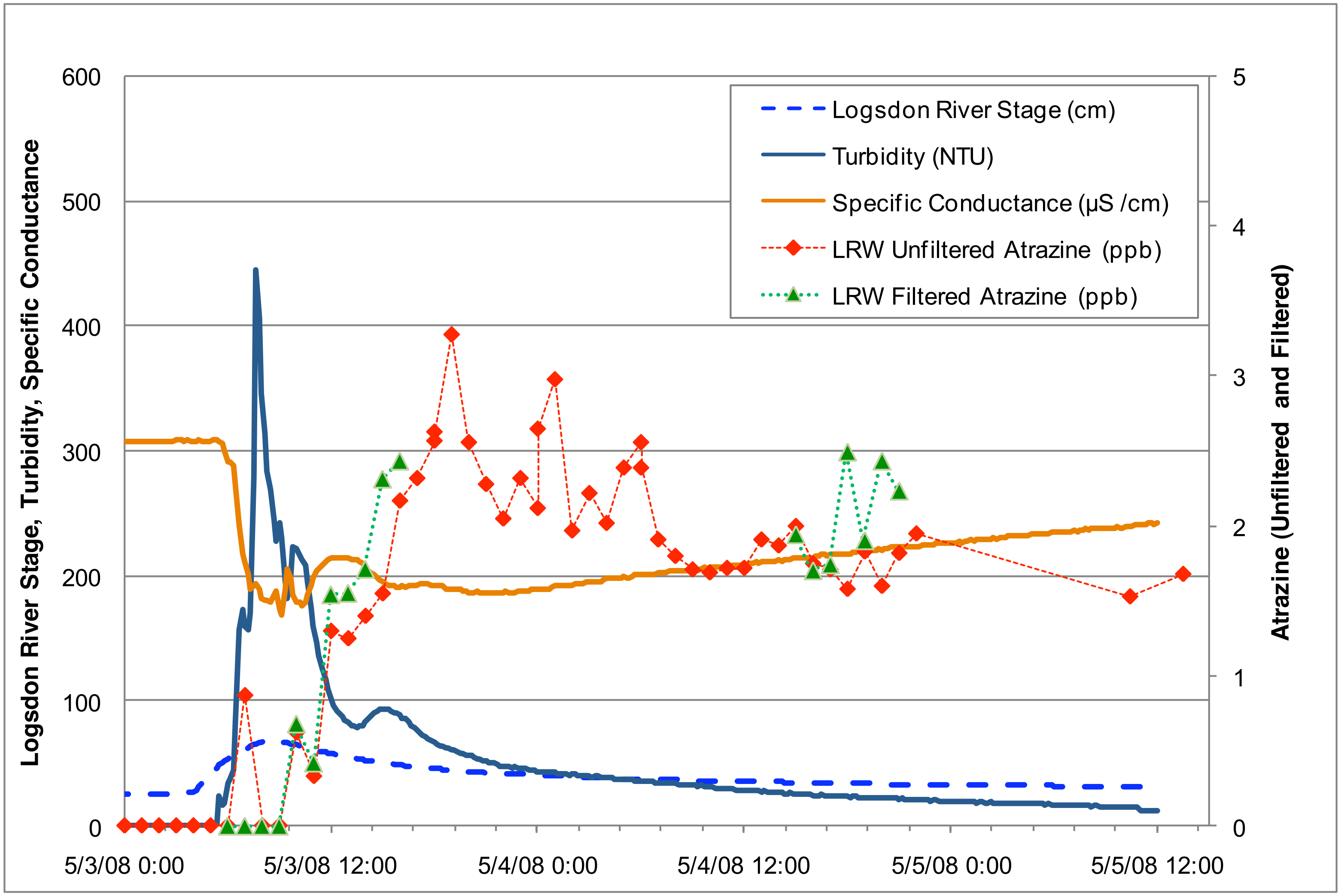

Figure 16. Atrazine levels, specific conductance and turbidity in Logsdon River: May 3-5, 2008.

River Wells began to increase (Figure 16). The first detection of atrazine was 0.87 ppb and occurred on the rising limb of the stage as the spC decreased. For the next two hours no atrazine was detected as the spC reached a sustained low and the turbidity peaked. The atrazine levels began to rise at 10:00 hours, which correlate with another peak in turbidity and spC minima. However, levels of atrazine continued to rise over the next 9 hours to a maximum of 3.28 ppb, while the turbidity and spC recovered partially before beginning the final, secondary fluctuations in these variables at 13:30 hours. This sustained increase in atrazine to levels above 2 ppb was thus roughly coincident with the arrival of the secondary peak in suspended sediment on the falling limb. Atrazine levels varied between 2 and 3 ppb for the remainder of the sampling period, as the turbidity and spC gradually recovered toward pre-storm values. Among the 62 samples analyzed for atrazine, only one of the samples exceeded the USEPA's maximum contaminant level of 3 ppb; however 25 samples exceeded the USEPA's aquatic life criterion of 1.8 µg/ L.

Several field-filtered atrazine samples were also collected to compare to the unfiltered samples (Figure 16). Filtered atrazine levels tended to be somewhat higher than unfiltered samples, suggesting that cross-contamination of successive samples from the filtering syringe may have occurred.

Although analysis of atrazine samples during Anderson's study (2002) suggested strong adsorption, the storm period covariation of sediment surrogates (turbidity and LISST data) with atrazine levels do not suggest that atrazine varies proportionally with sediment concentration. In addition, the small differences between the filtered and unfiltered samples do not reflect strong adsorption, although cross-contamination may have affected the filtered sample data. Thus, the observed relation between atrazine levels and suspended sediment concentrations is likely determined by some other factors, possibly related to the material characteristics of the sediment, or to how the pattern of surface sources of atrazine is related to the pattern of precipitation, recharge and travel times to the monitoring points.

3.3 Logsdon River: May 27-29, 2008

3.3.1 *Hydrologic Response*

An additional precipitation event occurred later in the month when two closely spaced periods of precipitation began on May 27, 2008. The National Park Service recorded 24.6 mm of precipitation at the Houchins Meadow station and 26.3 mm of precipitation at the Hamilton Valley station from 0:00 hours on May 27 to 12:00 hours on May 29 (Figure 17). While the cumulative totals were nearly identical, an analysis of the temporal patterns reflects the differences. The Houchins Meadow station received only 13.9 mm from 15:00 to 20:00 hours on May 27, while the Hamilton Valley station received 23.4 mm from 18:00 to 21:00 hours on the same day. The storm at the Houchins Meadow station was twice as long in duration, but the Hamilton Valley station received almost twice the volume of precipitation. Differences in the cumulative totals were also evident for the second period of precipitation. The station at Houchins Meadow recorded an additional 10.7 mm of precipitation from 4:00 to 8:00 hours on May 28 compared to the Hamilton Valley station which only recorded an additional 1.5 mm of precipitation from 5:00 to 7:00 hours on the same day. This individual period of precipitation recorded at the Houchins Meadow station was seven times the amount of precipitation recorded at the Hamilton Valley station. However, based on the hydrologic response of Logsdon

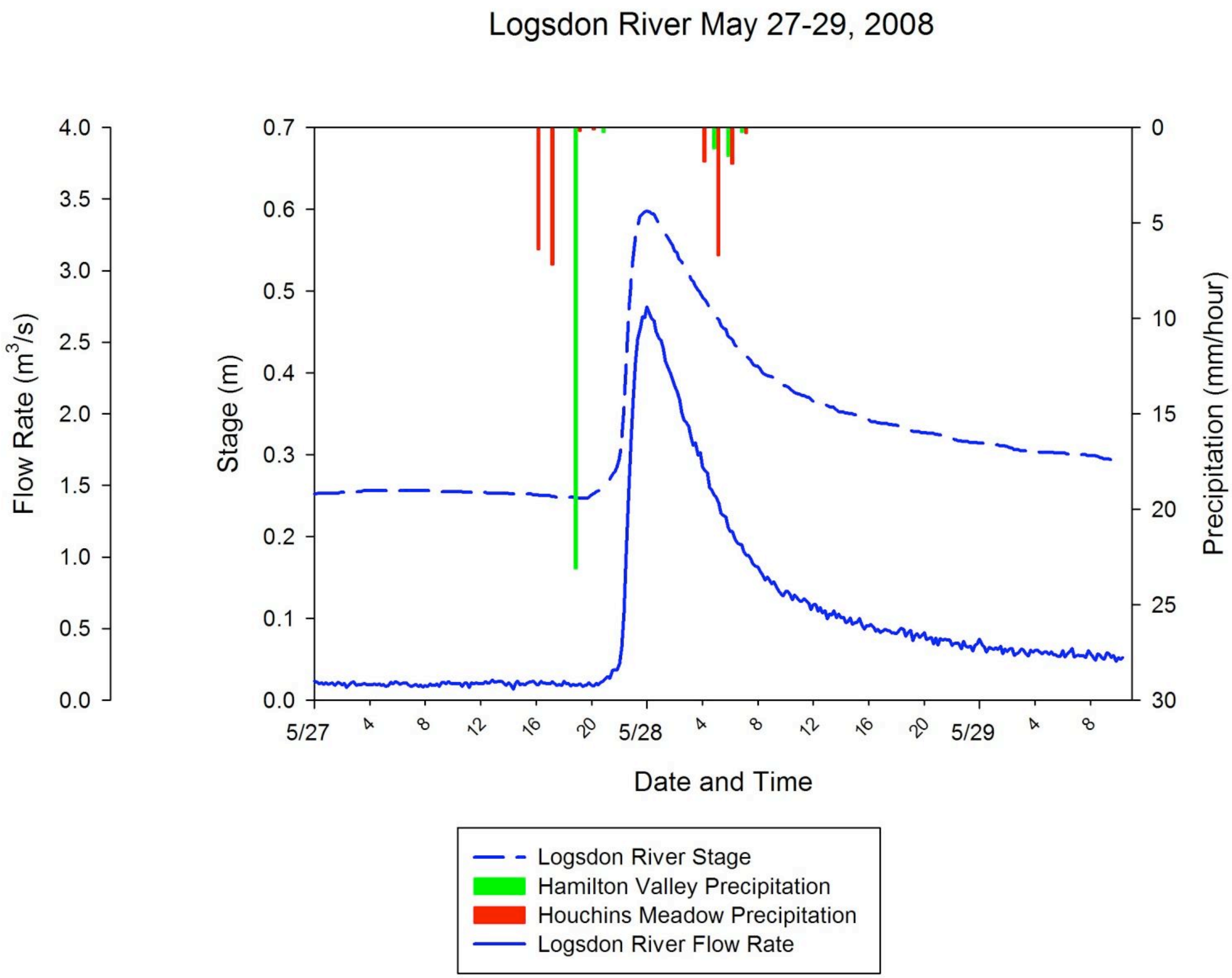

Figure 17. Precipitation, stage response and flow rate in Logsdon River and surface tributary: May 27-29, 2008.

River, the precipitation measured at the Hamilton Valley station is likely closer to representing the input of precipitation to the Cave City subbasin.

The disproportionate rainfall from the first period of precipitation recorded at the Hamilton Valley station created a flashy response in stage and flow rate within the Logsdon River conduit (Figure 17). Within an hour of the first period of precipitation that occurred at 19:00 hours on May 27, the rising limbs of the stage and flow rate began a steep climb. Prior to the rainfall, the stage was averaging 0.253 m and the flow rate was averaging 0.11 m^3/s. Only four hours after they began to rise, the stage peaked at 0.598 m and the flow rate peaked at 2.75 m^3/s. Both the stage and flow rate had a centroid lag-to-peak of 5.5 hours. Water levels in the Logsdon River had a rapid response to the first precipitation event that created a very steep increase in the discharge. The falling limbs of the stage and flow rate were more gradual and did not exhibit any distinct fluctuations related to the second period of precipitation. While this rapid response and gradual recovery is typical in Logsdon River, the steep incline of the rising limb differentiates this period of precipitation from the previous event.

3.3.2 *Water Quality*

The second precipitation event (May 27-29) was later in the spring season, thus the average temperature of the water in Logsdon River was warmer at 13.48° Celsius (Figure 18). Unlike the precipitation event earlier in the month, the water temperature did not decline for a prolonged period when the stage increased. Instead the water temperature began to increase on May 27, less than 2.5 hours after the stage and flow rate increased. The water temperature peaked at 14.59° Celsius, which was sustained for an

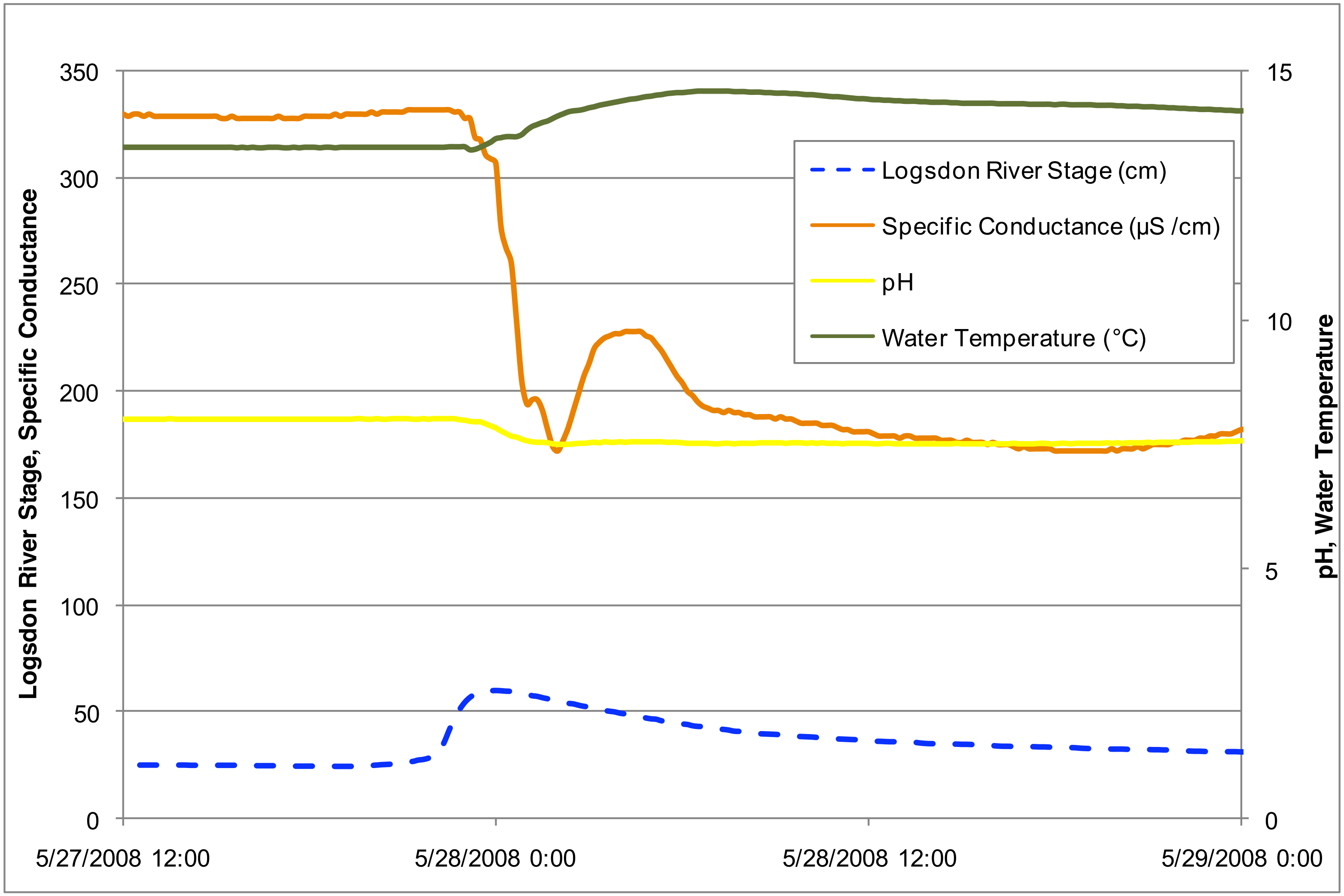

Figure 18. Stage, specific conductance, pH and water temperature in Logsdon River: May 27-29, 2008.

hour from 6:30 to 7:30 hours on May 28 on the falling limb of the stage and flow rate. After the water temperature peaked, it declined rather slowly with no increase in response to the second period of precipitation.

At 23:00 hours on May 27, 3 hours after the stage and flow rate of Logsdon River began to rise, the spC began to decline (Figure 18). The spC decreased from 330 μS to a low of 194 μS by 1:00 hours on May 28. The spC decrease was concurrent with the peak of the flow hydrograph. After falling to the first minima, the spC rose very briefly to 196 μS, but continued to decline to 172 μS at 2:00 hours indicating a second pulse of water from a distinct source. Following the two initial rapid decreases, spC began to rise again to a sustained value around 228 μS that lasted more than four hours reflecting a partial recovery from the initial dilute water pulses. Following these narrow minima, spC decreased again for a more sustained period occurring from 4:50 hours to 20:00 hours on May 28 before eventually recovering. Thus this generalized storm-period spC response consists of a rapid decrease of over 100 μS associated with the ~3 hour period following the flow peak and a ~3.5 hour period of somewhat higher, relatively stable values, followed by a second, much more gradual decrease of ~15 hours with an eventual recovery in spC to levels near pre-storm values. As with the early May event, these variations in spC are strongly correlated with similar fluctuations in turbidity and suspended sediment concentration, and reflect the arrival of distinct pulses of storm water through the karst drainage system, similar to the models proposed by Hess and White (1988), Anderson (2002) and Raeisi et al. (2007).

Changes in pH were again very gradual, but roughly concurrent with the initial decrease in spC (Figure 18). As the spC began to decline, the pH also decreased from

8.03 at 22:40 hours on May 27 to 7.53 at 2:00 hours on May 28. The pH values remained in the range of 7.53 to 7.58, with a minor decrease from 6:10 to 8:20 hours on May 28 that correlated with the secondary spC drop. As the spC began to recover, pH levels began to increase, reaching a maximum value of 7.69 at the end of the sampling. The pH response occurred on the falling limb of the flow hydrograph and consisted of a ~20 hour period of lower values associated with the arrival of storm water that increased the acidity of the cave water.

3.3.3 *Sediment Analysis*

Turbidity levels for the May 27-29 precipitation event did not begin to rise until almost three hours after the Logsdon River stage began to rise. The turbidity levels increased with two discrete peaks and a smaller secondary peak which all occurred on the falling limb of the hydrograph (Figure 19). The turbidity increased to 12.1 NTU at 22:50 hours on May 27, preceding the initial decrease in spC by 10 minutes. The turbidity continued to increase over the next two hours until the first peak of 472 NTU occurred at 1:00 hours on May 28 which correlates with the first spC minima. The turbidity values dropped briefly during the first spC increase, but peaked an hour later at 527 NTU concurrent with the lowest spC value. Over the next ~5 hours the turbidity declined during the recovery of the spC as the dilute water pulse moved through the conduit. The final turbidity peak of 262 NTU at 6:50 hours on May 28 occurred as the spC decreased rapidly again toward the sustained secondary minimum. Following this final peak, the turbidity values continued to decline over the remainder of the falling limb.

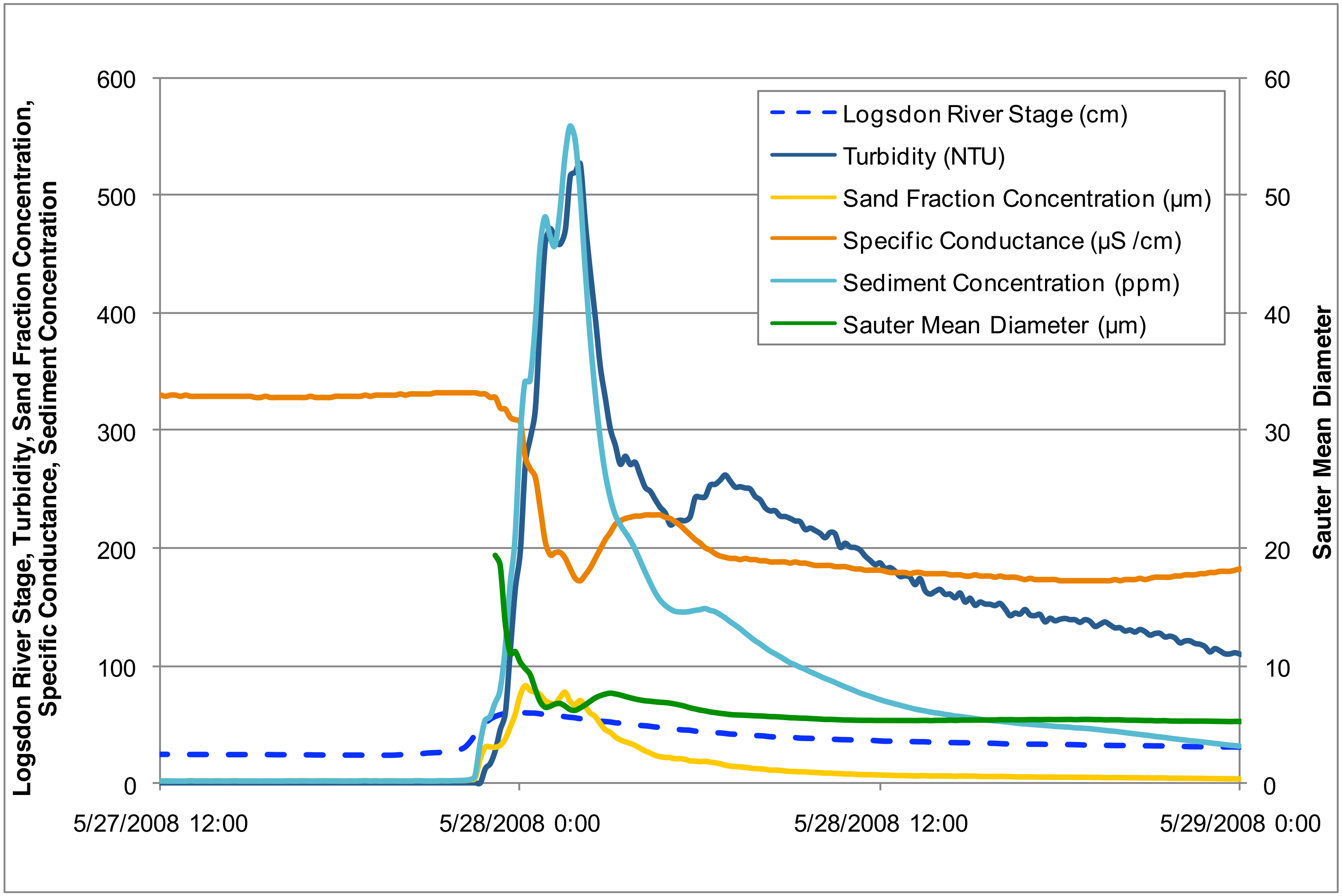

Figure 19. Sediment characteristics in Logsdon River: May 27-29, 2008.

Suspended sediment concentration varied synchronously with turbidity, as for the May 2-4 event (Figure 19). Based on the coarse fraction concentration from the LISST instrument signal at the Pete Strange Falls site, the largest peak in the sand fraction occurs prior to the initial turbidity peaks (Figure 19). An initial peak of 21.4 µm occurs at 22:40 hours, followed by gradual increases with the largest peak of 82.7 µm occurring at 0:10 hours on May 28. Following a decrease in the sand fraction, two additional peaks occur that correlate with the maximum turbidity signals. The minima in grain size (SMD) correspond initially to the peaks in sediment concentration and turbidity as well as the decreases in spC. The SMD began to decrease rapidly from 19.3 µm as the turbidity and sediment concentration increased and the spC decreased. During the initial peaks in turbidity and sediment concentration, the SMD had values of 6.5 µm and 6.2 µm. The SMD increased to 7.1 µm as the spC began a sustained period of recovery. During the final peak in turbidity and sediment concentration, the SMD was averaging 6 µm with a final peak of 7.7 µm occurring at 3:00 hours in between the two distinct turbidity peaks. The pattern of initial correspondence between the SMD, sediment concentration and turbidity is consistent with the predominantly silt and clay range (<63 µm) particles in suspension. However, additional peaks in the sand fraction occur on the falling limb of the stage immediately before and after the largest peak in turbidity. These peaks in the concentration of coarse particles on the falling limb of the hydrograph during the period of maximum turbidity levels and spC minima suggest that some of these coarser sediments may have been mobilized from the surface along with finer material, and that concentrations were influenced both by flow hydraulics within the cave and by the timing of inputs from the surface. Correlations between the turbidity and sediment concentration increases and spC variations strongly suggest pulses of water that carried allochthonous sediment from distinct surface points.

3.3.4 *Atrazine and Sediment*

Small but detectable levels of atrazine measured in both filtered and unfiltered samples from the Pete Strange Falls instrument site occurred as the turbidity values began to increase, indicating that the atrazine arrives with the initial increase in turbidity (Figure 20). The first three sets of atrazine samples had successively larger values as the turbidity increased and the spC decreased. Laboratory analyses of suspended sediment concentrations in the samples showed elevated values (619 and 417 ppm) relative to turbidity readings for the first two samples, possibly due to accumulated solids inside the pump tubing that were mobilized at the beginning of sampling, and to a higher proportion of coarse particles in suspension. During the initial turbidity peak and decrease in spC at 1:10 hours on May 28, the atrazine levels were 1.67 ppb for the unfiltered sample and 1.9 ppb for the filtered sample, while the suspended sediment concentration was 294 mg/ L. As the turbidity values reached the highest peak and the spC was at the lowest value, the unfiltered atrazine sample only increased to 1.71 ppb, while the suspended sediment concentration increased to 448 mg/ L. During this level of maximum turbidity and minimum spC, the value for the filtered atrazine sample declined to 1.87 ppb. This pattern of a slight increase in the unfiltered atrazine level and a slight decrease in the filtered atrazine level continued for the next sample as the turbidity began to decline and the spC entered a sustained recovery. Levels of atrazine in the filtered and unfiltered samples continued to rise through the secondary drop in spC and turbidity peak until

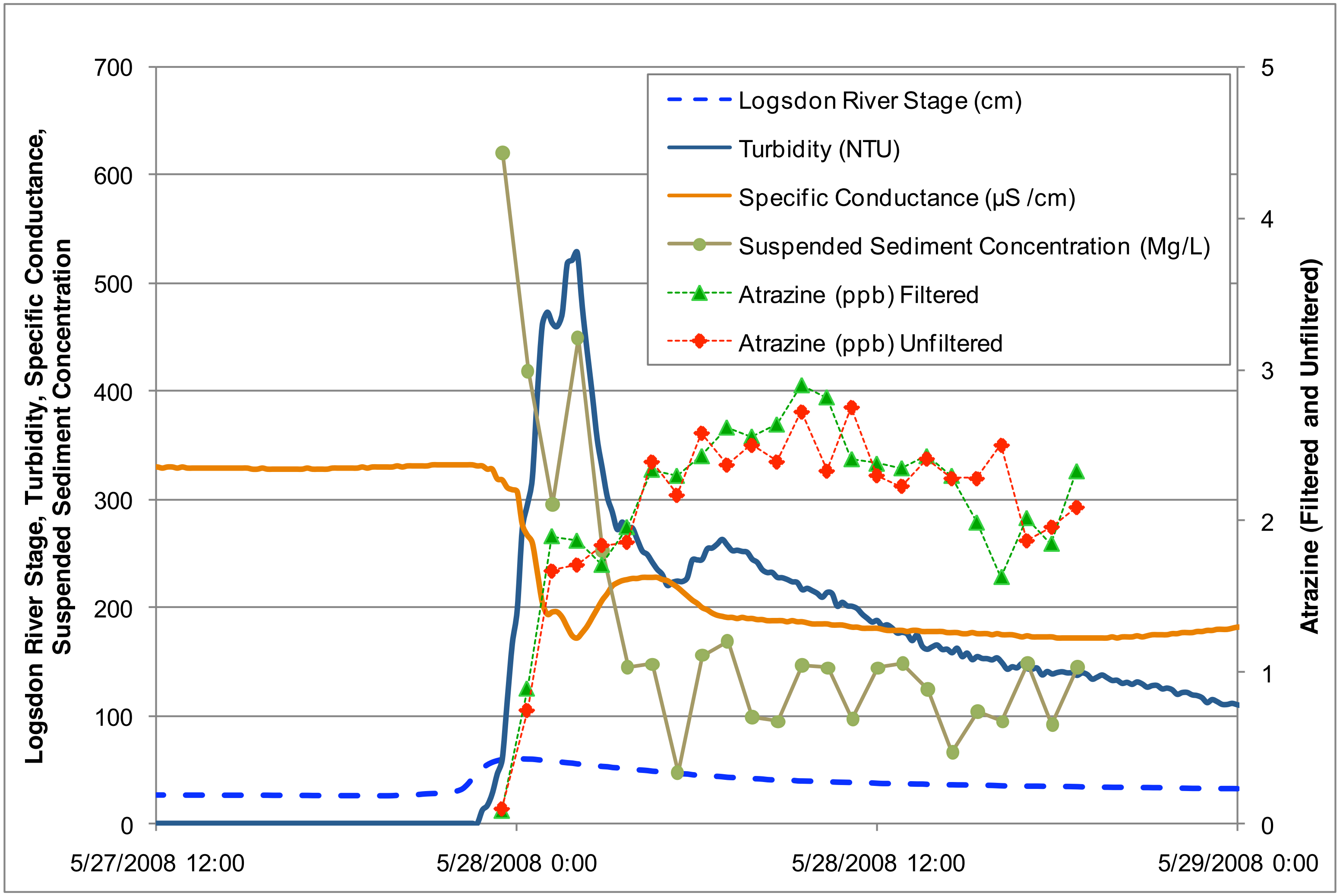

Figure 20. Atrazine levels, specific conductance, turbidity and suspended sediment concentration in Logsdon River: May 27-29, 2008.

around 10:00 hours, when atrazine concentrations began to decline gradually as both turbidity and spC values fell, similar to results from Anderson (2002). The highest levels of atrazine detections came from the filtered samples. While the atrazine levels did not exceed the USEPA's Maximum Contaminant Level, twenty of the twenty-four samples analyzed did exceed the USEPA aquatic life criterion of 1.8 μg/ L.

Although atrazine was found to be primarily associated with suspended sediments in Anderson's study (2002), in this case turbidity values from the LISST and measured suspended sediment concentrations were poorly correlated with atrazine concentrations (Figure 21). In addition, the suspended sediment grain size distributions obtained from lab analysis with the laser diffraction instrument do not suggest a correlation with the increase in atrazine levels. However, it remains possible that atrazine levels are correlated with some characteristic of the suspended sediment that is not captured by our monitoring data (turbidity, volumetric concentration, and mean grain size). While Anderson (2002) found evidence of strong atrazine sorption to suspended solids, analyses of filtered and unfiltered samples for the May 27-29 event suggest no systematic difference in pesticide concentration between the two types of samples (Figure 20). Although differences in sampling and laboratory analysis techniques could influence this difference in results, it is also possible that the association between atrazine and suspended solids is affected by environmental differences between Hawkins River and Logsdon River, including differences in sediment characteristics (Bosch and White 2004).

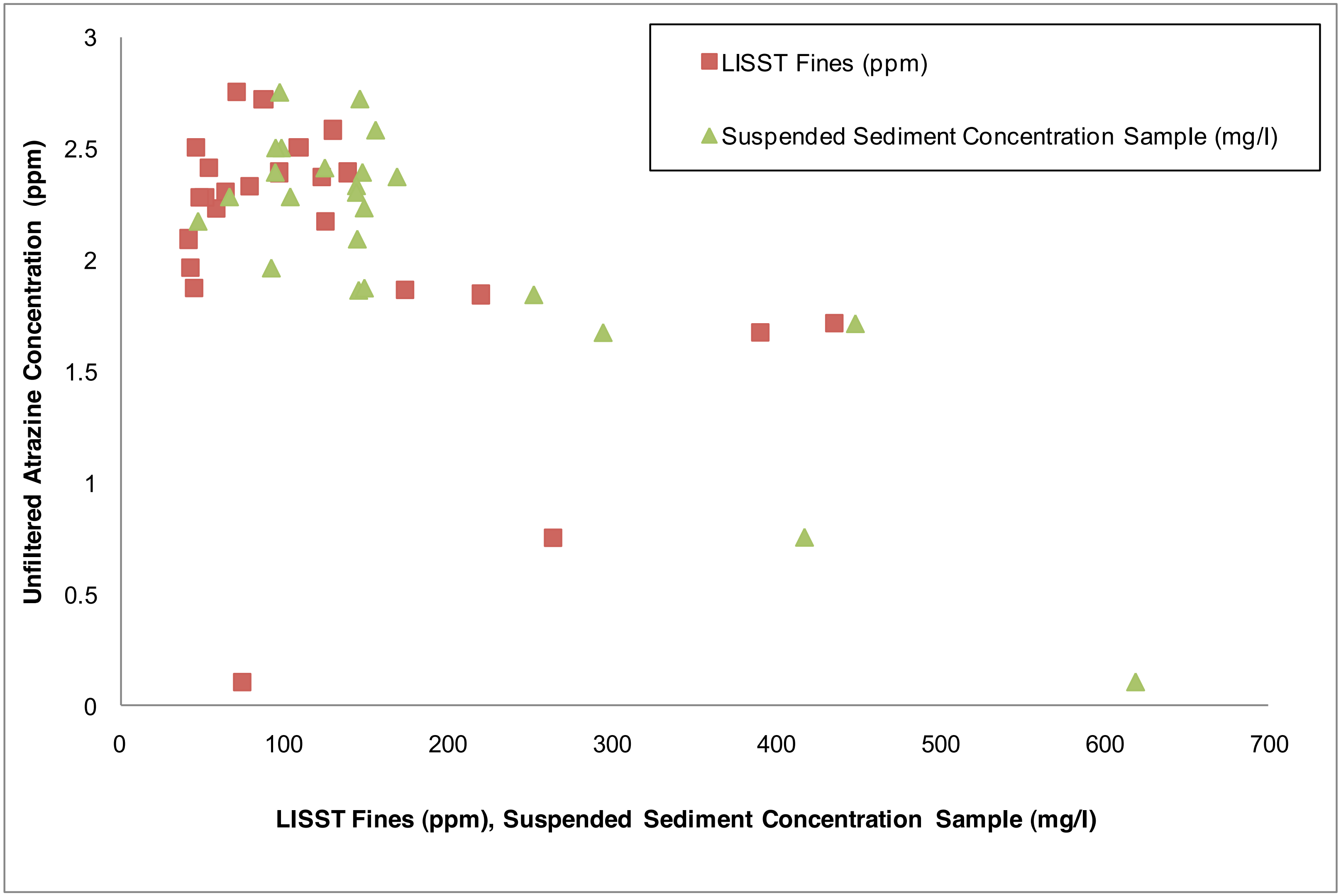

Figure 21-Correlation of unfiltered atrazine concentrations to turbidity values and suspended sediment concentration.

3.4 Comparison of the Precipitation Events

The variation of water quality parameters at the Pete Strange Falls instrument site within the Logsdon River reflects the rapid response of the conduit to runoff producing precipitation events (Table 4). Ongoing monitoring at the Pete Strange Falls instrument site in conjunction with water quality data from a surface tributary at the Joe Ray Weir and the Logsdon River Wells provides comparisons of the hydrologic response, water quality and sediment characteristics of the Logsdon River during two runoff producing precipitation events in May, 2008.

Precipitation totals recorded from May 2-4 were more than double the totals recorded from May 27-29. Although the stage and flow rate were higher during the May 2-4 precipitation event, the May 27-29 precipitation event had a quicker response mainly due to a one hour period in which 23 mm of precipitation was recorded at the Hamilton Valley station. The large volume of precipitation recorded at the Hamilton Valley station saturated the soil and mobilized surface waters that accelerated recharge as it moved into the aquifer. Thus, the high intensity rainfall on May 27 was sufficient to produce a more rapid flow increase compared to the May 2-4 precipitation event.

Changes in water temperature measured in the cave can often reflect the movement of the surface precipitation through the conduit. In winter there is typically a greater difference between temperatures from surface streams and water temperature in a cave, thus winter rains can be colder than the cave stream resulting in a decrease in water temperature as precipitation enters the aquifer. Likewise, summer rains can be warmer than the cave stream, raising its temperature. In the fall and spring, the temperature of

	May 2-4, 2008 Precipitation Event	May 27-29, 2008 Precipitation Event
Total Precipitation	59 mm (HV) 59.1 mm (HM)	26.3 mm (HV) 24.6 mm (HM)
Peak Stage	68.7 cm	59.8 cm
Peak Flow Rate	3.8 m^3/s	2.75 m^3/ s
Low Water Temperature	12.78° Celsius	13.47° Celsius
High Water Temperature	13.35° Celsius	14.59° Celsius
Low pH Value	7.24	7.53
High ph Value	7.85	8.03
Low spC Value	169 µS	172 µS
High spC Value	308 µS	330 µS
High Turbidity Value	445 NTU	527 NTU
Peak Sediment Concentration	340.8 ppm	559.2 ppm

Table 4. Water quality parameters and sediment response in Logsdon River.

surface and cave streams are in closer relation, thus there is not as much variation in water temperature in response to storm inputs. The water temperature differences recorded in the precipitation event of May 2-4 represented a winter response as the water temperature declined, while the precipitation event of May 27-29 was a summer response that reflected an increase in the water temperature as the rainfall moved from the surface through the conduit.

Runoff producing precipitation will also decrease the spC and pH due to the low concentration of hydrogen ions (pH) and other electrolytic solutes in rainwater relative to karst groundwater that has been in contact with soluble bedrock for some time. The spC will remain at a constant value for a certain lag time past the initial input of precipitation, if water levels in the aquifer have been stable (Hess and White, 1988). Once fresh runoff reaches the instrument site, a series of complicated dips and peaks occur that indicate the arrival times of water from tributaries entering the main trunk (Hess and White, 1988; Raeisi et al., 2007). During both precipitation events, the spC and pH declined in response to the surface precipitation as the stage increased. These dips in spC are directly interpretable as fresh input water pulses entering the conduit, while the spC minima correspond to the maximum dilution of the groundwater via the fresh surface water input (Hess and White, 1988). Both events displayed a general pattern consisting of an initial rapid decrease in spC and pH, followed by a prolonged partial recovery of values and then a secondary decline occurring later on the falling limb. Recovery of spC and pH values from this secondary decline was gradual, occurring over many days. The timing of the sequence of water quality variations relative to the flow hydrograph varied, with the

May 2-4 initial spC minimum corresponding to the peak flow rate, while the initial spC minimum on May 27-28 lagged the flow peak by 2 hours.

Rapid changes in spC for both events demonstrate the flushing of storm water through the Logsdon River conduit as described by Hess and White (1988) as well as Anderson (2002) who noted changes in spC and temperature that lagged behind the storm pulse. Differences in the frequency and timing of the dips in spC and pH differentiate the water quality responses of the two events. These differences may be attributed to differences in the number, volume, and travel times of distinct pulses of storm water that produce changes in the proportions of ions and other dissolved solids (Thomas, 1986). The later, secondary declines in spC may reflect the arrival of storm water from more distant surface inputs, or may indicate the return of storm water temporarily stored in the aquifer adjacent to the conduit, as suggested by Raeisi et al, (2007).

In general, increases in turbidity and sediment concentration were correlated with declines in spC. The timing of these variations in turbidity and sediment characteristics differed between the two precipitation events. During the May 2-4 event, turbidity values increased ~1.5 hours after the Logsdon River stage began to increase. The turbidity response during this precipitation event was characterized by four discrete peaks occurring on the rising limb and a smaller secondary peak on the falling limb. The largest peak in turbidity preceded the peak in stage and maximum flow rate by ~1 hour. During the May 27-29 event, the turbidity did not increase until ~3 hours after the Logsdon River stage began to increase with the largest peak in turbidity occurring ~2 hours after the peak in stage and maximum flow rate. The turbidity response for this precipitation event consisted of two discrete peaks and a smaller secondary peak on the falling limb of the hydrograph. Overall, the high turbidity peak and low spC pulse of the May 2-4 event occurs earlier (on the rising limb and just after the flow peak) relative to the flow hydrograph than the May 27-29 event, where the major turbidity rise and spC drops occur after the flow peak.

During both precipitation events, the fine sediment turbidity peaks coincided with peaks in sediment concentration as measured by the LISST (Figure 14, 19), and with concentrations derived from laboratory analysis of water samples (Figure 20). For both events the sand fraction peaks very close to the flow peak, but the secondary peak in turbidity is larger than the corresponding change in the LISST concentration, because the turbidity sensor is more sensitive to the concentration of fine particles (sand and silt), while the LISST accounts for the distribution of grain sizes in the concentration estimate it provides. For the early event, the turbidity - suspended sediment maximum precedes the flow and suspended sand concentration peaks, whereas the turbidity maximum lags behind both the flow peak and the sand fraction peak during the late May event.

Detections of atrazine from both in-cave monitoring sites (Pete Strange Falls and the Logsdon River Wells) increased during the initial turbidity peak and decline in spC, indicating that the atrazine arrives with the initial flush of surface waters that enters the conduit. The arrival of the atrazine with this initial pulse was consistent between the two precipitation events. For the May 2-4 event, the rise in atrazine occurs later relative to the turbidity rise and fall sequence than for the May 27-29 event. This difference is related to the distance between the monitoring stations where atrazine samples were collected. Distinct peaks in atrazine levels did not occur during periods of peak turbidity and continued to stay elevated on the falling limb of the hydrographs as turbidity declined progressively. These results were similar to Anderson (2002) who reported peak levels of atrazine after the turbidity peak. This pattern may reflect lower atrazine availability at the surface in areas that drain to recharge points lying closer to the monitoring/sampling locations. The overall pattern of spC dips, turbidity peaks, and atrazine concentrations suggests the arrival of relatively atrazine free water as the flow rises and peaks, possibly from inputs that are close to the Park boundary and are thus associated primarily with forested areas (Figure 6). The increase in atrazine preceding the secondary pulse of water on the falling limb suggests these precipitation inputs are from distal areas of the subbasin that have higher proportions of agricultural land (Figure 6).

For the May 27-29 precipitation event, the filtered atrazine data were compared to LISST sediment concentration data and to laboratory concentrations of suspended sediment but correlations are poor (Figure 21). In addition, no systematic relation between the filtered and unfiltered samples was evident, suggesting that if atrazine is sorbed to fine sediment particles this sorption involves only the fractions finer than 0.22 µm. Atrazine affinity with very fine particles is consistent with the small values of SMD estimated for the sediment in suspension (Figure 20), but analysis of the fine silt and clay particle size distributions does not correlate with increased atrazine levels. Atrazine concentrations may in fact be correlated with characteristics of the suspended sediment that are not captured effectively by our monitoring data, including fine organic material, complex metal oxides, clay minerals or a blend of these elements (Jenks et al., 1998; Anderson, 2002).

CHAPTER 4

CONCLUSIONS

Understanding the processes that control how agricultural pesticides such as atrazine are transported through karstic aquifers is necessary to estimate the magnitude and likely patterns of contamination resulting from agricultural land use. Observed patterns of suspended sediment and atrazine concentrations were related to inter-storm differences in patterns of precipitation and to agricultural land use within the Cave City subbasin. This study determined that storm-period transport of atrazine through a conduit-flow aquifer was associated with an initial peak of surface derived fine sediment inputs, but a commonly measured water quality parameter (turbidity) was not correlated to the concentration of atrazine and could not provide an indication of possible atrazine contamination during the pesticide application season.

Hydrologic and water quality data collected from study sites in Logsdon River, a conduit of the Turnhole Spring Groundwater Basin that drains the sinkhole plain within the Cave City groundwater subbasin, demonstrates the rapid response to precipitation events occurring in the Spring of 2008. While the peak stage and flow rate were higher for a May 2-4 precipitation event, the hydrologic response was much quicker for a May 27-29 precipitation event due to the intensity of precipitation near the Cave City subbasin. Water temperature responses in the cave reflected seasonal differences, including a decline in temperature during the early May event and an increase during the latter event. The spC and pH both declined as the stage increased in response to the surface precipitation during both events. Sudden drops in spC indicate the flushing of storm water through the conduit, followed by peaks and dips in spC that reflect subsequent pulses of storm water passing the instrument station. An overall correlation of spC reductions with increases in turbidity early on the flow hydrograph suggests the arrival of discrete inputs of relatively dilute, sediment laden water from the surface, followed by a secondary pulse of less turbid water later on the falling limb. This pattern of spC and turbidity responses suggests the initial input of water arrives from land within or near the park boundary, while the secondary pulse arrives from areas further away from the observation point, that have a lower proportion of forested land. An alternative explanation of the secondary water quality perturbation that occurs on the falling limb is that it reflects the return of storm water temporarily stored in the aquifer adjacent to the conduit (Raeisi et al., 2007).

Turbidity peaks during both precipitation events were associated with silt and clay size particles in suspension and coincide with peaks in sediment concentration measured in-situ and with concentrations derived from laboratory analysis of water samples for the latter event. The sand fraction peaks very close to the flow peak for both events suggesting flow hydraulics are the primary control on the flux of suspended sand. However, the turbidity max precedes the flow peak during the early May event, and lags behind both the flow peak and the sand fraction peak during the late May event due to differences in the hydrologic response of the conduit system to these precipitation events. These differences may be attributed to the flood wave crest traveling faster, relative to the water speed, for the late May event.

Atrazine values ranging from 12.4 ppb to >50 ppb at a surface tributary of the Logsdon River reflect the mobilization of atrazine from agricultural areas within the Cave

City subbasin. Detections of atrazine during the initial turbidity increase at both in-cave monitoring sites (Pete Strange Falls and the Logsdon River Wells), indicate that this atrazine arrives before the secondary pulse of turbid water passes the sampling point. The increase of atrazine concentrations to near steady values between 2 and 3 ppb was correlated with the secondary pulse of fine sediment laden water for both precipitation events. However, distinct peaks in atrazine levels did not occur during periods of peak turbidity and continued to stay elevated on the falling limb of the hydrographs as turbidity declined progressively, similar to results from Anderson (2002) who reported peak levels of atrazine after the turbidity peak in Hawkins River. The timing of atrazine transport relative to flow and other water quality variations in Logsdon River may reflect relatively low atrazine availability in surface recharge areas closer to the monitoring point. In addition, no systematic relation between atrazine concentration in filtered and unfiltered samples was evident, suggesting that if atrazine is sorbed to fine sediment particles this sorption involves only the fractions finer than 0.22 μm. Nor was atrazine positively correlated with concentrations of suspended sediment or the grain size distributions of samples for the May 27-29 precipitation event. Therefore, increased atrazine levels do not correlate simply with fine sediment concentration, but may be related to the geochemical composition of materials in suspension or to other factors affecting sorption such as preferential association with particular mineral fractions or an increase in fine organic material, both of which were not evaluated in the present study. Additional work is required to establish whether such geochemical factors are important controls on pesticide transport in the Cave City basin or other conduit-flow karst aquifers in agricultural landscapes.

Understanding the potential for karst aquifer contamination by pesticides is important for cave conservation efforts in agricultural landscapes. Water quality monitoring within Mammoth Cave National Park clearly cites non-point source runoff from agricultural practice as the major cause of contamination in the Turnhole Spring groundwater basin (Meiman, 2006). Atrazine levels at a surface tributary of Logsdon River greatly exceeded the USEPA's Maximum Contaminant Level of 3.0 ppb and the aquatic life criterion of 1.8 µg / L which were detected in 81 percent of these samples. Only one of the in-cave samples from either event exceeds the Maximum Contaminant Level, but several values were extremely close. In addition, seventeen of the thirty-three samples analyzed for atrazine concentrations from the early May event and twenty of the twenty-four samples from the late May event did exceed the USEPA aquatic life criterion. These findings support the need for on-going monitoring and mitigation of contamination within karst aquifers to protect cave fauna, particularly within areas that receive surface precipitation inputs from agricultural lands.

REFERENCES

Anderson, Michael S. 2002. Transport of the Herbicide Atrazine on Suspended Sediments during a Spring Storm Event in Mammoth Cave, Kentucky. M.S. Thesis, Western Kentucky University, Bowling Green, KY.

Anthony, Darlene M. 1998. Seasonal effects on the geochemical evolution of the Logsdon River, Mammoth Cave, Kentucky. M.S. Thesis, Western Kentucky University, Bowling Green, KY.

Anthony, Darlene M., Groves, Chris and Meiman, Joseph. 2003. Preliminary investigations of seasonal changes in the geochemical evolution of the Logsdon River, Mammoth Cave, Kentucky. Speleogenesis and Evolution of Karst Aquifers: The Virtual Scientific Journal 1 (4) (www.speleogenesis.com).

Barbash, Jack E. and Resek, Elizabeth A. 1996. Pesticides in Ground Water: Distributions, Trends, and Governing Factors. Ann Arbor Press, Inc., Chelsea, MI.

Bosch, Rachel F. and White, William B. 2004. Lithofacies and transport of sediments in Karstic aquifers, in Studies of Cave Sediments: Physical and Chemical Records of Paleoclimate, Ira Sasowsky, & John Mylroie, eds. Kluwer Academic/ Plenium Publishing. 1-22.

Crain, Angela S. 2006. Concentrations of Nutrients, Pesticides, and Suspended Sediment in Karst Terrain of the Sinking Creek Basin, Kentucky, 2004. United States Geological Survey Open-File Report 2006-1991.

Dougherty, Percy H. 1985. An overview of the Geology and Physical Geography of Kentucky, in Caves and Karst of Kentucky, Percy H. Dougherty, ed., Kentucky Geological Survey, Lexington, KY, pp. 1-23.

Ford, Derek C. and Williams, Paul W. 1989. Karst geomorphology and hydrology. Unwin Hyman, London.

Gale, Stephen J. 1989. The hydraulics of conduit flow in carbonate aquifers. Journal of Hydrology, 70, pp. 309-327.

Glennon, Alan and Groves, Chris. 2002. An examination of perennial stream drainage patterns within the Mammoth Cave watershed, Kentucky. Journal of Cave and Karst Studies, 64, pp. 82-91.

Goodmann, Peter T., Webb, Jim and Blanset, Jolene. 2002. The greater occurrence of agricultural herbicides in karst aquifers in Kentucky. North-Central Section (36th) and Southeastern Section (51st), GSA Joint Annual Meeting, Lexington, KY.

Granger, Darryl E., Fabel, Derek and Palmer, Arthur N., 2001. Pliocene–Pleistocene incision of the Green River, Kentucky, determined from radioactive decay of cosmogenic ^{26}Al and ^{10}Be in Mammoth Cave sediments. GSA Bulletin, 113, 825-836.

Gulden, Bob. 2008. World's longest caves. Available from: <http://www.caverbob.com/wlong.htm>

Hall, Clifford. 1996. Water quality variations and contaminant mass flux signatures relative to quick-flow recharge within the Turnhole Spring groundwater basin. M.S. Thesis, Eastern Kentucky University, Richmond, KY.

Hess, John W., Wells, Stephen G., Quinlan, James F. and White, William B. 1989. Hydrogeology of the south-central Kentucky karst. In Karst Hydrology Concepts from the Mammoth Cave Area, William B. White and Elizabeth L. White, eds., Van Nostrand Reinhold, New York, pp.15-63.

Hess, John W. and White William B., 1988. Storm response of the karstic carbonate aquifer of southcentral Kentucky. Journal of Hydrology, 99, 235-252.

Hess, John W. and White William B., 1989. Water budget and physical hydrology. In Karst Hydrology Concepts from the Mammoth Cave Area, William B. White and Elizabeth L. White, eds. Van Nostrand Reinhold, New York, 105-126.

Jenks, Brian M, Roeth, Fred W., Martin, Alex R., McCallister, Dennis L., 1998. Influence of surface and subsurface soil properties on atrazine sorption and degradation. Weed Science, 46, 1: 132-138.

Kambesis, Patricia. 2007. Agricultural contaminant source and transport in a karst groundwater basin. M.S. Thesis, Western Kentucky University, Bowling Green, KY.

Kentucky Department of Agriculture. 2007. Guidelines for Atrazine Use and Application for Groundwater and Surface Water Protection: Best Management Practices. Frankfort, KY.

Kingsbury, James A. 2003. Shallow Ground-Water Quality in Agricultural Areas of Northern Alabama and Middle Tennessee, 2000-2001. U.S. Geological Survey Water- Resources Investigations Report 03-4181.

Kogovšek, Janja and Šebela, Stanka. 2004. Water tracing through the vadose zone above Postojnska Jama, Slovenia. Environmental Geology, 45, 992-1001.

Lerch, Robert N., Erickson, Jeanne M. and Wicks, Carol M., 2001. Intensive water quality monitoring in two karst watersheds of Boone County, Missouri. National Cave and Karst Management Symposium: Tuscon, AZ.

Mahler, Barbara J., Lynch, Leo, and Bennett, P.C. 1999. Mobile sediment in an urbanizing karst aquifer: implications for contaminant transport. Environmental Geology, 39, 25-38.

Meiman, Joseph, Groves, Chris and Herstein, Shannon. 2001. In-cave dye tracing and drainage basin divides in the Mammoth cave karst aquifer, Kentucky, in U.S. Geological Survey Karst Interest Group Proceedings, St. Petersburg, Florida, February 13-16, 2001: USGS Water Resources Investigations Report 01-4011.

Meiman, Joseph. 2006. Mammoth Cave National Park: Water Resources Management Plan. National Park Service, U.S. Department of the Interior.

Miotke, Franz-Dieter and Palmer, Arthur N. 1972. Genetic relationship between cave landforms in the Mammoth Cave National Park area. Boehler Verlag, Germany.

National Agriculture Statistical Service. 2008. Kentucky Agricultural Facts. Available from: <http://www.nass.usda.gov/ky/>

Palmer, Arthur N., 1981. A geological guide to Mammoth Cave National Park. Zephyr Press, Teaneck, N.J.

Palmer, Arthur N., 1985. The Mammoth Cave region and Pennyroyal Plateau, in Caves and Karst of Kentucky, Percy H. Dougherty, ed., Kentucky Geological Survey: Lexington, KY, p. 97-118.

Palmer, Arthur N. 2007. Cave Geology. Cave Books, Dayton, OH.

Pronk, Michiel, Goldscheider, Nico and Zopfi, Jakob. 2007. Particle-size distribution as indicator for fecal bacteria contamination for drinking water from karst springs. Environmental Science & Technology: American Chemical Society.

Quinlan, James. F. and Ewers, Ralph O. 1989. Subsurface drainage in the Mammoth cave area. In Karst Hydrology Concepts from the Mammoth Cave Area, William B. White & Elizabeth L. White, eds. New York: Van Nostrand Reinhold, pp.65-104.

Quinlan, James F. and Ray, Joseph, 1989. Groundwater basins in Mammoth Cave region, Kentucky, showing springs, major caves, flow routes and potentiometric surface, National Park Service, Mammoth Cave Kentucky. Friends of Karst, Occasional Publication # 2.

Raeisi, Ezzat, Groves, Chris and Meiman, Joe. 2007. Effects of partial and full pipe flow on hydrochemographs of Logsdon river, Mammoth Cave Kentucky USA. Journal of Hydrology, 337, 1-10.

Ray, Joseph A. and Currens, James C., 1998a, Mapped karst ground-water basins in the Beaver Dam 30 x 60 Minute Quadrangle, Kentucky Geological Survey.

Ray, Joseph A. and Currens, James C., 1998b, Mapped karst ground-water basins in the Campbellsville 30 x 60 Minute Quadrangle, Kentucky Geological Survey.

Ryan, Martin and Meiman, Joseph. 1996. An examination of short-term variations in water quality at a karst spring in Kentucky. Ground Water, 34: 23-30.

Thomas, A.G. 1986. Specific conductance as an indicator of total dissolved solids in cold dilute waters. Hydrological Sciences Journal - des Sciences Hydrologiqucs, 31: 81-92.

United States Environmental Protection Agency, 2006. Technical factsheet on Atrazine. Available from: <http://www.epa.gov/ogwdw/dwh/t-soc/atrazine.html>

United States Environmental Protection Agency. 2006. Triazine cumulative risk assessment and atrazine, simazine, and propazine Decisions. Available from: <http://www.wpa.gov/oppsrrd1/cumulative/triazine_fs.htm>

United States Geological Survey. 1999. The Quality of Our Nation's Water-Nutrients and Pesticides. U.S. Geological Survey Circular 1225.

United States Geological Survey. 2002. Pesticides and nutrients in karst springs in the Green River basin, Kentucky, May-September, 2001. USGS Fact Sheet 133-01.

United States Geological Survey. 2006. Pesticides in the nation's streams and ground water, 1992-2001-A Summary. USGS Fact Sheet 133-01.

United States Geological Survey. 2008. NLCD Land Cover Class Definitions. Available from: <http://landcover.usgs.gov/classes.php>

Wehtje, G.R., Spalding, R.F., Burnside, O.C., Lowry, S.R. and Leavitt, R.C. 1983. Biological significance and fate of atrazine under aquifer conditions. Weed Science, 31: 610-618.

White, William B. 1988. Geomorphology and Hydrology of Karst Terrains. Oxford University Press: New York.

White, William B., 1989. Introduction to the karst hydrology of the Mammoth Cave area, In Karst Hydrology Concepts from the Mammoth Cave Area, William B. White and Elizabeth L. White, eds., Van Nostrand Reinhold: New York, p.1-13.

White, William B. 2007. A brief history of karst hydrogeology-contributions of the NSS. Journal of Cave and Karst Studies, 69: 13-26.

World Health Organization. 1990. Atrazine Health and Safety Guide. Geneva: World Health Organization for the International Program on Chemical Safety.

Worthington, Stephen R.H. 1991. Karst hydrogeology of the Canadian Rocky mountains. McMaster University, Hamilton, Ontario. Ph.D. Thesis, 227 pp.

APPENDIX A

Precipitation Data from NRCS Hamilton Valley and

Houchins Meadow Air Quality Stations:

May 2-4, 2008

Date & Time	Total Precipitation (mm) Hamilton Valley	Total Precipitation (mm) Houchins Meadow
5/2/08 0:00	0	0
5/2/08 1:00	0	0
5/2/08 2:00	0	0
5/2/08 3:00	0	0
5/2/08 4:00	0	0
5/2/08 5:00	0	0
5/2/08 6:00	0	0
5/2/08 7:00	0	0
5/2/08 8:00	0	0
5/2/08 9:00	0	0
5/2/08 10:00	0	0.4
5/2/08 11:00	0	6.7
5/2/08 12:00	1.78	6.2
5/2/08 13:00	3.05	1.6
5/2/08 14:00	2.54	0
5/2/08 15:00	0	0
5/2/08 16:00	0	0.7
5/2/08 17:00	0.76	4
5/2/08 18:00	2.54	0.8
5/2/08 19:00	1.02	0
5/2/08 20:00	0	0.3
5/2/08 21:00	0	0.1
5/2/08 22:00	0.25	1.1
5/2/08 23:00	7.62	1.3
5/3/08 0:00	1.02	3.3
5/3/08 1:00	3.05	7
5/3/08 2:00	7.11	7.6
5/3/08 3:00	7.62	7.4
5/3/08 4:00	10.16	4.8
5/3/08 5:00	6.35	0.3
5/3/08 6:00	1.27	5.4
5/3/08 7:00	2.79	0.1
5/3/08 8:00	0.051	0
5/3/08 9:00	0	0
5/3/08 10:00	0	0
5/3/08 11:00	0	0
5/3/08 12:00	0	0
5/3/08 13:00	0	0
5/3/08 14:00	0	0
5/3/08 15:00	0	0

5/3/08 16:00	0	0
5/3/08 17:00	0	0
5/3/08 18:00	0	0
5/3/08 19:00	0	0
5/3/08 20:00	0	0
5/3/08 21:00	0	0
5/3/08 22:00	0	0
5/3/08 23:00	0	0
5/4/08 0:00	0	0

APPENDIX B

Hydrologic Response Data: May 2-5, 2008

Date & Time	Joe Ray Weir Stage	Logsdon River Stage (cm)	Logsdon Flow Rate (m^3/s)
5/2/2008 12:00	45	25	0.12624
5/2/2008 12:10	45	25	0.13314
5/2/2008 12:20	45	25	0.12624
5/2/2008 12:30	45	25	0.09312
5/2/2008 12:40	45	25	0.13314
5/2/2008 12:50	45	25	0.129
5/2/2008 13:00	45	25	0.11796
5/2/2008 13:10	45	25	0.129
5/2/2008 13:20	46	25	0.12624
5/2/2008 13:30	46	24.9	0.13243344
5/2/2008 13:40	46	24.9	0.1145652
5/2/2008 13:50	46	24.9	0.12281208
5/2/2008 14:00	46	24.9	0.1145652
5/2/2008 14:10	46	24.9	0.10631832
5/2/2008 14:20	46	24.9	0.12556104
5/2/2008 14:30	47	24.9	0.11044176
5/2/2008 14:40	46	24.9	0.11868864
5/2/2008 14:50	47	24.9	0.11044176
5/2/2008 15:00	46	24.9	0.11593968
5/2/2008 15:10	46	24.9	0.12831
5/2/2008 15:20	46	24.9	0.12281208
5/2/2008 15:30	46	24.9	0.09669696
5/2/2008 15:40	47	24.9	0.09944592
5/2/2008 15:50	47	24.9	0.1214376
5/2/2008 16:00	47	24.8	0.13583376
5/2/2008 16:10	47	24.8	0.12214416
5/2/2008 16:20	47	24.8	0.12214416
5/2/2008 16:30	47	24.8	0.13172688
5/2/2008 16:40	46	24.8	0.11256144
5/2/2008 16:50	46	24.8	0.11529936
5/2/2008 17:00	46	24.8	0.10297872
5/2/2008 17:10	46	24.8	0.12488208
5/2/2008 17:20	46	24.8	0.13172688
5/2/2008 17:30	45	24.8	0.12625104
5/2/2008 17:40	45	24.8	0.12488208
5/2/2008 17:50	45	24.8	0.11803728
5/2/2008 18:00	45	24.8	0.11803728
5/2/2008 18:10	45	24.8	0.13583376
5/2/2008 18:20	45	24.8	0.10845456
5/2/2008 18:30	45	24.8	0.1002408
5/2/2008 18:40	44	24.8	0.1002408

5/2/2008 18:50	44	24.8	0.14404752
5/2/2008 19:00	44	24.8	0.1207752
5/2/2008 19:10	45	24.8	0.11803728
5/2/2008 19:20	45	24.8	0.10434768
5/2/2008 19:30	45	24.8	0.11666832
5/2/2008 19:40	45	24.9	0.10631832
5/2/2008 19:50	45	24.8	0.11119248
5/2/2008 20:00	45	24.9	0.1214376
5/2/2008 20:10	45	24.9	0.12831
5/2/2008 20:20	45	24.9	0.11319072
5/2/2008 20:30	45	24.9	0.1214376
5/2/2008 20:40	45	24.9	0.15167616
5/2/2008 20:50	44	24.9	0.1351824
5/2/2008 21:00	44	24.9	0.11181624
5/2/2008 21:10	44	24.9	0.12831
5/2/2008 21:20	44	24.9	0.13243344
5/2/2008 21:30	44	24.9	0.14342928
5/2/2008 21:40	44	25	0.13452
5/2/2008 21:50	44	25	0.1221
5/2/2008 22:00	44	25	0.13038
5/2/2008 22:10	44	25	0.14832
5/2/2008 22:20	44	25.1	0.12414792
5/2/2008 22:30	44	25.1	0.11167824
5/2/2008 22:40	44	25.1	0.11029272
5/2/2008 22:50	44	25.1	0.12691896
5/2/2008 23:00	44	25.1	0.12969
5/2/2008 23:10	44	25.2	0.12759792
5/2/2008 23:20	44	25.2	0.13872624
5/2/2008 23:30	44	25.2	0.12064272
5/2/2008 23:40	46	25.2	0.13038
5/2/2008 23:50	45	25.2	0.14289936
5/3/2008 0:00	45	25.2	0.11090544
5/3/2008 0:10	45	25.2	0.1442904
5/3/2008 0:20	45	25.2	0.13594416
5/3/2008 0:30	44	25.2	0.1164696
5/3/2008 0:40	44	25.2	0.11786064
5/3/2008 0:50	45	25.2	0.11925168
5/3/2008 1:00	44	25.2	0.13316208
5/3/2008 1:10	44	25.2	0.1234248
5/3/2008 1:20	43	25.2	0.11229648
5/3/2008 1:30	43	25.2	0.14150832
5/3/2008 1:40	43	25.2	0.14289936

5/3/2008 1:50	43	25.2	0.13177104
5/3/2008 2:00	43	25.2	0.09838608
5/3/2008 2:10	43	25.2	0.12759792
5/3/2008 2:20	43	25.2	0.10673232
5/3/2008 2:30	43	25.2	0.1234248
5/3/2008 2:40	43	25.3	0.13525968
5/3/2008 2:50	43	25.3	0.11291472
5/3/2008 3:00	43	25.2	0.12203376
5/3/2008 3:10	43	25.3	0.10593192
5/3/2008 3:20	43	25.3	0.11989752
5/3/2008 3:30	43	25.3	0.1171044
5/3/2008 3:40	43	25.3	0.13107
5/3/2008 3:50	43	25.4	0.10091424
5/3/2008 4:00	44	25.5	0.1057056
5/3/2008 4:10	44	25.7	0.12957408
5/3/2008 4:20	43	26.1	0.14667504
5/3/2008 4:30	43	26.8	0.1636104
5/3/2008 4:40	43	28.1	0.16279896
5/3/2008 4:50	43	30.5	0.2982708
5/3/2008 5:00	43	33.8	0.46771824
5/3/2008 5:10	43	37.2	0.71832624
5/3/2008 5:20	43	40	0.892692
5/3/2008 5:30	43	42.3	1.02357672
5/3/2008 5:40	43	44.4	1.23585936
5/3/2008 5:50	43	46.5	1.3836408
5/3/2008 6:00	43	48.5	1.5708516
5/3/2008 6:10	43	50.2	1.74104976
5/3/2008 6:20	43	51.8	1.87798992
5/3/2008 6:30	43	53.2	2.02389456
5/3/2008 6:40	43	54.5	2.1044976
5/3/2008 6:50	43	55.6	2.26140912
5/3/2008 7:00	43	56.6	2.33723184
5/3/2008 7:10	43	57.8	2.48342352
5/3/2008 7:20	43	59.1	2.6316024
5/3/2008 7:30	43	60.6	2.79650688
5/3/2008 7:40	43	62.1	2.9730696
5/3/2008 7:50	43	63.7	3.18440832
5/3/2008 8:00	43	65.1	3.32003472
5/3/2008 8:10	43	66.3	3.49914768
5/3/2008 8:20	43	67.3	3.5971608
5/3/2008 8:30	43	67.8	3.6429216
5/3/2008 8:40	43	68.5	3.7528248

5/3/2008 8:50	44	68.7	3.74115552
5/3/2008 9:00	48	68.7	3.79803912
5/3/2008 9:10	53	68.7	3.76011672
5/3/2008 9:20	58	68.6	3.75458016
5/3/2008 9:30	59	68.3	3.72288984
5/3/2008 9:40	60	67.7	3.64122144
5/3/2008 9:50	62	67.4	3.6211728
5/3/2008 10:00	64	66.7	3.49474824
5/3/2008 10:10	66	66.3	3.46620984
5/3/2008 10:20	70	65.5	3.3660108
5/3/2008 10:30	75	65.1	3.30206712
5/3/2008 10:40	80	64.2	3.19556976
5/3/2008 10:50	82	63.8	3.16482336
5/3/2008 11:00	81	63	3.051564
5/3/2008 11:10	80	62.4	2.99108688
5/3/2008 11:20	81	61.7	2.92298664
5/3/2008 11:30	85	61.2	2.87192112
5/3/2008 11:40	88	60.6	2.81323248
5/3/2008 11:50	91	60.1	2.67354888
5/3/2008 12:00	91	59.4	2.65173936
5/3/2008 12:10	91	59.1	2.5989792
5/3/2008 12:20	90	58.4	2.52577296
5/3/2008 12:30	89	58.1	2.49653904
5/3/2008 12:40	87	57.4	2.44058832
5/3/2008 12:50	86	57.1	2.41184568
5/3/2008 13:00	84	56.7	2.32891872
5/3/2008 13:10	82	56.1	2.26665312
5/3/2008 13:20	80	55.8	2.25737952
5/3/2008 13:30	78	55.3	2.23676232
5/3/2008 13:40	76	54.8	2.15564592
5/3/2008 13:50	74	54.6	2.14460592
5/3/2008 14:00	72	53.9	2.0838252
5/3/2008 14:10	71	53.6	2.06014992
5/3/2008 14:20	69	53.3	2.02189632
5/3/2008 14:30	68	52.7	1.98410088
5/3/2008 14:40	67	52.4	1.94363376
5/3/2008 14:50	67	52.2	1.88994624
5/3/2008 15:00	66	51.6	1.8648744
5/3/2008 15:10	65	51.3	1.83395688
5/3/2008 15:20	64	51.1	1.78432656
5/3/2008 15:30	64	50.7	1.75882416
5/3/2008 15:40	63	50.2	1.76321808

5/3/2008 15:50	63	50	1.68702
5/3/2008 16:00	62	49.8	1.66635312
5/3/2008 16:10	62	49.2	1.64846832
5/3/2008 16:20	62	49	1.606428
5/3/2008 16:30	62	48.8	1.5862248
5/3/2008 16:40	62	48.5	1.5547884
5/3/2008 16:50	61	48	1.5356616
5/3/2008 17:00	61	47.8	1.46311776
5/3/2008 17:10	61	47.6	1.47783408
5/3/2008 17:20	60	47.4	1.45574304
5/3/2008 17:30	60	46.9	1.42957272
5/3/2008 17:40	60	46.7	1.40524608
5/3/2008 17:50	59	46.5	1.4298432
5/3/2008 18:00	59	46.4	1.4164296
5/3/2008 18:10	59	46.1	1.36373016
5/3/2008 18:20	59	45.6	1.33839888
5/3/2008 18:30	59	45.5	1.3052292
5/3/2008 18:40	58	45.4	1.26717984
5/3/2008 18:50	58	45.3	1.27679568
5/3/2008 19:00	58	45.1	1.24607136
5/3/2008 19:10	58	44.6	1.25146992
5/3/2008 19:20	58	44.4	1.18929264
5/3/2008 19:30	58	44.3	1.19385216
5/3/2008 19:40	57	44.2	1.18617936
5/3/2008 19:50	57	44.1	1.21504344
5/3/2008 20:00	57	43.9	1.15117704
5/3/2008 20:10	57	43.7	1.16262
5/3/2008 20:20	56	43.3	1.09899648
5/3/2008 20:30	56	43.2	1.09874256
5/3/2008 20:40	56	43.1	1.1222688
5/3/2008 20:50	56	43	1.0934544
5/3/2008 21:00	55	42.9	1.08370608
5/3/2008 21:10	55	42.8	1.07635344
5/3/2008 21:20	55	42.6	1.05701136
5/3/2008 21:30	54	42.2	1.03037184
5/3/2008 21:40	54	42.1	1.00691184
5/3/2008 21:50	54	42	1.0090536
5/3/2008 22:00	54	41.9	0.97879296
5/3/2008 22:10	54	41.8	1.02480768
5/3/2008 22:20	54	41.8	1.03403712
5/3/2008 22:30	54	41.7	0.992328
5/3/2008 22:40	54	41.6	0.96917712

5/3/2008 22:50	54	41.3	0.9709932
5/3/2008 23:00	54	41	0.9590976
5/3/2008 23:10	53	40.9	0.94310616
5/3/2008 23:20	54	40.8	0.92718096
5/3/2008 23:30	53	40.8	0.9474504
5/3/2008 23:40	54	40.7	0.93154176
5/3/2008 23:50	53	40.7	0.94052832
5/4/2008 0:00	53	40.6	0.94931616
5/4/2008 0:10	54	40.5	0.8932164
5/4/2008 0:20	54	40.4	0.8819832
5/4/2008 0:30	54	40.2	0.90403008
5/4/2008 0:40	54	39.9	0.85511184
5/4/2008 0:50	54	39.8	0.8792232
5/4/2008 1:00	54	39.7	0.82869312
5/4/2008 1:10	55	39.6	0.82649616
5/4/2008 1:20	55	39.6	0.8527272
5/4/2008 1:30	55	39.5	0.8570052
5/4/2008 1:40	55	39.5	0.8264796
5/4/2008 1:50	55	39.4	0.80905296
5/4/2008 2:00	55	39.3	0.80905848
5/4/2008 2:10		39.2	0.78092304
5/4/2008 2:20		39.1	0.80687808
5/4/2008 2:30		38.8	0.82819632
5/4/2008 2:40		38.7	0.7682712
5/4/2008 2:50		38.6	0.77043504
5/4/2008 3:00		38.5	0.774702
5/4/2008 3:10		38.5	0.7513248
5/4/2008 3:20		38.4	0.73230288
5/4/2008 3:30		38.4	0.75773904
5/4/2008 3:40		38.3	0.75353832
5/4/2008 3:50		38.3	0.70914096
5/4/2008 4:00		38.2	0.75145728
5/4/2008 4:10		38.1	0.75147936
5/4/2008 4:20		38.1	0.73675752
5/4/2008 4:30		38	0.7347096
5/4/2008 4:40		37.9	0.73893792
5/4/2008 4:50		37.6	0.68915856
5/4/2008 5:00		37.5	0.72447
5/4/2008 5:10		37.5	0.69135
5/4/2008 5:20		37.4	0.68526144
5/4/2008 5:30		37.4	0.7203576
5/4/2008 5:40		37.3	0.6874308

5/4/2008 5:50	37.3	0.68948976
5/4/2008 6:00	37.3	0.66890016
5/4/2008 6:10	37.2	0.675204
5/4/2008 6:20	37.2	0.675204
5/4/2008 6:30	37.2	0.67725744
5/4/2008 6:40	37.1	0.69784704
5/4/2008 6:50	37.1	0.673272
5/4/2008 7:00	37	0.6447888
5/4/2008 7:10	37	0.681552
5/4/2008 7:20	36.9	0.65107608
5/4/2008 7:30	36.8	0.62481744
5/4/2008 7:40	36.7	0.6452856
5/4/2008 7:50	36.5	0.651606
5/4/2008 8:00	36.4	0.64769232
5/4/2008 8:10	36.3	0.62575584
5/4/2008 8:20	36.3	0.64378968
5/4/2008 8:30	36.2	0.65188752
5/4/2008 8:40	36.2	0.61392096
5/4/2008 8:50	36.1	0.62804664
5/4/2008 9:00	36.1	0.62605392
5/4/2008 9:10	36.1	0.63203208
5/4/2008 9:20	36	0.6440712
5/4/2008 9:30	36	0.632148
5/4/2008 9:40	36	0.6162504
5/4/2008 9:50	35.9	0.59658264
5/4/2008 10:00	35.9	0.58469256
5/4/2008 10:10	35.9	0.59261928
5/4/2008 10:20	35.8	0.57701424
5/4/2008 10:30	35.8	0.60270432
5/4/2008 10:40	35.7	0.57528096
5/4/2008 10:50	35.7	0.58513416
5/4/2008 11:00	35.6	0.55782672
5/4/2008 11:10	35.4	0.56031072
5/4/2008 11:20	35.3	0.5702964
5/4/2008 11:30	35.2	0.56078544
5/4/2008 11:40	35.2	0.60158928
5/4/2008 11:50	35.1	0.56294376
5/4/2008 12:00	35.1	0.56294376
5/4/2008 12:10	35.1	0.55906872
5/4/2008 12:20	35	0.561216
5/4/2008 12:30	35	0.539964
5/4/2008 12:40	35	0.522576
5/4/2008 12:50	35	0.576672

5/4/2008 13:00	34.9	0.5537088
5/4/2008 13:10	34.9	0.534444
5/4/2008 13:20	34.9	0.54792936
5/4/2008 13:30	34.9	0.54600288
5/4/2008 13:40	34.9	0.52866456
5/4/2008 13:50	34.8	0.52126224
5/4/2008 14:00	34.8	0.51742032
5/4/2008 14:10	34.8	0.54047184
5/4/2008 14:20	34.7	0.51006216
5/4/2008 14:30	34.7	0.51006216
5/4/2008 14:40	34.7	0.52538568
5/4/2008 14:50	34.6	0.47981808
5/4/2008 15:00	34.6	0.51801648
5/4/2008 15:10	34.5	0.508776
5/4/2008 15:20	34.5	0.5240112
5/4/2008 15:30	34.4	0.51856848
5/4/2008 15:40	34.2	0.49075872
5/4/2008 15:50	34.1	0.47037336
5/4/2008 16:00	34	0.5045256
5/4/2008 16:10	34	0.500772
5/4/2008 16:20	34	0.5026488
5/4/2008 16:30	33.9	0.50104248
5/4/2008 16:40	33.9	0.4804584
5/4/2008 16:50	33.9	0.4617456
5/4/2008 17:00	33.9	0.4991712
5/4/2008 17:10	33.8	0.46585248
5/4/2008 17:20	33.8	0.45838944
5/4/2008 17:30	33.8	0.48077856
5/4/2008 17:40	33.8	0.4882416
5/4/2008 17:50	33.7	0.50899128
5/4/2008 18:00	33.7	0.47922744
5/4/2008 18:10	33.7	0.46248528
5/4/2008 18:20	33.7	0.47364672
5/4/2008 18:30	33.7	0.43644192
5/4/2008 18:40	33.7	0.46992624
5/4/2008 18:50	33.6	0.45171024
5/4/2008 19:00	33.6	0.47025744
5/4/2008 19:10	33.6	0.4758216
5/4/2008 19:20	33.6	0.46469328
5/4/2008 19:30	33.5	0.4909188
5/4/2008 19:40	33.5	0.4705776
5/4/2008 19:50	33.5	0.4724268

5/4/2008 20:00	33.4	0.463512
5/4/2008 20:10	33.4	0.46719936
5/4/2008 20:20	33.4	0.4542936
5/4/2008 20:30	33.3	0.4344216
5/4/2008 20:40	33.3	0.40133472
5/4/2008 20:50	33.2	0.47147184
5/4/2008 21:00	33.1	0.42606984
5/4/2008 21:10	33	0.4374024
5/4/2008 21:20	32.9	0.41415216
5/4/2008 21:30	32.9	0.4468416
5/4/2008 21:40	32.9	0.41415216
5/4/2008 21:50	32.8	0.45078288
5/4/2008 22:00	32.8	0.4272456
5/4/2008 22:10	32.8	0.45621456
5/4/2008 22:20	32.8	0.46164624
5/4/2008 22:30	32.7	0.45469104
5/4/2008 22:40	32.7	0.41498016
5/4/2008 22:50	32.7	0.44566584
5/4/2008 23:00	32.7	0.42039528
5/4/2008 23:10	32.7	0.3897096
5/4/2008 23:20	32.6	0.41357808
5/4/2008 23:30	32.6	0.43697184
5/4/2008 23:40	32.6	0.46216512
5/4/2008 23:50	32.6	0.4243752
5/5/2008 0:00	32.6	0.42077616

Date & Time	Fluorescein Dye (ppb)	Rhodamine WT Dye (ppb)
5/2/2008 14:00	0.001	0.001
5/2/2008 15:00	0.001	0.008
5/2/2008 16:00	0.001	0.007
5/2/2008 17:00	0.001	0.001
5/2/2008 18:00	0.001	0.001
5/2/2008 19:00	0.001	0.007
5/2/2008 20:00	0.001	0.001
5/2/2008 21:00	0.001	0.001
5/2/2008 22:00	0.001	0.001
5/2/2008 23:00	0.001	0.001
5/3/2008 0:00	0.005	0.001
5/3/2008 1:00	0.001	0.001
5/3/2008 2:00	0.004	0.004
5/3/2008 3:00	0.001	0.001
5/3/2008 4:00	0.001	0.001
5/3/2008 5:00	0.001	0.001
5/3/2008 6:00	0.001	0.01
5/3/2008 7:00	0.001	0.036
5/3/2008 8:00	0.048	0.001
5/3/2008 9:00	0.001	0.001
5/3/2008 10:00	0.001	0.096
5/3/2008 11:00	20.4	28.9
5/3/2008 12:00	5.805	5.503
5/3/2008 13:00	2.079	9.217
5/3/2008 14:00	1.103	3.004
5/3/2008 15:00	0.905	
5/3/2008 16:00	0.925	0.552
5/3/2008 17:00	0.983	0.546
5/3/2008 18:00	0.975	0.471
5/3/2008 18:00	0.995	0.459
5/3/2008 19:00	0.943	0.431
5/3/2008 20:00	0.869	0.368
5/3/2008 21:00	0.886	0.333
5/3/2008 22:00	0.858	0.319
5/3/2008 23:00	0.871	0.316
5/4/2008 0:00	0.899	0.298
5/4/2008 0:00	0.948	0.303
5/4/2008 1:00	0.902	0.285
5/4/2008 2:00	0.869	0.289
5/4/2008 3:00	0.869	0.277
5/4/2008 4:00	0.872	0.249

5/4/2008 5:00	0.846	0.24
5/4/2008 6:00	0.841	0.22
5/4/2008 6:00	0.837	0.221
5/4/2008 7:00	0.826	0.21
5/4/2008 8:00	0.81	0.206
5/4/2008 9:00	0.778	0.184
5/4/2008 10:00	0.791	0.184
5/4/2008 11:00	0.769	0.172
5/4/2008 12:00	0.792	0.156
5/4/2008 13:00	0.794	0.174
5/4/2008 14:00	0.743	0.165
5/4/2008 15:00	0.757	0.145
5/4/2008 16:00	0.807	0.143
5/4/2008 17:00	0.806	0.139
5/4/2008 18:00	0.804	0.128
5/4/2008 19:00	0.786	0.124
5/4/2008 20:00	0.789	0.124
5/4/2008 21:00	0.786	0.123
5/4/2008 22:00	0.775	0.115
5/5/2008 10:25	0.645	0.085
5/5/2008 13:30	0.607	0.081

APPENDIX C

Water Quality Data: May 2-5, 2008

Date & Time	Temperature (°C)	pH	spC (µS /cm)
5/2/08 12:00	13.35	7.9	307
5/2/08 12:10	13.35	7.91	306
5/2/08 12:20	13.35	7.92	306
5/2/08 12:30	13.35	7.94	307
5/2/08 12:40	13.35	7.94	307
5/2/08 12:50	13.35	7.91	307
5/2/08 13:00	13.35	7.92	306
5/2/08 13:10	13.35	7.92	307
5/2/08 13:20	13.34	7.91	306
5/2/08 13:30	13.35	7.91	306
5/2/08 13:40	13.35	7.92	306
5/2/08 13:50	13.35	7.94	306
5/2/08 14:00	13.35	7.94	307
5/2/08 14:10	13.35	7.94	306
5/2/08 14:20	13.35	7.94	307
5/2/08 14:30	13.35	7.94	307
5/2/08 14:40	13.35	7.94	306
5/2/08 14:50	13.35	7.94	307
5/2/08 15:00	13.35	7.94	306
5/2/08 15:10	13.35	7.94	307
5/2/08 15:20	13.35	7.93	306
5/2/08 15:30	13.35	7.93	307
5/2/08 15:40	13.35	7.93	307
5/2/08 15:50	13.35	7.93	307
5/2/08 16:00	13.35	7.93	306
5/2/08 16:10	13.35	7.93	306
5/2/08 16:20	13.35	7.93	307
5/2/08 16:30	13.35	7.93	307
5/2/08 16:40	13.35	7.92	307
5/2/08 16:50	13.35	7.84	307
5/2/08 17:00	13.35	7.85	307
5/2/08 17:10	13.35	7.82	307
5/2/08 17:20	13.35	7.82	307
5/2/08 17:30	13.35	7.82	307
5/2/08 17:40	13.35	7.82	307
5/2/08 17:50	13.35	7.83	307
5/2/08 18:00	13.35	7.83	307
5/2/08 18:10	13.35	7.84	307
5/2/08 18:20	13.35	7.84	307
5/2/08 18:30	13.35	7.86	307

5/2/08 18:40	13.35	7.85	307
5/2/08 18:50	13.35	7.87	307
5/2/08 19:00	13.35	7.88	307
5/2/08 19:10	13.35	7.88	307
5/2/08 19:20	13.35	7.89	308
5/2/08 19:30	13.35	7.88	308
5/2/08 19:40	13.35	7.87	307
5/2/08 19:50	13.35	7.88	308
5/2/08 20:00	13.35	7.88	307
5/2/08 20:10	13.35	7.89	307
5/2/08 20:20	13.35	7.89	308
5/2/08 20:30	13.35	7.88	308
5/2/08 20:40	13.35	7.9	308
5/2/08 20:50	13.35	7.9	307
5/2/08 21:00	13.35	7.86	308
5/2/08 21:10	13.35	7.84	307
5/2/08 21:20	13.35	7.84	308
5/2/08 21:30	13.35	7.85	307
5/2/08 21:40	13.35	7.87	307
5/2/08 21:50	13.35	7.85	308
5/2/08 22:00	13.35	7.86	308
5/2/08 22:10	13.35	7.86	308
5/2/08 22:20	13.35	7.86	308
5/2/08 22:30	13.35	7.86	308
5/2/08 22:40	13.35	7.85	308
5/2/08 22:50	13.35	7.85	308
5/2/08 23:00	13.35	7.85	308
5/2/08 23:10	13.35	7.85	308
5/2/08 23:20	13.35	7.85	308
5/2/08 23:30	13.35	7.85	308
5/2/08 23:40	13.35	7.85	308
5/2/08 23:50	13.35	7.85	308
5/3/08 0:00	13.35	7.85	308
5/3/08 0:10	13.35	7.85	308
5/3/08 0:20	13.35	7.85	308
5/3/08 0:30	13.35	7.85	308
5/3/08 0:40	13.35	7.85	308
5/3/08 0:50	13.35	7.85	308
5/3/08 1:00	13.35	7.85	308
5/3/08 1:10	13.35	7.86	308
5/3/08 1:20	13.35	7.86	308
5/3/08 1:30	13.35	7.87	308

5/3/08 1:40	13.35	7.88	308
5/3/08 1:50	13.35	7.88	308
5/3/08 2:00	13.35	7.9	308
5/3/08 2:10	13.35	7.91	308
5/3/08 2:20	13.35	7.91	308
5/3/08 2:30	13.35	7.92	308
5/3/08 2:40	13.35	7.92	308
5/3/08 2:50	13.35	7.93	308
5/3/08 3:00	13.35	7.93	309
5/3/08 3:10	13.35	7.93	309
5/3/08 3:20	13.35	7.92	309
5/3/08 3:30	13.35	7.91	308
5/3/08 3:40	13.35	7.9	309
5/3/08 3:50	13.35	7.9	308
5/3/08 4:00	13.35	7.89	308
5/3/08 4:10	13.35	7.89	308
5/3/08 4:20	13.35	7.89	309
5/3/08 4:30	13.35	7.88	308
5/3/08 4:40	13.35	7.88	308
5/3/08 4:50	13.35	7.88	308
5/3/08 5:00	13.35	7.88	308
5/3/08 5:10	13.35	7.86	309
5/3/08 5:20	13.35	7.85	309
5/3/08 5:30	13.35	7.85	308
5/3/08 5:40	13.34	7.83	306
5/3/08 5:50	13.31	7.82	300
5/3/08 6:00	13.27	7.81	292
5/3/08 6:10	13.25	7.8	291
5/3/08 6:20	13.16	7.77	289
5/3/08 6:30	13.05	7.71	272
5/3/08 6:40	13.01	7.65	241
5/3/08 6:50	13.06	7.6	217
5/3/08 7:00	13.11	7.59	211
5/3/08 7:10	13.15	7.57	201
5/3/08 7:20	13.19	7.52	189
5/3/08 7:30	13.21	7.51	192
5/3/08 7:40	13.15	7.5	194
5/3/08 7:50	13.02	7.48	189
5/3/08 8:00	12.89	7.46	182
5/3/08 8:10	12.82	7.45	181
5/3/08 8:20	12.79	7.44	181
5/3/08 8:30	12.78	7.42	180

5/3/08 8:40	12.82	7.41	185
5/3/08 8:50	12.86	7.41	188
5/3/08 9:00	12.82	7.36	173
5/3/08 9:10	12.8	7.33	169
5/3/08 9:20	12.86	7.35	190
5/3/08 9:30	12.95	7.37	206
5/3/08 9:40	12.98	7.35	199
5/3/08 9:50	12.98	7.31	185
5/3/08 10:00	13	7.28	179
5/3/08 10:10	13.01	7.26	179
5/3/08 10:20	13.03	7.25	177
5/3/08 10:30	13.05	7.24	180
5/3/08 10:40	13.08	7.24	185
5/3/08 10:50	13.13	7.24	193
5/3/08 11:00	13.16	7.25	199
5/3/08 11:10	13.19	7.25	204
5/3/08 11:20	13.21	7.25	206
5/3/08 11:30	13.23	7.25	209
5/3/08 11:40	13.24	7.25	211
5/3/08 11:50	13.25	7.25	213
5/3/08 12:00	13.26	7.26	214
5/3/08 12:10	13.27	7.26	214
5/3/08 12:20	13.28	7.25	215
5/3/08 12:30	13.28	7.25	215
5/3/08 12:40	13.29	7.25	215
5/3/08 12:50	13.29	7.48	214
5/3/08 13:00	13.3	7.48	214
5/3/08 13:10	13.3	7.47	213
5/3/08 13:20	13.3	7.47	213
5/3/08 13:30	13.3	7.46	213
5/3/08 13:40	13.3	7.46	211
5/3/08 13:50	13.3	7.45	210
5/3/08 14:00	13.31	7.45	208
5/3/08 14:10	13.31	7.44	205
5/3/08 14:20	13.31	7.43	203
5/3/08 14:30	13.31	7.43	201
5/3/08 14:40	13.32	7.42	198
5/3/08 14:50	13.32	7.42	197
5/3/08 15:00	13.33	7.41	196
5/3/08 15:10	13.33	7.4	194
5/3/08 15:20	13.33	7.4	193
5/3/08 15:30	13.33	7.4	192

5/3/08 15:40	13.33	7.4	192
5/3/08 15:50	13.33	7.4	191
5/3/08 16:00	13.33	7.39	191
5/3/08 16:10	13.33	7.39	192
5/3/08 16:20	13.34	7.38	191
5/3/08 16:30	13.33	7.38	192
5/3/08 16:40	13.33	7.38	193
5/3/08 16:50	13.33	7.38	193
5/3/08 17:00	13.34	7.38	193
5/3/08 17:10	13.33	7.38	194
5/3/08 17:20	13.33	7.38	194
5/3/08 17:30	13.33	7.37	194
5/3/08 17:40	13.34	7.37	194
5/3/08 17:50	13.33	7.38	193
5/3/08 18:00	13.33	7.38	193
5/3/08 18:10	13.33	7.38	192
5/3/08 18:20	13.33	7.37	192
5/3/08 18:30	13.33	7.37	192
5/3/08 18:40	13.33	7.37	190
5/3/08 18:50	13.33	7.37	190
5/3/08 19:00	13.33	7.37	189
5/3/08 19:10	13.33	7.37	190
5/3/08 19:20	13.32	7.37	189
5/3/08 19:30	13.32	7.37	189
5/3/08 19:40	13.32	7.37	188
5/3/08 19:50	13.32	7.37	188
5/3/08 20:00	13.32	7.37	187
5/3/08 20:10	13.31	7.37	187
5/3/08 20:20	13.31	7.36	187
5/3/08 20:30	13.31	7.37	188
5/3/08 20:40	13.31	7.37	187
5/3/08 20:50	13.31	7.36	187
5/3/08 21:00	13.31	7.36	187
5/3/08 21:10	13.31	7.37	187
5/3/08 21:20	13.3	7.38	187
5/3/08 21:30	13.3	7.38	187
5/3/08 21:40	13.3	7.38	187
5/3/08 21:50	13.3	7.39	187
5/3/08 22:00	13.3	7.39	187
5/3/08 22:10	13.3	7.39	188
5/3/08 22:20	13.3	7.39	187
5/3/08 22:30	13.3	7.39	187

5/3/08 22:40	13.3	7.39	187
5/3/08 22:50	13.3	7.39	188
5/3/08 23:00	13.3	7.39	188
5/3/08 23:10	13.3	7.4	188
5/3/08 23:20	13.3	7.4	188
5/3/08 23:30	13.3	7.4	188
5/3/08 23:40	13.29	7.4	189
5/3/08 23:50	13.3	7.43	189
5/4/08 0:00	13.3	7.44	189
5/4/08 0:10	13.3	7.43	190
5/4/08 0:20	13.3	7.44	190
5/4/08 0:30	13.3	7.44	190
5/4/08 0:40	13.3	7.44	190
5/4/08 0:50	13.3	7.43	191
5/4/08 1:00	13.3	7.44	192
5/4/08 1:10	13.3	7.44	192
5/4/08 1:20	13.29	7.44	192
5/4/08 1:30	13.3	7.44	192
5/4/08 1:40	13.3	7.44	192
5/4/08 1:50	13.29	7.44	193
5/4/08 2:00	13.29	7.44	193
5/4/08 2:10	13.29	7.44	194
5/4/08 2:20	13.3	7.44	194
5/4/08 2:30	13.3	7.44	194
5/4/08 2:40	13.29	7.44	194
5/4/08 2:50	13.29	7.44	195
5/4/08 3:00	13.29	7.44	195
5/4/08 3:10	13.29	7.44	196
5/4/08 3:20	13.29	7.44	196
5/4/08 3:30	13.29	7.45	196
5/4/08 3:40	13.29	7.44	196
5/4/08 3:50	13.29	7.44	197
5/4/08 4:00	13.29	7.45	198
5/4/08 4:10	13.29	7.45	198
5/4/08 4:20	13.29	7.45	198
5/4/08 4:30	13.29	7.45	199
5/4/08 4:40	13.29	7.45	198
5/4/08 4:50	13.29	7.46	199
5/4/08 5:00	13.29	7.45	200
5/4/08 5:10	13.29	7.45	199
5/4/08 5:20	13.29	7.46	199
5/4/08 5:30	13.29	7.46	200

5/4/08 5:40	13.29	7.46	201
5/4/08 5:50	13.29	7.46	201
5/4/08 6:00	13.28	7.46	201
5/4/08 6:10	13.28	7.46	201
5/4/08 6:20	13.28	7.46	202
5/4/08 6:30	13.28	7.47	202
5/4/08 6:40	13.28	7.47	202
5/4/08 6:50	13.28	7.47	202
5/4/08 7:00	13.28	7.47	203
5/4/08 7:10	13.28	7.47	203
5/4/08 7:20	13.28	7.47	203
5/4/08 7:30	13.28	7.47	203
5/4/08 7:40	13.28	7.47	204
5/4/08 7:50	13.28	7.48	204
5/4/08 8:00	13.28	7.47	204
5/4/08 8:10	13.27	7.48	204
5/4/08 8:20	13.27	7.48	205
5/4/08 8:30	13.27	7.48	205
5/4/08 8:40	13.27	7.48	205
5/4/08 8:50	13.27	7.48	205
5/4/08 9:00	13.27	7.48	206
5/4/08 9:10	13.27	7.48	205
5/4/08 9:20	13.27	7.49	205
5/4/08 9:30	13.27	7.49	206
5/4/08 9:40	13.27	7.49	207
5/4/08 9:50	13.26	7.49	206
5/4/08 10:00	13.26	7.49	207
5/4/08 10:10	13.27	7.49	207
5/4/08 10:20	13.27	7.49	207
5/4/08 10:30	13.26	7.5	207
5/4/08 10:40	13.26	7.5	207
5/4/08 10:50	13.26	7.5	208
5/4/08 11:00	13.26	7.5	208
5/4/08 11:10	13.26	7.5	208
5/4/08 11:20	13.26	7.5	209
5/4/08 11:30	13.26	7.5	209
5/4/08 11:40	13.26	7.51	209
5/4/08 11:50	13.26	7.5	209
5/4/08 12:00	13.26	7.51	210
5/4/08 12:10			209
5/4/08 12:20			210
5/4/08 12:30			210

5/4/08 12:40	211
5/4/08 12:50	210
5/4/08 13:00	211
5/4/08 13:10	212
5/4/08 13:20	211
5/4/08 13:30	212
5/4/08 13:40	212
5/4/08 13:50	212
5/4/08 14:00	213
5/4/08 14:10	212
5/4/08 14:20	213
5/4/08 14:30	213
5/4/08 14:40	213
5/4/08 14:50	214
5/4/08 15:00	214
5/4/08 15:10	214
5/4/08 15:20	214
5/4/08 15:30	214
5/4/08 15:40	215
5/4/08 15:50	215
5/4/08 16:00	215
5/4/08 16:10	216
5/4/08 16:20	216
5/4/08 16:30	217
5/4/08 16:40	217
5/4/08 16:50	216
5/4/08 17:00	217
5/4/08 17:10	217
5/4/08 17:20	218
5/4/08 17:30	218
5/4/08 17:40	218
5/4/08 17:50	218
5/4/08 18:00	218
5/4/08 18:10	218
5/4/08 18:20	219
5/4/08 18:30	219
5/4/08 18:40	220
5/4/08 18:50	219
5/4/08 19:00	220
5/4/08 19:10	220
5/4/08 19:20	220
5/4/08 19:30	221

5/4/08 19:40	221
5/4/08 19:50	222
5/4/08 20:00	221
5/4/08 20:10	222
5/4/08 20:20	222
5/4/08 20:30	223
5/4/08 20:40	223
5/4/08 20:50	223
5/4/08 21:00	223
5/4/08 21:10	223
5/4/08 21:20	224
5/4/08 21:30	224
5/4/08 21:40	224
5/4/08 21:50	224
5/4/08 22:00	224
5/4/08 22:10	224
5/4/08 22:20	225
5/4/08 22:30	225
5/4/08 22:40	225
5/4/08 22:50	225
5/4/08 23:00	225
5/4/08 23:10	226
5/4/08 23:20	226
5/4/08 23:30	226
5/4/08 23:40	226
5/4/08 23:50	227
5/5/08 0:00	227
5/5/08 0:10	227
5/5/08 0:20	227
5/5/08 0:30	228
5/5/08 0:40	227
5/5/08 0:50	228
5/5/08 1:00	228
5/5/08 1:10	229
5/5/08 1:20	228
5/5/08 1:30	229
5/5/08 1:40	229
5/5/08 1:50	229
5/5/08 2:00	229
5/5/08 2:10	230
5/5/08 2:20	230
5/5/08 2:30	231

5/5/08 2:40	230
5/5/08 2:50	231
5/5/08 3:00	231
5/5/08 3:10	231
5/5/08 3:20	232
5/5/08 3:30	232
5/5/08 3:40	232
5/5/08 3:50	232
5/5/08 4:00	232
5/5/08 4:10	233
5/5/08 4:20	233
5/5/08 4:30	233
5/5/08 4:40	234
5/5/08 4:50	234
5/5/08 5:00	234
5/5/08 5:10	234
5/5/08 5:20	234
5/5/08 5:30	234
5/5/08 5:40	234
5/5/08 5:50	235
5/5/08 6:00	235
5/5/08 6:10	235
5/5/08 6:20	235
5/5/08 6:30	235
5/5/08 6:40	236
5/5/08 6:50	236
5/5/08 7:00	236
5/5/08 7:10	237
5/5/08 7:20	236
5/5/08 7:30	237
5/5/08 7:40	237
5/5/08 7:50	238
5/5/08 8:00	237
5/5/08 8:10	238
5/5/08 8:20	238
5/5/08 8:30	238
5/5/08 8:40	238
5/5/08 8:50	238
5/5/08 9:00	238
5/5/08 9:10	238
5/5/08 9:20	239
5/5/08 9:30	239

5/5/08 9:40	240
5/5/08 9:50	239
5/5/08 10:00	239
5/5/08 10:10	240
5/5/08 10:20	240
5/5/08 10:30	240
5/5/08 10:40	241
5/5/08 10:50	241
5/5/08 11:00	241
5/5/08 11:10	241
5/5/08 11:20	241
5/5/08 11:30	242
5/5/08 11:40	242
5/5/08 11:50	241
5/5/08 12:00	242

APPENDIX D

Sediment Analysis Data: May 2-5, 2008

Date & Time	Joe Ray Weir Atrazine (ppb)
5/3/2008 0:00	0
5/3/2008 1:00	0
5/3/2008 2:00	0
5/3/2008 3:00	0
5/3/2008 4:00	0
5/3/2008 5:00	0
5/3/2008 6:00	14.4
5/3/2008 7:00	22
5/3/2008 8:00	43.7
5/3/2008 9:00	>50
5/3/2008 10:00	21.2
5/3/2008 11:00	50
5/3/2008 12:00	50
5/3/2008 13:00	24.4
5/3/2008 14:00	24.4
5/3/2008 15:00	22.4
5/3/2008 16:00	21.6
5/3/2008 17:00	21.6
5/3/2008 18:00	18.6
5/3/2008 19:00	21
5/3/2008 20:00	16.4
5/3/2008 21:00	16.6
5/3/2008 22:00	19.3
5/3/2008 23:00	19
5/4/2008 0:00	17.1
5/4/2008 1:00	17
5/4/2008 2:00	17
5/4/2008 3:00	20.1
5/4/2008 4:00	18.1
5/4/2008 5:00	12.4
5/4/2008 6:00	21.4

Date & Time	LRW Filtered Atrazine (ppb)
5/3/2008 6:00	0
5/3/2008 7:00	0
5/3/2008 8:00	0
5/3/2008 9:00	0
5/3/2008 10:00	0.68
5/3/2008 11:00	0.42
5/3/2008 12:00	1.54
5/3/2008 13:00	1.55
5/3/2008 14:00	1.71
5/3/2008 15:00	2.31
5/3/2008 16:00	2.43

Date & Time	LRW Unfiltered Atrazine (ppb)
5/2/2008 14:00	0
5/2/2008 15:00	0
5/2/2008 16:00	0
5/2/2008 17:00	0
5/2/2008 18:00	0
5/2/2008 19:00	0
5/2/2008 20:00	0
5/2/2008 21:00	0
5/2/2008 22:00	0
5/2/2008 23:00	0
5/3/2008 0:00	0
5/3/2008 1:00	0
5/3/2008 2:00	0
5/3/2008 3:00	0
5/3/2008 4:00	0
5/3/2008 5:00	0
5/3/2008 6:00	0
5/3/2008 7:00	0.87
5/3/2008 8:00	0
5/3/2008 9:00	0
5/3/2008 10:00	0.62
5/3/2008 11:00	0.33
5/3/2008 12:00	1.3
5/3/2008 13:00	1.25
5/3/2008 14:00	1.4
5/3/2008 15:00	1.55

5/3/2008 16:00	2.17
5/3/2008 17:00	2.32
5/3/2008 18:00	2.57
5/3/2008 18:00	2.63
5/3/2008 19:00	3.28
5/3/2008 20:00	2.56
5/3/2008 21:00	2.28
5/3/2008 22:00	2.05
5/3/2008 23:00	2.32
5/4/2008 0:00	2.12
5/4/2008 0:00	2.65
5/4/2008 1:00	2.98
5/4/2008 2:00	1.97
5/4/2008 3:00	2.22
5/4/2008 4:00	2.02
5/4/2008 5:00	2.39
5/4/2008 6:00	2.56
5/4/2008 6:00	2.39
5/4/2008 7:00	1.91
5/4/2008 8:00	1.8
5/4/2008 9:00	1.71
5/4/2008 10:00	1.69
5/4/2008 11:00	1.72
5/4/2008 12:00	1.72
5/4/2008 13:00	1.91
5/4/2008 14:00	1.87
5/4/2008 15:00	2
5/4/2008 16:00	1.75
5/4/2008 17:00	1.71
5/4/2008 18:00	1.58
5/4/2008 19:00	1.83
5/4/2008 20:00	1.6
5/4/2008 21:00	1.82
5/4/2008 22:00	1.95
5/5/2008 10:25	1.53
5/5/2008 13:30	1.68

Date & Time	Turbidity (NTU)	TSS (mg/L)	Sand Fraction (µm)	Sediment Conc. (ppm)	SMD (µm)
5/3/2008 0:00	0	2	2.938		
5/3/2008 0:10	0		2.988		
5/3/2008 0:20	0		2.962		
5/3/2008 0:30	0		2.949		
5/3/2008 0:40	0		2.944		
5/3/2008 0:50	0		2.98		
5/3/2008 1:00	0	1.6	3.034		
5/3/2008 1:10	0		3.03		
5/3/2008 1:20	0		3.017		
5/3/2008 1:30	0		2.996		
5/3/2008 1:40	0		3.117		
5/3/2008 1:50	0		3.106		
5/3/2008 2:00	0	2.4	3.164		
5/3/2008 2:10	0		3.093		
5/3/2008 2:20	0		3.049		
5/3/2008 2:30	0		3.056		
5/3/2008 2:40	0		3.161		
5/3/2008 2:50	0		3.152		
5/3/2008 3:00	0	2.5	3.216		
5/3/2008 3:10	0		3.178		
5/3/2008 3:20	0		3.16		
5/3/2008 3:30	0		3.144		
5/3/2008 3:40	0		3.206		
5/3/2008 3:50	0		3.191		
5/3/2008 4:00	0	2.5	3.223		
5/3/2008 4:10	0		3.228		
5/3/2008 4:20	0		3.066		
5/3/2008 4:30	0		3.061		
5/3/2008 4:40	0		3.049		
5/3/2008 4:50	0		2.848		
5/3/2008 5:00	0	2	2.896		
5/3/2008 5:10	0		2.995		
5/3/2008 5:20	1.8		5.607	8.463	
5/3/2008 5:30	23.7		12.844	23.809	
5/3/2008 5:40	16.3		15.758	30.197	
5/3/2008 5:50	18.4		15.741	33.326	
5/3/2008 6:00	34.4	97.2	18.152	44.592	16.327
5/3/2008 6:10	36.9		19.649	47.949	16.688
5/3/2008 6:20	44.9		21.284	57.075	14.904
5/3/2008 6:30	84		26.607	91.5	10.862
5/3/2008 6:40	157		31.779	138.317	8.922

5/3/2008 6:50	172.5		34.684	146.914	8.95
5/3/2008 7:00	159.4	541.7	32.016	132.932	9.235
5/3/2008 7:10	156.1		33.68	135.182	9.591
5/3/2008 7:20	170.2		35.833	147.478	9.356
5/3/2008 7:30	280		40.647	226.709	6.742
5/3/2008 7:40	445		42.544	340.842	5.531
5/3/2008 7:50	406		50.521	308.915	6.392
5/3/2008 8:00	345.9	185.7	59.502	288.987	7.628
5/3/2008 8:10	314		65.374	270.893	8.669
5/3/2008 8:20	284.3		65.096	247.719	9.503
5/3/2008 8:30	269.2		66.799	236.62	10.247
5/3/2008 8:40	244.1		66.09	222.205	11.006
5/3/2008 8:50	228.1		67.842	223.589	11.285
5/3/2008 9:00	242	194.3	71.444	242.346	10.983
5/3/2008 9:10	230.6		70.848	233.862	11.536
5/3/2008 9:20	195.3		67.261	209.981	12.44
5/3/2008 9:30	182		63.368	201.757	12.102
5/3/2008 9:40	201.2		60.683	212.485	10.706
5/3/2008 9:50	223.4		58.112	221.047	9.797
5/3/2008 10:00	221.7	262.5	55.289	216.166	9.575
5/3/2008 10:10	216.2		55.003	214.393	9.737
5/3/2008 10:20	212.3		52.407	212.988	9.7
5/3/2008 10:30	208.9		51.464	207.441	9.943
5/3/2008 10:40	195.8		48.47	190.667	10.305
5/3/2008 10:50	173.9		45.113	172.42	10.721
5/3/2008 11:00	159.3	218.2	42.183	156.694	11.071
5/3/2008 11:10	145.7		39.771	144.331	11.296
5/3/2008 11:20	135.3		36.403	133.283	11.375
5/3/2008 11:30	126.2		34.019	123.246	11.511
5/3/2008 11:40	117.3		31.497	113.701	11.639
5/3/2008 11:50	109.5		29.325	104.76	11.764
5/3/2008 12:00	100.8	184.7	26.972	97.101	11.793
5/3/2008 12:10	95.9		25.561	91.628	11.841
5/3/2008 12:20	92		24.05	86.905	11.76
5/3/2008 12:30	89.9		22.651	82.935	11.662
5/3/2008 12:40	87.5		21.988	80.13	11.614
5/3/2008 12:50	83.8		20.956	77.262	11.523
5/3/2008 13:00	83.1	167.2	20.21	74.635	11.429
5/3/2008 13:10	80		19.157	72.122	11.306
5/3/2008 13:20	79.8		18.869	70.568	11.242
5/3/2008 13:30	78.5		17.632	68.657	10.99
5/3/2008 13:40	79.3		17.553	68.405	10.839
5/3/2008 13:50	80.5		17.105	68.459	10.58

5/3/2008 14:00	83	96.2	16.646	68.797	10.288
5/3/2008 14:10	86.4		16.375	69.171	10.031
5/3/2008 14:20	87.2		16.351	69.656	9.796
5/3/2008 14:30	89.5		15.827	69.421	9.541
5/3/2008 14:40	92		15.644	69.026	9.394
5/3/2008 14:50	92.9		15.334	68.037	9.232
5/3/2008 15:00	93	64.6	14.61	66.348	9.063
5/3/2008 15:10	93.4		14.247	64.815	8.972
5/3/2008 15:20	92.6		13.501	62.779	8.837
5/3/2008 15:30	91.2		12.728	60.763	8.695
5/3/2008 15:40	89.7		12.744	59.45	8.657
5/3/2008 15:50	90		12.295	57.589	8.568
5/3/2008 16:00	88.9	58.4	11.791	55.79	8.492
5/3/2008 16:10	86.4		11.303	53.925	8.452
5/3/2008 16:20	85.1		11.099	52.339	8.423
5/3/2008 16:30	82.6		10.55	50.339	8.364
5/3/2008 16:40	80.2		10.256	48.727	8.348
5/3/2008 16:50	77.7		9.91	47.004	8.306
5/3/2008 17:00	76.5	50.7	9.616	45.543	8.304
5/3/2008 17:10	73.9		8.983	43.776	8.239
5/3/2008 17:20	72.1		8.82	42.392	8.249
5/3/2008 17:30	71.1		8.619	41.076	8.207
5/3/2008 17:40	69.5		8.512	39.883	8.222
5/3/2008 17:50	68.1		8.429	38.743	8.217
5/3/2008 18:00	66.5	74.6	8.049	37.448	8.155
5/3/2008 18:10	65.5		7.68	36.057	8.077
5/3/2008 18:20	64.3		7.614	35.09	8.056
5/3/2008 18:30	63.1		7.499	34.155	8.024
5/3/2008 18:40	62		7.25	33.154	7.968
5/3/2008 18:50	61.4		7.083	32.15	7.906
5/3/2008 19:00	60.2	53.3	6.764	31.157	7.827
5/3/2008 19:10	60.4		6.654	30.359	7.796
5/3/2008 19:20	58.8		6.715	29.76	7.802
5/3/2008 19:30	58.3		6.185	28.691	7.676
5/3/2008 19:40	57.9		6.192	28.197	7.682
5/3/2008 19:50	56.7		5.842	27.256	7.592
5/3/2008 20:00	55.7	45	5.805	26.742	7.577
5/3/2008 20:10	55.8		5.577	26.003	7.52
5/3/2008 20:20	54		5.566	25.529	7.532
5/3/2008 20:30	53.6		5.482	24.983	7.515
5/3/2008 20:40	52.6		5.121	24.198	7.43
5/3/2008 20:50	51.9		5.238	23.832	7.471

5/3/2008 21:00	51.2	42.5	5.132	23.299	7.421
5/3/2008 21:10	50.7		5.048	22.748	7.404
5/3/2008 21:20	49.7		4.935	22.304	7.385
5/3/2008 21:30	49.6		5.021	22.043	7.404
5/3/2008 21:40	49.2		4.815	21.56	7.352
5/3/2008 21:50	47.8		4.75	21.148	7.34
5/3/2008 22:00	47.8	37.4	4.746	20.787	7.302
5/3/2008 22:10	47.8		4.665	20.454	7.285
5/3/2008 22:20	47.4		4.52	20.102	7.231
5/3/2008 22:30	46.2		4.52	19.829	7.222
5/3/2008 22:40	47		4.461	19.474	7.189
5/3/2008 22:50	46		4.349	19.171	7.149
5/3/2008 23:00	45.5	37.9	4.309	18.947	7.145
5/3/2008 23:10	45.5		4.349	18.781	7.151
5/3/2008 23:20	45.3		4.285	18.443	7.114
5/3/2008 23:30	44.4		4.262	18.21	7.12
5/3/2008 23:40	44.8		4.229	17.991	7.113
5/3/2008 23:50	44.2		4.212	17.721	7.088
5/4/2008 0:00	43.6	44.9	4.152	17.467	7.062
5/4/2008 0:10	43.3				
5/4/2008 0:20	43.2				
5/4/2008 0:30	42.9				
5/4/2008 0:40	42.6				
5/4/2008 0:50	43.2				
5/4/2008 1:00	42.3				
5/4/2008 1:10	41.8				
5/4/2008 1:20	41.4				
5/4/2008 1:30	41.2				
5/4/2008 1:40	40.9				
5/4/2008 1:50	40.5				
5/4/2008 2:00	41				
5/4/2008 2:10	40.7				
5/4/2008 2:20	39.9				
5/4/2008 2:30	40.3				
5/4/2008 2:40	39.8				
5/4/2008 2:50	40				
5/4/2008 3:00	39.2				
5/4/2008 3:10	38.9				
5/4/2008 3:20	39.5				
5/4/2008 3:30	39.2				
5/4/2008 3:40	39.1				
5/4/2008 3:50	38.4				

5/4/2008 4:00	38
5/4/2008 4:10	37.9
5/4/2008 4:20	37.9
5/4/2008 4:30	37.4
5/4/2008 4:40	37.3
5/4/2008 4:50	37.2
5/4/2008 5:00	37
5/4/2008 5:10	37
5/4/2008 5:20	36.6
5/4/2008 5:30	36.5
5/4/2008 5:40	36.1
5/4/2008 5:50	36
5/4/2008 6:00	35.6
5/4/2008 6:10	35.4
5/4/2008 6:20	36.1
5/4/2008 6:30	35.1
5/4/2008 6:40	35.3
5/4/2008 6:50	34.4
5/4/2008 7:00	34.3
5/4/2008 7:10	33.7
5/4/2008 7:20	33.8
5/4/2008 7:30	34
5/4/2008 7:40	33.7
5/4/2008 7:50	33.6
5/4/2008 8:00	33.6
5/4/2008 8:10	32.9
5/4/2008 8:20	32.6
5/4/2008 8:30	31.9
5/4/2008 8:40	32.2
5/4/2008 8:50	32.3
5/4/2008 9:00	32.3
5/4/2008 9:10	32.1
5/4/2008 9:20	31.3
5/4/2008 9:30	31.9
5/4/2008 9:40	31
5/4/2008 9:50	31
5/4/2008 10:00	30.9
5/4/2008 10:10	30.4
5/4/2008 10:20	30.1
5/4/2008 10:30	30
5/4/2008 10:40	29.8
5/4/2008 10:50	29.3

5/4/2008 11:00	29.4
5/4/2008 11:10	29.2
5/4/2008 11:20	29.2
5/4/2008 11:30	28.8
5/4/2008 11:40	28.5
5/4/2008 11:50	27.9
5/4/2008 12:00	28.4
5/4/2008 12:10	28.1
5/4/2008 12:20	27.6
5/4/2008 12:30	27.5
5/4/2008 12:40	27.6
5/4/2008 12:50	28
5/4/2008 13:00	27.2
5/4/2008 13:10	27.4
5/4/2008 13:20	26.6
5/4/2008 13:30	27.1
5/4/2008 13:40	26.4
5/4/2008 13:50	26.2
5/4/2008 14:00	26.6
5/4/2008 14:10	26.2
5/4/2008 14:20	25.4
5/4/2008 14:30	25.7
5/4/2008 14:40	26
5/4/2008 14:50	25
5/4/2008 15:00	25.1
5/4/2008 15:10	24.7
5/4/2008 15:20	24.5
5/4/2008 15:30	24.7
5/4/2008 15:40	25
5/4/2008 15:50	24.4
5/4/2008 16:00	24.2
5/4/2008 16:10	24.2
5/4/2008 16:20	23.9
5/4/2008 16:30	24.6
5/4/2008 16:40	24.1
5/4/2008 16:50	23.8
5/4/2008 17:00	24
5/4/2008 17:10	23.9
5/4/2008 17:20	23.5
5/4/2008 17:30	23.6
5/4/2008 17:40	23.6
5/4/2008 17:50	23.1

5/4/2008 18:00	23.1
5/4/2008 18:10	22.9
5/4/2008 18:20	23.1
5/4/2008 18:30	23
5/4/2008 18:40	22.9
5/4/2008 18:50	22.7
5/4/2008 19:00	22.5
5/4/2008 19:10	22.4
5/4/2008 19:20	22.5
5/4/2008 19:30	22.5
5/4/2008 19:40	22.6
5/4/2008 19:50	22.3
5/4/2008 20:00	22.3
5/4/2008 20:10	22.1
5/4/2008 20:20	21.7
5/4/2008 20:30	21.6
5/4/2008 20:40	21.8
5/4/2008 20:50	21.9
5/4/2008 21:00	21.3
5/4/2008 21:10	21.6
5/4/2008 21:20	21.2
5/4/2008 21:30	21
5/4/2008 21:40	20.7
5/4/2008 21:50	20.6
5/4/2008 22:00	20.9
5/4/2008 22:10	20.4
5/4/2008 22:20	20.1
5/4/2008 22:30	20
5/4/2008 22:40	20
5/4/2008 22:50	19.7
5/4/2008 23:00	20.1
5/4/2008 23:10	20
5/4/2008 23:20	19.8
5/4/2008 23:30	19.4
5/4/2008 23:40	19.6
5/4/2008 23:50	19.7
5/5/2008 0:00	19.2
5/5/2008 0:10	19.2
5/5/2008 0:20	19.2
5/5/2008 0:30	19
5/5/2008 0:40	19
5/5/2008 0:50	18.9

5/5/2008 1:00	18.8
5/5/2008 1:10	19.2
5/5/2008 1:20	18.8
5/5/2008 1:30	18.3
5/5/2008 1:40	18.9
5/5/2008 1:50	18.8
5/5/2008 2:00	18.3
5/5/2008 2:10	18.4
5/5/2008 2:20	18.7
5/5/2008 2:30	18
5/5/2008 2:40	18.1
5/5/2008 2:50	18.1
5/5/2008 3:00	18
5/5/2008 3:10	17.7
5/5/2008 3:20	17.5
5/5/2008 3:30	18
5/5/2008 3:40	17.6
5/5/2008 3:50	17.8
5/5/2008 4:00	17.3
5/5/2008 4:10	17.9
5/5/2008 4:20	17.3
5/5/2008 4:30	17.2
5/5/2008 4:40	17.1
5/5/2008 4:50	17.5
5/5/2008 5:00	17.1
5/5/2008 5:10	17.5
5/5/2008 5:20	17.1
5/5/2008 5:30	17
5/5/2008 5:40	17.1
5/5/2008 5:50	16.7
5/5/2008 6:00	16.5
5/5/2008 6:10	16.9
5/5/2008 6:20	16.1
5/5/2008 6:30	16.5
5/5/2008 6:40	16.4
5/5/2008 6:50	16.2
5/5/2008 7:00	16.4
5/5/2008 7:10	16.4
5/5/2008 7:20	16
5/5/2008 7:30	16.1
5/5/2008 7:40	15.7
5/5/2008 7:50	16.1

5/5/2008 8:00	16.3
5/5/2008 8:10	15.5
5/5/2008 8:20	16.2
5/5/2008 8:30	15.9
5/5/2008 8:40	15.4
5/5/2008 8:50	15.2
5/5/2008 9:00	15.4
5/5/2008 9:10	15.1
5/5/2008 9:20	15.2
5/5/2008 9:30	15.4
5/5/2008 9:40	15.4
5/5/2008 9:50	15.2
5/5/2008 10:00	15.2
5/5/2008 10:10	15.2
5/5/2008 10:20	14.9
5/5/2008 10:30	15.4
5/5/2008 10:40	14.6
5/5/2008 10:50	14.6
5/5/2008 11:00	11.9
5/5/2008 11:10	11.8
5/5/2008 11:20	11.9
5/5/2008 11:30	11.8
5/5/2008 11:40	11.7
5/5/2008 11:50	11.3
5/5/2008 12:00	11.7

APPENDIX E

Precipitation Data from NRCS Hamilton Valley and

Houchins Meadow Air Quality Stations:

May 27-29, 2008

Date and Time	Total Precipitation (mm): Hamilton Valley	Total Precipitation (mm): Houchins Meadow
5/27/08 0:00	0	0
5/27/08 1:00	0	0
5/27/08 2:00	0	0
5/27/08 3:00	0	0
5/27/08 4:00	0	0
5/27/08 5:00	0	0
5/27/08 6:00	0	0
5/27/08 7:00	0	0
5/27/08 8:00	0	0
5/27/08 9:00	0	0
5/27/08 10:00	0	0
5/27/08 11:00	0	0
5/27/08 12:00	0	0
5/27/08 13:00	0	0
5/27/08 14:00	0	0
5/27/08 15:00	0	0
5/27/08 16:00	0	6.39998
5/27/08 17:00	0	7.1998
5/27/08 18:00	0	0
5/27/08 19:00	23.114	0.199999
5/27/08 20:00	0	0.099999
5/27/08 21:00	0.254	0
5/27/08 22:00	0	0
5/27/08 23:00	0	0
5/28/08 0:00	0	0
5/28/08 1:00	0	0
5/28/08 2:00	0	0
5/28/08 3:00	0	0
5/28/08 4:00	0	1.7999
5/28/08 5:00	1.106	6.69998
5/28/08 6:00	1.524	1.89999
5/28/08 7:00	0.254	0.299999
5/28/08 8:00	0	0
5/28/08 9:00	0	0
5/28/08 10:00	0	0
5/28/08 11:00	0	0
5/28/08 12:00	0	0
5/28/08 13:00	0	0
5/28/08 14:00	0	0

5/28/08 15:00	0	0
5/28/08 16:00	0	0
5/28/08 17:00	0	0
5/28/08 18:00	0	0
5/28/08 19:00	0	0
5/28/08 20:00	0	0
5/28/08 21:00	0	0
5/28/08 22:00	0	0
5/28/08 23:00	0	0
5/29/08 0:00	0	0

APPENDIX F

Hydrologic Response Data: May 27-29, 2008

Date & Time	Logsdon River Stage (cm)	Logsdon River Flow Rate (m^3/ s)
5/27/08 12:00	25.4	0.113533
5/27/08 12:10	25.4	0.114935
5/27/08 12:20	25.4	0.130358
5/27/08 12:30	25.3	0.117104
5/27/08 12:40	25.3	0.121294
5/27/08 12:50	25.3	0.142242
5/27/08 13:00	25.3	0.125484
5/27/08 13:10	25.3	0.128277
5/27/08 13:20	25.3	0.128277
5/27/08 13:30	25.3	0.132467
5/27/08 13:40	25.3	0.119898
5/27/08 13:50	25.3	0.104535
5/27/08 14:00	25.3	0.122691
5/27/08 14:10	25.2	0.110905
5/27/08 14:20	25.2	0.07752
5/27/08 14:30	25.2	0.120643
5/27/08 14:40	25.2	0.135944
5/27/08 14:50	25.2	0.106732
5/27/08 15:00	25.2	0.115079
5/27/08 15:10	25.2	0.109514
5/27/08 15:20	25.2	0.119252
5/27/08 15:30	25.2	0.126207
5/27/08 15:40	25.2	0.128989
5/27/08 15:50	25.1	0.132461
5/27/08 16:00	25.1	0.110293
5/27/08 16:10	25.1	0.106136
5/27/08 16:20	25	0.1359
5/27/08 16:30	25	0.11796
5/27/08 16:40	25	0.11658
5/27/08 16:50	25	0.1152
5/27/08 17:00	25	0.11382
5/27/08 17:10	24.9	0.132433
5/27/08 17:20	24.9	0.11594
5/27/08 17:30	24.8	0.102979
5/27/08 17:40	24.8	0.112561
5/27/08 17:50	24.8	0.102979
5/27/08 18:00	24.8	0.134465
5/27/08 18:10	24.8	0.11393
5/27/08 18:20	24.8	0.118037
5/27/08 18:30	24.8	0.100241
5/27/08 18:40	24.8	0.109824

5/27/08 18:50	24.7	0.105115
5/27/08 19:00	24.7	0.106478
5/27/08 19:10	24.7	0.113296
5/27/08 19:20	24.7	0.094207
5/27/08 19:30	24.7	0.102388
5/27/08 19:40	24.7	0.106478
5/27/08 19:50	24.8	0.123513
5/27/08 20:00	25.1	0.104751
5/27/08 20:10	25.3	0.100346
5/27/08 20:20	25.5	0.118374
5/27/08 20:30	25.6	0.109117
5/27/08 20:40	25.8	0.127399
5/27/08 20:50	26.3	0.135066
5/27/08 21:00	26.6	0.151787
5/27/08 21:10	26.8	0.16509
5/27/08 21:20	27	0.154723
5/27/08 21:30	27.6	0.209404
5/27/08 21:40	27.9	0.210613
5/27/08 21:50	28.5	0.211358
5/27/08 22:00	29.4	0.256733
5/27/08 22:10	31.4	0.37422
5/27/08 22:20	35.7	0.610752
5/27/08 22:30	41.5	1.019431
5/27/08 22:40	46.8	1.395432
5/27/08 22:50	51	1.820162
5/27/08 23:00	54.3	2.111602
5/27/08 23:10	56.6	2.359102
5/27/08 23:20	58.1	2.522196
5/27/08 23:30	59.1	2.598979
5/27/08 23:40	59.5	2.679268
5/27/08 23:50	59.7	2.671943
5/28/08 0:00	59.8	2.749112
5/28/08 0:10	59.7	2.698306
5/28/08 0:20	59.5	2.662846
5/28/08 0:30	59.4	2.651739
5/28/08 0:40	58.9	2.570529
5/28/08 0:50	58.4	2.528997
5/28/08 1:00	58.1	2.515782
5/28/08 1:10	57.4	2.456431
5/28/08 1:20	57.1	2.367719
5/28/08 1:30	56.5	2.32055
5/28/08 1:40	56	2.287265

5/28/08 1:50	55.6	2.239925
5/28/08 2:00	54.9	2.196025
5/28/08 2:10	54.7	2.160691
5/28/08 2:20	53.9	2.101677
5/28/08 2:30	53.6	2.009852
5/28/08 2:40	53	1.95761
5/28/08 2:50	52.5	1.935834
5/28/08 3:00	52.2	1.910116
5/28/08 3:10	51.5	1.838434
5/28/08 3:20	51.2	1.779425
5/28/08 3:30	50.6	1.797166
5/28/08 3:40	50.2	1.710568
5/28/08 3:50	49.9	1.730385
5/28/08 4:00	49.3	1.632858
5/28/08 4:10	49	1.603723
5/28/08 4:20	48.6	1.590276
5/28/08 4:30	48	1.485319
5/28/08 4:40	47.7	1.467865
5/28/08 4:50	47.1	1.435854
5/28/08 5:00	46.7	1.418135
5/28/08 5:10	46.5	1.37594
5/28/08 5:20	45.8	1.304009
5/28/08 5:30	45.5	1.292671
5/28/08 5:40	45.3	1.281797
5/28/08 5:50	44.6	1.207155
5/28/08 6:00	44.3	1.17918
5/28/08 6:10	44.1	1.178529
5/28/08 6:20	43.5	1.130687
5/28/08 6:30	43.2	1.098743
5/28/08 6:40	43.1	1.09134
5/28/08 6:50	42.7	1.087879
5/28/08 7:00	42.2	1.03736
5/28/08 7:10	42	1.009054
5/28/08 7:20	41.8	1.010964
5/28/08 7:30	41.5	0.982778
5/28/08 7:40	41	0.950045
5/28/08 7:50	40.9	0.936333
5/28/08 8:00	40.8	0.929433
5/28/08 8:10	40.5	0.899923
5/28/08 8:20	40	0.877236
5/28/08 8:30	39.8	0.837481
5/28/08 8:40	39.7	0.863756

5/28/08 8:50	39.6	0.839612
5/28/08 9:00	39.5	0.813397
5/28/08 9:10	39.3	0.826413
5/28/08 9:20	38.8	0.787503
5/28/08 9:30	38.7	0.763999
5/28/08 9:40	38.6	0.744866
5/28/08 9:50	38.5	0.727948
5/28/08 10:00	38.4	0.764098
5/28/08 10:10	38.3	0.759881
5/28/08 10:20	38.1	0.734654
5/28/08 10:30	37.8	0.701402
5/28/08 10:40	37.6	0.73482
5/28/08 10:50	37.5	0.71412
5/28/08 11:00	37.4	0.695584
5/28/08 11:10	37.3	0.691549
5/28/08 11:20	37.2	0.710112
5/28/08 11:30	37.1	0.689655
5/28/08 11:40	37	0.677467
5/28/08 11:50	36.8	0.632943
5/28/08 12:00	36.5	0.66571
5/28/08 12:10	36.3	0.665831
5/28/08 12:20	36.3	0.619745
5/28/08 12:30	36.2	0.647891
5/28/08 12:40	36.1	0.610112
5/28/08 12:50	36.1	0.626054
5/28/08 13:00	36	0.568558
5/28/08 13:10	35.9	0.604509
5/28/08 13:20	35.8	0.5948
5/28/08 13:30	35.8	0.624442
5/28/08 13:40	35.5	0.577693
5/28/08 13:50	35.3	0.601473
5/28/08 14:00	35.2	0.578273
5/28/08 14:10	35.2	0.580216
5/28/08 14:20	35.1	0.541631
5/28/08 14:30	35.1	0.547444
5/28/08 14:40	35	0.57474
5/28/08 14:50	35	0.530304
5/28/08 15:00	34.9	0.54215
5/28/08 15:10	34.9	0.544076
5/28/08 15:20	34.8	0.571207
5/28/08 15:30	34.7	0.529217
5/28/08 15:40	34.6	0.497007

5/28/08 15:50	34.5	0.524011
5/28/08 16:00	34.3	0.518828
5/28/08 16:10	34.1	0.53249
5/28/08 16:20	34	0.512033
5/28/08 16:30	34	0.480127
5/28/08 16:40	33.9	0.4973
5/28/08 16:50	33.9	0.474845
5/28/08 17:00	33.8	0.482644
5/28/08 17:10	33.8	0.49757
5/28/08 17:20	33.8	0.488242
5/28/08 17:30	33.7	0.482948
5/28/08 17:40	33.7	0.468066
5/28/08 17:50	33.6	0.468403
5/28/08 18:00	33.6	0.464693
5/28/08 18:10	33.5	0.485371
5/28/08 18:20	33.5	0.502014
5/28/08 18:30	33.4	0.494855
5/28/08 18:40	33.3	0.445451
5/28/08 18:50	33.1	0.471748
5/28/08 19:00	33	0.488407
5/28/08 19:10	32.9	0.414152
5/28/08 19:20	32.8	0.452593
5/28/08 19:30	32.8	0.465267
5/28/08 19:40	32.8	0.43992
5/28/08 19:50	32.7	0.452886
5/28/08 20:00	32.7	0.470936
5/28/08 20:10	32.7	0.4222
5/28/08 20:20	32.6	0.431573
5/28/08 20:30	32.6	0.440571
5/28/08 20:40	32.6	0.393783
5/28/08 20:50	32.5	0.435498
5/28/08 21:00	32.5	0.385266
5/28/08 21:10	32.4	0.430447
5/28/08 21:20	32.4	0.421505
5/28/08 21:30	32.3	0.428984
5/28/08 21:40	32.3	0.418287
5/28/08 21:50	32.2	0.418634
5/28/08 22:00	32	0.383969
5/28/08 22:10	31.9	0.398481
5/28/08 22:20	31.8	0.398851
5/28/08 22:30	31.7	0.39571
5/28/08 22:40	31.7	0.358963

5/28/08 22:50	31.6	0.411768
5/28/08 23:00	31.6	0.378625
5/28/08 23:10	31.6	0.371648
5/28/08 23:20	31.5	0.379028
5/28/08 23:30	31.5	0.342514
5/28/08 23:40	31.5	0.385984
5/28/08 23:50	31.5	0.392939
5/29/08 0:00	31.4	0.427952
5/29/08 0:10	31.4	0.388087
5/29/08 0:20	31.4	0.37422
5/29/08 0:30	31.4	0.337822
5/29/08 0:40	31.3	0.371162
5/29/08 0:50	31.3	0.362524
5/29/08 1:00	31.3	0.355613
5/29/08 1:10	31.2	0.366393
5/29/08 1:20	31.2	0.35606
5/29/08 1:30	31.1	0.377096
5/29/08 1:40	31.1	0.323878
5/29/08 1:50	31.1	0.359929
5/29/08 2:00	31	0.339809
5/29/08 2:10	30.9	0.357335
5/29/08 2:20	30.8	0.362838
5/29/08 2:30	30.6	0.312904
5/29/08 2:40	30.6	0.326417
5/29/08 2:50	30.6	0.331485
5/29/08 3:00	30.5	0.357197
5/29/08 3:10	30.5	0.350462
5/29/08 3:20	30.5	0.323525
5/29/08 3:30	30.5	0.310056
5/29/08 3:40	30.4	0.350849
5/29/08 3:50	30.4	0.334068
5/29/08 4:00	30.4	0.349171
5/29/08 4:10	30.4	0.352527
5/29/08 4:20	30.3	0.337844
5/29/08 4:30	30.3	0.324463
5/29/08 4:40	30.3	0.336171
5/29/08 4:50	30.3	0.339516
5/29/08 5:00	30.3	0.321118
5/29/08 5:10	30.3	0.341189
5/29/08 5:20	30.3	0.3161
5/29/08 5:30	30.2	0.318248
5/29/08 5:40	30.2	0.306578

5/29/08 5:50	30.2	0.308245
5/29/08 6:00	30.2	0.346587
5/29/08 6:10	30.2	0.301577
5/29/08 6:20	30.1	0.32868
5/29/08 6:30	30.1	0.33865
5/29/08 6:40	30.1	0.361911
5/29/08 6:50	30.1	0.303758
5/29/08 7:00	30.1	0.312065
5/29/08 7:10	30	0.314196
5/29/08 7:20	30	0.309228
5/29/08 7:30	30	0.31254
5/29/08 7:40	30	0.299292
5/29/08 7:50	29.9	0.346013
5/29/08 8:00	29.9	0.326208
5/29/08 8:10	29.9	0.306402
5/29/08 8:20	29.9	0.278344
5/29/08 8:30	29.8	0.323326
5/29/08 8:40	29.7	0.318816
5/29/08 8:50	29.6	0.293088
5/29/08 9:00	29.5	0.287065
5/29/08 9:10	29.5	0.331032
5/29/08 9:20	29.5	0.324518
5/29/08 9:30	29.4	0.297305
5/29/08 9:40	29.4	0.315156
5/29/08 9:50	29.4	0.269716
5/29/08 10:00	29.4	0.297305
5/29/08 10:10	29.4	0.285945
5/29/08 10:20	29.3	0.29938

APPENDIX G

Water Quality Data: May 27-29, 2008

Date & Time	Temperature (°C)	spC (µS /cm)	pH
5/27/08 12:00	13.48	330	8.02
5/27/08 12:10	13.48	329	8.02
5/27/08 12:20	13.48	330	8.02
5/27/08 12:30	13.48	330	8.02
5/27/08 12:40	13.48	329	8.02
5/27/08 12:50	13.48	330	8.02
5/27/08 13:00	13.48	329	8.02
5/27/08 13:10	13.48	329	8.02
5/27/08 13:20	13.48	329	8.02
5/27/08 13:30	13.48	329	8.03
5/27/08 13:40	13.48	329	8.02
5/27/08 13:50	13.48	329	8.02
5/27/08 14:00	13.48	329	8.02
5/27/08 14:10	13.48	329	8.02
5/27/08 14:20	13.48	329	8.02
5/27/08 14:30	13.48	329	8.02
5/27/08 14:40	13.48	329	8.02
5/27/08 14:50	13.48	329	8.02
5/27/08 15:00	13.48	329	8.02
5/27/08 15:10	13.48	328	8.02
5/27/08 15:20	13.48	328	8.02
5/27/08 15:30	13.48	329	8.02
5/27/08 15:40	13.47	328	8.02
5/27/08 15:50	13.48	328	8.02
5/27/08 16:00	13.47	328	8.02
5/27/08 16:10	13.48	328	8.02
5/27/08 16:20	13.47	328	8.02
5/27/08 16:30	13.47	328	8.02
5/27/08 16:40	13.48	328	8.02
5/27/08 16:50	13.48	328	8.02
5/27/08 17:00	13.48	329	8.02
5/27/08 17:10	13.47	328	8.02
5/27/08 17:20	13.47	328	8.02
5/27/08 17:30	13.48	328	8.02
5/27/08 17:40	13.47	328	8.02
5/27/08 17:50	13.48	329	8.02
5/27/08 18:00	13.48	329	8.02
5/27/08 18:10	13.48	329	8.02
5/27/08 18:20	13.47	329	8.02
5/27/08 18:30	13.48	329	8.02
5/27/08 18:40	13.48	329	8.02

5/27/08 18:50	13.47	330	8.02
5/27/08 19:00	13.48	329	8.02
5/27/08 19:10	13.48	330	8.02
5/27/08 19:20	13.48	330	8.02
5/27/08 19:30	13.48	330	8.03
5/27/08 19:40	13.48	330	8.03
5/27/08 19:50	13.48	330	8.02
5/27/08 20:00	13.48	331	8.02
5/27/08 20:10	13.48	330	8.03
5/27/08 20:20	13.48	331	8.02
5/27/08 20:30	13.48	331	8.02
5/27/08 20:40	13.48	331	8.03
5/27/08 20:50	13.48	331	8.03
5/27/08 21:00	13.48	331	8.03
5/27/08 21:10	13.48	332	8.03
5/27/08 21:20	13.48	332	8.02
5/27/08 21:30	13.48	332	8.02
5/27/08 21:40	13.48	332	8.03
5/27/08 21:50	13.48	332	8.02
5/27/08 22:00	13.48	332	8.03
5/27/08 22:10	13.48	332	8.03
5/27/08 22:20	13.48	332	8.03
5/27/08 22:30	13.49	332	8.03
5/27/08 22:40	13.49	331	8.03
5/27/08 22:50	13.49	331	8.01
5/27/08 23:00	13.49	328	8
5/27/08 23:10	13.43	328	7.98
5/27/08 23:20	13.44	319	7.97
5/27/08 23:30	13.48	318	7.97
5/27/08 23:40	13.53	311	7.93
5/27/08 23:50	13.58	309	7.89
5/28/08 0:00	13.65	307	7.85
5/28/08 0:10	13.67	277	7.79
5/28/08 0:20	13.69	267	7.74
5/28/08 0:30	13.69	260	7.69
5/28/08 0:40	13.69	233	7.67
5/28/08 0:50	13.73	205	7.63
5/28/08 1:00	13.82	194	7.6
5/28/08 1:10	13.89	196	7.58
5/28/08 1:20	13.93	196	7.57
5/28/08 1:30	13.97	191	7.57
5/28/08 1:40	14	182	7.56

5/28/08 1:50	14.05	174	7.54
5/28/08 2:00	14.1	172	7.53
5/28/08 2:10	14.14	177	7.53
5/28/08 2:20	14.18	183	7.53
5/28/08 2:30	14.2	191	7.54
5/28/08 2:40	14.21	199	7.55
5/28/08 2:50	14.23	207	7.55
5/28/08 3:00	14.26	213	7.56
5/28/08 3:10	14.28	220	7.57
5/28/08 3:20	14.31	223	7.56
5/28/08 3:30	14.33	225	7.58
5/28/08 3:40	14.35	226	7.57
5/28/08 3:50	14.37	227	7.57
5/28/08 4:00	14.39	227	7.58
5/28/08 4:10	14.41	228	7.57
5/28/08 4:20	14.43	228	7.58
5/28/08 4:30	14.44	228	7.58
5/28/08 4:40	14.46	228	7.58
5/28/08 4:50	14.48	226	7.58
5/28/08 5:00	14.49	225	7.58
5/28/08 5:10	14.51	222	7.58
5/28/08 5:20	14.52	219	7.58
5/28/08 5:30	14.54	215	7.57
5/28/08 5:40	14.55	211	7.57
5/28/08 5:50	14.56	207	7.57
5/28/08 6:00	14.56	204	7.56
5/28/08 6:10	14.57	200	7.55
5/28/08 6:20	14.58	198	7.55
5/28/08 6:30	14.59	195	7.55
5/28/08 6:40	14.59	193	7.55
5/28/08 6:50	14.59	192	7.55
5/28/08 7:00	14.59	191	7.54
5/28/08 7:10	14.59	191	7.54
5/28/08 7:20	14.59	190	7.55
5/28/08 7:30	14.59	191	7.55
5/28/08 7:40	14.58	190	7.54
5/28/08 7:50	14.58	190	7.55
5/28/08 8:00	14.58	189	7.55
5/28/08 8:10	14.57	189	7.55
5/28/08 8:20	14.57	188	7.55
5/28/08 8:30	14.57	188	7.56
5/28/08 8:40	14.56	188	7.56

5/28/08 8:50	14.56	188	7.56
5/28/08 9:00	14.55	187	7.56
5/28/08 9:10	14.55	188	7.56
5/28/08 9:20	14.55	187	7.55
5/28/08 9:30	14.54	187	7.56
5/28/08 9:40	14.54	186	7.56
5/28/08 9:50	14.53	185	7.56
5/28/08 10:00	14.52	185	7.55
5/28/08 10:10	14.52	185	7.56
5/28/08 10:20	14.51	185	7.55
5/28/08 10:30	14.5	184	7.56
5/28/08 10:40	14.49	184	7.55
5/28/08 10:50	14.48	184	7.55
5/28/08 11:00	14.48	183	7.55
5/28/08 11:10	14.47	182	7.54
5/28/08 11:20	14.46	182	7.55
5/28/08 11:30	14.45	181	7.55
5/28/08 11:40	14.44	181	7.55
5/28/08 11:50	14.44	181	7.55
5/28/08 12:00	14.43	181	7.55
5/28/08 12:10	14.42	180	7.54
5/28/08 12:20	14.42	179	7.54
5/28/08 12:30	14.41	179	7.55
5/28/08 12:40	14.41	179	7.55
5/28/08 12:50	14.4	179	7.54
5/28/08 13:00	14.4	178	7.54
5/28/08 13:10	14.39	179	7.54
5/28/08 13:20	14.39	179	7.54
5/28/08 13:30	14.39	178	7.54
5/28/08 13:40	14.38	178	7.54
5/28/08 13:50	14.38	178	7.54
5/28/08 14:00	14.37	178	7.54
5/28/08 14:10	14.37	178	7.54
5/28/08 14:20	14.37	177	7.54
5/28/08 14:30	14.37	177	7.54
5/28/08 14:40	14.36	177	7.54
5/28/08 14:50	14.36	176	7.55
5/28/08 15:00	14.35	176	7.54
5/28/08 15:10	14.35	177	7.54
5/28/08 15:20	14.35	176	7.54
5/28/08 15:30	14.35	176	7.54
5/28/08 15:40	14.35	176	7.54

5/28/08 15:50	14.35	175	7.54
5/28/08 16:00	14.35	176	7.54
5/28/08 16:10	14.34	175	7.54
5/28/08 16:20	14.34	175	7.54
5/28/08 16:30	14.34	175	7.54
5/28/08 16:40	14.34	174	7.55
5/28/08 16:50	14.34	173	7.54
5/28/08 17:00	14.34	174	7.54
5/28/08 17:10	14.33	173	7.54
5/28/08 17:20	14.33	173	7.54
5/28/08 17:30	14.33	173	7.55
5/28/08 17:40	14.33	173	7.55
5/28/08 17:50	14.33	173	7.54
5/28/08 18:00	14.32	172	7.54
5/28/08 18:10	14.33	172	7.55
5/28/08 18:20	14.33	172	7.55
5/28/08 18:30	14.32	172	7.54
5/28/08 18:40	14.32	172	7.55
5/28/08 18:50	14.32	172	7.55
5/28/08 19:00	14.32	172	7.55
5/28/08 19:10	14.32	172	7.55
5/28/08 19:20	14.31	172	7.55
5/28/08 19:30	14.31	172	7.55
5/28/08 19:40	14.31	172	7.56
5/28/08 19:50	14.31	173	7.55
5/28/08 20:00	14.3	172	7.56
5/28/08 20:10	14.3	173	7.55
5/28/08 20:20	14.29	173	7.56
5/28/08 20:30	14.29	173	7.56
5/28/08 20:40	14.29	174	7.56
5/28/08 20:50	14.28	173	7.56
5/28/08 21:00	14.28	174	7.57
5/28/08 21:10	14.28	175	7.56
5/28/08 21:20	14.27	175	7.57
5/28/08 21:30	14.27	175	7.57
5/28/08 21:40	14.26	175	7.57
5/28/08 21:50	14.26	176	7.57
5/28/08 22:00	14.25	176	7.57
5/28/08 22:10	14.25	177	7.57
5/28/08 22:20	14.24	177	7.57
5/28/08 22:30	14.24	177	7.58
5/28/08 22:40	14.23	178	7.58

5/28/08 22:50	14.23	178	7.58
5/28/08 23:00	14.23	179	7.58
5/28/08 23:10	14.22	179	7.58
5/28/08 23:20	14.22	180	7.58
5/28/08 23:30	14.21	180	7.59
5/28/08 23:40	14.21	180	7.59
5/28/08 23:50	14.2	181	7.59
5/29/08 0:00	14.2	182	7.6

APPENDIX H

Sediment Analysis Data: May 27-29, 2008

Date & Time	Atrazine (ppb) Unfiltered	Atrazine (ppb) Filtered	Sed. Concentration (Mg/L)
5/27/08 23:30	0.1	0.08	619.52
5/28/08 0:20	0.75	0.89	417.34
5/28/08 1:10	1.67	1.9	294.36
5/28/08 2:00	1.71	1.87	448.40
5/28/08 2:50	1.84	1.71	252.03
5/28/08 3:40	1.86	1.96	145.08
5/28/08 4:30	2.39	2.34	147.38
5/28/08 5:20	2.17	2.3	46.99
5/28/08 6:10	2.58	2.43	155.43
5/28/08 7:00	2.37	2.62	168.51
5/28/08 7:50	2.5	2.56	97.93
5/28/08 8:40	2.39	2.64	94.15
5/28/08 9:30	2.72	2.9	145.81
5/28/08 10:20	2.33	2.82	143.73
5/28/08 11:10	2.75	2.41	96.84
5/28/08 12:00	2.3	2.38	143.66
5/28/08 12:50	2.23	2.35	148.43
5/28/08 13:40	2.41	2.43	124.42
5/28/08 14:30	2.28	2.3	66.17
5/28/08 15:20	2.28	1.99	103.30
5/28/08 16:10	2.5	1.63	94.36
5/28/08 17:00	1.87	2.02	148.57
5/28/08 17:50	1.96	1.85	91.73
5/28/08 18:40	2.09	2.33	144.24

Date & Time	Turbidity (NTU)	Sand Fraction (µm)	Sediment Conc. (ppm)	SMD (µm)
5/27/08 12:00	0	3.095	2.777	
5/27/08 12:10	0	3.066	2.74	
5/27/08 12:20	0	2.978	2.705	
5/27/08 12:30	0	2.899	2.625	
5/27/08 12:40	0	2.862	2.614	
5/27/08 12:50	0	2.895	2.625	
5/27/08 13:00	0	3.209	2.845	
5/27/08 13:10	0	3.05	2.712	
5/27/08 13:20	0	3.045	2.753	
5/27/08 13:30	0	3.072	2.74	
5/27/08 13:40	0	2.991	2.708	
5/27/08 13:50	0	3.054	2.741	
5/27/08 14:00	0	3.049	2.759	

5/27/08 14:10	0	2.975	2.685
5/27/08 14:20	0	3.036	2.738
5/27/08 14:30	0	3.121	2.813
5/27/08 14:40	0	2.943	2.67
5/27/08 14:50	0	2.967	2.683
5/27/08 15:00	0	2.997	2.708
5/27/08 15:10	0	3.004	2.704
5/27/08 15:20	0	2.935	2.647
5/27/08 15:30	0	3.009	2.714
5/27/08 15:40	0	2.987	2.682
5/27/08 15:50	0	2.934	2.638
5/27/08 16:00	0	2.926	2.666
5/27/08 16:10	0	3.017	2.707
5/27/08 16:20	0	3.087	2.765
5/27/08 16:30	0	2.993	2.697
5/27/08 16:40	0	3.127	2.791
5/27/08 16:50	0	3.081	2.776
5/27/08 17:00	0	2.989	2.695
5/27/08 17:10	0	3.02	2.7
5/27/08 17:20	0	3.082	2.761
5/27/08 17:30	0	3.097	2.802
5/27/08 17:40	0	3.02	2.726
5/27/08 17:50	0	3.057	2.752
5/27/08 18:00	0	2.998	2.689
5/27/08 18:10	0	2.941	2.656
5/27/08 18:20	0	2.994	2.712
5/27/08 18:30	0	2.97	2.68
5/27/08 18:40	0	3.046	2.749
5/27/08 18:50	0	3.246	2.887
5/27/08 19:00	0	2.956	2.699
5/27/08 19:10	0	3.152	2.831
5/27/08 19:20	0	2.973	2.703
5/27/08 19:30	0	3.055	2.745
5/27/08 19:40	0	3.083	2.784
5/27/08 19:50	0	3.03	2.741
5/27/08 20:00	0	2.995	2.714
5/27/08 20:10	0	3	2.725
5/27/08 20:20	0	2.957	2.672
5/27/08 20:30	0	3.174	2.855
5/27/08 20:40	0	3.156	2.836
5/27/08 20:50	0	2.974	2.702
5/27/08 21:00	0	2.944	2.703

5/27/08 21:10	0	2.956	2.7	
5/27/08 21:20	0	3.156	2.854	
5/27/08 21:30	0	3.112	2.824	
5/27/08 21:40	0	3.148	2.846	
5/27/08 21:50	0	3.308	3.013	
5/27/08 22:00	0	3.322	3.135	
5/27/08 22:10	0	3.409	3.321	
5/27/08 22:20	0	3.968	3.936	
5/27/08 22:30	0	5.446	6.743	
5/27/08 22:40	0	21.441	33.604	
5/27/08 22:50	12.1	31.178	53.792	
5/27/08 23:00	16.5	31.506	57.175	
5/27/08 23:10	27.7	31.236	68.685	19.349
5/27/08 23:20	45.7	32.718	79.23	18.498
5/27/08 23:30	59.5	38.101	112.526	13.674
5/27/08 23:40	113.3	48.011	168.035	11.051
5/27/08 23:50	165.8	58.844	207.344	11.215
5/28/08 0:00	197.7	74.884	291.934	10.322
5/28/08 0:10	271.8	82.725	341.806	9.773
5/28/08 0:20	293.9	78.803	342.671	9.256
5/28/08 0:30	318.3	77.27	386.387	8.035
5/28/08 0:40	395.3	75.237	454.255	6.968
5/28/08 0:50	460	70.285	482.052	6.502
5/28/08 1:00	472	68.218	466.52	6.584
5/28/08 1:10	462	67.409	457.698	6.775
5/28/08 1:20	459	73.047	486.667	6.813
5/28/08 1:30	471	77.287	532.305	6.584
5/28/08 1:40	517	69.614	559.152	6.299
5/28/08 1:50	520	66.58	549.009	6.24
5/28/08 2:00	527	70.394	505.728	6.444
5/28/08 2:10	477	65.625	442.138	6.707
5/28/08 2:20	435	59.891	382.993	7.002
5/28/08 2:30	396.2	57.004	335.484	7.291
5/28/08 2:40	354.5	51.098	296.627	7.479
5/28/08 2:50	327.8	46.035	266.012	7.61
5/28/08 3:00	301.6	43.775	244.896	7.691
5/28/08 3:10	287.6	40.027	229.923	7.63
5/28/08 3:20	271.4	37.41	221.063	7.536
5/28/08 3:30	278.2	35.872	214.498	7.413
5/28/08 3:40	271.2	34.494	208.106	7.301
5/28/08 3:50	272.9	32.778	200.084	7.198
5/28/08 4:00	262.1	30.391	190.559	7.112

5/28/08 4:10	251.6	28.154	180.921	7.046
5/28/08 4:20	248.3	26.378	171.846	7.007
5/28/08 4:30	241.2	24.443	163.371	6.96
5/28/08 4:40	234.6	23.32	156.747	6.924
5/28/08 4:50	229.8	22.682	152.215	6.894
5/28/08 5:00	219.8	22.542	149.101	6.844
5/28/08 5:10	222.5	21.627	146.97	6.764
5/28/08 5:20	223.7	21.646	146.45	6.68
5/28/08 5:30	223.3	21.049	146.313	6.575
5/28/08 5:40	226.8	19.756	146.793	6.444
5/28/08 5:50	243.1	19.635	147.709	6.355
5/28/08 6:00	243.3	19.154	148.268	6.258
5/28/08 6:10	243.8	19.452	149.268	6.19
5/28/08 6:20	253.5	18.773	147.83	6.1
5/28/08 6:30	254.3	18.201	146.68	6.044
5/28/08 6:40	257.9	17.398	144.324	5.983
5/28/08 6:50	262.2	16.234	141.617	5.933
5/28/08 7:00	257	15.526	138.335	5.881
5/28/08 7:10	251.9	15.044	135.389	5.853
5/28/08 7:20	252.2	14.789	132.396	5.838
5/28/08 7:30	251.1	14.374	128.816	5.822
5/28/08 7:40	250.3	13.834	125.438	5.797
5/28/08 7:50	243.9	13.388	122.06	5.774
5/28/08 8:00	241	13.164	119.41	5.764
5/28/08 8:10	234.3	12.767	116.273	5.736
5/28/08 8:20	231.6	12.051	113.311	5.706
5/28/08 8:30	231.7	12.059	110.923	5.699
5/28/08 8:40	227.2	11.86	108.556	5.674
5/28/08 8:50	226.8	11.31	105.926	5.645
5/28/08 9:00	225.2	10.954	103.342	5.614
5/28/08 9:10	223.1	10.874	101.538	5.601
5/28/08 9:20	222.4	10.631	99.466	5.578
5/28/08 9:30	215.8	10.676	97.745	5.57
5/28/08 9:40	217	10.227	95.715	5.541
5/28/08 9:50	214.9	10.115	93.821	5.521
5/28/08 10:00	212.4	9.851	91.941	5.499
5/28/08 10:10	208.8	9.551	89.927	5.469
5/28/08 10:20	213.3	9.57	88.379	5.473
5/28/08 10:30	212	9.308	86.533	5.453
5/28/08 10:40	200.6	9.14	84.65	5.435
5/28/08 10:50	204.1	8.834	82.839	5.417
5/28/08 11:00	200.9	8.846	81.13	5.416

5/28/08 11:10	200.4	8.629	79.434	5.401
5/28/08 11:20	198.3	8.322	77.607	5.394
5/28/08 11:30	193.2	8.216	76.152	5.39
5/28/08 11:40	189.4	8.259	74.829	5.391
5/28/08 11:50	185.9	8.064	73.334	5.381
5/28/08 12:00	187.3	7.963	71.889	5.383
5/28/08 12:10	182.4	7.825	70.56	5.382
5/28/08 12:20	183.3	7.758	69.425	5.38
5/28/08 12:30	180.3	7.569	68.26	5.379
5/28/08 12:40	175.8	7.519	67.174	5.378
5/28/08 12:50	176.4	7.485	66.043	5.377
5/28/08 13:00	174.9	7.392	64.976	5.376
5/28/08 13:10	168.8	7.227	63.897	5.372
5/28/08 13:20	174	7.357	63.079	5.38
5/28/08 13:30	163.7	7.419	62.321	5.387
5/28/08 13:40	160.8	7.153	61.437	5.369
5/28/08 13:50	163	7.151	60.695	5.384
5/28/08 14:00	164.7	7.268	60.19	5.391
5/28/08 14:10	160.6	7.073	59.319	5.388
5/28/08 14:20	160.8	7.172	58.802	5.405
5/28/08 14:30	157.6	6.881	57.931	5.383
5/28/08 14:40	161.7	7.119	57.602	5.41
5/28/08 14:50	154	7.022	56.955	5.411
5/28/08 15:00	157.2	7.029	56.451	5.413
5/28/08 15:10	151.2	6.997	55.844	5.417
5/28/08 15:20	154	6.774	55.269	5.417
5/28/08 15:30	152.3	6.694	54.697	5.417
5/28/08 15:40	152.1	6.705	54.252	5.423
5/28/08 15:50	151	6.698	53.811	5.428
5/28/08 16:00	152.8	6.802	53.494	5.45
5/28/08 16:10	148.2	6.672	52.973	5.441
5/28/08 16:20	142.4	6.603	52.561	5.452
5/28/08 16:30	144.6	6.441	52.115	5.437
5/28/08 16:40	143.7	6.302	51.52	5.436
5/28/08 16:50	147.6	6.391	51.28	5.444
5/28/08 17:00	143	6.382	50.919	5.455
5/28/08 17:10	142.4	6.331	50.582	5.455
5/28/08 17:20	143.4	6.219	50.255	5.449
5/28/08 17:30	137.1	6.233	49.921	5.46
5/28/08 17:40	140.2	6.252	49.646	5.463
5/28/08 17:50	138	6.169	49.156	5.452
5/28/08 18:00	139.3	6.122	48.92	5.459

5/28/08 18:10	140	6.095	48.625	5.462
5/28/08 18:20	139	6.162	48.463	5.469
5/28/08 18:30	138.9	6.028	47.899	5.448
5/28/08 18:40	136.7	6.1	47.781	5.466
5/28/08 18:50	139	6.054	47.455	5.471
5/28/08 19:00	137.5	6	47.193	5.468
5/28/08 19:10	133.2	5.917	46.69	5.452
5/28/08 19:20	135	5.944	46.284	5.454
5/28/08 19:30	137	5.763	45.707	5.431
5/28/08 19:40	134.5	5.774	45.323	5.439
5/28/08 19:50	132	5.798	44.93	5.437
5/28/08 20:00	132.1	5.837	44.45	5.435
5/28/08 20:10	129.3	5.758	43.888	5.409
5/28/08 20:20	130.2	5.709	43.319	5.403
5/28/08 20:30	128.4	5.691	42.808	5.401
5/28/08 20:40	130.6	5.669	42.266	5.389
5/28/08 20:50	128.8	5.543	41.765	5.376
5/28/08 21:00	125.8	5.618	41.353	5.379
5/28/08 21:10	127.2	5.452	40.628	5.354
5/28/08 21:20	127.3	5.581	40.176	5.359
5/28/08 21:30	124.2	5.546	39.749	5.362
5/28/08 21:40	124.9	5.342	39.083	5.335
5/28/08 21:50	123.4	5.359	38.533	5.333
5/28/08 22:00	119.2	5.291	38.039	5.326
5/28/08 22:10	120.8	5.256	37.568	5.332
5/28/08 22:20	120.9	5.195	36.995	5.327
5/28/08 22:30	118.7	5.167	36.56	5.324
5/28/08 22:40	118	5.177	36.189	5.328
5/28/08 22:50	116	5.05	35.688	5.325
5/28/08 23:00	111.5	5.01	35.153	5.318
5/28/08 23:10	114.3	4.96	34.609	5.312
5/28/08 23:20	112.4	4.909	34.181	5.304
5/28/08 23:30	109.9	4.846	33.631	5.298
5/28/08 23:40	109.8	4.797	33.153	5.287
5/28/08 23:50	110.8	4.805	32.813	5.303
5/29/08 0:00	109.6	4.714	32.347	5.297