CONSEQUENCES OF RESERVOIR DRAINAGE ON DOWNSTREAM WATER CHEMISTRY, SUSPENDED SEDIMENT, AND NUTRIENTS, SOUTHWEST MISSOURI

A Thesis

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Master of Science in Resource Planning

By

Mark W. Bowen

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CONSEQUENCES OF RESERVOIR DRAINAGE ON DOWNSTREAM WATER CHEMISTRY, SUSPENDED SEDIMENT, AND NUTRIENTS, SOUTHWEST MISSOURI

Department of Geography, Geology, and Planning

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ABSTRACT

Construction and subsequent draining of reservoirs can have dramatic affects on the release of nutrients and sediments to waterways. This study describes how the temporary draining of a small reservoir for dam repair influences downstream water quality. The Valley Mill Reservoir has a surface area of 6.1 hectares and volume of 150,000 m^3 when filled. Water chemistry monitoring and water sampling were performed at six sites during baseflow and ten sites during runoff events for one year. Water samples were analyzed for total nitrogen (TN), total phosphorous (TP), and total suspended sediment (TSS) concentrations. Results indicate that draining of Valley Mill Reservoir caused only minor changes in water chemistry. However, reservoir drainage caused significant erosion of the exposed lake bed as well as the stream channel upstream of the reservoir. Increases in TSS lagged behind drainage but increased dramatically once drainage was complete. Mean TSS increased from 7.5 mg/L upstream of the reservoir to 20.7 mg/L in reservoir outflow during baseflow. During storm events, TSS increased over 100 percent to nearly 100 mg/L in the drained reservoir outflow, with a maximum concentration of 525 mg/L. The increase in TSS resulted in TP increases during baseflow and storm events, since TP is known to attach to sediment. Mean outflowing TP increased by 10 percent to 43 ug/L during baseflow and by 20 percent to 207 ug/L following storm events. Total nitrogen remained below 5 mg/L at all monitoring sites and decreased by 5 to 15 percent after flowing over the exposed lakebed. Therefore, draining of Valley Mill Reservoir may have caused degradation of water quality downstream of reservoir outflow due to large amounts of sediment and phosphorus being released from the drained reservoir.

KEYWORDS: water quality, reservoir drainage, sediment, phosphorus, nitrogen

This abstract is approved as to form and content

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CHAPTER ONE

INTRODUCTION

Human actions have contributed to the decline of water quality in water bodies worldwide. One of the most dramatic of these actions has been the damming of streams and rivers to construct reservoirs, which alter the flow of water, sediment, and nutrients through the river system. Reservoirs have both positive and negative impacts on the local environment. Some positive functions of dams and reservoirs include providing a water supply for drinking water, industrial uses, and irrigation, flood control, hydro-power generation, recreational uses, and improving water quality (Baxter, 1977). Negative effects of dams and reservoirs include barriers for fish migration, reservoir sedimentation, decreased sediment and nutrient supply to downstream reaches, eutrophication, and increased channel erosion downstream of reservoirs (Baxter, 1977; Ligon *et al.*, 1995; Shields *et al.*, 2000).

There are currently over 75,000 dams in the United States. The greatest rate of dam construction occurred between the late 1950's to the late 1970's, with few dams constructed after 1980 (Graf, 1999). The average age of dams in the United States is 40 years (Shuman, 1995), so reservoir drainage for dam repair or removal is increasingly becoming necessary. Approximately one-third of reservoirs greater than fifty years old have lost between 25-50 percent of their original storage volume, while about 10 percent have lost all their original storage volume (Thornton, 1990). Since many of the reservoirs in the United States are over 50 years old, reservoir drainage may be necessary for dredging of accumulated sediments to increase reservoir storage volume.

Since sediments and nutrients accumulate in reservoirs, drainage is likely to release these pollutants downstream. Of the few reservoir drainage studies conducted in the United States, most have focused on the effects that dam removal has on channel form and sediment delivery to downstream reaches (Ligon *et al.*, 1995; Shields *et al.*, 2000; Egan, 2001; Doyle *et al.*, 2002; Pizzuto, 2002). Dam removal and reservoir drainage are emerging fields in science, and relatively few environmental studies have accompanied drainage operations. Most drainage studies have evaluated the effects of reservoir drainage associated with dam removals rather than temporary drainage. Therefore, the effects that temporary drainage for reservoir management has on sediment and nutrient transport are not well understood.

The State of Missouri ranks fifth in the nation of states with the most dams at 3,541 (Shuman, 1995). There are 16 dams located within Greene County and 44 more in the six bordering counties (Missouri Department of Natural Resources, 1980). All of these dams were built before 1980 and will be in need of repair in the near future. This study is the first in the region to scientifically evaluate the effects that temporary reservoir drainage has on downstream water quality. Since there are 60 dams in the immediate area, this study is essential, as other dams are likely in need of repair, which may require reservoir drainage.

This study focuses on the 6.1 hectare Valley Mill Reservoir (VMR), drained to repair an ageing dam and remove excess sediments from the basin. Valley Mill Reservoir is located in Greene County, Missouri, and within the Springfield city limits. Springfield is the third largest city in the state with a population of approximately 151,000 (U.S.Census, 2003). Springfield receives 20-25% of its drinking water supply from Fulbright Spring (Wright Water Engineers, 1995). Fulbright Spring receives 60-70% of its recharge from a swallow-hole located on the South Dry Sac River (SDSR), approximately 300 meters downstream of the confluence of the SDSR and VMR outflow (Coulter, 2003). In 1908, the Springfield Water Company purchased VMR, since it was a valuable water source for the city (Bullard, 2000). Given that VMR is an important drinking water source, it is critical to maintain a high level of water quality in outflow.

RESEARCH QUESTIONS

This study will fill gaps in knowledge about the effects that reservoir drainage has on downstream water quality. It is currently unknown how water quality is affected by reservoir drainage. There are four main questions addressed by this thesis. First, how is sediment and nutrient transport influenced by reservoir drainage? Phosphorus movement through streams is relatively slow and dependent on sediment transport (Stanley and Doyle, 2002). While nitrogen is transported through aquatic systems in both particulate and dissolved phases in runoff, it is highly soluble and does not sorb as strongly to sediment as compared to phosphorus (USEPA, 1999A). The key question in relation to this thesis is to what extent reservoir drainage remobilizes stored sediment and nutrients from the now exposed lake bed.

Second, how does discharge influence water quality and sediment and nutrient transport after flowing over the exposed lake bed? Baseflow is the constant stream discharge not influenced by precipitation (Dodds, 2002). Baseflow is the typical flow in a watershed, and geomorphic change is gradual and limited during baseflow conditions (Leopold *et al.*, 1964). Following storm events, stream stage and water velocity increase, resulting in scouring and erosion of the streambed (Leopold *et al.*, 1964). However, to what extent does the change in flow energy and associated chemical regimes influence the remobilization of pollutants?

Third, does draining a reservoir create a significant source of pollution? Most excess nutrients and sediments in a watershed enter streams from nonpoint sources; comparing a drained reservoir as a point source of pollution to nonpoint pollution sources throughout the watershed will determine if the reservoir provides a greater source of pollution than the rest of the watershed. Does the drained lake bed represent a significant source of pollution from the watershed as a whole when compared to other sources or tributary inputs in the watershed?

Finally, does reservoir drainage significantly impact other water quality parameters? Turbidity, pH, water temperature, total dissolved solids concentration, and dissolved oxygen concentration will also be evaluated during this study. These parameters are typically considered when determining the quality of water resources and therefore will be included in this study.

PURPOSE AND OBJECTIVES

The purpose of this study is to evaluate the effects of reservoir drainage on water chemistry and sediment and nutrient transport to downstream reaches of the SDSR in Southwest Missouri. The effects of reservoir drainage must be better understood to protect downstream reaches and the habitats these reaches support from degradation during future reservoir drainage operations. The primary objectives of this thesis are to:

1. **Quantify and compare reservoir inflow and outflow water chemistry, total nitrogen (TN), total phosphorus (TP), and total suspended sediment (TSS) concentrations during baseflow and storm event flow.**

No previous studies have been conducted on reservoir drainage operations in the Ozarks region. By evaluating changes in water quality after flowing over the exposed lake bed during baseflow and event flow, an estimate of pollution emanating from the drained reservoir can be calculated for a range of discharges. With a better understanding of how water quality changes with changing flow conditions, management efforts can be improved to account for changes in discharge to prevent downstream water quality degradation for future drainage operations.

2. **Evaluate temporal trends in water quality and sediment and nutrient transport.**

Evaluating temporal changes in water quality trends will determine if water quality is influenced by seasonal climate and land use patterns. If water quality and sediment and nutrient transport are influenced by seasonal changes, seasons with the greatest degradation in water quality and the highest sediment and nutrient transport can be targeted. Also, by evaluating temporal transport trends, it can be determined if most of the sediment and nutrients are released shortly after drainage or if it is steady long-term release. Management efforts can then be directed towards preventing either higher level but shorter-term pollution releases or lower level but longer-term pollution releases.

3. **Compare drained reservoir contributions to watershed water quality trends.**

Valley Mill Reservoir outflowing water quality will be compared to water quality trends throughout the watershed. Comparing VMR to nonpoint pollution sources throughout the watershed will determine if VMR provides a greater source of pollution than other land uses in the watershed. This will allow management efforts to address both point sources as well as nonpoint sources of pollution in the Valley Mill watershed.

HYPOTHESES

It is hypothesized that water quality in the SDSR will degrade due to increased sediment and phosphorus eroded from the drained reservoir and transported downstream. Draining of a reservoir causes an increase in water velocity upstream of the dam, which causes a channel to form in the drained lake bed as sediment is eroded downstream (Stanley and Doyle, 2002). Phosphorus readily sorbs to sediment and is primarily transported with eroded sediment (USEPA, 1999A). However, nitrogen concentration should decrease following reservoir drainage due to increased sediment-water contact causing denitrification (Stanley and Doyle, 2002). Denitrification is the process in which bacteria convert nitrate to N_2 gas which is released from the water (Dodds, 2002). In addition, since water velocity increases with drainage, it is also believed that draining of the reservoir will result in increased erosion of the stream channel upstream of the reservoir.

Also, it is believed that the drained VMR is the greatest source of pollution within the Valley Mill watershed. Valley Mill Reservoir acted as a pollution trap for several decades before it was drained, which allowed for the storage and long-term accumulation of sediment and other associated pollutants. The drainage of VMR will allow for loosely consolidated sediments to be exposed for an extended period of time. This area of exposed fine-grained sediment is like no other in the watershed and will likely erode quickly and impact water quality more than any other area of the watershed.

BENEFITS OF THE STUDY

This is the first study in southwest Missouri to evaluate how water chemistry and sediment and nutrient transport are affected by reservoir drainage. Few reservoirs remain drained long enough to permit a scientific evaluation of the processes that occur during drainage. This allows for a unique examination of a potentially growing problem since many reservoirs in the Ozarks region are reaching the end of their intended lifespan. This study is especially important for southwest Missouri since there are over 60 dams in and surrounding Greene County and several more in the Ozarks region (Missouri Department of Natural Resources, 1980).

The primary benefit of this study will be an improved understanding of how water quality is impacted by reservoir drainage. By monitoring water chemistry and sediment and nutrient concentrations, changes in water quality due to reservoir drainage can be quantified. This study will also lead to improved protection of water quality during future reservoir drainage operations. Reservoir drainage operations will be increasingly common in the Ozarks since many of the reservoirs in the area were constructed over 40 years ago. Given that our understanding of erosional processes and water quality impacts will be enhanced, future reservoir drainage operations can be managed to reduce those effects on downstream ecological communities.

CHAPTER TWO

LITERATURE REVIEW

Research on reservoirs has generally not focused on the implications of reservoir drainage on downstream water quality. There is significant literature on the effects that dams and reservoirs have on aquatic ecosystems such as sediment transport, water chemistry, water quality, geomorphology, nutrient dynamics, and ecology (Baxter, 1977; Kennedy and Walker, 1990; Thornton, 1990; Jones and Knowlton, 1993; Heimann, 1995; Ligon *et al.*, 1995; Shields *et al.*, 2000). In spite of this research, how these processes are affected by reservoir drainage is not well understood. In fact, few ecological studies have accompanied dam removal and reservoir drainage operations in the United States (Stanley *et al.*, 2002). Recently, however, the importance of reservoir drainage has been recognized, and there is a growing body of literature (Childers *et al.*, 2000; Rye, 2000; Egan, 2001; Bushaw-Newton *et al.*, 2002; Doyle *et al.*, 2002; Pizzuto, 2002; Pohl, 2002; Stanley and Doyle, 2002). While researchers are gaining a better understanding of reservoir drainage impacts, much work is still needed to increase our knowledge and awareness of the interrelated processes that occur following reservoir drainage.

SEDIMENT AND NUTRIENT PROBLEMS

Sediment is the number one non-point source pollutant of our nation's waters (USEPA, 1990). Sediment erosion and transport to streams is a natural and necessary geomorphic process in stream development. However, human activities have greatly increased erosion rates and sediment loads delivered to streams. The most significant sources of sediment in watersheds originate from agricultural land uses (Waters, 1995) and construction sites (Schueler, 2000). Row-crop cultivation on floodplains and livestock grazing in riparian zones are considered the primary agricultural practices causing increased sediment delivery to streams (Waters, 1995). Construction sites are also significant temporary sources of sediment to streams; sediment export is 20 to 2,000 times greater at construction sites than any other land use (Schueler, 2000). Stream channels can experience severe ecological impacts due to increases in suspended and deposited sediment. Impacts of suspended sediment on aquatic ecosystems include light attenuation, reduced species diversity and density, increased water treatment costs, taste and odor problems in drinking water, and transport of nutrients and other pollutants (USEPA, 1999B; Schueler, 2000; Davies-Colley and Smith, 2001). Deposited sediment impacts include benthic smothering, reduced habitat value, decreased species diversity and density, decreased dissolved oxygen concentrations, and loss of reservoir storage (USEPA, 1999B; Schueler, 2000).

Nutrients, such as nitrogen and phosphorus, can also impair water resources due to internal nutrient loading (Klotz and Linn, 2001) and accelerated eutrophication (Carpenter *et al.*, 1998). Phosphorus readily sorbs to sediments and is primarily transported to streams and lakes in surface runoff with eroded sediment (USEPA, 1999A). Nitrogen does not sorb as strongly to sediment and is transported to aquatic systems in both particulate and dissolved phases in runoff (USEPA, 1999A). Excessive inputs of these nutrients can lead to tremendous plant growth and eutrophication of waterways. Eutrophication is one of the most common impairments of surface waters in the United States and accounts for ~50% of the impaired lakes and ~60% of the impaired river reaches in the U.S. (USEPA, 1996). Phosphorus and nitrogen are primarily removed from the water column by sedimentation, uptake by aquatic organisms, and denitrification (Jansson *et al.*, 1994; USEPA, 1999A).

RESERVOIR INFLUENCE ON WATER QUALITY

Reservoirs severely alter the flow of streams and rivers, water quality, and sediment and nutrient transport. When a stream or river flows into a reservoir, water velocity decreases. With decreased water velocity, the ability of the stream to transport sediment decreases, resulting in the development of a delta and sedimentation of the reservoir (Thornton, 1990). Thornton (1990) asserts that approximately one third of the reservoirs in the Midwest, the Great Plains, and the southeast and southwest United States greater than fifty years old have lost between 25-50 percent of their original storage volume, while about 10 percent have lost all their original storage volume.

Baxter (1977) states that the concentrations of constituents in reservoirs are highly dependent on inflowing waters and that reservoirs typically improve inflowing water quality by allowing suspended solids to settle out. These deposited sediments are then easily eroded when the water level is lowered. Baxter (1977) also states that most of the inflowing sediment load is deposited when the stream first enters the standing body of water, forming a delta. As a result, sediment accumulation in reservoirs is greatest near the sources of inflow and decrease longitudinally towards the dam; nutrient concentration has also been found to exhibit similar patterns (Kennedy and Walker, 1990).

RESERVOIR WATER LEVEL DRAWDOWN

Reservoir water level drawdown is a widely practiced multipurpose tool used for reservoir management. Reservoir drawdown can be used to address several problems associated with reservoirs such as aquatic plant control (Massarelli, 1983; Cooke *et al.*, 1993), improving water quality (USEPA, 1977), controlling internal phosphorus loading (Jacoby *et al.*, 1982), monitoring sediment erosion (Vernieu, 1997; Childers *et al.*, 2000), dam repair, dredging, as well as other improvement projects. Reservoir drawdown is a versatile, well-established practice useful in dealing with a wide range of reservoir problems.

An experimental drawdown of Lake Mills, in northwestern Washington, was conducted to determine the effects that lowering Lake Mills would have on sediment transport and water quality downstream of the reservoir (Childers *et al.*, 2000). The water level was lowered 18 feet, and data was collected on stream flow, suspended sediment and bedload, water quality, deposited sediment, and cross-sectional surveys of the lake bed and delta. During drawdown rapid lateral and vertical erosion of the channel occurred in the delta of the reservoir. The maximum suspended sediment concentration was recorded at 6,110 mg/L downstream of the delta, and it was estimated that 300,000 cubic yards of sediment were transported downstream during the two week experiment (Childers *et al.*, 2000). Suspended sediment concentrations in downstream reaches of the reservoir increased during reservoir drawdown, which could potentially have negative impacts on water quality.

A study conducted by William Vernieu (1997) examined the effects of reservoir drawdown on sediment re-suspension in Lake Powell. Prolonged drought conditions in the Upper Colorado River Basin caused water levels to decrease to approximately 27 m below full pool from 1987 to 1993. This steady drawdown exposed extensive alluvial deposits in which the Colorado River channel first down-cut and then began eroding laterally as the channel began to meander. Vernieu (1997) found that sediment concentrations increased dramatically in the lower portions of the river in areas of the exposed delta just before entering the reservoir. Significant increases in total nutrient concentrations were also measured and exhibited trends similar to sediment concentrations.

RESERVOIR DRAINAGE AND DAM REMOVAL

Over 75,000 dams have been constructed on U. S. rivers, while over 400 dams at least 1.8 m tall or 30.5 m wide have been removed since 1922 (Pohl, 2002). Reservoirs have a limited lifespan, and since most reservoirs were constructed before 1970, dam removal operations are likely to increase in the near future. With removal comes a series of erosional and depositional processes upstream and downstream of the dam in which headcut migration and channel incision erode sediment from the former impoundment and deposit it on downstream reaches (Doyle *et al.*, 2003). However, since few dam removal operations in the United States have been accompanied by ecological studies, the impacts of reservoir drainage and dam removal are not well understood.

Ecology and Water Quality Impacts

Reservoir drainage and dam removal cause profound ecological impacts on aquatic systems. Sediment deposition on downstream reaches has caused severe declines in macroinvertebrate and fish communities following previous dam removal operations (Stanley and Doyle, 2003). However, drainage can restore man-made reservoir ecosystems to natural riverine ecosystems because riverine taxa can quickly replace fish and macroinvertebrates adapted to slow-moving water and riparian vegetation immediately begins growing in the nutrient rich exposed lake bed (Stanley and Doyle, 2003).

Bushaw-Newton *et al.* (2002) assessed the ecological impacts of the removal of a 2 m high dam on Manatawny Creek in southeastern Pennsylvania. For the study, researchers evaluated changes in geomorphology, sediment characteristics, water quality, and biology due to dam removal. Ten months after removal, the stream channel upstream of the dam down-cut approximately 0.5 m, and fine-grained sediments were eroded and transported downstream. Downstream of the dam, the stream channel aggraded approximately 0.5 m. Results indicate water quality degradation was minimal and short-term, likely due to the short residence time (less than 2 hours) of the reservoir before dam removal (Bushaw-Newton *et al.*, 2002). Algae and benthic macroinvertebrate communities were not significantly impacted by dam removal, while fish abundance initially declined following removal but increased above pre-removal levels within one year after removal (Bushaw-Newton *et al.*, 2002).

Water quality was monitored following the removal of two Minnesota dams in 1999 (Rye, 2000). Monitoring was conducted before, during, and after dam removal to assess the impacts of dam removal on water quality. The Appleton Dam was removed in stages, which allowed time for vegetation growth in the lake bed before complete dam removal. The Frazee Dam reservoir was drained before removal, also allowing for vegetation to stabilize the lake bed. Total suspended sediment concentration initially increased with a gradual, steady decline following removal of the Appleton Dam (Rye, 2000). Sediment concentration also increased following the removal of the Frazee Dam but returned to pre-removal concentrations within two months (Rye, 2000). Results of monitoring indicate that these two dam removals only caused short-term impacts to water quality.

Geomorphic Processes and Sediment and Nutrient Transport

Stanley and Doyle (2002) studied the geomorphic changes of reservoir bottoms following dam removal. They suggest that channel development in formerly impounded reservoirs goes through six geomorphic stages of development. The first stage is the original conditions that trap inflowing sediments and nutrients. The second stage occurs when reservoir drainage begins and water level lowers, increasing water velocity and sediment-water contact. Nitrogen retention should occur during the second stage and progressively increase during the remaining stages because greater sediment-water contact should amplify denitrification, which removes nitrogen from the water and releases it to the atmosphere. During the third stage the stream begins degrading into the lake bed and large amounts of sediment will be transported downstream. Mass wasting of the newly formed stream channel and further down cutting and sediment transport characterizes the fourth stage. Nearly all sediment erosion and phosphorus transport will occur during the third and fourth stages. The fifth and sixth stages involve aggradation and finally stabilization of the new stream channel. Therefore, sediment and nutrient transport downstream will lag following the initial drainage, but will be dramatic once the stream begins forming in the exposed lake bed before finally reaching equilibrium.

Doyle *et al.* (2003) studied the effects that dam removal has on stream channel geomorphic processes. Researchers examined the channel response of two rivers in southern Wisconsin following dam removal. Both river channels that formed in the former impoundments adjusted to removal first by bed degradation, then widening and finally aggradation (Doyle *et al.*, 2002). However, erosion occurred throughout the length of one channel while the other was controlled by head-cut migration due to consolidated fine-grained sediment (Doyle *et al.*, 2002). Large amounts of fine-grained sediment were removed from both reservoirs immediately following dam removal, but later sediment erosion was controlled by the rate of channel adjustment.

WATER QUALITY TRENDS IN SMALL WATERSHEDS

Coulter *et al.* (2001) conducted a study of water quality in a small (350 acre) mixed-use watershed. The purpose of the study was to evaluate the implications of urban development on water quality within the watershed. For the study, bi-weekly water samples were collected throughout the watershed for a one-year period. Results indicate that the main water quality problems associated with urban areas in the watershed were high turbidity and total suspended sediment concentrations from increased sediment delivery due to construction activities, while agricultural regions supplied increased concentrations of nitrogen and phosphorous to the streams (Coulter *et al.*, 2001).

Kuusemets and Mander (2002) examined nitrogen and phosphorus leaching in a 378 hectare agricultural watershed in southern Estonia. About 60 percent of the watershed is used for agriculture while 30 percent is natural forests and bogs. The upper watershed flows into a small storage lake, which then flows into the lower watershed. Nutrient leaching varied widely throughout the watershed and was dependent on land use, agricultural practices, soil conditions, relief, and hydrogeological conditions. Research also showed that phosphorous was primarily removed by sedimentation, especially in the storage lake (Kuusemets and Mander, 2002). However, they found that the storage capacity of the lake had been exceeded and became a source of phosphorous.

REGIONAL RESERVOIR STUDIES

Research was conducted on the physical, chemical and biological characteristics of three reservoirs in Missouri (Heimann, 1995). Water quality, sedimentation patterns, and nutrient concentrations were all examined, and Heimann (1995) found that all three lakes were experiencing problems with sedimentation. Over 1,000 acre-ft of sediment was deposited in each of the three lakes over a 30 to 50 year period (Heimann, 1995). Heimann (1995) also found that reservoir bottom sediments had high concentrations of nitrogen and phosphorous, potentially causing eutrophication. Heimann (1995) determined that these sedimentation and nutrient problems are most likely occurring due to increased urbanization and agricultural practices in the watersheds.

Jones and Knowlton (1993) analyzed the regional patterns of the limnology of Missouri reservoirs. Fellows Lake and McDaniel Lake, both located within the Ozarks Highland region in Greene County, north of VMR, were included in the study. They found that McDaniel Lake had a total phosphorus concentration of 54 ug/L and a total nitrogen concentration of 0.55 mg/L and was classified as eutrophic (Jones and Knowlton, 1993). Fellows Lake was sampled twice and had a mean total phosphorus concentration of 13 ug/L and a mean total nitrogen concentration of 0.21 mg/L and was classified as mesotrophic (Jones and Knowlton, 1993). Jones and Knowlton (1993) state that 45 percent of the mesotrophic and 10 percent of the eutrophic lakes in Missouri are located within the Ozarks Highland region, indicating that nutrients are a potential problem for reservoirs in the region.

SUMMARY

Reservoirs act as sinks for inflowing sediment and nutrients, but when drained they are likely to become a source for these pollutants to downstream reaches. The increased sediment and nutrient loads transported and deposited downstream of reservoirs can damage habitat and cause eutrophication resulting in decreased species density and diversity. Many of Missouri's reservoirs are ageing and experiencing eutrophication and sedimentation problems. These reservoirs will increasingly be in need of drainage to remove the excess sediment and nutrients accumulating within the reservoir. Studies have addressed the ecological and geomorphic processes that occur following reservoir drainage to gain insight into the implications associated with drainage. However, the magnitude and effects of reservoir drainage are site-specific and dependent upon several variables. A better understanding of the water quality impacts that occur following reservoir drainage in southwest Missouri requires additional research to determine the extent and consequences of drainage on sediment and nutrient transport downstream.

CHAPTER THREE

STUDY AREA

This chapter describes the climate, hydrology, geology, soils, and land uses of the Valley Mill watershed and the VMR Study Area. The VMR Study Area is a sub-section of the Valley Mill watershed, which includes VMR, Sanders Spring, Jarrett Spring, and the SDSR. The Valley Mill watershed is situated on the Ozarks Plateau within Greene County, Missouri.

VALLEY MILL WATERSHED

The Valley Mill watershed drains approximately 12.7 km^2 in Greene County, Missouri (Figure 3.1). The watershed is located on the urban fringe of Springfield, Missouri, which is the third largest city in the state with a population of 151,000 (U.S.Census, 2003). Approximately half the watershed is within city limits; the remaining portion is in more rural Greene County. Greene County is located in southwest Missouri on the Springfield and Ozarks Plateaus. The Valley Mill watershed drains from south to northwest into VMR. Elevation ranges from 433 m at the southern boundary to 366 m at the spillway of VMR. All streams in the watershed flow into the reservoir before discharging into the SDSR upstream of a major losing section on that river. The SDSR, which is a sub-watershed of the larger Osage River drainage basin, loses most of its flow to a swallow-hole located approximately 300 m downstream of VMR outflow (Bullard *et al.*, 2001). This sub-surface flow recharges Fulbright Spring, which supplies 20–25 percent of the drinking water for the City of Springfield (Wright Water Engineers, 1995).

Figure 3.1 Map of Valley Mill Watershed

Climate

The Valley Mill watershed has a temperate climate with mild winters and warm summers. The thirty-year mean temperature for Springfield, MO is approximately 13.5^{o} Celsius (NOAA, 2003A). Normal temperature ranges in degrees Celsius in Springfield are: -3.3^{o} – 6.6^{o} in winter, 10.4^{o} – 15.8^{o} in spring, 21.6^{o} – 27.8^{o} in summer, and 11.7^{o} – 17.8^{o} degrees in the fall (NOAA, 2003B). The average annual precipitation for Springfield is approximately 114 cm, with most of the rainfall occurring during the months of March through June (NOAA, 2003A). There were 117 days of measurable rainfall during the study period of March 1, 2002 to March 31, 2003 totaling approximately 103 cm, more than 10 percent below normal, with September, October, November, and December receiving only about 50 percent of the normal precipitation (NOAA, 2003A). The watershed also received approximately 107 cm of snowfall during the study period. The 2002/2003 snowfall season was the fourth greatest ever recorded in Springfield (NOAA, 2003C).

Hydrology

The Valley Mill watershed drains an area that contains a reservoir, several springs, and a number of ephemeral tributaries. Although the exact date of construction is unknown, the original Valley Mill dam was built by the McCracken Mill Co. around the period of the Civil War. The modern reservoir dimensions were created in 1908 when the basin was cleared and a new dam erected (Figure 3.2). The current dam dimensions are 30 m wide and 5.5 m tall. Field and GIS mapping of VMR bathymetry by Susan Licher for her thesis project in the Resource Planning program at Southwest Missouri

State University shows that VMR is 506 m long and averages 105 m wide and 2.5 m deep, with a pre-drainage storage volume of 150,000 m^3 and surface area of 6.1 hectares (Licher, 2003). The water renewal rate of VMR was about 115 hours during baseflow conditions.

Drainage of VMR began on March 19, 2002. As soon as the lake bed was exposed, vegetation immediately began growing in the drained impoundment (Figure 3.3). Vegetation growth was rapid with willow trees over six feet tall covering a large expanse of the exposed lake bed within 6 months of drainage; vegetation grew to over 2.5 m within 18 months (Figure 3.4).

Figure 3.2 Valley Mill Reservoir with Water Level at Full Pool

Figure 3.3 Valley Mill Reservoir, June 2002

Figure 3.4 Willow Trees and Other Vegetation Growth on the Dry Lake Bed within the Drained Valley Mill Reservoir, August 2003

A 1-meter diameter pipe that had been installed near the base of the reservoir was used to drain VMR. A valve located at the base of spillway was used to control the rate of water level drawdown. A small detention pond was constructed below the valve to trap outflowing sediment and other pollutants before discharging into the SDSR (Figure 3.5). Reservoir drainage was complete in less than two months. However, the drainpipe was not located at the very base of the reservoir, so a shallow pool remained within the reservoir during the entire study period (Figure 3.6). While the depth of the pool was typically less than 1 m, depth fluctuated with storm events. Following storm events, water depth in the pool would increase but would typically return to base level within one week. The reservoir completely refilled in May 2002 after 15.5 cm of rainfall inundated the watershed over a one-week period. The reservoir was completely re-drained by early June; it was the only time that the reservoir was refilled during the study period.

The Valley Mill watershed is "flashy" and responds quickly to storm events, requiring at least 2–4 cm of rainfall before significant runoff in the channels occur, depending upon antecedent conditions. All tributaries in the upper watershed are ephemeral and only flow immediately following storm events. Monitoring sites US-1, US-2, US-3, and US-4 are all located along ephemeral tributaries (Figure 3.7).

Figure 3.5 Detention Pond and Drainage Valve Located at the Base of the Valley Mill Reservoir Spillway

Figure 3.6 Shallow Pool Remaining in Valley Mill Reservoir

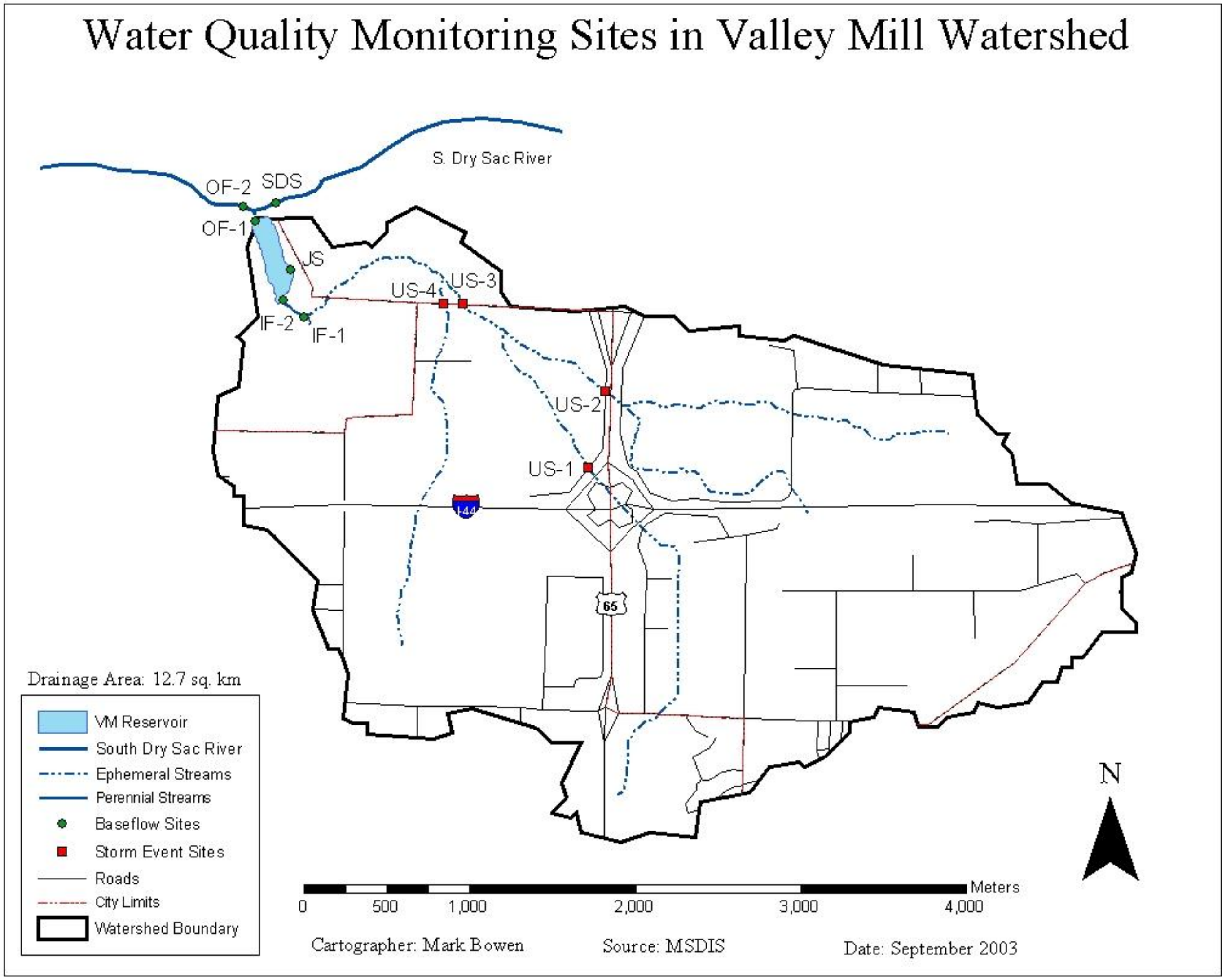

Figure 3.7 Water Quality Monitoring Sites within the Valley Mill Watershed

Springs provide the only perennial water source in the watershed and all springs are located within a few hundred meters of VMR within the VMR Study Area. The largest perennial water source is Sanders Spring, located approximately 200 m upstream of the reservoir (Figure 3.1 & Figure 3.8). Estimated discharge from Sanders Spring ranged from 0.14 m^3/s in February 2003 to 0.84 m^3/s in May 2003 following a period of heavy rains. Mean baseflow discharge from Sanders Spring during the study period was estimated at 0.34 m^3/s, and mean storm discharge was estimated at 0.91 m^3/s.

Figure 3.8 Headwaters of Sanders Spring Near Monitoring Site IF-1

Jarrett Spring is the only other significant perennial water source in the watershed (Figure 3.1). Jarrett Spring had an estimated discharge ranging from 0.01 m^3/s to 0.04 m^3/s and a combined mean baseflow and event discharge of approximately 0.02 m^3/s, less than 5 percent of total reservoir inflow. Total mean baseflow inflow was approximately 0.36 m^3/s. Outflowing discharge from VMR (Site OF-1, Figure 3.7) ranged from approximately 0.18 m^3/s to 2.33 m^3/s. Outflowing mean baseflow discharge was estimated at 0.40 m^3/s, and mean storm event discharge was estimated at 2.51 m^3/s. The difference of 0.04 m^3/s between mean baseflow inflow and outflow is attributed to the increased outflow during reservoir drainage.

A USGS gage (#06918493 South Fork Dry Sac River near Springfield, MO) was installed on the SDSR just downstream of the confluence with VMR outflow in 1996. Site OF-2 is located near the USGS gage (Figure 3.7). During the study period, discharge at the gage ranged from 0.03 m^3/s to 12.35 m^3/s with a mean discharge of 0.5 m^3/s (USGS, 2003).

Geology and Soils

The Valley Mill watershed is located in an area of karst topography. Features typical of karst terrains include caves, springs, losing streams, and sinkholes which can provide a nearly direct hydraulic connection between surface and ground waters (Waite and Thomson, 1993). All these karst features, which are capable of transporting contaminants in surface water to groundwater with little or no purification, are present in the Valley Mill watershed. The karst terrain in the Valley Mill watershed is formed by the dissolution of easily erodable limestone, which dominates the watershed.

The watershed is primarily composed of Mississippian aged limestone of the Burlington-Keokuk, Elsey, Northview, and Compton Formations (Emmett *et al.*, 1978). The Burlington-Keokuk Formation underlies most of the watershed and is the exposed surface formation; below that is the Elsey Formation (Wright Water Engineers, 1995). The Northview and Compton Formations are only found on the Valley Mill Horst. The Valley Mill Horst is formed by two fault lines, the Valley Mill and Brown Faults, trending east-west through the watershed just south of the Valley Mill Reservoir (Waite and Thomson, 1993; Wright Water Engineers, 1995). The Strafford Fault also runs through the watershed, north and east from the Valley Mill Fault across the SDSR (Wright Water Engineers, 1995).

The Valley Mill watershed consists of three general soil associations: Goss-Wilderness-Peridge, Pembroke-Eldon-Creldon, and Wilderness-Viration (Hughes, 1982). These three associations are composed of deep, well-drained to moderately well-drained, gently sloping to strongly sloping soils located on uplands and terraces (Hughes, 1982). The watershed is composed of several series of silt loam and cherty silt loam soils. Silt loam soils of the Newtonian, Viration, Peridge, and Pembroke series dominate the upland areas along the southern edge of the watershed (Hughes, 1982). Wilderness and Goss cherty silt loam soils are predominantly found near the reservoir and along stream channels (Hughes, 1982).

Land Use

The Valley Mill watershed, located on the urban-fringe of Springfield, Missouri, drains a mix of land uses including industrial, commercial, residential, and agricultural lands (Figure 3.9). Interstate-44 and U.S. Highway 65 also pass through the watershed, approximately quartering it. Land cover includes significant areas of grassland and pasture as well as deciduous forest.

Monitoring sites US-1 and US-2 drain runoff from an industrial park located southeast of the I-44/U.S. 65 intersection and other industries in that area. The tributary upstream of site US-1 flows entirely through industrial land uses. Upstream of site US-2 the tributary is split, with the southern tributary draining industrial areas as well as forest and pasture, and the northern tributary draining forest, pasture, and a small farm. Development for the Legacy of Flight Museum began along the northern tributary in the spring of 2002 but was halted shortly thereafter. This resulted in a large expanse of disturbed soil with no vegetation to prevent erosion during the entire study period.

Site US-1 and US-2 tributaries then flow from southwest to northeast through a 250-acre golf course. The confluence of these two tributaries is near the northwest border of the golf course, just upstream of monitoring site US-3. The golf course has a series of small ponds along both tributaries, as well as several high-density residential complexes along the southwest edge of the property. Runoff from the golf course flows past monitoring sites US-3 and US-4 before these tributaries join to form the primary ephemeral tributary that drains into VMR. The US-4 tributary flows from south to north along the western boundary of the golf course and drains runoff from residences and cattle grazing operations, as well as the golf course north of Interstate-44. South of I-44 this tributary drains grassland as well as several commercial areas.

Below the confluence of the US-3 and US-4 tributaries the channel has forest on its northern bank and pasture on its southern. Several single-family residences are located south of the tributary, and runoff from this area reaches the tributary by overland flow. Once the tributary enters VMR Study Area it flows through forest before reaching the reservoir. South of the main ephemeral tributary and west of the US-4 tributary, no noticeable stream channels are present. This area is dominated by grassland and pasture. There are also large expanses of deciduous forest, mostly located near VMR. Several single-family residences are located along the western edge of the watershed. Runoff from this area reaches the tributaries by overland flow.

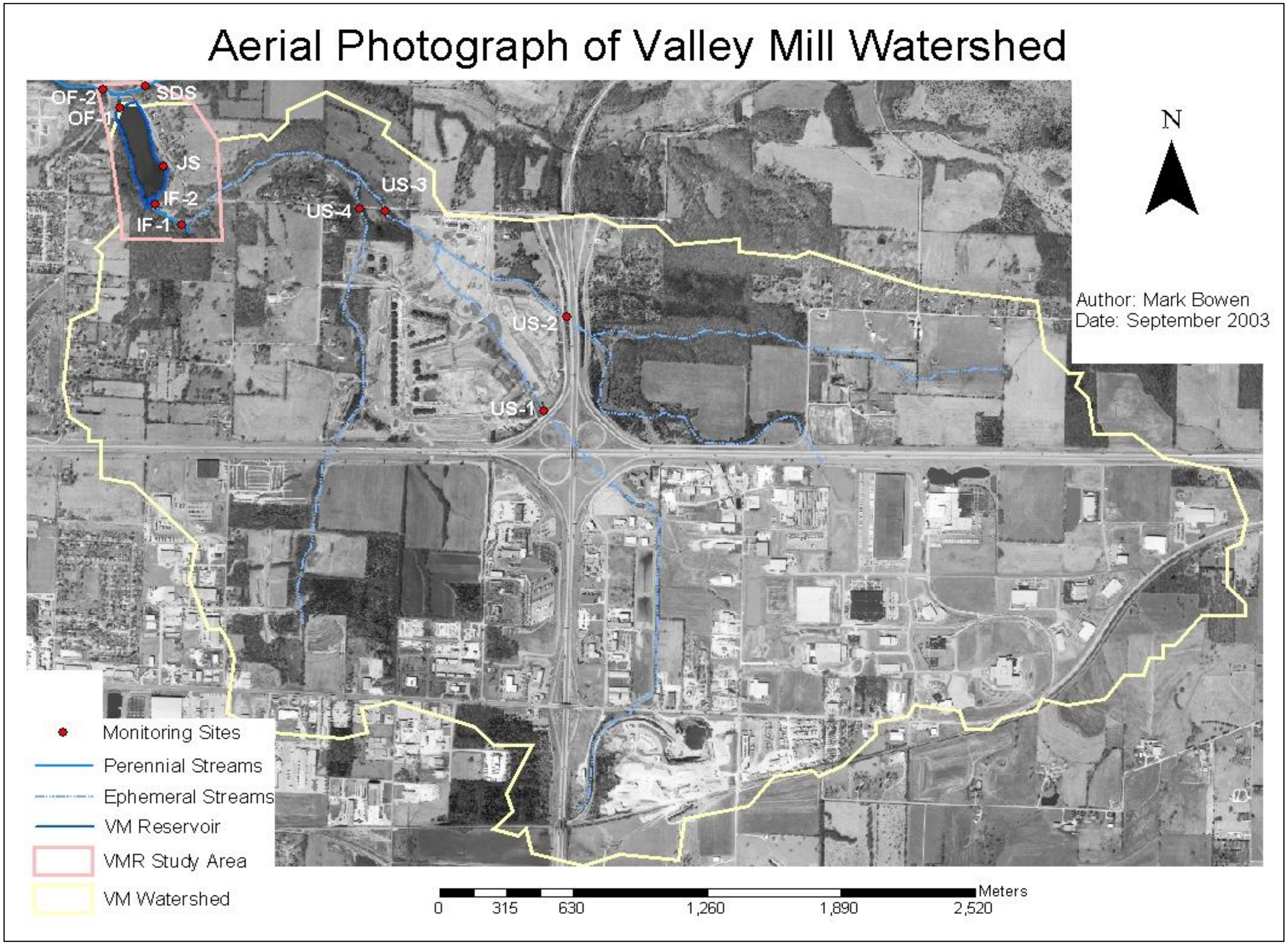

Figure 3.9 Aerial Photograph of Valley Mill Watershed Including Monitoring Sites and VMR Study Area

VALLEY MILL RESERVOIR STUDY AREA

Most of the monitoring and assessment activities of this study focused on the VMR Study Area, which is a component of the Valley Mill watershed (Figure 3.10). This area includes the reservoir, major springs, inflowing tributaries, downstream receiving waters of the SDSR, and the USGS gage. Six of the ten monitoring sites were located within VMR Study Area, and all the baseflow monitoring sites were within it (Figures 3.7 and 3.10). The VMR Study Area is only a small section of the watershed and encompasses less than 0.5 km^2 of the 12.7 km^2 watershed.

The soils and geologic features in the study area are similar to those throughout the watershed. The Valley Mill Horst as well as the Valley Mill and Brown Faults run through the study area. The study area is primarily composed of deciduous forest, but approximately seven single-family residences are located a few hundred meters from the east bank of Valley Mill Reservoir (Figure 3.11). The west and south sides of the reservoir are surrounded by forest except for a small wetland immediately upstream of the reservoir. Both Sanders Spring and the ephemeral tributary flow through forest until reaching the wetland and reservoir.

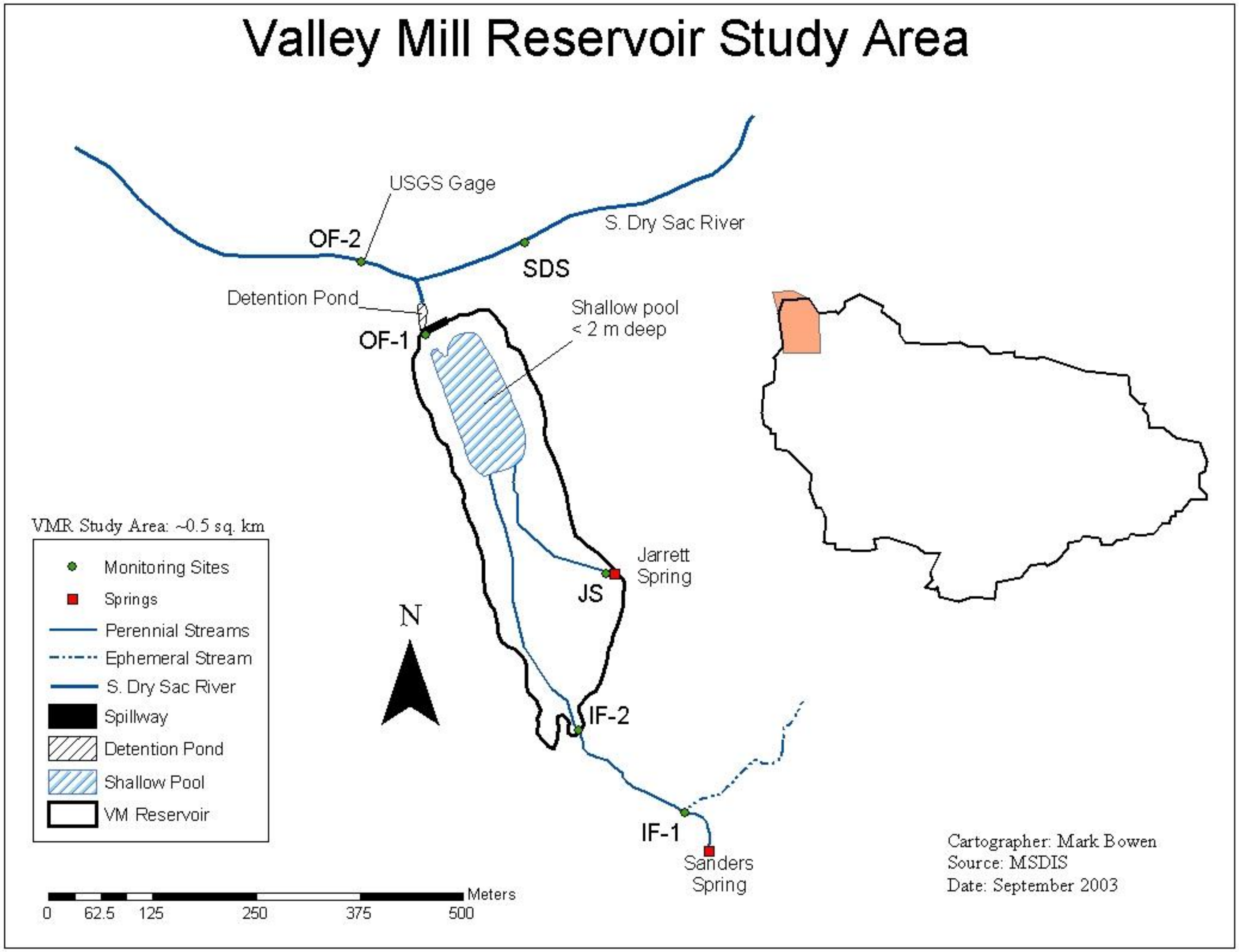

Figure 3.10 Map of Valley Mill Reservoir Study Area

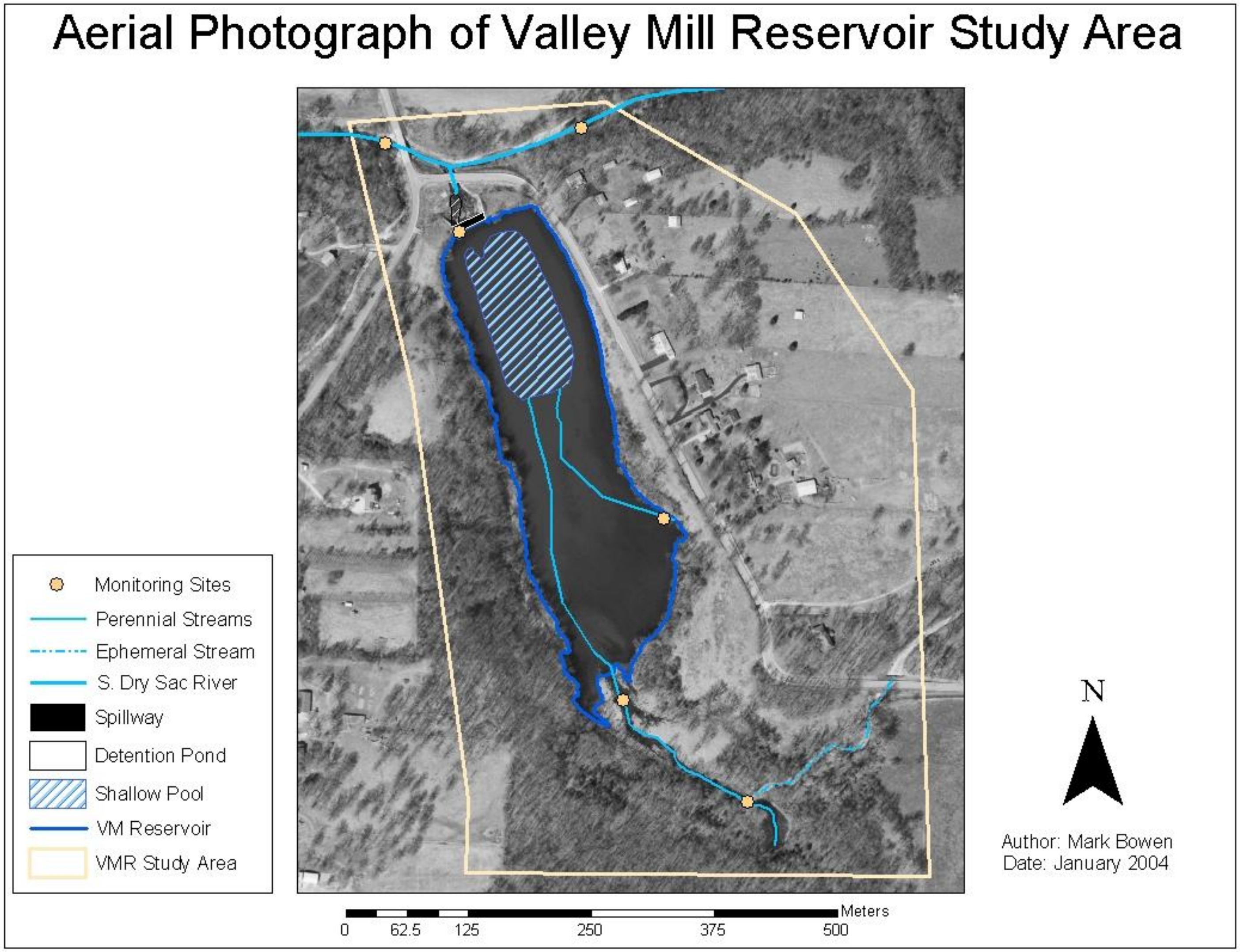

Figure 3.11 Aerial Photograph of Valley Mill Reservoir Study Area Including Monitoring Site Locations

CHAPTER FOUR

METHODOLOGY

This section describes the research design and methodology used to collect and analyze data for this study. Determining the effects of reservoir drainage on water quality required extensive field, laboratory, and computer-based work. All field and laboratory methods followed Standard Operating Procedures (SOPs) approved by the United States Environmental Protection Agency. Data was collected in the field using a water-quality meter, collecting grab water samples, measuring stage, surveying cross-sectional area and longitudinal profiles of stream channels, recording detailed field notes, and using a digital camera for extensive photography. Laboratory methods involved the analysis of water samples to determine total suspended sediment, total nitrogen, and total phosphorus concentrations. Computer-based methods included the collection and processing of Geographic Information System (GIS) data and analyzing field data utilizing statistical software.

FIELD METHODS

Sampling Design

Ten water quality monitoring sites were established throughout Valley Mill watershed covering all major tributaries and hydrologic features within the watershed (Figure 3.7). At every monitoring site a GPS point was collected for use with GIS software. Six monitoring sites were located in the VMR Study Area to thoroughly measure the effects of reservoir drainage on water quality. However, following drainage, flow ceased at site SDS (Figure 3.10), so sampling at this site ceased in June 2002. Jarrett Spring (Site JS, Figure 3.10) was below the water surface of the reservoir before drainage, but became accessible in June 2002, once drainage was complete. All sites within the VMR Study Area were monitored during baseflow and storm event conditions.

Four sites were established in the upper watershed along ephemeral tributaries to determine the upstream pollution contributions. These sites were only monitored following storm events since the channels did not contain flow during baseflow conditions. Data from the upstream sites were also used to compare with water quality trends from the VMR Study Area to determine if the drained reservoir was a significant pollution source within the watershed.

Sample Collection

Water quality monitoring began in March 2002 and continued until March 2003. Water samples were collected approximately once per month during baseflow conditions at all sites within VMR Study Area. However, two samples were collected the first month of sampling and samples were not collected in July 2002, for a total of thirteen baseflow sampling trips during the study period. Water samples were also collected immediately following significant storm events at all sites with flowing water. Eleven storm events were monitored during the study period, all within six months of reservoir drainage.

Before sampling trips, all equipment was cleaned and rinsed with deionized water. Sample bottles were washed in the laboratory with a two percent HCl solution and rinsed with deionized water daily for three consecutive days. Prior to sample collection, each bottle was triple rinsed in the field with ambient water. Two grab samples were collected at each monitoring site from the deepest part of the channel. Flow at all sites was well mixed, so sampling from the deepest part of the channel provided a representative sample. One 500 mL sample was collected to determine total nitrogen and total phosphorus concentrations. These samples were immediately preserved in the field by adding concentrated H_2SO_4 to the sample until pH was below 2. Samples were then placed on ice. One 1000 mL sample was collected to measure total suspended sediment concentration. These samples were immediately placed on ice. Upon returning to the laboratory, all samples were placed in a refrigerator until analysis. One field duplicate and one field blank were prepared for each constituent sampled for each sampling trip.

Water Chemistry

Water chemistry was monitored approximately bi-weekly during baseflow conditions and immediately following storm events using a Horiba U-22 Multi-Parameter Water Quality Monitoring System at all sites containing flow. Water chemistry was monitored twenty-three times at baseflow conditions during the study period and eleven storm events were monitored. The Horiba U-22 monitoring system consists of a hand-held computer with a digital readout and a submersible sensor probe. The Horiba U-22 system simultaneously collects and stores pH, water temperature, dissolved oxygen concentration, conductivity, turbidity, and total dissolved solids concentration. Data for each site was stored in the Horiba U-22 memory and downloaded to a computer upon returning to the laboratory. The Horiba U-22 system is accurate to within $\pm$ 0.3^{o} C for water temperature, $\pm$ 1 percent for conductivity, $\pm$ 0.1 mg/L for dissolved oxygen, $\pm$ 0.05

for pH, ± 5 percent for turbidity, and ± 2 g/L for total dissolved solids. The Horiba U-22 system was automatically calibrated with a standard calibration solution before each sampling trip. The Horiba U-22 system was manually calibrated every four to six months using prepared standards to further ensure accuracy. Cleaning and general maintenance followed guidelines outlined in the manual.

Stream Gaging

Surveys were conducted at each monitoring site using an auto-level and stadia rod to determine cross-sectional area at each site and longitudinal profile of the stream channel immediately upstream and downstream of each site. Staff gages were installed at the four upstream sites to measure stage since these four sites were located at concrete box culverts. A stadia rod was used to measure stage at all other sites at the deepest part of the channel. Monuments were installed at all cross-sections to ensure that stage measurements were taken at the exact same location every time.

LABORATORY METHODS

Trained laboratory personnel from the Chemistry Department at Southwest Missouri State University conducted all water sample analysis. All water sample analyses adhered to SOPs approved by the United States Environmental Protection Agency. All methods also followed procedures outlined in Standard Methods for the Examination of Water and Wastewater (Eaton *et al.*, 1995) and methods developed by the United States Environmental Protection Agency.

Nitrogen

All water samples were analyzed to determine total nitrogen concentration, which is a measure of all forms of nitrogen present in the water sample. Total nitrogen concentrations were determined by the second-derivative spectroscopic method after an alkaline persulfate digestion procedure (USEPA, 1987; Crumpton *et al.*, 1992). The detection limit was $\leq$ 0.1 mg/L with an upper range limit of 5 mg/L.

Preserved water samples were first returned to a pH between 6 - 8 using NaOH. Ten milliliters of each neutralized sample was then combined with a digestion reagent and placed in an autoclave at 120^{o} C for 30 minutes. Digested samples were removed from the autoclave, and 0.4 ml of 6M HCl was added to each sample. Samples were then analyzed using a spectrophotometer after the device had been calibrated. Four reagent blanks as well as six prepared standards, a laboratory control check standard, and a quality control check standard were first analyzed to calibrate the spectrophotometer and ensure proper readings and results. Prepared water samples were then analyzed using the spectrophotometer. A laboratory control check, a reagent blank, a matrix spike, one laboratory duplicate, and one field duplicate were also analyzed for every twelve water samples analyzed. The spectrophotometer software automatically displayed results expressed as total nitrogen concentration in mg/L.

Phosphorus

All water samples were analyzed to determine total phosphorus concentration, which is a measure of all forms of phosphorus present in the water sample, including organic phosphorus. Total phosphorus samples were analyzed using the ascorbic acid reduction phosphomolybdate method after an acid persulfate digestion procedure based on EPA Method 365.2 and Standard Methods 4500-P (USEPA, 1983; USEPA, 1987; Eaton *et al.*, 1995). The detection limit of this method was $\leq$ 0.010 mg/L with an upper range limit of 2.0 mg/L.

All water samples were first neutralized using NaOH to bring pH between 6 and 8. Twenty milliliters of the neutralized sample was combined with 0.4 ml of 5.4M H_2SO_4 and 0.16 g $(NH_4)_2S_2O_8$ in a test tube and then placed in an autoclave at 120^{o} C for 30 minutes to digest the samples. After sample digestion, 0.75 ml 6M NaOH and one drop of phenolphthalein solution was added to each sample. Then 6M NaOH was added to each sample until the sample turned pink. After that, 5.4M H_2SO_4 was added to each sample until the pink cleared. Three milliliters of a mixed molybdate reagent solution was added to each sample; samples were then analyzed using a spectrophotometer set at wavelength 880 nm. Six standard solutions and three reagent blanks were first analyzed to develop a calibration curve. Water samples were analyzed with one reagent blank, one laboratory control check, one quality control check, one matrix spike, one field duplicate, and one laboratory duplicate for every twelve water samples analyzed. Absorbance readings were recorded and entered into an Excel spreadsheet to calculate total phosphorus concentration in mg/L using the calibration curve developed using the standard solutions and reagent blanks.

Total Suspended Sediment

All water samples were analyzed to determine total suspended sediment concentration, which is a measure of all sediment retained on a filter after the water sample has passed through. Total suspended sediment concentration was determined by collecting suspended sediments on pre-weighed glass-fiber filters, drying the filters at 103-105^{o} C, and then reweighing according to Standard Methods 2540D and EPA Method 160.2 (USEPA, 1983; Eaton *et al.*, 1995). This method has a detection limit of 0.5 mg/L and a minimum quantification interval of 0.1 mg/L.

A glass-fiber filter was placed in a filtration apparatus with a vacuum attached. Each filter was rinsed with three 20 ml volumes of water and then dried in an oven at 103^{o} C to 105^{o} C for at least one hour. Each filter was weighed to a precision of 0.1 mg. After that the filters were re-inserted into the filtration apparatus, and a measured volume of the water sample was passed through the filter.

Filters were placed in an oven at 103^{o} C to 105^{o} C for at least one hour, cooled, and then weighed. This process was repeated for each filter until mass change was less than 0.5 mg between successive weighing. Total suspended sediment concentration was calculated by subtracting the initial filter mass from the filter mass plus residue, multiplying by 1000, and then dividing by the sample volume. Results are expressed in mg/L with a precision of 0.1 mg/L. For every set of samples analyzed, two laboratory duplicates were analyzed and at least one laboratory blank. The percent difference between the two duplicates should have been less than twenty percent of their average, and the blank value should have been less than 0.5 mg/L.

COMPUTER-BASED METHODS

GIS Database

The GIS database for this study was used to display and evaluate spatial data for the watershed including water quality data collected from each monitoring site. All GIS analyses were performed using ArcGIS. GIS data used for this study consisted of GPS, transportation, and hydrology data, as well as aerial photographs. All GPS data was collected in the field using a Garmin GPS 12XL hand-held unit that is accurate to within 15 m. Transportation and hydrology GIS data was downloaded from the Missouri Spatial Data Information Service website at http://misdis.missouri.edu (MSDIS, 2003). Transportation data was created by the Missouri Department of Transportation based on 1995 U.S. Census TIGER files. The United States Geological Survey created the stream network data for Valley Mill watershed in 1990. Aerial photographs of the Valley Mill watershed were obtained from the Greene County GIS Department. The photographs had already been ortho-rectified with a Universal Transverse Mercator projection. The aerial photographs were used to create the VMR outline as well as the SDSR GIS data by means of "heads-up" digitizing. Heads-up digitizing is the process by which vectors are created from raster data directly from the computer monitor using the mouse (Longley *et al.*, 2001). All GIS data, excluding the aerial photographs, were converted to the Albers Equal Area map projection. Microsoft Access was used to create a database compatible with ArcGIS containing GPS and water quality data.

Stream Discharge

Stream discharge was estimated by two methods: developing stage-discharge rating curves and using previously developed regional rating curves. The first method required stage and velocity measurements for each monitoring site. Since stream velocity was too low at most sites to register on a velocity meter, velocity was estimated using Manning's Equation and survey data. Cross-sectional area was calculated for a range of water stages and multiplied by velocity data to estimate a range of discharges. These estimated discharges were then plotted against the water stages to create a discharge rating curve equation for each monitoring site (Table 5.14). Stage data could then be input into the equations to calculate an estimated discharge for a given water level.

A second method, which utilized regional rating curves, was also used to estimate discharge. The regional rating curves were developed by Dr. Robert Pavlowsky of Southwest Missouri State University (Pavlowsky *et al.*, 2002). Dr. Pavlowsky created the regional rating curves using USGS gage data from the Ozarks region of Missouri to create mean and 10-percentile rating curves based on drainage area. The drainage area of each monitoring site was calculated and input into the rating curve equations developed by Dr. Pavlowsky to estimate mean and 10-percentile discharges for each monitoring site.

Pollution Loading

Pollution loads were calculated for each monitoring site for total dissolved solids, total suspended sediment, total phosphorus, and total nitrogen. Pollution loads were calculated for each site and constituent on each sampling date by multiplying pollution concentration by discharge to calculate pollution loads in kg/day. Mean daily pollution loads were also calculated for each site and constituent by multiplying the mean constituent concentrations for the entire study-period by mean estimated discharge. Mean pollution loads were calculated for each site using estimated discharge from both of the discharge methods discussed above. While calculating pollution loads using this method is believed to produce results high in error, the data is still useful in analyzing pollution transport trends but not specific values.

Data Management and Analysis

All data collected from the field, the Horiba U-22 system, laboratory analysis, and other sources were entered into a Microsoft Excel spreadsheet. All water quality data were entered into the spreadsheet and sorted by site. The mean, median, standard deviation, coefficient of variance, and minimum and maximum values were calculated for each water quality parameter for each site. Percent difference of water quality variables between monitoring sites was calculated by two methods in Excel: mean difference and average monthly difference. Mean difference was determined by calculating the mean value of all samples for each variable at every monitoring site. The difference between sites was calculated for each variable using the equation (SiteA – Site B)/Site B * 100 to determine the relative difference between monitoring sites. Average monthly difference was calculated using the same formula, except percent difference between sites was determined for each variable each month, and then the average of this difference was calculated to determine the relative difference weighted by month. Excel was also used to plot cross-sectional and longitudinal survey data to determine cross-sectional area of each sampling site and the slope of the stream channels.

CHAPTER FIVE

RESULTS & DISCUSSION

This chapter presents the results of a one-year evaluation of the effects of reservoir drainage on water quality. The water quality parameters discussed are water chemistry, such as pH, dissolved oxygen concentration, and turbidity, and total dissolved solids, nitrogen, phosphorus, and total suspended sediment concentrations and loads. Results are divided into three sections: baseflow water quality, storm event water quality, and pollution loads. Also presented in this chapter is a discussion of the implications of reservoir drainage on the downstream receiving water bodies and impacts to Fulbright Spring, a comparison to other reservoir drainage studies, and a description of future work. All data for this study are contained in Appendix A: baseflow data, Appendix B: storm event data, and Appendix C: pollution load data. The appendices also contain all other data collected during this study, but not necessarily addressed in this thesis, such as pre-drainage water quality, automatic water sampler and data logger data, bacteria data, precipitation data, and a channel survey.

BASEFLOW WATER QUALITY

During baseflow conditions, pH, dissolved oxygen (DO) concentration, water temperature, total dissolved solids (TDS) concentration, and turbidity were measured twenty one times at sites IF-1, IF-2, OF-1, and OF-2 from April 2002 to March 2003. These parameters were measured seventeen times at site JS from June 2002 to March 2003. Site SDS was monitored six times from April 2002 to July 2002, when flow

Table 5.1 Summary of Baseflow Water Quality Data

		BASEFLOW					
		IF-1	**IF-2**	**JS**	**OF-1**	**OF-2**	**SDS**
		Spring	Inflow	Spring	Outflow	Gage	Receiving
Estimated Q (m3/s)	**Mean**	0.34	-	0.02	0.40	**0.37**	0.47
	MIN	0.14	-	0.01	0.18	**0.04**	0.16
	MAX	0.84	-	0.04	2.33	**2.18**	1.27
pH	**Mean**	6.6	6.7	6.8	7.3	7.5	7.6
	MIN	6.3	6.4	6.5	6.7	7.0	7.3
	MAX	6.9	7.1	7.1	8.0	7.9	7.8
DO (mg/l)	**Mean**	5.3	6.7	4.2	8.5	8.3	8.6
	MIN	1.9	3.1	1.1	4.6	4.8	7.6
	MAX	9.6	10.9	10.9	15.2	12.3	9.6
TEMP (C)	**Mean**	15.2	15.4	14.5	15.9	16.2	17.6
	MIN	13.9	14.2	10.7	8.4	7.8	13.4
	MAX	16.5	17.5	17.5	22.1	23.0	21.4
TURB (NTU)	**Mean**	12.9	18.2	12.6	56.4	48.0	2.6
	MIN	0.0	0.0	0.0	4.9	4.3	1.3
	MAX	65.0	120.0	45.5	550.0	395.0	4.5
TDS (mg/l)	**Mean**	429	431	302	386	379	277
	MIN	350	350	241	330	260	230
	MAX	579	589	340	453	455	300
TSS (mg/l)	**N =**	11	11	8	11	11	3
	Mean	7.5	10.8	1.5	20.7	24.7	1.9
	MIN	0.7	2.8	0.4	3.6	4.3	0.1
	MAX	36.4	30.6	3.0	41.6	106.4	2.8
TP (ug/l)	**N =**	11	10	8	11	11	3
	Mean	38	37	36	43	48	65
	MIN	12	13	20	20	20	11
	MAX	81	77	87	88	91	140
TN (mg/l)	**N =**	11	11	8	11	11	3
	Mean	2.3	2.3	2.0	2.0	2.3	2.8
	MIN	1.6	1.1	1.0	0.0	1.4	1.7
	MAX	4.7	4.4	2.4	4.0	4.8	4.8

ceased at this site. Total suspended sediment (TSS), total nitrogen (TN), and total phosphorus (TP) concentration was sampled eleven times at sites IF-1, IF-2, OF-1, and OF-2. Jarrett Spring was sampled eight times and site SDS three times. All baseflow water quality data is contained in Appendix A. Baseflow data is summarized in Table 5.1.

Water Chemistry

Table 5.2 presents the mean values of each water quality variable tested and the mean and average monthly-weighted difference of each variable between monitoring sites. Water temperature and pH remained nearly constant from site IF-1 to IF-2. However, DO concentration and turbidity increased significantly between the two sites. Mean DO concentration increased from 5.3 mg/L to 6.7 mg/L over the 200 m reach between sites IF-1 and IF-2, a mean increase of 26 percent with an average monthly increase of approximately 30 percent. Turbidity increase was even greater with an average monthly increase of nearly 37 percent and a mean increase over 40 percent.

Discharge from Sanders Spring flowed approximately 350 m over exposed lake bed downstream of site IF-2 into a shallow pool within the reservoir and mixed with

Table 5.2 Baseflow Water Quality Changes Between Sites IF-1 & IF-2

	BASEFLOW			
	IF-1 Spring	**IF-2 Inflow**	**Mean % Change**	**Avg Monthly % Change**
Temp (C)	15.2	15.4	-	-
pH	6.6	6.7	-	-
DO (mg/l)	5.3	6.7	26.4	32.5
Turb (NTU)	12.9	18.2	40.9	36.9
TDS (mg/l)	429	431	0	0
TSS (mg/l)	7.5	10.8	44.0	397.0
TP (ug/l)	38	37	-3	-3
TN (mg/l)	2.3	2.3	0.0	0.0

Jarrett Spring water before discharging through the drainage valve at site OF-1. Discharge from Jarrett Spring was less than 10 percent of Sanders Spring discharge and had similar water quality, so the effects of Jarrett Spring on outflowing water quality were assumed to be negligible.

From Sanders Spring (site IF-1) to VMR outflow (site OF-1), pH increased on every sampling date; mean pH increased from 6.6 at site IF-1 to 7.3 in reservoir outflow (Table 5.3). This increase in pH may have been caused by several factors such as the exsolution of CO_2, denitrification, and carbonate mineral dissolution (Langmuir, 1997). Groundwater generally has a higher CO_2 concentration than surface waters (Langmuir, 1997). Dissolved oxygen concentration in groundwater discharged from Sanders Spring increased as it flowed through the drained VMR, causing a decrease in CO_2 concentration, so less CO_2 was available to form acids. Also, nitrogen concentration decreased after flowing over the exposed lake bed, possibly due to denitrification, which increases pH. Finally, inflowing spring water flowed over exposed calcium-carbonate sediment within the reservoir before discharging into the SDSR.

Mean water temperature increase was only 0.7^{o} C between sites IF-1 and OF-1 (Table 5.3). Water temperature in discharge from Sanders Spring was nearly constant year-round, only fluctuating from 13.5^{o} C to 16.5^{o} C. However, water temperature in discharge from the reservoir fluctuated seasonally. Reservoir discharge had warmer temperatures than Sanders Spring from late spring to early fall and cooler temperatures

Table 5.3 Baseflow Water Quality Changes Between Sites IF-1 & OF-1

	BASEFLOW			
	IF-1 Inflow	**OF-1 Outflow**	**Mean % Change**	**Avg Monthly % Change**
Temp (C)	15.2	15.9	-	-
pH	6.6	7.3	-	-
DO (mg/l)	5.3	8.5	61.3	85.4
Turb (NTU)	12.9	56.4	335.7	440.1
TDS (mg/l)	429	386	-10	-10
TSS (mg/l)	7.5	20.7	176.0	1,227.2
TP (ug/l)	38	43	12	32
TN (mg/l)	2.3	2.0	-13.0	-15.7

from late fall to early spring (Figure 5.1). Therefore, average temperature change for the entire study period was minimal.

Dissolved oxygen concentration increased from Sanders Spring to VMR outflow on every sampling date (Figure 5.2). Mean DO concentration was approximately 60 percent higher at site OF-1 compared to IF-1 (Table 5.3). Groundwater often contains little or no dissolved oxygen, but measurable DO concentrations are not uncommon (Hem, 1985). Therefore, it was expected that DO concentration would increase after flowing over the lake bed during baseflow since oxygen-poor groundwater provided the only source of inflow during baseflow conditions.

Turbidity measurements increased in eighteen of the twenty-one measurements from site IF-1 to site OF-1. Turbidity increased an average of 43.5 NTU, or 440 percent, from Sanders Spring to reservoir outflow after flowing through the exposed lake bed (Table 5.3). Turbidity is a measure of the light scattered or absorbed in water and is caused by suspended particles in the water column such as sediment and organic and inorganic materials (Eaton *et al.*, 1995). The nephelometric turbidity measurement used

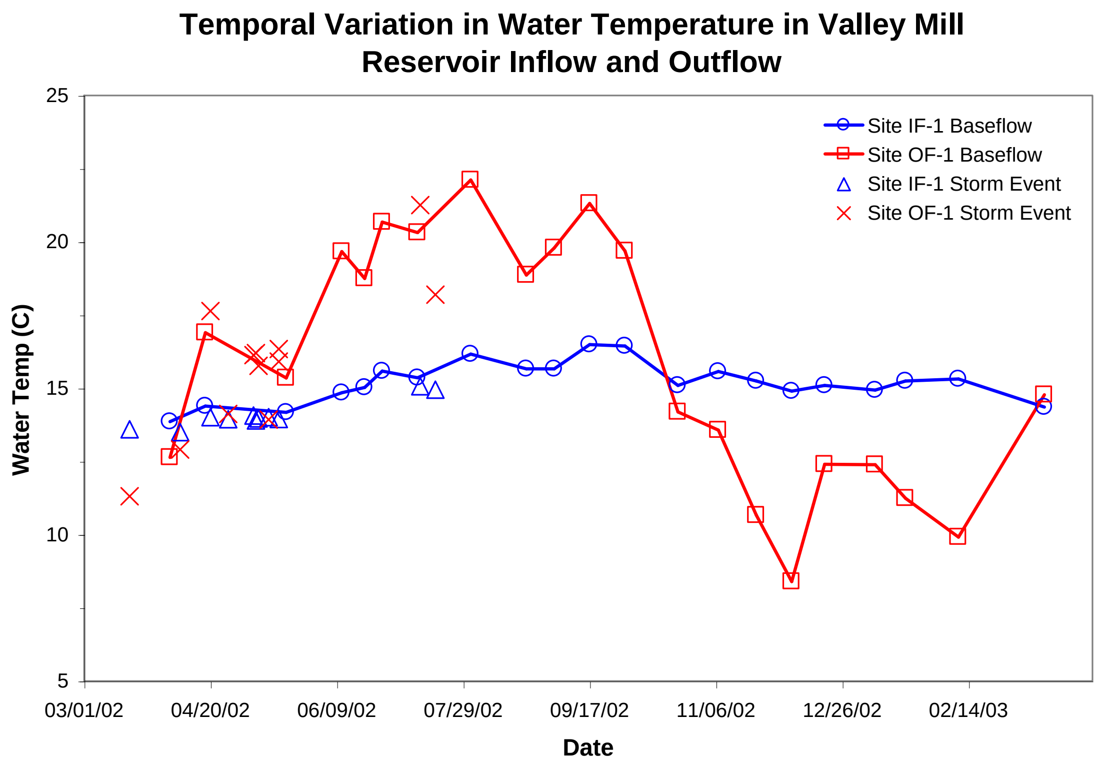

Figure 5.1 Temporal Variation in Water Temperature Between Sites IF-1 and OF-1

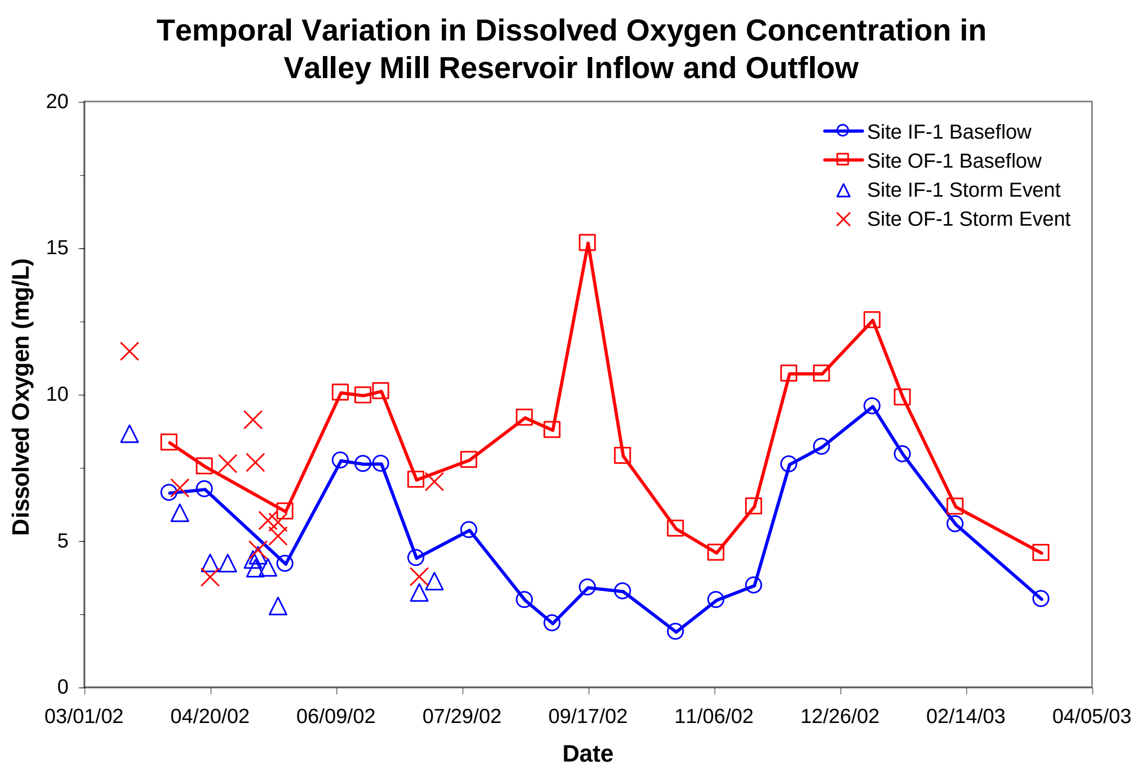

Figure 5.2 Temporal Variation in DO Concentration Between Sites IF-1 and OF-1

in this study is only a relative measure of the side scattering of light and is dependent on the particle size, not sediment concentration (Davies-Colley and Smith, 2001). However, as suspended sediment concentration increases, turbidity typically increases since more light-scattering materials are present in the water. As seen below, suspended sediment concentration increased after flowing over the lake bed, which caused turbidity to also increase.

Outflow from VMR flowed through a small detention pond before discharging into the SDSR, roughly 50 m upstream of site OF-2. Water chemistry remained nearly unchanged from site OF-1 to OF-2 after flowing through this detention pond (Table 5.4). Site SDS, located on the SDSR approximately 100 m upstream of the confluence with VMR outflow, was selected to evaluate the effects of reservoir outflow on the receiving water body. Water chemistry at site SDS was similar to VMR outflow except turbidity, which was nearly 2,000 percent higher at site OF-2 (Table 5.5). Mean turbidity increased from 2.6 NTU at site SDS to 48.0 at site OF-2. This indicates that outflow from VMR has much more fine-grained material suspended in the water column, which reduces water clarity, than the SDSR.

Table 5.4 Baseflow Water Quality Changes Between Sites OF-1 & OF-2

	BASEFLOW			
	OF-1 Outflow	**OF-2 Outflow**	**Mean % Change**	**Avg Monthly % Change**
Temp (C)	15.9	16.2	-	-
pH	7.3	7.5	-	-
DO (mg/l)	8.5	8.3	-2.9	-0.8
Turb (NTU)	56.4	48.0	-14.9	-27.8
TDS (mg/l)	386	379	-2	-2
TSS (mg/l)	20.7	24.7	19.3	17.5
TP (ug/l)	43	48	13	11
TN (mg/l)	2.0	2.3	15.0	11.8

Table 5.5 Baseflow Water Quality Changes Between Sites SDS & OF-2

	BASEFLOW			
	SDS Upstream	**OF-2 Outflow**	**Mean % Change**	**Avg Monthly % Change**
Temp (C)	17.6	16.2	-	-
pH	7.6	7.5	-	-
DO (mg/l)	8.6	8.3	-3.5	3.9
Turb (NTU)	2.6	48.0	1746.2	351.1
TDS (mg/l)	277	379	37	17
TSS (mg/l)	1.9	24.7	1,200	2,176
TP (ug/l)	65	48	-26	-8
TN (mg/l)	2.8	2.3	-17.9	6.2

Dissolved Solids and Suspended Sediment Concentrations

Total dissolved solids concentration remained constant between sites IF-1 and IF-2, so the 200 m reach between the two sites did not affect TDS concentration (Table 5.2). However, TDS concentration decreased from Sanders Spring to VMR outflow on every sampling date by an average of approximately 10 percent, or 40 mg/L (Table 5.3). Between sites OF-1 and OF-2 TDS concentration remained nearly constant. Therefore, the detention pond below the reservoir did not affect TDS concentration. Total dissolved solids concentration at site SDS was much lower than VMR outflow, indicating the Valley Mill watershed delivers an increased TDS load to the SDSR.

Total dissolved solids is the measure of solids in water that passes through a filter with a pore size of 2.0 um or smaller (Eaton *et al.*, 1995). Many types of algae and bacteria in water can utilize dissolved solids by assimilation and uptake, which likely caused TDS concentration to decrease between sites IF-1 to OF-1 (Dodds, 2002). Another factor leading to a reduction in TDS concentration between the two sites may have been the mixing and dilution of spring-water with reservoir water. Outflow from

Valley Mill watershed had higher TDS concentrations than the upper SDSR because groundwater, which is in contact with highly soluble limestone longer than surface water, was the only source of flow in the Valley Mill watershed during baseflow conditions.

Total suspended sediment concentration increased from site IF-1 to IF-2 on nine of eleven sampling dates. Mean TSS concentration increased over 40 percent between the two sites (Table 5.2). Total suspended sediment increased between sites IF-1 and OF-1 on all of the eleven sampling dates except May 20, 2002, when the reservoir was re-filled (Appendix A). Figure 5.3 shows the ratio of TSS concentration at site OF-1 to site IF-1. If the ratio is greater than 1.0, TSS concentration increased from site IF-1 to OF-1 on that date; if the ratio is less than 1.0, TSS concentration decreased. The greatest TSS increases occurred on the first sampling date in April 2002, from July to November 2002, and from January to March 2003. Sediment concentrations between sites IF-1 and OF-1 were similar in May, June, November, and December 2002. Concentrations were at background levels at both sites in May and November 2002 and elevated at both sites in June and December 2002.

The expected sediment removal trend that occurs following drainage is described in Stanley and Doyle's 2002 study on the geomorphic effects of reservoir drainage and dam removal. They state that six stages of geomorphic change of the stream channel within the reservoir will occur following drainage: (1) original conditions that trap inflowing sediments and nutrients; (2) reservoir drainage begins and water level lowers; (3) degradation into the lake bed and erosion of large amounts of sediment; (4) mass wasting of the stream channel and further down cutting and sediment transport; (5)

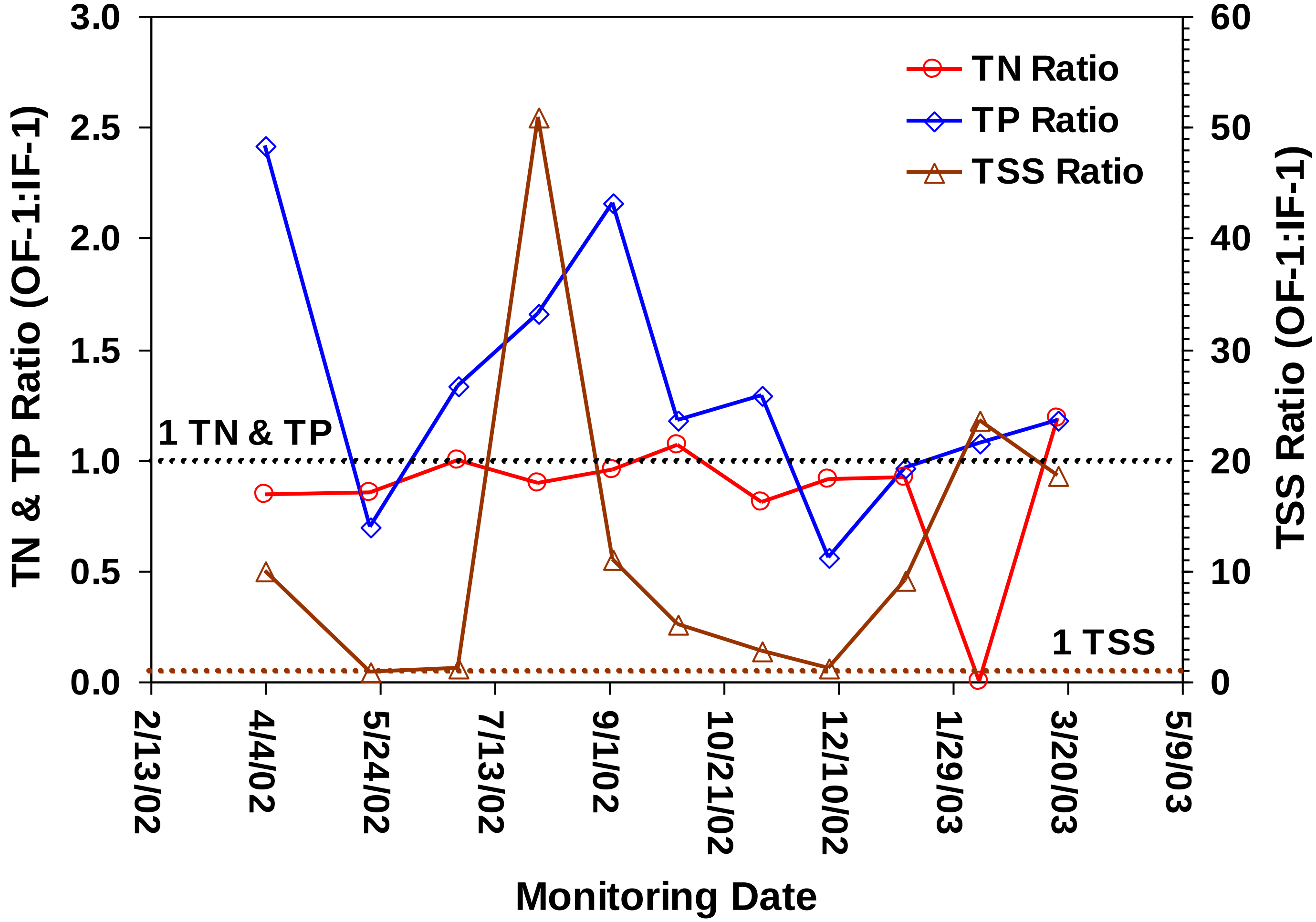

Figure 5.3 OF-1:IF-1 Total Suspended Sediment, Total Nitrogen, & Total Phosphorus Concentration Ratio

aggradation of the stream bed; and (6) stabilization of the new stream channel within the reservoir.

Sediment transport trends in this study were similar to those proposed by Stanley and Doyle (2002). Sediment concentration did not significantly increase until over three months after drainage began. In August 2002, however, sediment concentration dramatically increased. Sediment concentration remained elevated in outflow, slowly decreasing each month until dramatically increasing again in January 2003. This increase in winter is possibly due to repeated freezing and thawing of the reservoir bed sediments causing mass wasting of the stream banks. The study was completed before the stream channel reached stages 5 and 6. Results also indicate that draining of VMR caused significant erosion of the 200 m reach of stream channel upstream of VMR.

Mean TSS concentration at OF-2 was approximately 20 percent higher than site OF-1, at 24.7 mg/L (Table 5.4). However, TSS concentration decreased four out of the first five sampling dates and the last two sampling dates (Appendix A). Total suspended sediment concentration increased an average of 87 percent from site OF-1 to OF-2 between October 2002 and January 2003. The detention pond below the reservoir outflow valve may have become saturated with sediment and begun to act as a sediment source, rather than trap, starting in October 2002. Site SDS TSS concentration was lower than sites OF-1 and OF-2 on every sampling date, illustrating that the Valley Mill watershed was the primary sediment source to downstream reaches of the SDSR, not the upper SDSR watershed.

Nutrient Concentrations

Total phosphorus discharged from Sanders Spring had a mean concentration of 38 ug/L during the study period and only exceeded 50 ug/L on three sampling dates (Appendix A). Mean TP concentration only differed by 3 percent between sites IF-1 and IF-2 (Table 5.2). Mean TP concentration between sites IF-1 and OF-1 increased by only 12 percent; however, monthly TP concentrations increased an average of over 30 percent (Table 5.3).

Figure 5.3 is a graph of the ratio of site OF-1 TP concentration to site IF-1. Total phosphorus concentrations decreased from site IF-1 to site OF-1 in May 2002 following heavy rains and December 2002 following rain and heavy snow. Phosphorus concentration increased the greatest in August and September 2002; sediment concentration also increased significantly these months. Approximately 95 percent of phosphorus transported in aquatic systems is attached to particulate matter in the water column (Hem, 1985). By comparing the total phosphorus ratio to the total suspended sediment ratio, it was determined that phosphorus trends correlated well with sediment trends (Figure 5.3). Thus, a link between phosphorus and sediment transport is indicated.

Total phosphorus concentration decreased slightly between sites OF-1 and OF-2 during the first three months of the study and in October, November, and January (Appendix A). However, TP concentration increased 35 percent or more between these two sites on four sampling dates. Mean phosphorus concentration at site SDS was approximately 25 percent higher than site OF-2. However, this higher mean TP concentration is attributed to one elevated sampling date; median TP concentration at site SDS was slightly lower than VMR outflow (Appendix A).

Total nitrogen concentrations remained at low levels at all sites throughout VMR Study Area. Concentration did not exceed 5 mg/L at any monitoring site and only exceeded 2.5 mg/L on one sampling date, May 20, 2002. Total nitrogen concentration decreased an average of 0.3 mg/L, approximately 15 percent, from Sanders Spring to VMR outflow. The greatest decreases in TN concentration occurred in February 2003 when TN concentration was only 1.7 mg/L at Sanders Spring but was below detection limits in VMR outflow and in May 2002 when the reservoir was re-filled by heavy rains. All other decreases in TN concentration were less than 0.5 mg/L. Stanley and Doyle (2002) state that nitrogen removal from the water should occur following reservoir drainage because greater sediment-water contact should amplify denitrification. Therefore, the slight decrease in nitrogen concentration after flowing over the exposed lake bed is attributed to denitrification within the drained reservoir.

Temporal Transport Trends

Baseflow water quality data was evaluated temporally to determine if water quality parameters displayed any seasonal trends. Sediment and nutrient transport trends were also evaluated to determine if most sediment and nutrients were released quickly following drainage or were released steadily throughout the study period. Figures 5.4 to 5.7 show the temporal trends of water chemistry and sediment, phosphorus, and nitrogen concentrations at sites IF-1 and OF-1.

Sanders Spring (Site IF-1)

Water quality at site IF-1 did not exhibit any strong temporal trends (Figures 5.4 and 5.5). The pH of discharge from Sanders Spring remained nearly constant during the study period since it is strongly buffered by limestone weathering throughout the region (Figure 5.4). Water temperature and DO concentration displayed slight seasonal patterns. Water temperature was slightly warmer during the summer and cooler during spring and winter, while DO concentration was lowest during the summer and higher during spring and winter (Figure 5.4). Turbidity varied considerably from month to month (Figure 5.4). Discharge from Sanders Spring varied seasonally, with highest discharges in the spring and decreasing to the end of winter, but increased on the last sampling date in March 2003 (Figure 5.5). Sediment concentration at site IF-1 peaked in June and December 2002 but remained low on all other sampling dates (Figure 5.5). Phosphorus concentration varied widely from month to month, while nitrogen concentration peaked in May 2002 but remained steady for the rest of the study period (Figure 5.5).

Reservoir Outflow (Site OF-1)

Water quality at site OF-1 also did not exhibit any strong temporal patterns (Figures 5.6 and 5.7). Of the water chemistry parameters monitored, only water temperature displayed a seasonal pattern (Figure 5.6). Outflowing pH remained near constant, while DO concentration and turbidity varied considerably month to month (Figure 5.6). Discharge at site OF-1 was similar to site IF-1, with higher discharge in the spring and decreasing to winter then increasing in March 2003 (Figure 5.7). Sediment concentration displayed a trend with a lag in increase following drainage, and then a

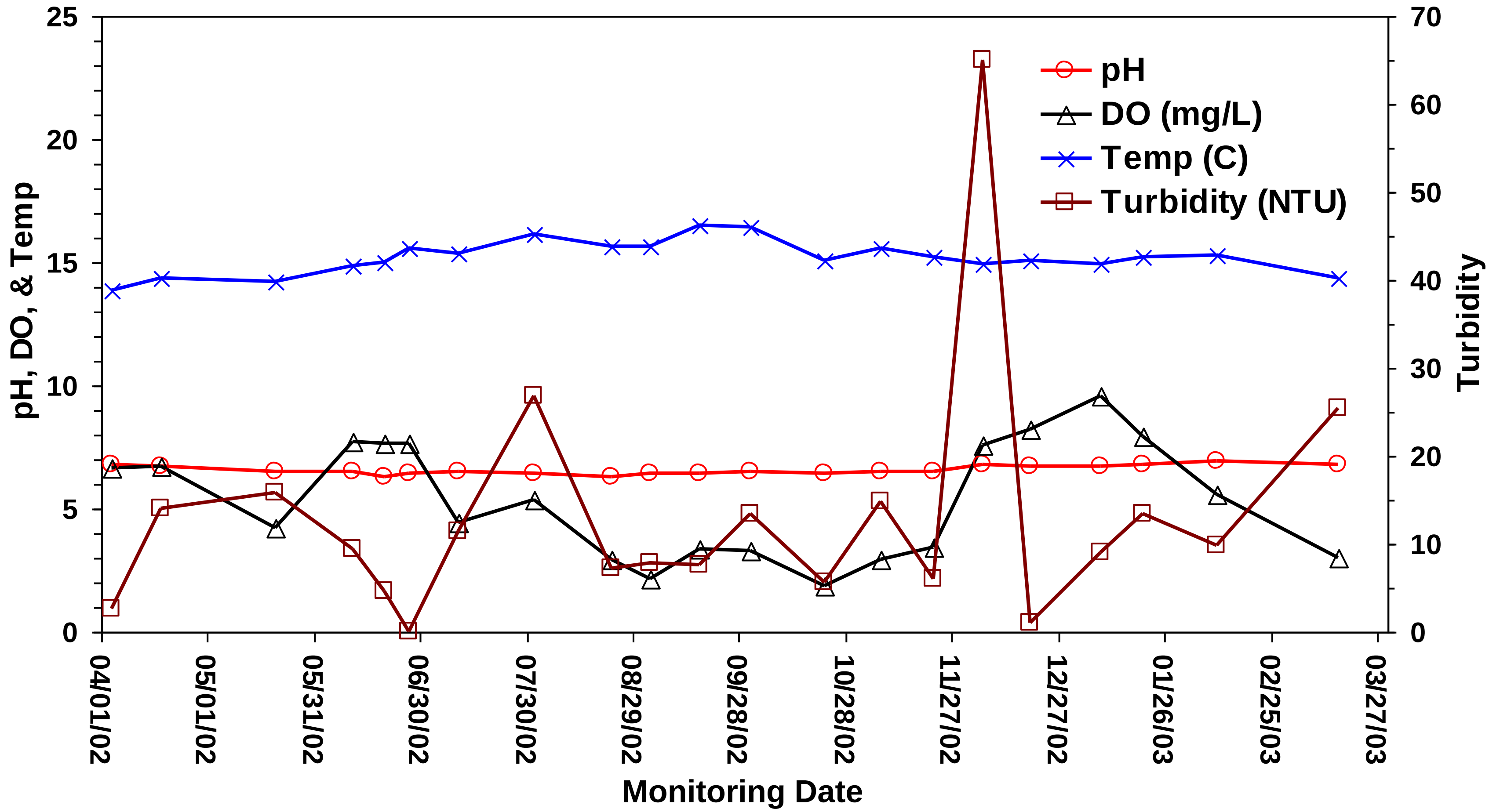

Figure 5.4 Water Chemistry at Site IF-1 During Baseflow

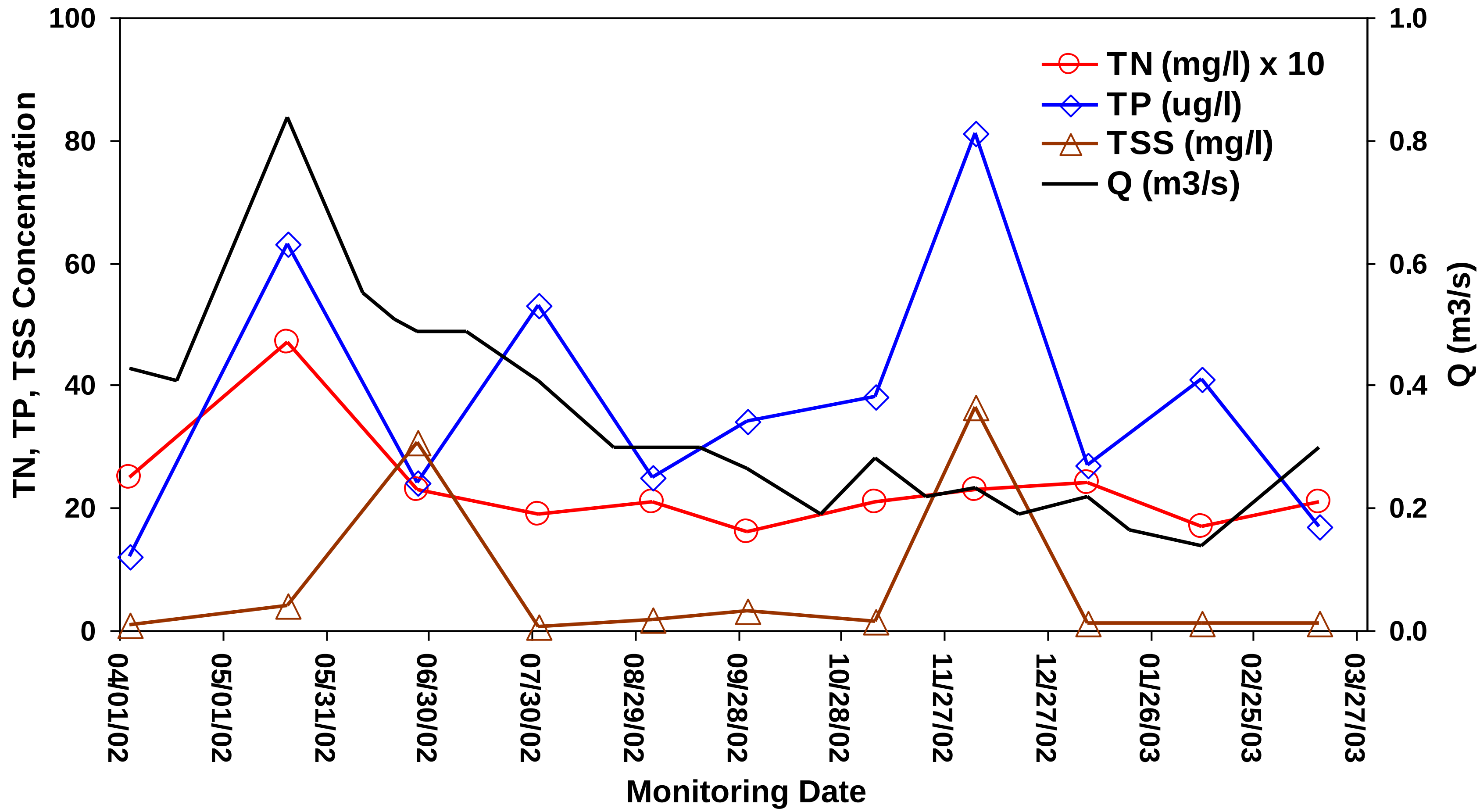

Figure 5.5 Total Suspended Sediment, Total Nitrogen, Total Phosphorus, & Discharge at Site IF-1 During Baseflow

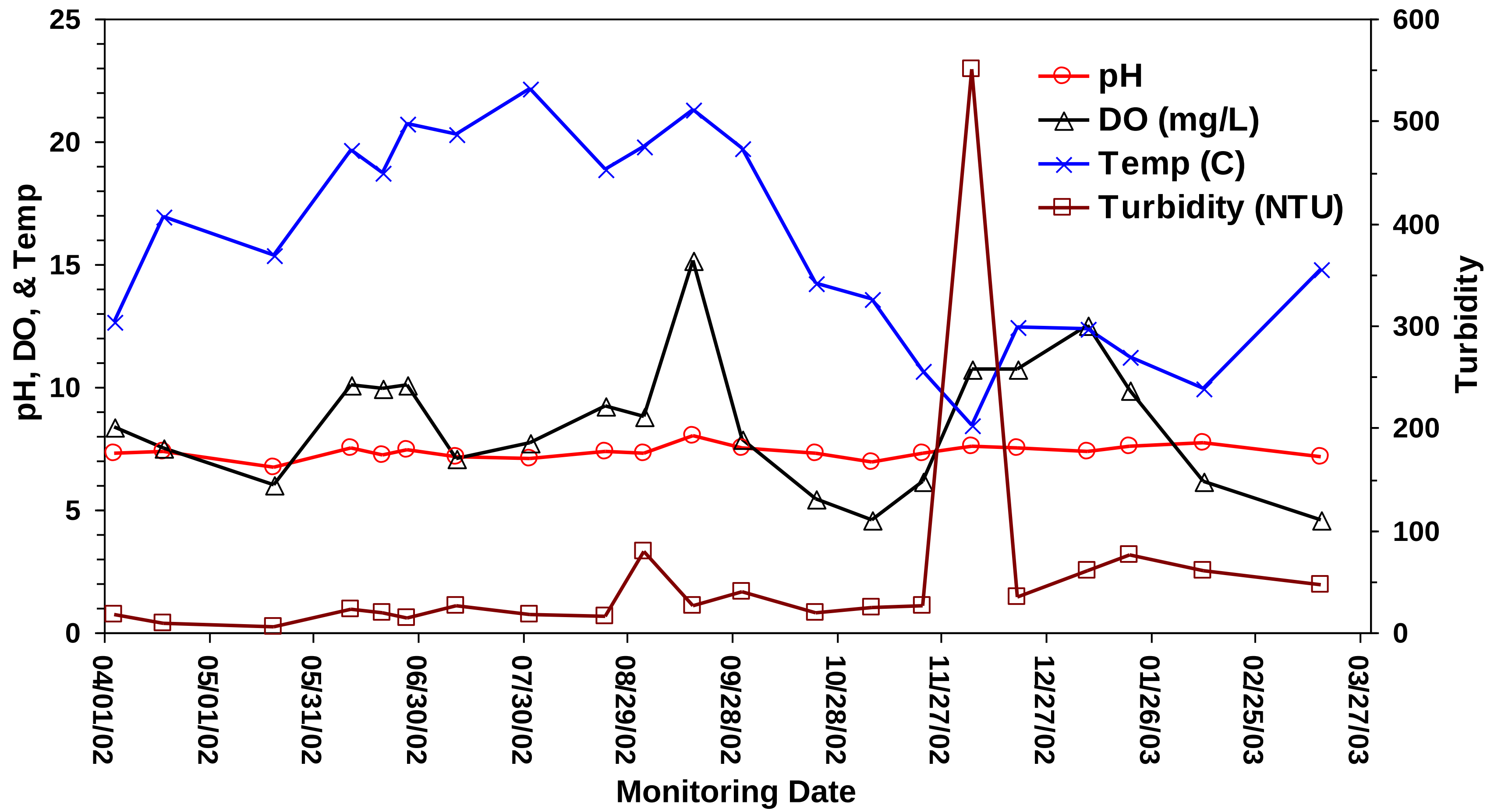

Figure 5.6 Water Chemistry at Site OF-1 During Baseflow

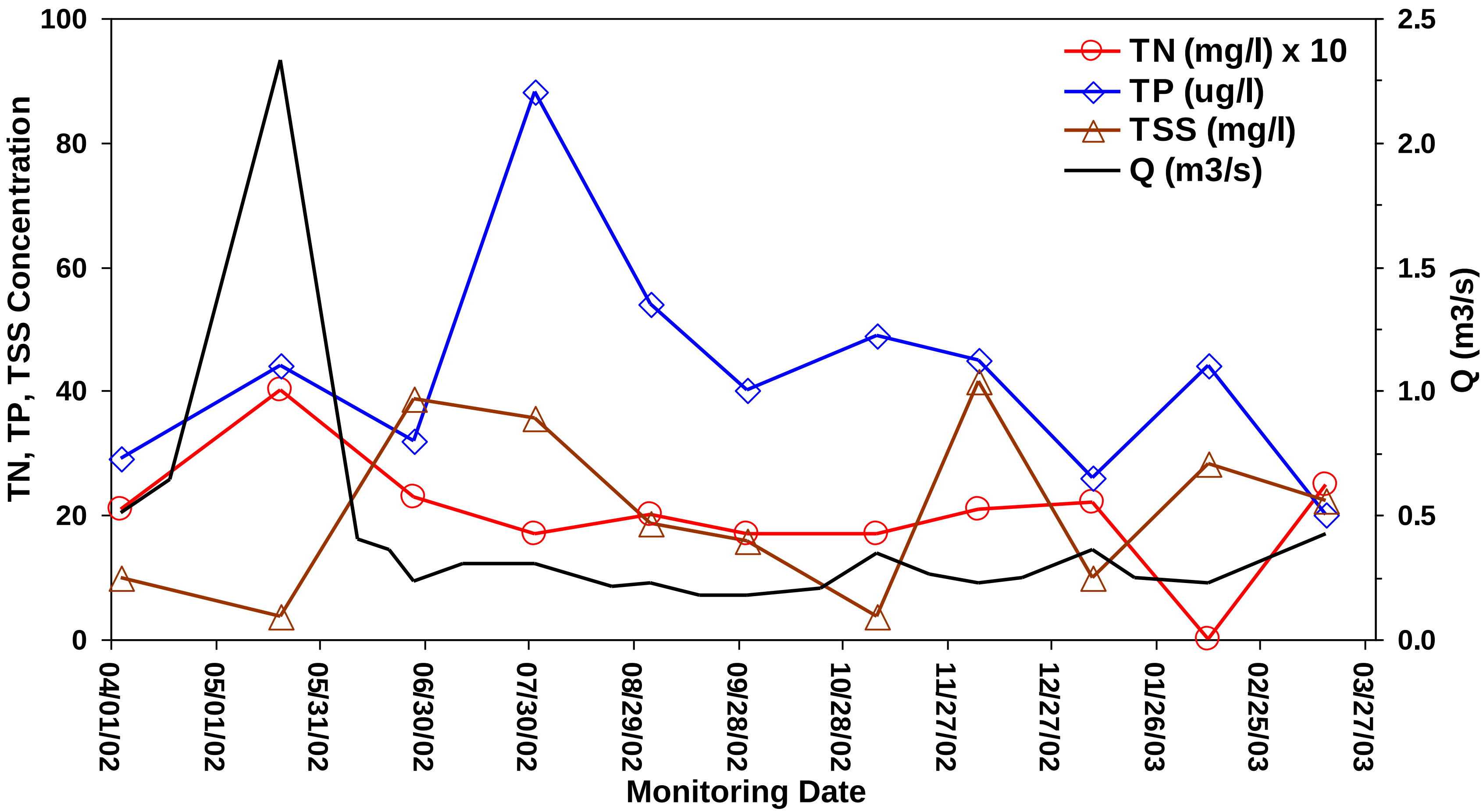

Figure 5.7 Total Suspended Sediment, Total Nitrogen, Total Phosphorus & Discharge at Site OF-1

significant increase three months after drainage, followed by a steady decrease to December 2002. During the winter, sediment concentration varied considerably month to month, which may have been caused by continual freezing and thawing of the exposed sediment within the reservoir causing mass wasting of the stream banks. Phosphorus and nitrogen trends at site OF-1 were also similar to site IF-1. Most peaks and dips in nutrient concentrations occurred on the same dates at both sampling sites. However, phosphorus concentration at site OF-1 was consistently higher than site IF-1.

Daily Nutrient Trends

A "snapshot look" at nutrient distribution in VMR Study Area was conducted on May 30, 2003 to determine how nitrogen and phosphorus vary in discharge from Sanders Spring to outflow from VMR into the SDSR. Another objective of this one-day study was to determine if nitrogen and phosphorus were transported downstream along the SDSR or remained near the outflow source from the reservoir. Sixteen sample sites were selected: five sites on the main channel of Sanders Spring above the reservoir, five sites on the main channel within the reservoir, two sites along Jarrett Spring within the reservoir, and five sites along the SDSR downstream of the reservoir (Figure 5.8). Water samples for TN and TP analysis were collected and analyzed following the same procedures as the rest of the study, and water chemistry was monitored using the Horiba U-22 Water Quality Monitoring System.

Total phosphorus concentration during this study varied from 20.7 ug/L at site SS-2 to 67.3 ug/L at site R-3 (Table 5.6). Total phosphorus concentrations were lowest in discharge from Sanders Spring and remained below 30 ug/L at all Sanders Spring sites except site SS-5. The first sampling site within the reservoir had a lower TP concentration than SS-5, but TP concentration increased as it flowed over the exposed lake bed until reaching the shallow pool remaining in the lower end of the reservoir (Figure 5.9). Phosphorus concentration also increased along Jarrett Spring after flowing over the lake bed until reaching the shallow pool. Concentration at site R-5, the reservoir outflow, was similar to Sanders Spring upstream of the reservoir, indicating the small pool traps most of the phosphorus eroded from within the reservoir (Table 5.6). Phosphorus concentrations then increased below the detention pond, indicating that the detention pond may have reached its maximum retention capacity and became a source of phosphorus to downstream reaches (Figure 5.9).

Total nitrogen concentration varied from 1.5 mg/L at site SDS-3 to 2.8 mg/L at site SS-4 (Table 5.6). Total nitrogen concentrations were above 2.0 mg/L at all sites along Sanders Spring channel upstream of the shallow pool at the lower end of the reservoir (Figure 5.9). Nitrogen concentration decreased to 1.6 mg/L at site R-5 and remained below 2.0 mg/L at all sites below the reservoir (Figure 5.9). Concentrations were also below 2.0 mg/L in Jarrett Spring discharge (Table 5.6).

Water chemistry variables also displayed spatial variability, with the shallow pool causing the most dramatic variation. Turbidity and TDS concentration decreased from site R-4 to R-5, while water temperature and DO concentration increased between these two sites (Figure 5.10). Sanders Spring pH gradually and steadily increased from site SS-1 to SDS-5 (Figure 5.10). Downstream of VMR outflow, water temperature and TDS concentration remained near constant (Figure 5.10). From VMR outflow to site SDS-5, DO steadily decreased, while turbidity fluctuated along the SDSR (Figure 5.10).

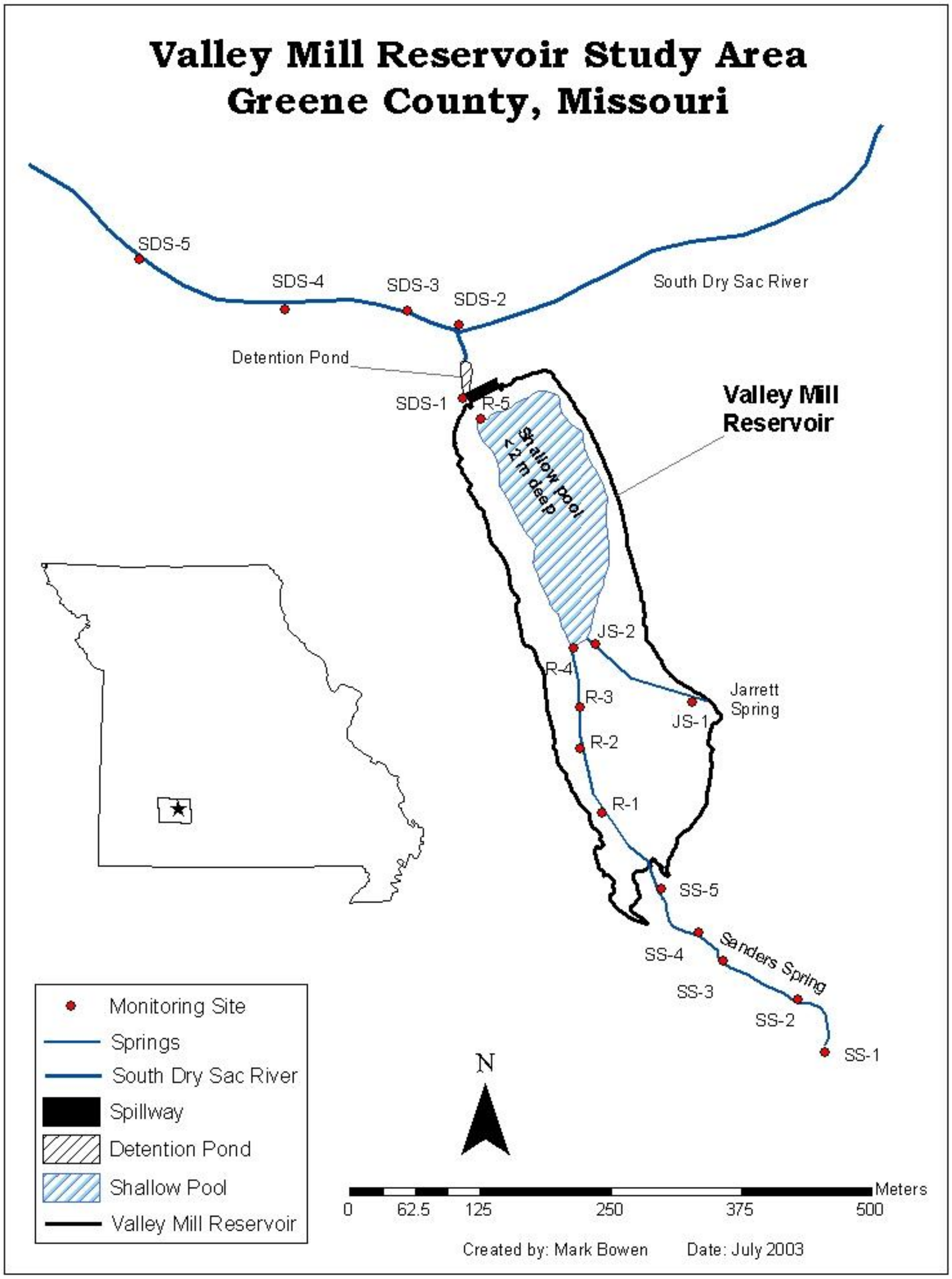

Figure 5.8 Map of Spatial Distribution Study Sites within VMR Study Area

Table 5.6 Results of Snapshot Study of VMR Study Area

Site	TN (mg/L)	TP (ug/L)	TDS (mg/L)	TURB (NTU)	pH	DO (mg/L)	Temp (C)
JS-1	1.7	25.6	249	215.0	7.2	6.3	15.5
JS-2	1.9	39.5	249	154.0	7.2	7.6	16.1
SS-1	2.4	23.6	403	181.0	6.8	6.3	14.5
SS-2	2.4	20.7	399	117.0	6.8	7.7	15.1
SS-3	2.4	26.2	403	102.0	6.8	9.0	15.5
SS-4	2.8	27.2	403	156.0	6.9	8.9	15.6
SS-5	2.4	48.2	403	149.0	6.9	9.2	15.7
R-1	2.4	30.4	404	220.0	7.0	9.2	15.9
R-2	2.4	49.2	404	141.0	7.0	9.4	16.0
R-3	2.4	67.3	404	164.0	7.0	9.4	16.1
R-4	2.2	54.0	405	151.0	7.0	9.4	16.2
R-5	1.6	26.2	335	63.4	7.3	12.0	18.4
SDS-1	1.7	26.6	333	64.8	7.4	11.4	18.2
SDS-2	1.6	42.7	322	99.2	7.5	11.1	18.4
SDS-3	1.5	40.5	328	63.7	7.5	11.1	18.3
SDS-4	1.6	41.4	327	59.6	7.5	11.0	18.3
SDS-5	1.7	32.7	327	47.8	7.6	10.5	18.2
MIN	1.5	20.7	322	47.8	6.8	6.3	14.5
MAX	2.8	67.3	405	220.0	7.6	12.0	18.4
MEAN	2.1	37.1	373	118.6	7.1	9.7	16.7
MEDIAN	2.4	32.7	403	117.0	7.0	9.4	16.1

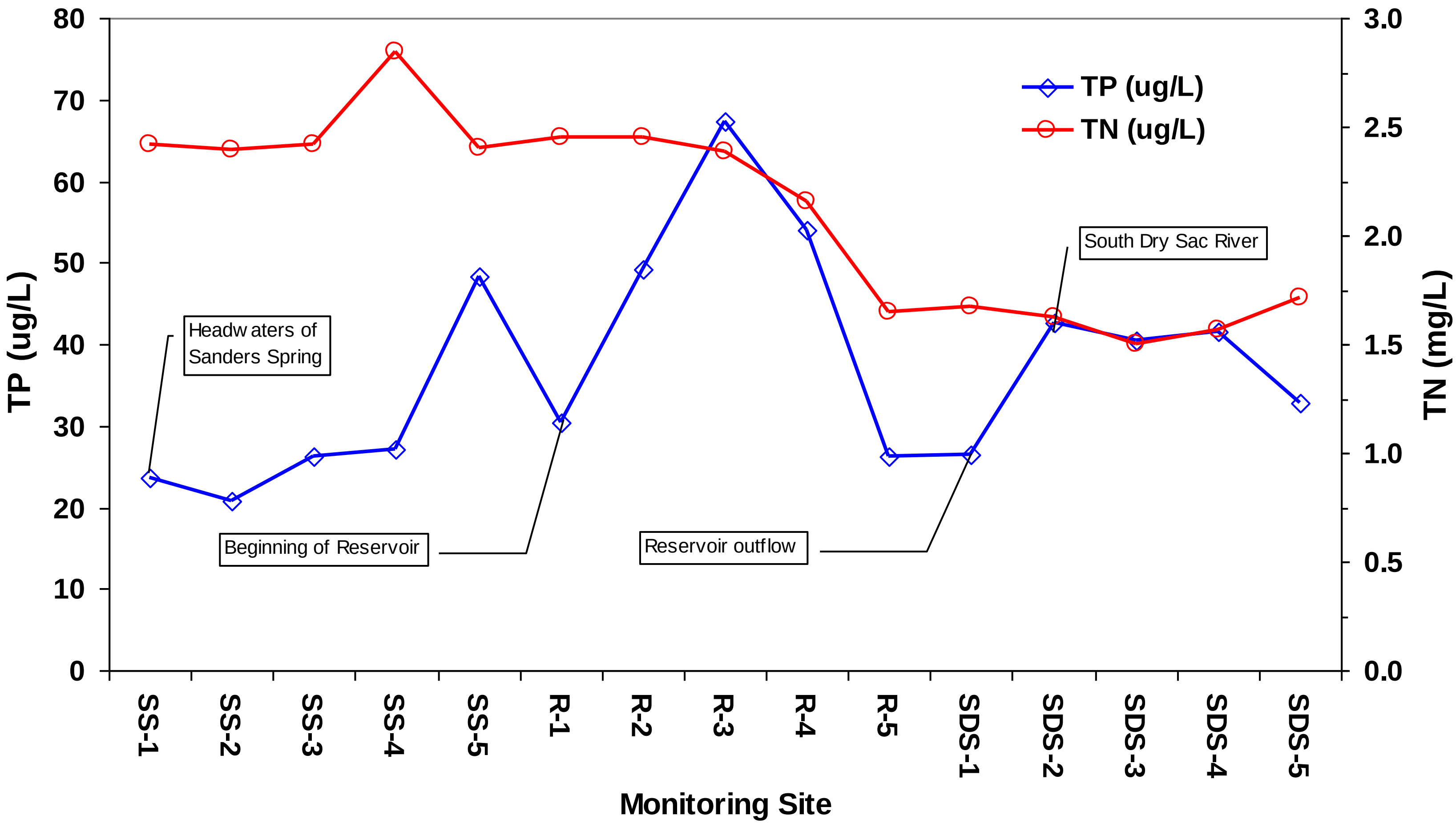

Figure 5.9 Longitudinal Variability of Total Nitrogen & Total Phosphorus within VMR Study Area

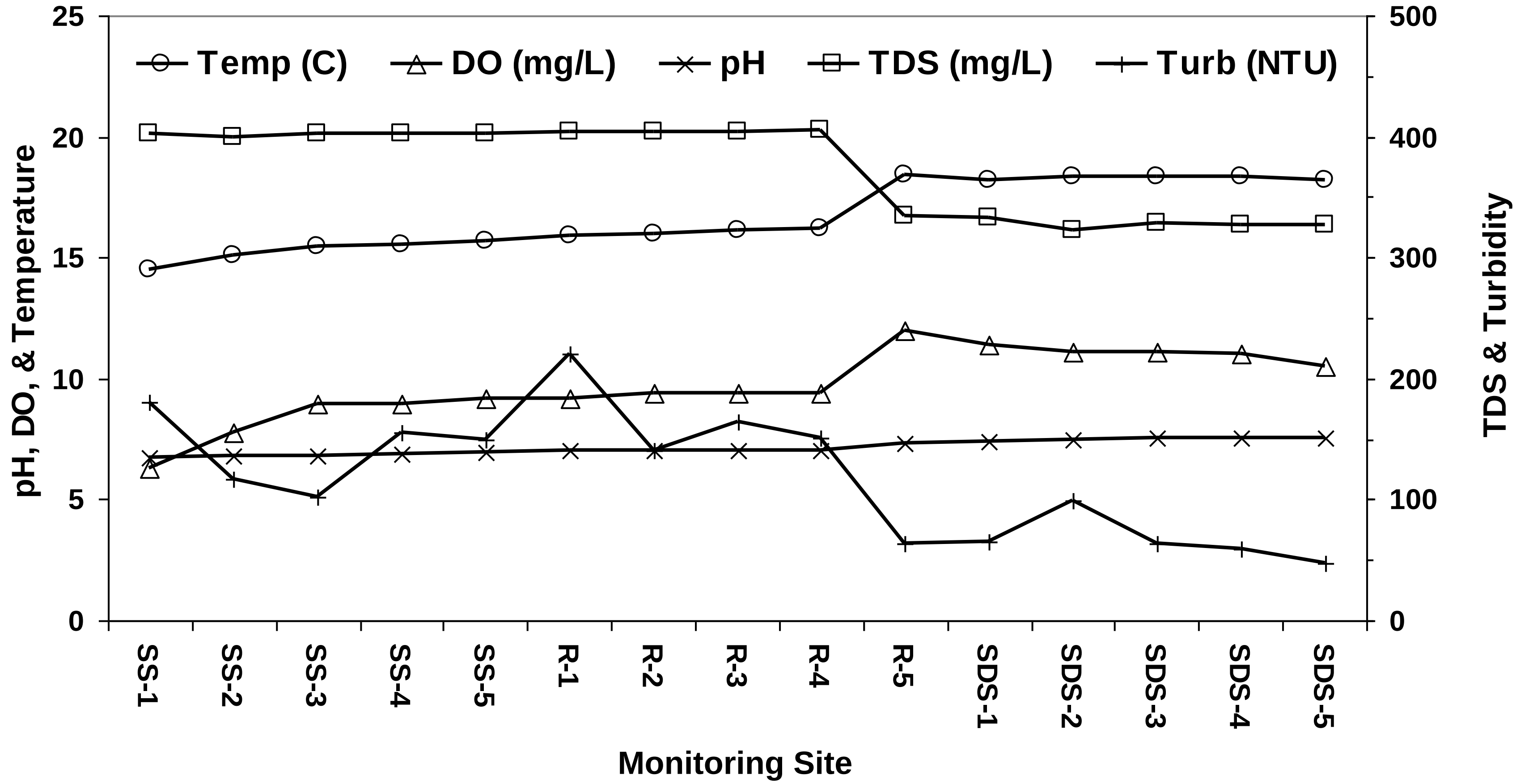

Figure 5.10 Longitudinal Variability of pH, DO, Temperature, Total Dissolved Solids, & Turbidity within VMR Study Area

STORM EVENT WATER QUALITY

Following storm events, water chemistry was monitored eleven times at sites US-1, US-2, and IF-1, twelve times at sites US-3, US-4, IF-2, OF-1, and OF-2, ten times at site SDS, and twice at site JS. Total nitrogen, total phosphorus, and total suspended sediment were monitored ten times at sites US-1, US-2, and IF-1, eleven times at sites US-3, US-4, IF-2, OF-1, and OF-2, six times at site SDS, and twice at site JS. The first storm event was monitored on March 19, 2002 and the last storm event was monitored on July 18, 2002. All storm event water quality data is contained in Appendix B and summarized in Table 5.7.

Water Chemistry

Inflowing water chemistry varied considerably among sites and storm events (Appendix B). Water chemistry between sites IF-1 and IF-2 varied more following storm events than during baseflow. The ephemeral tributary that drains runoff from the upper watershed flows into Sanders Spring channel between sites IF-1 and IF-2. Mean water temperature increased by 1.5^{o} C between the two sites, while pH increased from 6.6 to 6.8 (Table 5.8). Percent increase in DO concentration following storm events was similar to increases during baseflow at nearly 28 percent (Table 5.8). However, turbidity increased over 200 percent from site IF-1 to IF-2 following storm events. This indicates that runoff from the upper watershed is supplying an increased sediment load to VMR following storm events.

Table 5.7 Summary of Storm Event Water Quality Data

		VMR STUDY AREA STORM EVENTS						UPPER WATERSHED STORM EVENTS			
		IF-1	**IF-2**	**JS**	**OF-1**	**OF-2**	**SDS**	**US-1**	**US-2**	**US-3**	**US-4**
		Spring	Inflow	Inflow	Outflow	Gage		Upstream	Upstream	Upstream	Upstream
Estimated Q (m3/s)	**Mean**	0.91	-	0.02	2.50	**3.60**	0.87	0.37	1.76	1.48	0.26
	MIN	0.45	-	0.02	0.57	**0.18**	0.54	0.02	0.08	0.05	0.03
	MAX	1.45	-	0.02	7.31	**12.35**	2.05	1.12	6.44	5.14	0.95
pH	**Mean**	6.6	6.8	6.7	7.1	7.3	7.3	7.6	7.2	7.4	7.6
	MIN	6.2	6.4	6.6	7.0	7.0	6.6	7.4	6.9	7.1	7.4
	MAX	7.0	7.0	6.7	7.5	7.6	7.8	7.8	7.6	7.9	8.0
DO (mg/l)	**Mean**	4.5	5.8	2.0	6.1	7.8	8.2	7.6	6.6	6.5	7.8
	MIN	2.8	3.5	1.1	3.8	4.4	7.4	4.8	4.1	4.3	4.4
	MAX	8.7	9.0	2.8	9.1	11.0	10.8	10.7	10.3	10.6	11.0
Temp (C)	**Mean**	14.1	15.6	17.4	15.8	15.6	14.5	17.0	16.3	16.6	15.9
	MIN	13.5	13.2	17.2	11.3	11.0	10.8	10.4	9.5	9.0	10.3
	MAX	15.1	22.3	17.6	21.3	21.3	18.0	24.0	23.2	24.3	22.6
Turb (NTU)	**Mean**	6.5	21.8	4.5	70.6	44.3	18.8	149.5	152.5	112.6	167.3
	MIN	3.8	3.7	3.1	3.6	5.1	3.4	1.0	20.6	5.6	8.3
	MAX	14.7	61.2	5.8	263.0	235.0	79.7	999.0	547.0	638.0	912.0
TDS (mg/l)	**Mean**	368	365	305	333	242	181	154	531	332	198
	MIN	270	180	300	190	120	100	0	90	40	100
	MAX	430	540	310	440	370	270	360	1,600	600	390
TSS (mg/l)	**N =**	9	11	2	11	10	7	10	10	11	11
	Mean	18.9	47.8	4.0	99.5	61.3	45.5	21.9	147.0	43.7	39.5
	MIN	0.5	5.6	0.8	16.8	12.8	1.9	9.9	10.1	10.0	7.2
	MAX	100.4	170.4	7.2	524.8	324.0	215.4	72.2	475.4	170.6	125.8
TP (ug/l)	**N =**	10	11	2	11	11	6	10	10	11	11
	Mean	66	171	74	207	177	139	161	742	380	254
	MIN	6	14	67	35	31	15	64	115	128	58
	MAX	208	615	81	395	449	452	280	1,553	735	1015
TN (mg/l)	**N =**	10	11	2	11	11	6	10	9	11	11
	Mean	2.4	2.3	2.0	2.2	2.0	1.7	1.5	3.4	2.1	2.1
	MIN	2.0	1.4	1.9	1.8	1.6	1.4	0.9	2.0	0.4	1.0
	MAX	4.1	4.4	2.0	2.9	2.7	2.2	2.3	6.2	4.0	4.6

Table 5.8 Storm Event Water Quality Changes Between Sites IF-1 & IF-2

	STORM EVENT			
	IF-1 Spring	**IF-2 Inflow**	**Mean % Change**	**Avg Monthly % Change**
Temp (C)	14.1	15.6	-	-
pH	6.6	6.8	-	-
DO (mg/l)	4.5	5.8	27.7	32.1
Turb (NTU)	6.5	21.8	232.8	281.9
TDS (mg/l)	368	365	-1	2
TSS (mg/l)	18.9	47.8	153.1	815.7
TP (ug/l)	66	171	161	240
TN (mg/l)	2.4	2.3	-3.1	-7.4

Outflowing water chemistry also varied widely among storm events. However, water chemistry remained nearly unchanged from site IF-2 to OF-1. Comparisons in water quality changes are made between sites OF-2 and IF-2 rather than IF-1 to account for changes in water quality due to runoff from the upper watershed. Water temperature, pH, and DO concentration all displayed slight increases from site IF-2 to OF-1 (Table 5.9). However, mean turbidity more than tripled after flowing over the exposed lake bed, despite the fact that inflowing water had elevated turbidity measurements (Table 5.9).

From site OF-1 to site OF-2, water temperature and pH remained nearly constant (Table 5.9). Turbidity and DO concentration varied considerably though. Dissolved oxygen concentration continued to increase to site OF-2, with a mean increase near 30 percent (Table 5.10). However, turbidity was significantly reduced from site OF-1 to site OF-2. The detention pond installed below reservoir outflow effectively removed sediment in VMR outflow for the first six months of this study, when all the storm events were sampled. Turbidity at site SDS was much lower than at site OF-1, so outflow mixing with runoff from the upper SDSR watershed may have also decreased turbidity.

Table 5.9 Storm Event Water Quality Changes Between Sites IF-2 & OF-1

	STORM EVENT			
	IF-2 Inflow	**OF-1 Outflow**	**Mean % Change**	**Avg Monthly % Change**
Temp (C)	15.6	15.8	-	-
pH	6.8	7.1	-	-
DO (mg/l)	5.8	6.1	5.5	13.3
Turb (NTU)	21.8	70.6	224.6	187.1
TDS (mg/l)	365	333	-9	-6
TSS (mg/l)	47.8	99.5	108.2	159.2
TP (ug/l)	171	207	21	123
TN (mg/l)	2.3	2.2	-4.7	2.7

Dissolved Solids and Suspended Sediment Concentrations

Total dissolved solids concentration decreased within VMR Study Area following storm events (Appendix B). Site IF-1 had a mean TDS concentration approximately 15 percent lower than the baseflow mean concentration. Total dissolved solids concentration at site IF-2 was nearly identical to site IF-1, even with the addition of runoff from the upper watershed (Table 5.8). Total dissolved solids concentration also remained nearly unchanged after flowing over the exposed lake bed with a mean decrease less than 10 percent between sites IF-2 and OF-1 (Table 5.9). However, TDS concentration was significantly lower at site OF-2 (Table 5.10). Runoff from the upper SDSR watershed had considerably lower TDS concentrations (Table 5.11), so VMR outflow mixing with runoff in the SDSR likely caused the reduced TDS concentration at site OF-2.

Table 5.10 Storm Event Water Quality Changes Between Sites OF-1 & OF-2

	STORM EVENT			
	OF-1 Outflow	OF-2 Outflow	Mean % Change	Avg Monthly % Change
Temp (C)	15.8	15.6	-	-
pH	7.1	7.3	-	-
DO (mg/l)	6.1	7.8	28.1	25.4
Turb (NTU)	70.6	44.3	-37.3	-26.4
TDS (mg/l)	333	242	-27	-28
TSS (mg/l)	99.5	61.3	-38.4	-15.5
TP (ug/l)	207	177	-15	-15
TN (mg/l)	2.2	2.0	-9.1	-7.5

Table 5.11 Storm Event Water Quality Changes Between Sites SDS & OF-2

	STORM EVENT			
	SDS Upstream	OF-2 Outflow	Mean % Change	Avg Monthly % Change
Temp (C)	14.5	15.6	-	-
pH	7.3	7.3	-	-
DO (mg/l)	8.2	7.8	-4.9	-0.3
Turb (NTU)	18.8	44.3	135.6	81.4
TDS (mg/l)	181	242	34	22
TSS (mg/l)	45.5	61.3	34.7	325.3
TP (ug/l)	139	177	27	29
TN (mg/l)	1.7	2.0	17.6	14.2

Total suspended sediment concentration fluctuated widely among storm events (Appendix B). However, TSS concentration consistently increased from site IF-1 to IF-2 to OF-1. Mean TSS concentration at site IF-1 more than doubled following storm events compared to baseflow, while mean TSS concentration at site IF-2 more than quadrupled. Runoff from the upper watershed and possibly erosion of the stream channel between sites IF-1 and IF-2 caused mean TSS concentration to increase by more than 150 percent (Table 5.8). Even though TSS concentration in inflow was more than four times higher during storm events, mean TSS concentration still more than doubled after flowing through the drained reservoir (Table 5.9). Total suspended sediment concentration decrease from site OF-1 to OF-2 was nearly identical to the decrease in turbidity between the two sites. Mean TSS concentration decreased by 38 percent from site OF-1 to site OF-2 (Table 5.10). Site SDS had a mean TSS concentration less than half of VMR outflow (Table 5.7). Therefore, sediment trapped by the detention pond as well as mixing with runoff from the upper SDSR watershed caused a decrease in TSS concentration at site OF-2.

Nutrient Concentrations

Total phosphorus concentration in the Valley Mill watershed displayed broad variability following storm events (Appendix B). However, concentrations consistently increased from site IF-1 to IF-2 to OF-1, similar to TSS concentration increases. Mean concentration at site IF-1 was 66 ug/L following storm events. Mean TP concentration at site IF-2 was 171 ug/L, an increase over 150 percent (Table 5.8). Total phosphorus concentration did not increase between these two sites during baseflow, therefore runoff from the upper watershed caused a significant increase in inflowing TP concentration. Phosphorus concentration continued to increase after flowing over the exposed lake bed. Mean TP concentration at site OF-1 was 207 ug/L, an increase of over 20 percent from site IF-2 (Table 5.9). Mean TP concentration at site OF-2 was 15 percent lower than OF-1 at 177 ug/L (Table 5.10). Total phosphorus concentration at site SDS averaged approximately 30 percent lower than site OF-2 (Table 5.11), indicating the drained reservoir is supplying phosphorus enriched water to the SDSR.

Total nitrogen concentration at Sanders Spring remained low following storm events and only exceeded 2.5 mg/L in one sample (Appendix B). Nitrogen concentration at site IF-2 also remained low, with a mean TN concentration of 2.3 mg/L, only 0.1 mg/L less than site IF-1 (Table 5.8). Outflowing TN concentration at site OF-1 had a mean of 2.2 mg/L, approximately 5 percent lower than site IF-2 (Table 5.9). Mean TN concentration at site OF-2 was 2.0 mg/L and only 1.7 mg/L at site SDS (Table 5.11). Total nitrogen concentration decreased or remained unchanged between sites OF-1 and OF-2 in ten of eleven samples (Appendix B). While mean nitrogen concentration was higher in VMR outflow than runoff from the upper SDSR watershed, mean TN concentrations in the SDSR still remained low downstream of VMR outflow.

Storm Event Water Quality Changes

The draining of VMR affected several water quality parameters during storm events. Temperature and pH increased slightly from Sanders Spring to VMR outflow. Although dissolved oxygen concentration increased approximately 30 percent, this increase mostly occurred between sites IF-1 and IF-2, where oxygen-rich surface runoff mixed with oxygen-poor groundwater (Table 5.8). Total nitrogen and total dissolved solids concentrations were also only slightly impacted by reservoir drainage following storm events, decreasing less than 10 percent (Table 5.9). Following storm events discharge increased, so inflowing water had less contact with the exposed lake bed and remained within the drained reservoir for a shorter period. Therefore, pH, temperature, total dissolved solids and total nitrogen concentration, which are dependent on sediment-water contact, were not as affected by the drained reservoir following storm events as compared to baseflow.

However, turbidity, total suspended sediment concentration, and total phosphorus concentrations all increased on average over 100 percent after flowing through the drained VMR (Table 5.9). Reservoir drainage had the greatest impact on turbidity; mean VMR outflow turbidity was more than ten times higher than mean turbidity at Sanders Spring. From site IF-1 to site IF-2, turbidity increased an average of 15 NTU; between sites IF-2 and OF-1 turbidity increased an average of nearly 50 NTU, almost a 200 percent increase (Table 5.9). While runoff from the upper watershed increased turbidity, the drained VMR had a greater impact on turbidity.

Total suspended sediment concentration was also significantly impacted by reservoir drainage following storm events. Total suspended sediment discharging from Sanders Spring had a storm event mean concentration of 18.9 mg/L while VMR outflow had a storm event mean concentration of 99.5 mg/L (Table 5.7). Total suspended sediment concentration increased an average of 29 mg/L between sites IF-1 and IF-2 due to runoff from the upper watershed and increased on average an additional 52 mg/L after flowing over the exposed lake bed. Although TSS concentration in inflow increased due to runoff from the upper watershed, the increased discharge and the more than 300 m reach of loosely consolidated sediment within the reservoir allowed for an even greater increase in outflowing TSS concentration following storm events.

Total phosphorus concentration was the only other variable tested to be significantly impacted by reservoir drainage following storm events. Phosphorus concentration discharging from Sanders Spring had a mean concentration of 66 ug/L, but more than doubled to 171 ug/L by site IF-2 (Table 5.8). Total phosphorus concentration continued to increase in the drained VMR to a mean of 207 ug/L at site OF-1.

Sediment and phosphorus concentration increased significantly following most storm events, while nitrogen concentration remained nearly constant. Figure 5.11 shows the ratio of pollution concentrations at site OF-1 compared to site IF-2, similar to Figure 5.3. Sediment concentration following storm events increased from site IF-2 to OF-1 on every sampling date except July 12, 2002 (Figure 5.11). Sediment concentration increase was greatest during the first five storm events sampled. Phosphorus concentration increased after eight storm events, remained constant after one, and decreased after two storms from site IF-2 to OF-1 (Figure 5.11). By comparing the total phosphorus ratio to total suspended sediment ratio in Figure 5.11, it was determined that phosphorus increase had a similar trend as total suspended sediment increase following storm events. This trend also occurred during baseflow conditions. Total nitrogen concentration differed between sites IF-2 to OF-1 by less than 20 percent on all but two storm event sampling dates.

The May 17, 2002 storm event, caused by over 4.5 cm of precipitation after over 15 cm of precipitation saturated the watershed the previous ten days, was sampled twice in order to sample the rising and falling limbs of the storm hydrograph. It appears that the rising limb was sampled at site IF-2 on the first sampling trip, but the shallow pool within the reservoir delayed it from reaching site OF-1. Pollution concentrations at site OF-1 were near baseflow levels on the first sampling trip. By the second round of sampling, sediment and nutrient concentration had returned to near baseflow levels at site IF-2 but was elevated at site OF-1. This shows that the drained reservoir still delays

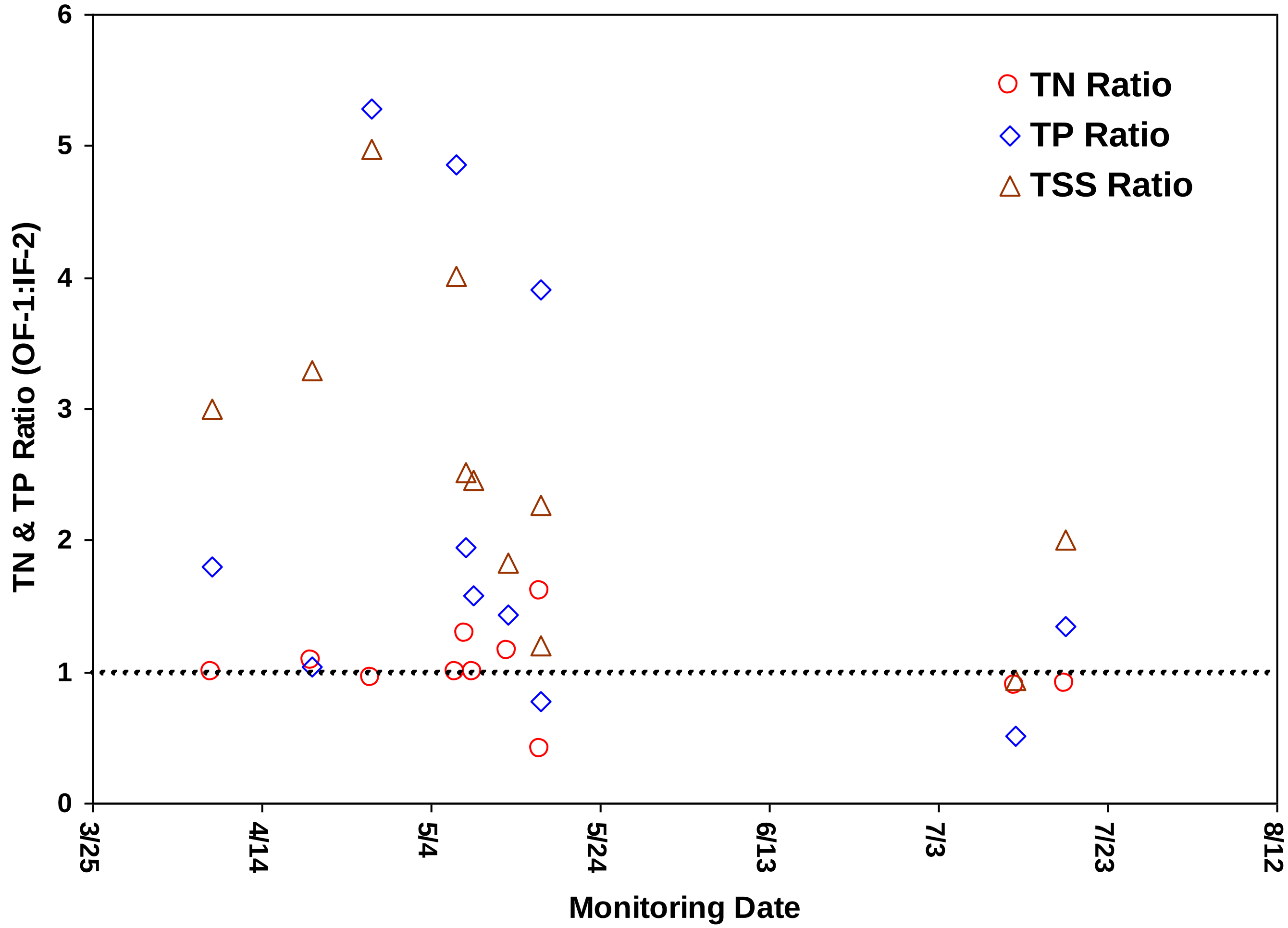

Figure 5.11 OF-1:IF-2 Total Suspended Sediment, Total Nitrogen, & Total Phosphorus Concentration Ratios

the movement of runoff pollution loads from reaching the SDSR and therefore may still act as a pollutant trap during larger storm events if sedimentation occurs in the lower basin of the reservoir. Therefore, a lag in the storm hydrograph at the basin scale in a flashy system can influence the measurements and relationships between rainfall, discharge, and pollution transport.

Upper Watershed Water Quality

Four sites in the upper Valley Mill watershed were monitored following storm events to determine if water quality in the upper watershed was similar to the VMR Study Area. Water temperature, pH, and dissolved oxygen concentration were all comparable to sites within VMR Study Area (Table 5.7). However, turbidity measurements in the upper watershed sites were consistently and significantly higher than turbidity within VMR Study Area. Since turbidity at site IF-2 was much lower, either the suspended material does not make it to VMR Study Area, or it is significantly diluted by discharge from Sanders Spring.

Total dissolved solids concentration varied among the upper watershed monitoring sites (Appendix B). Sites US-1 and US-2 had mean TDS concentrations comparable to concentrations in runoff from the upper SDSR watershed (Table 5.7). Site US-3 had a mean TDS concentration similar to VMR outflow (Table 5.7). However, site US-2 had the highest mean and maximum TDS concentrations of all monitoring sites. Mean TDS concentration at site US-2 was 40 to nearly 200 percent higher than mean TDS concentrations within VMR Study Area. Site US-2 drained runoff from a construction site, a small farm, and an industrial park. Additional sampling sites within this drainage area would be necessary to target the exact source of the increased dissolved solids.

Total suspended sediment concentration at sites US-1, US-3, and US-4 were similar to TSS concentrations within VMR Study Area (Table 5.7). Concentration at these sites ranged from 9.9 mg/L to 170.6 mg/L (Appendix B). Site US-2, draining an area undergoing construction during the study, had the highest mean TSS concentration of any site at 147.0 mg/L, more than 50 percent higher than any site within VMR Study Area. However, most of the sediment load from this site was removed by a series of detention ponds within the 250-acre golf course before reaching site US-3 and therefore did not reach VMR Study Area.

Total phosphorus concentration at all upper watershed sites was higher than VMR outflow except site US-1 (Table 5.7). However, much of the phosphorus was either removed from the water by the detention ponds within the golf course or diluted by Sanders Spring discharge before reaching site IF-2 (Appendix B). Site US-2 drains agricultural areas, while sites US-3 and US-4 drain a 250-acre golf course. Three of the upper watershed monitoring sites had TN concentrations similar to VMR Study Area; however, site US-2 had the highest mean and maximum TN concentrations (Table 5.7). Again, this site drains runoff from a small farm and industrial park. A target for future monitoring efforts should be aimed at reducing nonpoint pollution inputs within the watershed.

POLLUTION LOADING

Previous results focused on concentrations of water quality indicators. However, to understand the transport rates, concentrations must be multiplied by discharge in order to determine the load or mass of pollution being transported from the watershed. Pollution loads within the Valley Mill watershed were estimated by two methods due to problems associated with calculating discharge. The watershed is in an area of karst geology, which alters typical flow conditions. There are several reaches where stream flow is lost to the stream bed. A 250-acre golf course located in the upper watershed has a series of small detention ponds throughout the property. These ponds disrupt the flow of water to sites US-3 and US-4. Also, Sanders Spring had a higher discharge than expected for its drainage area based on regional comparisons, indicating the spring is connected to a larger underground water source.

However, efforts were made in the study to provide the best estimates possible describing pollution loads within the Valley Mill watershed. The first method used to estimate loads involved estimating water velocity using Manning's N equation and survey data along with measured stage data to create discharge rating curves. These rating curves were used with stage measurements to estimate discharge for each sampling date. Mean baseflow and storm event discharges and mean baseflow and storm event constituent concentrations were calculated for each site and multiplied together to determine the mean pollution loads.

The second method involved creating load rating equations by multiplying measured pollution concentrations by estimated discharges of a given frequency and then plotting that against estimated discharge. Mean and 10-percentile discharges for each site were calculated utilizing regional rating curves developed by Dr. Robert Pavlowsky using USGS gage data from the Ozarks Region in Missouri (Pavlowsky *et al.*, 2002) (Table 5.12). The mean and 10-percentile discharges obtained from the regional rating curves were then input to the load rating equations to calculate mean daily and 10-percentile pollution loads. Discharge could not be calculated for sites IF-1 and JS, since they are located on springs whose drainage areas are unknown.

Table 5.12 Regional Rating Curve Data (adapted from Pavlowsky et al., 2002)

Model Form: Q = B0 x Ad^B1								
Discharge	**Model Coefficients**			**Discharge (ft^3/s) for give Drainage Area (mi^2)**				
	B0	B1	R^2	0.1	1	10	100	1000
7-day Low	0.019	1.094	0.77	0.002	0.019	0.238	2.96	36.7
90%	0.043	1.153	0.91	0.003	0.043	0.611	8.69	123.8
Median	0.134	1.165	0.98	0.009	0.134	1.96	28.6	419.1
Mean	0.931	1.002	0.99	0.093	0.931	9.35	94.0	944.3
10%	1.686	1.018	0.99	0.162	1.69	17.6	183.4	1,912.7
2-year Flood	256.7	0.690	0.87	52.4	256.7	1,256.8	6,152.9	30,121.5
Max Flood	1,014.9	0.630	0.91	238	1,015	4,330	18,477	78,836

Estimated Mean Daily Discharge

Pollution loads were calculated for both mean baseflow and mean storm event conditions, but pollution load comparisons between inflow and outflow could only be made during baseflow since discharge at site IF-2 could not estimated. During baseflow conditions, mean inflowing pollution loads were the sum of loads from Sanders Spring and Jarrett Spring, sites IF-2 and JS. The mean daily inflow and outflow pollution loads are presented in Table 5.13.

Using this method, total dissolved solids loads remained nearly constant from inflow to outflow, differing by only 1 percent. The mean TN load was reduced by approximately 2 kg/day after flowing over the exposed lake bed, which was only a 3 percent reduction. The phosphorus load increased by nearly 30 percent, or 0.3 kg/day, after flowing over the lake bed. Outflowing TSS load increased approximately 125 percent, nearly 400 kg/day after flowing through the loosely consolidated lake bed. Sediment load also increased between sites IF-1 and IF-2 by over 40 percent or nearly 100 kg/day. All other pollution loads between sites IF-1 and IF-2 were similar.

Table 5.13 Mean Sample Discharge x Mean Sample Concentration Load Data

Site	Mean Sample Qi (m3/s)	Total N (mg/L)	Total P (mg/L)	TSS (mg/L)	TDS (mg/L)	Daily Load TN (kg/day)	Daily Load TP (kg/day)	Daily Load TSS (kg/day)	Daily Load TDS (kg/day)
IF-1	0.34	2.3	0.038	7.5	429	67.6	1.1	220.3	12,602
IF-2	0.34	2.3	0.037	10.8	431	67.6	1.1	317.3	12,661
OF-1	0.40	2.0	0.043	20.7	386	69.1	1.5	715.4	13,340
OF-2	0.37	2.3	0.048	24.7	379	73.5	1.5	789.6	12,116
SDS	0.47	2.8	0.065	1.9	277	113.7	2.6	77.2	11,248
JS	0.02	2.0	0.036	1.5	302	3.5	0.1	2.6	522

Regional Rating Curve

Load rating equations were created for TDS, TSS, TP, and TN for each sampling site (Table 5.14). The load rating equation for site IF-2 was created using only baseflow data since discharge could not be estimated following storm events. Baseflow load rating curves were also developed for site OF-1 to compare inflow and outflow baseflow pollution loads. Comparisons were also made for the 10-percentile flow within the Valley Mill watershed (Table 5.15).

Inflowing and outflowing nitrogen and dissolved solids loads were strongly correlated with discharge, with R^2 values of 0.94 and 0.98 for nitrogen and R^2 values of 0.97 and 0.98 for dissolved solids. Therefore, discharge is a good predictor of TN and TDS loads for VMR Study Area. The R^2 value for the TP loads was lower at 0.51 for site IF-2 and 0.73 for site OF-1. For TSS loads, site IF-2 had an R^2 value of 0.29, while site OF-1 had an R^2 value of only 0.04. This is likely because a wide enough range of discharge was not sampled during baseflow conditions. If storm event samples are included at site OF-1, the R^2 value increases to 0.70.

The draining of Valley Mill Reservoir caused a decrease in TDS load by approximately 1,050 kg/day during the mean and 10-percentile flows from site IF-2 to OF-1. Total suspended sediment load increased 316 kg/day between sites IF-2 and OF-1 during mean flow, but only 285 kg/day during the 10-percentile flow. Total nitrogen load increased by 4 kg/day, almost 30 percent, while TP load increased by 0.27 kg/day, over 130 percent during mean flow. During the 10-percentile flow, percent differences were less, with nitrogen increasing less than 10 percent and phosphorus increasing approximately 60 percent.

Table 5.14 Load Rating Curve Equation Data

Site	Water Quality Variable	B0	B1	R^2
	Load (kg/day) = B0 * Q (m^3/s)^B1			
US-1	Total Nitrogen (n = 10)	136.9	1.08	0.97
	Total Phosphorous (n= 10)	14.3	1.08	0.92
	Total Suspended Sediment (n= 10)	2,141.1	1.18	0.94
	Total Dissolved Solids (n= 1)	9,673	0.93	0.80
US-2	Total Nitrogen (n = 9)	270.9	0.91	0.92
	Total Phosphorous (n= 10)	48.2	0.73	0.61
	Total Suspended Sediment (n= 10)	6,996.1	1.14	0.62
	Total Dissolved Solids (n= 11)	26,522	0.41	0.43
US-3	Total Nitrogen (n = 11)	151.1	1.02	0.88
	Total Phosphorous (n= 11)	27.8	1.08	0.93
	Total Suspended Sediment (n= 11)	2,269.9	1.33	0.93
	Total Dissolved Solids (n= 12)	24,842	0.87	0.84
US-4	Total Nitrogen (n = 11)	147.2	0.95	0.82
	Total Phosphorous (n= 11)	8.6	0.69	0.53
	Total Suspended Sediment (n= 11)	3,636	1.31	0.71
	Total Dissolved Solids (n= 12)	14,252	0.96	0.86
IF-1	Total Nitrogen (n = 21)	217.3	1.15	0.92
	Total Phosphorous (n= 21)	4.1	1.41	0.58
	Total Suspended Sediment (n= 20)	637.4	1.98	0.48
	Total Dissolved Solids (n= 32)	29,853	0.81	0.97
IF-2	Total Nitrogen (n = 11)	356.0	1.57	0.94
	Total Phosphorous (n= 10)	4.5	1.50	0.51
	Total Suspended Sediment (n= 11)	766.6	1.11	0.29
	Total Dissolved Solids (n= 21)	29,457	0.81	0.97
OF-1	Total Nitrogen (n = 21)	187.8	1.05	0.97
	Total Phosphorous (n= 22)	7.9	1.64	0.90
	Total Suspended Sediment (n= 22)	2,805.1	1.39	0.70
	Total Dissolved Solids (n= 32)	29,301	0.89	0.99
OF-2	Total Nitrogen (n = 22)	182.0	1.03	0.98
	Total Phosphorous (n= 22)	7.2	1.26	0.87
	Total Suspended Sediment (n= 21)	2,076.9	1.04	0.77
	Total Dissolved Solids (n= 33)	23,445	0.83	0.96
SDS	Total Nitrogen (n = 7)	179.5	1.13	0.83
	Total Phosphorous (n= 7)	5.2	1.57	0.67
	Total Suspended Sediment (n= 7)	359.5	1.53	0.29
	Total Dissolved Solids (n= 11)	19,469	0.81	0.99

Table 5.15 Load Data Derived from Regional Rating Curves

Site	Area (mi^2)	Discharge (m^3/s)		Mean Pollution Load (kg/day)				10% Flow Pollution Load (kg/day)			
		Mean	10%	TDS	TSS	TP	TN	TDS	TSS	TP	TN
US-1	1.77	0.047	0.085	563	58.0	0.53	5.0	977	116.8	1.00	9.6
US-2	1.74	0.046	0.084	7,505	209.1	5.09	16.4	9,606	415.5	7.90	28.4
US-3	3.78	0.100	0.185	3,351	106.2	2.31	14.4	5,723	240.6	4.49	27.0
US-4	0.84	0.022	0.040	365	24.5	0.62	3.9	648	53.6	0.93	6.9
IF-1	-	-	-	-	-	-	-	-	-	-	-
IF-2 (baseflow)	4.87	0.129	0.239	5,607	78.9	0.21	14.3	9,240	156.5	0.53	37.6
JS	-	-	-	-	-	-	-	-	-	-	-
OF-1	4.94	0.131	0.243	4,800	166.3	0.28	22.2	8,319	392.6	0.78	42.5
OF-1 (baseflow)	4.94	0.131	0.243	4,549	395.1	0.48	18.3	8,182	441.6	0.86	40.5
OF-2	13.7	0.363	0.686	10,111	724.0	2.01	64.1	17,147	1,403.4	4.48	123.4
SDS	8.75	0.232	0.434	5,962	38.4	0.52	34.4	9,902	100.2	1.40	69.9

Comparison of Methods

The two methods discussed above produced significantly different results (Table 5.16); however, pollution load trends are somewhat similar. The large difference in load values is due to the difference between estimated discharges. For example, a mean discharge of 0.131 m^3/s was calculated using the regional rating curve at site OF-1, while estimating mean discharge using stage data resulted in a mean discharge of 0.40 m^3/s, which was over three times higher.

Using the mean discharge-concentration method, TDS remained nearly the same between inflow and outflow. Using the regional rating curve method, TDS decreased by less than 20 percent, which is within the assumed error range. The increase in TSS load is similar, although percent difference between sites is not. Total suspended sediment load increased 396 kg/day using the mean discharge-concentration method, while calculated

TSS load increase was 316 kg/day using the regional rating curve method. The calculated increase in TP load was nearly identical with both methods. The biggest difference in load determination was between TN load calculations. Using the mean discharge-concentration method, TN load decreased by approximately 2 kg/day. The regional rating curve approach calculated a TN load increase of 4 kg/day. Therefore the two methods produced similar results for TSS and TP loads. Results of TDS data for the two methods differed by less than 20 percent, but TN load data differed by over 30 percent.

In karst headwater streams with obvious sinkholes, springs, fractures and other typical karst features, perhaps regional rating curves do not provide accurate discharge estimates. These karst features significantly alter the hydrology of the Valley Mill watershed, which is apparent when comparing the two methods for estimating discharge. Also, few discharge gages exist on drainage basins less than 20 km^2, and local karst hydrology may vary, adding to the difficulty of calibrating regional rating curves for small watersheds.

Table 5.16 Comparison of Results of Two Pollution Load Calculation Methods

Site	Estimated Mean Q * Mean Concentration				Regional Rating Curve Q * Mean Concentration				% Difference			
	TDS	**TSS**	**TP**	**TN**	**TDS**	**TSS**	**TP**	**TN**	**TDS**	**TSS**	**TP**	**TN**
IF-2	12,661	317.3	1.1	67.6	5,607	78.9	0.21	14.3	126	302	426	373
OF-1	13,340	715.4	1.5	69.1	4,800	166.3	0.28	22.2	178	330	432	211
OF-2	12,116	789.6	1.5	73.5	10,111	724.0	2.01	64.1	20	9	-25	15
SDS	11,248	77.2	2.6	113.7	5,962	38.4	0.52	34.4	89	101	396	230

IMPLICATIONS OF RESERVOIR DRAINGE

Valley Mill Reservoir, when filled, acted as a trap for inflowing sediment and nutrients from the upper watershed. Once the reservoir was drained, it became a source of sediment and nutrients to the SDSR. Although a detention basin was built below the spillway to trap outflowing sediment, it proved ineffective at trapping sediment for the duration of this one-year study.

Much of the sediment delivered to the SDSR was eroded from within the drained VMR due to down-cutting and widening of newly formed stream channels in the exposed lake bed (Figures 5.12 to 5.20). For the purpose of comparison the reservoir was divided into three sections: lower reservoir (0 to 100 m upstream of the shallow pool); middle reservoir (100 m to 200 m upstream of the shallow pool); and upper reservoir (200 m upstream of the shallow pool to the end of the reservoir). A survey of Sanders Spring stream channel within the reservoir was conducted in July 2003 to determine the average width and depth of the channel (Appendix F). Sanders Spring down-cut an average of 0.86 m with an average channel width of approximately 2.7 m within VMR. However, most of this degradation and lateral widening occurred in the upper and middle reservoir, where a significant delta had been formed. In the lower reservoir, less sediment had accumulated and therefore little down-cutting and widening occurred in this area. Sanders Spring channel in the lower reach of the reservoir down-cut an average of 0.46 m and had an average width of 2.2 m. The middle reservoir reach experienced the most lateral erosion of the stream channel, with an average width of 3.6 m. This reach also down-cut considerably more than the lower reach, with an average channel depth of 0.92 m. The upper reservoir reach, where the greatest sediment deposition occurred when the reservoir was filled, had the greatest average channel depth at 1.2 m. Average channel width in the upper reach was only 2.4 m, slightly higher than the lower reach but considerably lower than the middle reach.

By multiplying the volume of the channel (average width x average depth x length) by the bulk density of the sediment eroded, assumed to be 1.3 Mg/m^3, the mass of sediment removed from Sanders Spring channel within VMR can be estimated. The lower reach had a channel volume of 101 m^3; the middle reach had a channel volume of 331 m^3; the upper reach had a channel volume of 374 m^3. Therefore, the total volume of the eroded Sanders Spring channel within VMR was 806 m^3. With a bulk density of 1.3

Mg, it was estimated that 1048 Mg of sediment was removed from the Sanders Spring channel that formed in the drained reservoir. This mass does not include sediment removed due to the formation of the Jarrett Spring channel within VMR or sediment eroded from the channel reach upstream of the reservoir. The mass of sediment eroded calculated from the channel survey varies from the pollution load data, further indicating errors associated with pollution load data.

Figures 5.12, 5.13, and 5.14 exemplify the fact that little sediment erosion occurred within the lower reservoir. The three pictures taken in June 2002, March 2003, and August 2003, respectively, illustrate that following drainage and even over one year after drainage, the channel did not substantially down-cut or widen. The middle reservoir reach eroded much more quickly and to a greater extent than the lower reach. Less than three months after drainage began, a headcut migrated through the middle reach causing significant down-cutting of the channel (Figure 5.15). The channel then began to erode laterally, and in March and August 2003, the middle reach had the widest stream channel (Figures 5.16 and 5.17). The greatest sediment deposition as well as the greatest down-cutting occurred in the upper reservoir reach. Figure 5.18 shows the headcut, which had already migrated through the middle reach by June 2002, causing erosion in the upper reach. By March 2003 most of this reach down-cut over 1 m, but little lateral erosion occurred (Figure 5.19). However, from March 2003 to August 2003 the channel eroded more laterally than vertically (Figure 5.20).

The headcut, which originated within the reservoir, eventually migrated approximately 100 m upstream of the reservoir. This caused significant erosion of the stream channel upstream of the reservoir. However, further headcut migration was blocked by large woody debris in the channel (Figure 5.21). Had the headcut been allowed to erode further upstream, the effects of reservoir drainage would have been even greater.

By comparing sites OF-1, OF-2, and SDS, the water quality changes in the SDSR due to reservoir drainage can be determined. Mean sediment concentration and turbidity were more than an order of magnitude greater at site OF-2 compared to site SDS during baseflow (Table 5.5). This increased sediment delivered to the SDSR, which was deposited on the stream bed for several hundred meters downstream of VMR outflow, also reduced water clarity, which is apparent in Figure 5.22. The increased turbidity and sediment load may cause a decline in fish and macroinvertebrate communities and diversity, as well as cause an increase in water treatment costs for Fulbright Spring (Schueler, 2000).

Figure 5.12 Sanders Spring Channel Formed in the Lower Reservoir June 11, 2002

Figure 5.13 Sanders Spring Channel Formed in the Lower Reservoir March 3, 2003

Figure 5.14 Sanders Spring Channel Formed in the Lower Reservoir August 20, 2003

Figure 5.15 Sanders Spring Channel Formed in the Middle Reservoir June 11, 2002

Figure 5.16 Sanders Spring Channel Formed in the Middle Reservoir March 3, 2003

Figure 5.17 Sanders Spring Channel Formed in the Middle Reservoir August 20, 2003

Figure 5.18 Sanders Spring Channel Formed in the Upper Reservoir June 11, 2002

Figure 5.19 Sanders Spring Channel Formed in the Upper Reservoir March 3, 2003

Figure 5.20 Sanders Spring Channel Formed in the Upper Reservoir August 20, 2003

Figure 5.21 Large Woody Debris Preventing Headcut Migration Upstream of VMR

Figure 5.22 Fine-Grained Sediment Deposited and Suspended in the S. Dry Sac River

Concentrations of phosphorus greater than 20 ug/L typically accelerate eutrophication of reservoirs (Sharpley *et al.*, 1999), while concentrations greater than 100 ug/L accelerate eutrophication of streams (USGS, 1999). A maximum contaminant level of 10 mg/L of nitrogen in water was established by the United States EPA since concentrations greater than this can be a threat to human health (USEPA, 1988). Nitrogen concentrations at all monitoring sites were well below this maximum contaminant level. However, phosphorus concentrations at sites OF-1 and OF-2 were above 100 ug/L during all but three storm events, indicating that the draining of VMR may cause an acceleration of eutrophication in the SDSR downstream of VMR outflow, due to increased phosphorus delivery following storm events.

A total maximum daily load (TMDL) study was conducted for the James River, which flows from the northeast of Springfield to the southwest into Table Rock Lake. A target of 75 ug/L for phosphorus and 1.5 mg/L for nitrogen was established for this river, which was listed as impaired by the Missouri Department of Natural Resources due to elevated nutrient levels (MODNR, 2003). Nitrogen concentration at site OF-1 and OF-2 exceeded the James River target of 1.5 mg/L in all but one sample. The phosphorus target of 75 ug/L was exceeded once during baseflow at site OF-1 and nine times during storm events. Site OF-2 exceeded the target three times during baseflow and eight times during storm events. This further indicates that the draining of VMR may cause increased eutrophication in the lower SDSR.

Greater efforts need to be made in future reservoir drainage operations to reduce the transport of sediment during drainage. Since phosphorus is associated with sediment, targeting sediment will also reduce phosphorus concentration. By draining a reservoir in stages, sediment erosion can be reduced or remain trapped within the reservoir. This method was used in a study by Marty Rye (2000) who found that by lowering the reservoir in stages, vegetation rapidly grew in the exposed lake bed, increasing the stabilization of reservoir sediment, which reduced sediment erosion. Other management efforts should be focused on improving the trapping capabilities of detention ponds. This study found that the detention pond constructed below VMR outflow effectively trapped outflowing sediment for the first five months of reservoir drainage but ceased to trap sediment after that. By creating a series of detention ponds, a larger detention pond, or maintaining and removing sediment from the current detention pond, sediment removal in outflow could have been greater, reducing sediment and phosphorus delivery to the SDSR and Fulbright Spring.

COMPARISON OF RESULTS TO PREVIOUS STUDIES

Several reservoir drainage studies have taken place in the United States; however most of those studies dealt with dam removal rather than temporary drainage. The changes that occur in an aquatic system due to dam removal are considerably different than those that occur during the temporary dewatering of a reservoir. However, it is still important to compare the studies to determine differences and similarities with various drainage methods.

Table 5.17 lists the physical effects of dam removal on several rivers in the United States. The table, which was adapted from (Hart *et al.*, 2002), shows that increased sediment transport is a common result of dam removal. Increased sediment transport was the most significant problem associated with the drainage of the VMR, which is similar to these other studies. Stanley and Doyle (2003) states that suspended sediment concentration increases greatly after drainage, and high turbidity may persist for months. This trend was apparent at VMR, with suspended sediment concentration and turbidity remaining elevated one year after drainage began.

Marty Rye (2000) studied two dam removal operations in Minnesota, summarized in Figures 5.23 and 5.24. Sediment concentrations in outflow from VMR followed a similar trend with a large increase followed by a steady decrease. However, sediment concentration was much lower in VMR outflow, and this trend was not apparent the last four months of the study (Figure 5.7). Ozarks sediment concentrations in general are lower than Upper Midwest streams.

William Vernieu (1997) studied the natural water level drawdown of Lake Powell due to drought conditions in the upper watersheds. Results indicated that erosion of the exposed lake bed was significant and resulted in increases in phosphorus concentrations within the drained reservoir. The sediment and phosphorus concentrations were more than an order magnitude higher than VMR, but trends were similar with sediment and nutrient concentrations increasing due to water level drawdown. Finally, Childers *et al.* (2000) conducted an experimental 18-foot drawdown of Lake Mills in Washington to determine the possible effects of the removal of the lake's dam. They found that significant down-cutting into the lake bed occurred until the newly formed streambed eroded down to base level, which was limited by the water level. After base level was reached, significant lateral erosion occurred. Although the amount of sediment eroded from Lake Mills was much higher than VMR, erosion within VMR also occurred by first down-cutting then widening of the stream channel within the drained reservoir.

Table 5.17 Selected Studies on the Effects of Dam Removal on Sediment Transport (adapted from Hart *et al.* 2002)

Dam River System (Dam Life Span)	Estimated Size Height by Length (m) Impoundment	Physical	Reference
Edwards Dam			
Kennebec River, ME	7 x 280	Erosion at dam site;	Casper et al. 2001;
(1837-1999)	462	bank slumping	O'Donnell et al. 2001
Ft. Edward Dam			
Hudson River, NY	9 x 179	Increased sediment transport	Shuman 1995
(1998-1973)	79		
Grangeville Dam			
Clearwater River, ID	17 x 134	Increased sediment transport	Winter 1990
(1903-1963)	n.d.		
Kettle River Dam			
Kettle River, MN	6 x 46	Increased sediment transport	Johnson 2001
(1915-1995)	n.d.		
Lewiston Dam			Williams 1977
Clearwater River, ID	14 x 323	Increased sediment transport	Winter 1990;
(1927-1973)	n.d.		Shuman 1995
Manatawny Creek Dam		Increased sediment transport;	Bushaw-Newton 2001;
Manatawny Creek, PA	2 x 30	downstream channel	Hart et al. 2001;
(late 1700s-2000)	1.5	aggradation; channel formation	Horwitz et al. 2001;
			Johnson et al. 2001
Newaygo Dam			
Muskegon River, MI	n.d.	Increased sediment transport	Simons and Simons
(1853-1968)	n.d.		1991
Oak Street Dam			
Baraboo River, WI	4 x 63	Increased sediment transport;	Catalano et al. 2001;
(1860-2000)	6-15	channel formation	Stanley et al. 2002

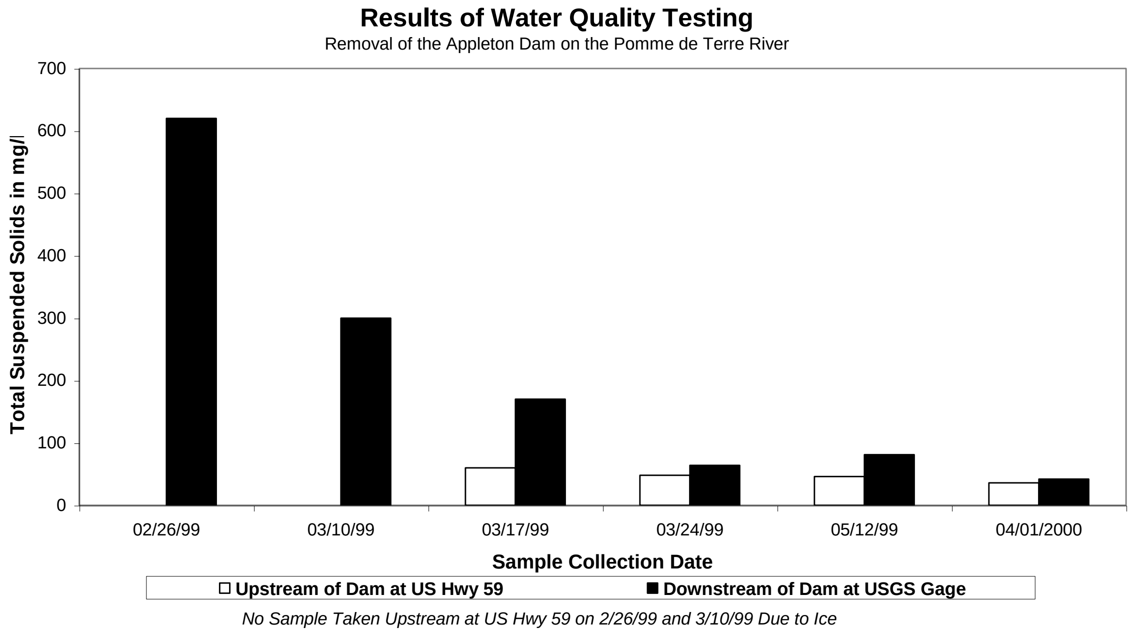

Figure 5.23 Appleton Dam Removal Impacts on Water Quality (adapted from Rye 2000)

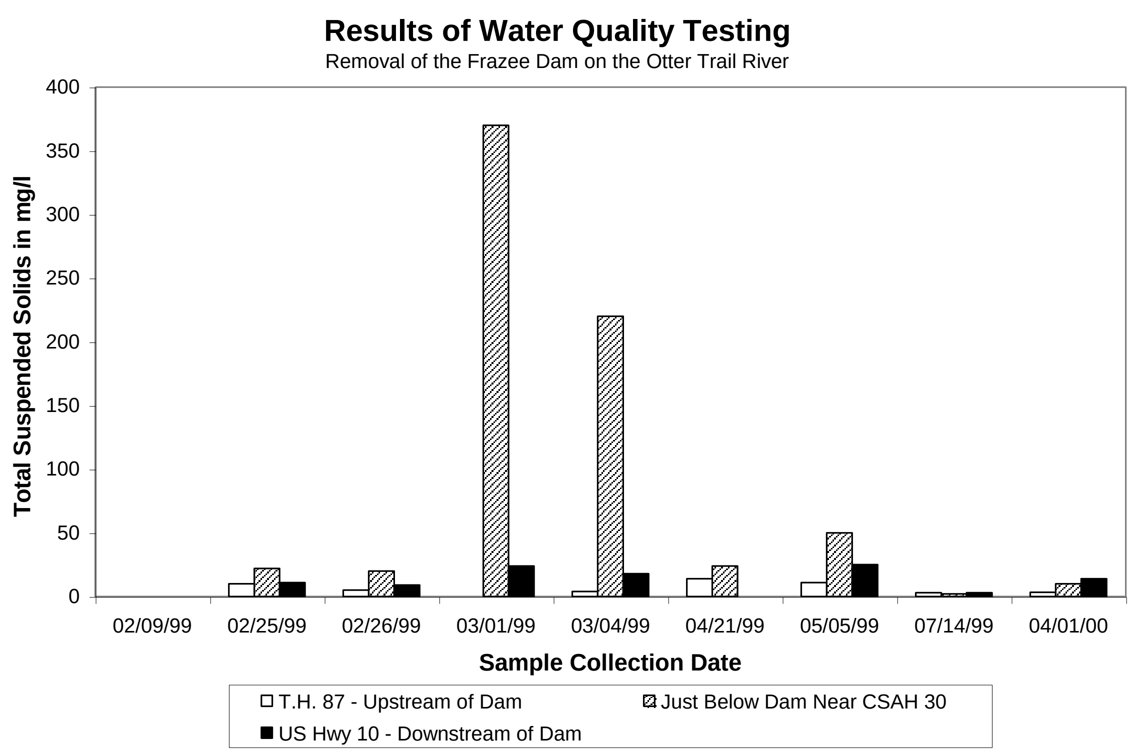

Figure 5.24 Frazee Dam Removal Impacts on Water Quality (adapted from Rye 2000)

The processes that occurred within VMR due to reservoir drainage were similar to other reservoir drainage operations. However, these processes of erosion and transport happened more slowly and at a much lower magnitude than these other studies. This is likely because VMR is a small reservoir that was only temporarily drained; the dam was not removed. The other studies addressed either temporary drainage of much larger reservoirs than VMR or dam removal operations, which were also conducted on larger reservoirs.

FUTURE WORK

Continuing research in the Valley Mill watershed could provide new insight into the complicated effects of reservoir drainage as well as expand upon results from this one-year reservoir drainage study. Three specific issues should be addressed in future work: improving upon discharge measurements; sampling for heavy metals, nutrients, and other pollutants associated with industrial discharges further up in the watershed; and time series analysis of pollution transport trends from Sanders Spring.

By improving upon discharge measurements, a more accurate estimate of sediment and nutrient loads delivered to the South Dry Sac River could be calculated. Discharge could have been calculated more accurately using a low-flow velocity meter at each sampling site at a range of water levels to develop site-specific rating curves. Also, since the Valley Mill watershed drains runoff from several industrial areas, the potential for contamination of water resources, especially Fulbright Spring, by heavy metals and other industrial contaminants exists. Therefore, future water quality monitoring should address the issue of transport of heavy metals within and from the Valley Mill watershed.

Although efforts were made to determine the short-term pollution transport trends of Sanders Spring and the primary ephemeral tributary using an automatic water sampler and data logger (Appendix E), lack of equipment and time constraints made it difficult to obtain accurate results. By using methodology from previous studies (Vivian and Quinton, 1993; Ryan and Meiman, 1996; Appel and Hudak, 2001) and focusing the study on these two sites, better results could be obtained. The magnitude and duration of water quality degradation during an entire storm event could be determined by continually monitoring single storm events, instead of collecting one grab sample per storm.

CHAPTER SIX

SUMMARY & CONCLUSIONS

The Valley Mill Reservoir, when filled, has a surface area of 6.1 hectares and a storage volume of 150,000 m^3. The reservoir was drained in March 2002 to repair an ageing dam, remove excess sediment that had accumulated within the reservoir, and enhance the filtering capacity of the wetland just upstream of the reservoir. A flow-through valve installed at the base of the spillway was used to drain the reservoir. This method did not allow for the complete drainage of the reservoir, so a small pool typically less than two meters deep remained in the lower end of the reservoir near the spillway. Water quality monitoring indicated that outflowing water from the drained reservoir had elevated sediment and phosphorus concentrations. However, comparing these results to other reservoir drainage operations indicates that maximum and mean sediment concentration was lower in VMR outflow than other reservoir drainage studies that have taken place across the United States. The lower sediment concentrations may have been due to the slower drainage method used for the Valley Mill Reservoir, the fact that it is a small reservoir, the shallow pool that remained within the reservoir, and the main source of baseflow inflow being springs with relatively good water quality.

The primary results of the Valley Mill Reservoir drainage study indicate:

1. **Draining of the Valley Mill Reservoir caused increased erosion and transport of sediment and phosphorus from the Valley Mill watershed, but not nitrogen.**

Once drainage of VMR was complete, two stream channels were formed by erosion and bank slumping in the newly exposed lake bed by inflow from Sanders Spring and Jarrett Spring. Flow from these two springs began down-cutting and later widening the stream channel into the lake bed. This caused mean suspended sediment concentration to increase from approximately 10 mg/L to 20 mg/L during baseflow and increase from approximately 50 mg/L to 100 mg/L following storm events. Maximum TSS concentration in outflow during baseflow was only 42 mg/L, but storm event maximum TSS concentration was much higher at 525 mg/L.

The increased sediment erosion and transport also caused an increase in phosphorus transport. Mean baseflow phosphorus concentration increased from 38 ug/L to 43 ug/L, while mean storm event phosphorus concentration increased from 171 ug/L to 207 ug/L. The draining of VMR caused a decrease in nitrogen concentration in outflow, likely due to increased sediment-water contact increasing denitrification rates. Mean TN concentration decreased 2.3 mg/L to 2.0 mg/L, or 13 percent, during baseflow conditions. Total nitrogen concentration also decreased following storm events, but only from 2.3 mg/L to 2.2 mg/L, or 5 percent.

The effects of reservoir drainage on sediment and phosphorus concentration were magnified during storm event flows. However, the effects of drainage on nitrogen concentration were damped during storm event flow. This is because of the different processes that affected these constituents due to reservoir drainage. With increasing discharge, the ability of the stream to erode and transport sediment and associated phosphorus increases. Therefore, as flow increases it is expected that sediment and phosphorus concentration would also increase. Conversely, nitrogen concentration was reduced due to denitrification within the reservoir. Denitrification is the process in which bacteria in sediment convert nitrate to N_2 gas which is released from the water (Dodds, 2002). As discharge increased during storm events, water was in contact with the lake bed for less time, so denitrification rates were reduced during higher flows.

2. **Draining of Valley Mill Reservoir caused erosion of the 200 m reach of stream channel upstream of the reservoir.**

The draining of VMR caused water velocity to increase as flow was directed along the steeper lake bed. This increased water velocity caused the stream channel upstream of the reservoir, between monitoring sites IF-1 and IF-2, to erode vertically as well as laterally. A headcut eventually migrated approximately 100 m through this stream reach, but was prevented by large woody debris from migrating all the way through the reach. Total suspended sediment concentration increased by nearly 50 percent from site IF-1 to site IF-2, indicating that erosion of the channel was occurring. This increased erosion could only be measured during baseflow conditions since runoff from the upper Valley Mill watershed entered via tributary confluence between these two sites, radically changing water quality.

3. **Water chemistry was only slightly impacted by drainage of Valley Mill Reservoir.**

Mean water temperature changed by less than 2^{o} C, pH by less than 1, and total dissolved solids concentration by less than ten percent after flowing over the exposed lake bed. Dissolved oxygen concentration and turbidity increased significantly though. Except for turbidity, these changes were less during storm event flow.

Water temperature was nearly constant from inflow to outflow during both baseflow and storm event flow. Outflow increased by less than 1 pH during baseflow, and only 0.3 pH during storm event flow. The increase in pH may have been due to exsolution of CO_2, denitrification, and contact with calcium-carbonate sediment within the reservoir. All three of these factors were reduced during storm event flow. The TDS concentration may have been reduced by assimilation and uptake of these solids by algae and bacteria present in the water and soils. Again, increased flow would reduce this rate of uptake, leading to less reduction of TDS concentration during event flow.

Dissolved oxygen concentration increased by nearly 2 mg/L after flowing through the drained reservoir during baseflow. Since oxygen-poor groundwater provided the only source of inflow during baseflow, it was expected that DO concentration would increase. Even without draining of VMR, DO concentration would have increased after being discharged from the springs due to photosynthesis, which releases oxygen, and turbulence of the water, which causes mixing with atmospheric oxygen. During storm event flow, DO concentration only increased by approximately 5 percent since discharge from Sanders Spring mixed with runoff with higher DO concentration before entering the drained reservoir.

Turbidity, which is related to water clarity, is dependent on the concentration of suspended material in the water column. Turbidity measurements increased significantly after flowing over the exposed lake bed during both baseflow and storm event flow. Total suspended sediment concentration also increased after flowing over the exposed lake bed during baseflow and storm event flow, causing increased turbidity.

4. **Valley Mill Reservoir was the second greatest sediment and nutrient source within the Valley Mill watershed, but the greatest source to the South Dry Sac River.**

During baseflow conditions, the drained VMR is by far the greatest sediment and nutrient source within the Valley Mill watershed. The watershed only has flow from

Sanders and Jarrett Springs during baseflow conditions, both of which discharge directly into VMR. However, during storm events the entire watershed is a potential sediment and nutrient source. The area drained by monitoring site US-2 becomes the greatest sediment, phosphorus, and nitrogen source during runoff events. Mean TSS concentration at site US-2 was nearly 50 mg/L higher than site OF-1. Mean TP concentration was over 3 times higher than VMR outflow. Site US-2 was also a much greater nitrogen source within the watershed than VMR.

Site US-2, with an estimated drainage area of approximately 4.5 km^2, drained a mix of land uses that included a small farm, industrial park, and an area undergoing development. Vast expanses of sediment were exposed during the entire study period due to development. Also, row crops were grown on the small farm, which typically increases sediment and nutrient concentration in runoff. However, most of the sediment and nutrients eroded from this drainage area were not transported to Valley Mill Reservoir or the South Dry Sac River. Runoff from site US-2 flowed through a series of detention ponds located on a golf course between monitoring sites US-2 and US-3. These detention ponds reduced TSS concentration by more than a third, while TP concentration was reduced by nearly half. Total nitrogen concentration was also reduced by over 60 percent. Therefore, although the drainage area of site US-2 is the greatest sediment and nutrient source within the watershed, the drained Valley Mill Reservoir is the greatest sediment and nutrient source to the South Dry Sac River. Future efforts to identify pollution sources should look in more depth at the sub-watershed area about site US-2.

5. **Draining of the Valley Mill Reservoir may have adversely affected the South Dry Sac River and Fulbright Spring.**

Turbidity and nutrient and suspended sediment concentration increased considerably at site OF-2 following reservoir drainage. Water samples were collected at site OF-2 once a week the first four weeks before drainage began (Appendix D). Total suspended sediment concentration did not exceed 2.0 mg/L in any of the four samples collected before drainage. Mean sediment concentration at site OF-2 following drainage was 24.7 mg/L, more than an order of magnitude greater. Total phosphorus concentration at site OF-2 ranged from below detection limits to 10 ug/L with a mean of 4 ug/L before drainage. Mean TP concentration at site OF-2 following drainage was 48 ug/L; again more than an order of magnitude increase. Total nitrogen concentration at site OF-2 increased from 1.8 mg/L before drainage to 2.3 mg/L following drainage. Turbidity was measured the first six weeks before drainage and mean turbidity was 5.3 NTU. Following drainage, mean turbidity increased to 48 NTU -- nearly an order of magnitude increase.

Turbidity, TSS, and TP concentrations all increased by approximately an order of magnitude at site OF-2 following reservoir drainage, while TN concentration increased by approximately 25 percent. The increased sediment load was obvious when conducting visual surveys along the South Dry Sac River. Water clarity was noticeably reduced downstream of Valley Mill Reservoir outflow, and significant fine-grained sediment deposition occurred on the channel bed of the South Dry Sac River (Figure 5.22). With the increased nutrient load, eutrophication may become a problem in the near future.

A spatial study of nutrient and water chemistry trends in the VMR Study Area found that elevated phosphorus and turbidity levels persisted to the swallow-hole located on the South Dry Sac River, which recharges Fulbright Spring. Therefore, it is likely that Fulbright Spring is receiving an increased sediment and phosphorus load due to reservoir drainage, albeit to only a moderate degree. These increased pollution loads may reduce the water quality of Fulbright Spring, which can increase water treatment costs.

In closing, the draining of Valley Mill Reservoir decreased water quality downstream of the reservoir and increased erosion on the lake bed and upstream of the reservoir. While most water chemistry variables were only slightly impacted by drainage, sediment and nutrient releases from the drained reservoir were significant due to long-term accumulation of these pollutants while the reservoir was filled. The Watershed Committee of the Ozarks is attempting to improve the long-term pollution reducing capabilities of Valley Mill Reservoir while preventing the accumulation of excess sediment and nutrients within the basin. Efforts are currently underway to improve the filtering capacity of the wetland upstream of the reservoir by increasing the size and plant diversity of the wetland, as well as reducing the velocity of stream flow within the wetland before it reaches the reservoir.

Greater efforts could have been made to reduce or prevent the problems associated with the draining of Valley Mill Reservoir. Improved reservoir drainage techniques such as drainage of the reservoir in stages, installation of a larger detention pond below outflow, and re-filling the reservoir more quickly could have reduced the volume of sediment and nutrients delivered to the South Dry Sac River. Since many dams and reservoirs in southwest Missouri will be in need of repair in the near future, management efforts must be implemented to reduce sediment delivery to downstream waters during reservoir drainage.

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APPENDIX A

Baseflow Water Quality Data

Site IF-1 Baseflow Water Quality Data

Sampling Date	Stage (m)	Estimated Q (m3/s)	Total N (mg/L)	Total P (ug/L)	TSS (mg/L)	E. coli (cfu)	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	TEMP (C)	TDS (mg/L)
04/04/02	0.37	0.43	2.5	12	1.0	5	6.8	0.635	2.7	6.6	13.9	410
04/18/02	0.36	0.41	-	-	-	10	6.7	0.652	14.0	6.8	14.4	420
05/20/02	0.55	0.84	4.7	63	4.1	52	6.5	0.541	15.9	4.2	14.2	350
06/11/02	0.43	0.55	-	-	-	31	6.5	0.590	9.5	7.7	14.9	380
06/20/02	0.41	0.51	-	-	-	-	6.3	0.613	4.6	7.6	15.0	390
06/27/02	0.40	0.49	2.3	24	30.6	96	6.4	0.591	0.0	7.6	15.6	380
07/11/02	0.40	0.49	-	-	-	-	6.5	0.585	11.4	4.4	15.4	370
08/01/02	0.36	0.41	1.9	53	0.7	63	6.4	0.647	26.8	5.4	16.2	410
08/23/02	0.30	0.30	-	-	-	-	6.3	0.711	7.3	3.0	15.7	460
09/03/02	0.30	0.30	2.1	25	1.7	63	6.4	0.702	7.9	2.2	15.7	450
09/17/02	0.30	0.30	-	-	-	-	6.4	0.658	7.7	3.4	16.5	420
10/01/02	0.28	0.26	1.6	34	3.1	41	6.5	0.672	13.5	3.3	16.4	430
10/22/02	0.23	0.19	-	-	-	-	6.4	0.692	5.7	1.9	15.1	440
11/07/02	0.29	0.28	2.1	38	1.4	-	6.5	0.722	14.9	3.0	15.6	460
11/22/02	0.25	0.22	-	-	-	-	6.5	0.754	6.1	3.5	15.3	480
12/06/02	0.26	0.23	2.3	81	36.4	-	6.8	0.630	65.0	7.6	14.9	400
12/19/02	0.23	0.19	-	-	-	5	6.7	0.710	1.0	8.2	15.1	450
01/08/03	0.25	0.22	2.4	27	1.1	10	6.7	0.691	9.0	9.6	14.9	442
01/20/03	0.21	0.16	-	-	-	-	6.8	0.680	13.5	7.9	15.3	435
02/10/03	0.19	0.14	1.7	41	1.2	5	6.9	0.905	9.8	5.6	15.3	579
03/16/03	0.30	0.30	2.1	17	1.2	31	6.8	0.702	25.5	3.0	14.4	449
# of Samples	**21**	**21**	**11**	**11**	**11**	**12**	**21**	**21**	**21**	**21**	**21**	**21**
Mean	**0.32**	**0.34**	**2.3**	**38**	**7.5**	**34**	**6.6**	**0.671**	**12.9**	**5.3**	**15.2**	**429**
Minimum	**0.19**	**0.14**	**1.6**	**12**	**0.7**	**5**	**6.3**	**0.541**	**0.0**	**1.9**	**13.9**	**350**
Maximum	**0.55**	**0.84**	**4.7**	**81**	**36.4**	**96**	**6.9**	**0.905**	**65.0**	**9.6**	**16.5**	**579**
Median	**0.30**	**0.30**	**2.1**	**34**	**1.4**	**31**	**6.5**	**0.672**	**9.5**	**5.4**	**15.3**	**430**
Stand. Dev.	**0.09**	**0.17**	**0.8**	**21**	**13.0**	**30**	**0.2**	**0.076**	**13.8**	**2.3**	**0.7**	**48**
Coeff Var.	**27.64**	**48.60**	**35.6**	**55**	**172.8**	**86**	**2.8**	**11.303**	**106.3**	**44.0**	**4.5**	**11**

Site IF-2 Baseflow Water Quality Data

Sampling Date	Stage (m)	Estimated Q (m3/s)	Total N (mg/L)	Total P (ug/L)	TSS (mg/L)	E. coli (cfu)	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	TEMP (C)	TDS (mg/L)
04/04/02	0.24	-	2.4	13	2.8	10	6.9	0.636	4.3	8.3	14.3	410
04/18/02	0.40	-	-	-	-	5	6.8	0.650	14.0	7.0	15.3	420
05/20/02	0.42	-	4.4	77	25.9	240	6.7	0.546	14.7	5.7	14.8	350
06/11/02	0.18	-	-	-	-	20	6.6	0.590	3.2	9.5	15.3	380
06/20/02	0.23	-	-	-	-	-	6.4	0.617	0.0	8.7	15.4	390
06/27/02	0.25	-	2.4	27	5.9	161	6.4	0.596	6.6	8.9	16.3	380
07/11/02	0.32	-	-	-	-	-	6.4	0.607	9.1	4.5	15.4	390
08/01/02	0.20	-	1.8	72	7.3	52	6.6	0.654	17.7	7.1	17.0	420
08/23/02	0.20	-	-	-	-	-	6.4	0.707	10.3	5.0	16.1	450
09/03/02	0.16	-	2.1	19	4.4	96	6.4	0.704	7.2	4.1	16.1	450
09/17/02	0.15	-	-	-	-	-	6.5	0.655	9.5	6.2	17.5	420
10/01/02	0.26	-	1.7	26	15.5	85	6.8	0.673	11.6	5.2	17.0	430
10/22/02	0.20	-	-	-	-	-	6.7	0.691	8.0	3.6	14.9	440
11/07/02	0.30	-	2.1	31	4.8	-	6.6	0.720	17.4	4.1	15.5	460
11/22/02	0.29	-	-	-	-	-	6.7	0.757	9.0	4.4	14.8	480
12/06/02	0.27	-	2.5	62	30.6	-	7.0	0.600	120.0	8.9	14.2	390
12/19/02	0.27	-	-	-	-	5	6.8	0.710	0.0	9.9	14.7	450
01/08/03	0.26	-	2.2	26	2.8	5	6.9	0.690	16.7	10.9	15.0	442
01/20/03	0.20	-	-	-	-	-	7.1	0.708	11.8	9.2	14.9	453
02/10/03	0.19	-	1.1	-	13.0	5	7.1	0.920	76.3	6.1	14.9	589
03/16/03	0.23	-	2.2	15	5.9	5	6.9	0.703	15.5	3.1	14.7	450
# of Samples	**21**	-	**11**	**10**	**11**	**12**	**21**	**21**	**21**	**21**	**21**	**21**
Mean	**0.25**	-	**2.3**	**37**	**10.8**	**57**	**6.7**	**0.673**	**18.2**	**6.7**	**15.4**	**431**
Minimum	**0.15**	-	**1.1**	**13**	**2.8**	**5**	**6.4**	**0.546**	**0.0**	**3.1**	**14.2**	**350**
Maximum	**0.42**	-	**4.4**	**77**	**30.6**	**240**	**7.1**	**0.920**	**120.0**	**10.9**	**17.5**	**589**
Median	**0.24**	-	**2.2**	**27**	**5.9**	**15**	**6.7**	**0.673**	**10.3**	**6.2**	**15.3**	**430**
Stand. Dev.	**0.07**	-	**0.8**	**24**	**9.6**	**76**	**0.2**	**0.078**	**27.9**	**2.4**	**0.9**	**49**
Coeff Var.	**28.28**	-	**35.9**	**65**	**88.4**	**133**	**3.5**	**11.549**	**153.2**	**35.3**	**5.9**	**11**

Site OF-1 Baseflow Water Quality Data

Sampling Date	Stage (m)	Estimated Q (m3/s)	Total N (mg/L)	Total P (ug/L)	TSS (mg/L)	E. coli (cfu)	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	TEMP (C)	TDS (mg/L)
04/04/02	0.08	0.51	2.1	29	10.0	20	7.3	0.607	17.8	8.3	12.6	390
04/18/02	0.09	0.64	-	-	-	20	7.4	0.572	8.2	7.5	16.9	370
05/20/02	0.22	2.33	4.0	44	3.6	389	6.7	0.526	4.9	6.0	15.4	340
06/11/02	0.07	0.40	-	-	-	52	7.5	0.533	23.1	10.1	19.7	340
06/20/02	0.06	0.36	-	-	-	-	7.2	0.559	18.7	10.0	18.8	360
06/27/02	0.05	0.23	2.3	32	38.6	52	7.4	0.548	13.0	10.1	20.7	350
07/11/02	0.06	0.30	-	-	-	-	7.2	0.580	26.1	7.1	20.3	370
08/01/02	0.06	0.30	1.7	88	35.6	63	7.1	0.595	16.8	7.8	22.1	380
08/23/02	0.05	0.21	-	-	-	-	7.3	0.631	16.0	9.2	18.9	400
09/03/02	0.05	0.22	2.0	54	18.6	146	7.3	0.604	78.2	8.8	19.8	390
09/17/02	0.05	0.18	-	-	-	-	8.0	0.598	25.0	15.2	21.3	380
10/01/02	0.04	0.18	1.7	40	15.8	240	7.5	0.630	40.2	7.9	19.7	400
10/22/02	0.05	0.21	-	-	-	-	7.3	0.600	19.5	5.4	14.2	380
11/07/02	0.07	0.34	1.7	49	3.8	-	7.0	0.682	24.7	4.6	13.6	440
11/22/02	0.06	0.26	-	-	-	-	7.3	0.698	24.9	6.2	10.7	450
12/06/02	0.05	0.23	2.1	45	41.6	-	7.6	0.520	550.0	10.7	8.4	330
12/19/02	0.06	0.25	-	-	-	52	7.5	0.620	35.0	10.7	12.4	400
01/08/03	0.07	0.36	2.2	26	10.0	30	7.4	0.628	60.0	12.5	12.4	402
01/20/03	0.06	0.25	-	-	-	-	7.6	0.621	76.2	9.9	11.2	397
02/10/03	0.05	0.23	0.0	44	28.2	20	7.7	0.707	59.2	6.2	9.9	453
03/16/03	0.08	0.43	2.5	20	22.2	5	7.1	0.616	46.8	4.6	14.8	394
# of Samples	**21**	**21**	**11**	**11**	**11**	**12**	**21**	**21**	**21**	**21**	**21**	**21**
Mean	**0.07**	**0.40**	**2.0**	**43**	**20.7**	**91**	**7.3**	**0.604**	**56.4**	**8.5**	**15.9**	**386**
Minimum	**0.04**	**0.18**	**0.0**	**20**	**3.6**	**5**	**6.7**	**0.520**	**4.9**	**4.6**	**8.4**	**330**
Maximum	**0.22**	**2.33**	**4.0**	**88**	**41.6**	**389**	**8.0**	**0.707**	**550.0**	**15.2**	**22.1**	**453**
Median	**0.06**	**0.26**	**2.1**	**44**	**18.6**	**52**	**7.3**	**0.604**	**24.9**	**8.3**	**15.4**	**390**
Stand. Dev.	**0.04**	**0.46**	**0.9**	**18**	**13.7**	**115**	**0.3**	**0.052**	**115.0**	**2.7**	**4.2**	**34**
Coeff Var.	**54.42**	**113.90**	**45.9**	**43**	**66.0**	**127**	**3.6**	**8.551**	**204.0**	**31.3**	**26.6**	**9**

Site OF-2 Baseflow Water Quality Data

Sampling Date	Stage (m)	Estimated Q (m3/s)	Total N (mg/L)	Total P (ug/L)	TSS (mg/L)	E. coli (cfu)	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	TEMP (C)	TDS (mg/L)
04/04/02	0.59	0.28	2.0	20	5.5	30	7.6	0.479	6.6	8.6	13.4	310
04/18/02	0.55	0.24	-	-	-	85	7.5	0.531	12.5	7.7	17.1	340
05/20/02	0.85	2.18	4.8	41	4.3	175	7.0	0.405	4.3	7.4	16.2	260
06/11/02	0.51	0.37	-	-	-	86	7.7	0.518	12.5	10.4	19.9	330
06/20/02	0.50	0.20	-	-	-	-	7.3	0.548	10.7	10.4	19.5	350
06/27/02	0.47	0.13	2.1	30	32.8	63	7.5	0.544	10.8	9.5	20.9	350
07/11/02	0.50	0.15	-	-	-	-	7.3	0.581	13.4	6.9	20.9	370
08/01/02	0.45	0.09	1.7	91	29.6	63	7.4	0.589	11.1	7.4	23.0	380
08/23/02	0.44	0.11	-	-	-	-	7.5	0.619	10.5	7.5	19.8	400
09/03/02	0.45	0.08	2.3	76	17.6	155	7.5	0.642	17.1	7.7	19.4	410
09/17/02	0.46	0.07	-	-	-	-	7.9	0.603	16.2	9.7	21.7	390
10/01/02	0.43	0.04	1.4	29	30.0	161	7.6	0.619	22.2	6.9	20.1	400
10/22/02	0.46	0.04	-	-	-	-	7.5	0.603	18.1	5.7	14.1	390
11/07/02	0.50	0.65	1.9	45	6.8	-	7.2	0.685	23.3	5.2	13.8	440
11/22/02	0.46	0.62	-	-	-	-	7.4	0.698	24.3	5.6	10.4	450
12/06/02	0.50	0.54	2.3	67	106.4	-	7.8	0.550	230.0	11.2	7.8	350
12/19/02	0.42	0.57	-	-	-	5	7.7	0.620	30.0	11.3	12.5	400
01/08/03	0.50	0.71	2.4	22	12.4	41	7.5	0.621	30.9	12.3	12.5	398
01/20/03	0.45	0.54	-	-	-	-	7.8	0.617	58.9	10.6	11.2	395
02/10/03	0.45	0.05	1.8	84	10.0	20	7.9	0.710	395.0	6.6	10.2	455
03/16/03	0.50	0.20	2.4	27	15.8	10	7.6	0.617	50.2	4.8	15.1	395
# of Samples	**21**	**21**	**11**	**11**	**11**	**12**	**21**	**21**	**21**	**21**	**21**	**21**
Mean	**0.50**	**0.37**	**2.3**	**48**	**24.7**	**75**	**7.5**	**0.590**	**48.0**	**8.3**	**16.2**	**379**
Minimum	**0.42**	**0.04**	**1.4**	**20**	**4.3**	**5**	**7.0**	**0.405**	**4.3**	**4.8**	**7.8**	**260**
Maximum	**0.85**	**2.18**	**4.8**	**91**	**106.4**	**175**	**7.9**	**0.710**	**395.0**	**12.3**	**23.0**	**455**
Median	**0.47**	**0.20**	**2.1**	**41**	**15.8**	**63**	**7.5**	**0.603**	**17.1**	**7.7**	**16.2**	**390**
Stand. Dev.	**0.09**	**0.47**	**0.9**	**26**	**29.0**	**60**	**0.2**	**0.072**	**92.7**	**2.2**	**4.4**	**47**
Coeff Var.	**18.22**	**126.23**	**39.1**	**54**	**117.5**	**81**	**2.9**	**12.208**	**193.0**	**26.7**	**27.5**	**12**

Site JS Baseflow Water Quality Data

Sampling Date	Stage (m)	Estimated Q (m3/s)	Total N (mg/L)	Total P (ug/L)	TSS (mg/L)	E. coli (cfu)	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	TEMP (C)	TDS (mg/L)
06/11/02	0.30	0.02	-	-	-	253	6.9	0.442	45.5	4.8	15.9	290
06/20/02	0.25	0.01	-	-	-	-	6.8	0.464	0.0	4.6	16.6	300
07/11/02	0.24	0.01	-	-	-	-	6.5	0.453	21.6	1.5	17.5	290
08/01/02	0.29	0.02	2.1	87	1.3	143	6.5	0.488	6.2	2.1	17.4	320
08/23/02	0.32	0.03	-	-	-	-	6.7	0.495	9.6	1.8	17.0	320
09/03/02	0.32	0.03	2.3	23	1.3	148	6.6	0.527	6.3	1.1	16.8	340
09/17/02	0.37	0.04	-	-	-	-	6.5	0.500	3.8	1.6	16.4	320
10/01/02	0.26	0.02	2.0	30	2.7	226	6.6	0.510	8.3	1.2	15.8	330
10/22/02	0.27	0.02	-	-	-	-	6.9	0.497	7.0	2.2	14.8	320
11/07/02	0.32	0.03	2.3	36	0.5	-	6.7	0.526	12.2	3.1	13.6	340
11/22/02	0.31	0.02	-	-	-	-	6.7	0.534	10.0	2.6	13.4	340
12/06/02	0.27	0.02	2.4	33	3.0	-	7.1	0.400	0.0	8.8	13.2	260
12/19/02	0.24	0.01	-	-	-	41	6.9	0.430	0.0	8.1	12.4	280
01/08/03	0.30	0.02	2.4	20	0.4	52	6.9	0.432	9.2	10.9	10.8	280
01/20/03	0.27	0.02	-	-	-	-	6.9	0.448	14.9	9.4	10.7	291
02/10/03	0.31	0.02	1.0	21	1.6	10	7.1	0.424	29.7	5.3	11.4	275
03/16/03	0.34	0.03	1.7	36	0.8	10	7.0	0.371	30.0	2.6	12.1	241
# of Samples	**17**	**17**	**8**	**8**	**8**	**8**	**17**	**17**	**17**	**17**	**17**	**17**
Mean	**0.29**	**0.02**	**2.0**	**36**	**1.5**	**110**	**6.8**	**0.467**	**12.6**	**4.2**	**14.5**	**302**
Minimum	**0.24**	**0.01**	**1.0**	**20**	**0.4**	**10**	**6.5**	**0.371**	**0.0**	**1.1**	**10.7**	**241**
Maximum	**0.37**	**0.04**	**2.4**	**87**	**3.0**	**253**	**7.1**	**0.534**	**45.5**	**10.9**	**17.5**	**340**
Median	**0.30**	**0.02**	**2.2**	**32**	**1.3**	**98**	**6.8**	**0.464**	**9.2**	**2.6**	**14.8**	**300**
Stand. Dev.	**0.04**	**0.01**	**0.5**	**22**	**1.0**	**96**	**0.2**	**0.047**	**12.4**	**3.2**	**2.4**	**30**
Coeff Var.	**12.41**	**29.73**	**23.6**	**61**	**66.3**	**87**	**3.1**	**10.151**	**98.7**	**75.6**	**16.7**	**10**

Site SDS Baseflow Water Quality Data

Sampling Date	Stage (m)	Estimated Q (m3/s)	Total N (mg/L)	Total P (ug/L)	TSS (mg/L)	E. coli (cfu)	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	TEMP (C)	TDS (mg/L)
04/04/02	0.32	0.47	1.7	11	0.1	74	7.7	0.410	1.3	8.7	13.4	270
04/18/02	0.28	0.35	-	-	-	110	7.7	0.409	4.5	8.0	16.8	270
05/20/02	0.50	1.27	4.8	140	2.7	161	7.3	0.358	3.8	7.6	16.4	230
06/11/02	0.28	0.35	-	-	-	272	7.8	0.442	2.0	9.6	18.6	290
06/20/02	0.23	0.22	-	-	-	-	7.7	0.458	1.6	9.3	19.2	300
06/27/02	0.20	0.16	2.0	42	2.8	382	7.7	0.466	2.1	8.7	21.4	300
# of Samples	**6**	**6**	**3**	**3**	**3**	**5**	**6**	**6**	**6**	**6**	**6**	**6**
Mean	**0.30**	**0.47**	**2.8**	**65**	**1.9**	**200**	**7.6**	**0.424**	**2.6**	**8.6**	**17.6**	**277**
Minimum	**0.20**	**0.16**	**1.7**	**11**	**0.1**	**74**	**7.3**	**0.358**	**1.3**	**7.6**	**13.4**	**230**
Maximum	**0.50**	**1.27**	**4.8**	**140**	**2.8**	**382**	**7.8**	**0.466**	**4.5**	**9.6**	**21.4**	**300**
Median	**0.28**	**0.35**	**2.0**	**42**	**2.7**	**161**	**7.7**	**0.426**	**2.1**	**8.7**	**17.7**	**280**
Stand. Dev.	**0.11**	**0.40**	**1.7**	**67**	**1.5**	**126**	**0.2**	**0.040**	**1.3**	**0.8**	**2.8**	**27**
Coeff Var.	**35.11**	**86.22**	**58.5**	**104**	**82.0**	**63**	**2.2**	**9.450**	**50.6**	**8.8**	**15.6**	**10**

APPENDIX B

Storm Event Water Quality Data

Site US-1 Storm Event Water Quality Data

Sampling Date	Stage (m)	Estimated Q (m3/s)	Total N (mg/L)	Total P (ug/L)	TSS (mg/L)	E. Coli (cfu)	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	TEMP (C)	TDS (mg/L)
03/19/2002	0.03	0.09	-	-	-	536	7.8	0.977	1.0	10.7	10.4	630
04/20/2002	0.09	0.46	0.9	185	16.4	12230	7.6	0.107	361.0	7.9	18.6	70
04/27/2002	0.02	0.04	1.2	124	18.8	3076	7.7	0.228	34.9	7.4	14.2	150
05/07/2002	0.01	0.02	1.3	198	16.4	9804	7.8	0.152	17.1	7.7	18.5	100
05/08/2002	0.15	1.12	1.7	178	72.2	4352	7.5	0.087	999.0	7.8	16.4	60
05/09/2002	0.08	0.36	1.4	77	12.9	2098	7.4	0.326	25.0	8.0	15.9	210
05/13/2002	0.01	0.02	1.3	64	9.9	864	7.5	0.138	56.2	7.7	13.4	90
05/17/2002	0.13	0.83	2.3	160	17.0	1466	7.5	0.007	112.0	8.4	16.8	0
05/17/2002	0.10	0.58	2.1	96	21.9	2086	7.6	0.308	4.7	8.6	16.4	200
07/12/2002	0.08	0.36	1.4	280	21.5	4978	7.7	0.136	19.2	4.8	22.8	90
07/18/2002	0.05	0.18	0.9	244	11.6	19608	7.6	0.134	14.4	5.4	24.0	90
# of Samples	**11**	**11**	**10**	**10**	**10**	**11**	**11**	**11**	**11**	**11**	**11**	**11**
Mean	**0.07**	**0.37**	**1.5**	**161**	**21.9**	**5554**	**7.6**	**0.236**	**149.5**	**7.6**	**17.0**	**154**
Minimum	**0.01**	**0.02**	**0.9**	**64**	**9.9**	**536**	**7.4**	**0.007**	**1.0**	**4.8**	**10.4**	**0**
Maximum	**0.15**	**1.12**	**2.3**	**280**	**72.2**	**19608**	**7.8**	**0.977**	**999.0**	**10.7**	**24.0**	**630**
Median	**0.08**	**0.36**	**1.4**	**169**	**16.7**	**3076**	**7.6**	**0.138**	**25.0**	**7.8**	**16.4**	**90**
Stand. Dev.	**0.05**	**0.36**	**0.5**	**71**	**18.1**	**5966**	**0.1**	**0.263**	**300.2**	**1.5**	**3.9**	**169**
Coeff Var.	**69.52**	**97.86**	**31.9**	**44**	**82.9**	**107**	**1.7**	**111.196**	**200.8**	**20.3**	**22.9**	**110**

Site US-2 Storm Event Water Quality Data

Sampling Date	Stage (m)	Estimated Q (m3/s)	Total N (mg/L)	Total P (ug/L)	TSS (mg/L)	E. Coli (cfu)	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	TEMP (C)	TDS (mg/L)
03/19/2002	0.06	0.22	-	-	-	1935	7.3	2.540	41.3	10.3	9.5	1600
04/20/2002	0.22	2.27	4.5	1286	253.8	241920	7.2	0.701	211.0	6.8	18.6	450
04/27/2002	0.07	0.28	4.3	1033	475.4	141360	7.2	0.729	547.0	6.4	13.9	470
05/07/2002	0.03	0.08	6.2	1230	39.3	68670	7.4	2.150	31.6	5.1	17.8	1400
05/08/2002	0.30	3.90	2.2	521	161.4	61310	6.9	0.133	84.4	7.5	16.6	90
05/09/2002	0.15	1.31	2.1	388	61.0	54750	7.0	0.224	33.5	7.2	14.5	150
05/13/2002	0.05	0.27	2.0	292	31.2	48384	6.9	0.340	20.6	5.9	12.1	220
05/17/2002	0.42	6.44	3.8	115	77.1	48384	7.0	0.155	84.8	7.5	16.1	100
05/17/2002	0.20	2.10	2.7	208	10.1	34657	7.2	0.188	47.5	7.5	15.2	120
07/12/2002	0.19	1.90	-	1553	327.6	48384	7.6	0.534	547.0	4.1	21.4	340
07/18/2002	0.10	0.61	2.7	792	33.2	39726	7.3	1.470	29.0	4.8	23.2	900
# of Samples	**11**	**11**	**9**	**10**	**10**	**11**	**11**	**11**	**11**	**11**	**11**	**11**
Mean	**0.16**	**1.76**	**3.4**	**742**	**147.0**	**71771**	**7.2**	**0.833**	**152.5**	**6.6**	**16.3**	**531**
Minimum	**0.03**	**0.08**	**2.0**	**115**	**10.1**	**1935**	**6.9**	**0.133**	**20.6**	**4.1**	**9.5**	**90**
Maximum	**0.42**	**6.44**	**6.2**	**1553**	**475.4**	**>48384**	**7.6**	**2.540**	**547.0**	**10.3**	**23.2**	**1600**
Median	**0.15**	**1.31**	**2.7**	**657**	**69.1**	**>48384**	**7.2**	**0.534**	**47.5**	**6.8**	**16.1**	**340**
Stand. Dev.	**0.12**	**1.95**	**1.4**	**509**	**156.7**	**65669**	**0.2**	**0.846**	**202.2**	**1.7**	**3.9**	**536**
Coeff Var.	**74.26**	**110.70**	**41.8**	**69**	**106.6**	**91**	**2.8**	**101.509**	**132.6**	**25.6**	**24.2**	**101**

Site US-3 Storm Event Water Quality Data

Sampling Date	Stage (m)	Estimated Q (m3/s)	Total N (mg/L)	Total P (ug/L)	TSS (mg/L)	E. Coli (cfu)	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	TEMP (C)	TDS (mg/L)
03/19/2002	0.02	0.05	-	-	-	240	7.2	0.803	11.7	10.6	9.0	510
04/08/2002	0.03	0.09	1.2	240	11.5	17329	7.9	0.563	11.7	5.7	10.5	360
04/20/2002	0.25	2.86	2.9	735	170.6	241920	7.9	0.677	246.0	6.6	19.4	430
04/27/2002	0.03	0.09	1.1	128	10.0	581	7.1	0.747	9.1	5.0	13.7	480
05/07/2002	0.04	0.15	3.0	678	25.1	4106	7.5	0.264	18.8	6.0	19.0	170
05/08/2002	0.35	4.92	1.3	283	48.4	24192	7.4	0.067	638.0	8.2	16.4	40
05/09/2002	0.02	0.05	1.5	242	38.3	19863	7.4	0.416	5.6	6.7	16.4	270
05/13/2002	0.12	0.88	1.6	225	17.9	31061	7.4	0.484	11.7	5.1	14.0	310
05/17/2002	0.36	5.14	2.4	346	47.7	31061	7.3	0.306	185.0	7.9	16.9	200
05/17/2002	0.20	2.00	3.7	240	37.6	6896	7.4	0.634	19.4	7.1	16.4	410
07/12/2002	0.16	1.39	0.4	535	61.3	5848	7.5	0.980	182.0	4.3	24.3	600
07/18/2002	0.04	0.15	4.0	533	12.2	22397	7.3	0.310	12.1	4.4	23.6	200
# of Samples	**12**	**12**	**11**	**11**	**11**	**12**	**12**	**12**	**12**	**12**	**12**	**12**
Mean	**0.14**	**1.48**	**2.1**	**380**	**43.7**	**33791**	**7.4**	**0.521**	**112.6**	**6.5**	**16.6**	**332**
Minimum	**0.02**	**0.05**	**0.4**	**128**	**10.0**	**240**	**7.1**	**0.067**	**5.6**	**4.3**	**9.0**	**40**
Maximum	**0.36**	**5.14**	**4.0**	**735**	**170.6**	**>241920**	**7.9**	**0.980**	**638.0**	**10.6**	**24.3**	**600**
Median	**0.08**	**0.51**	**1.6**	**283**	**37.6**	**18596**	**7.4**	**0.524**	**15.5**	**6.3**	**16.4**	**335**
Stand. Dev.	**0.13**	**1.89**	**1.2**	**205**	**45.5**	**66492**	**0.2**	**0.262**	**186.9**	**1.8**	**4.6**	**163**
Coeff Var.	**95.20**	**127.58**	**55.7**	**54**	**104.1**	**197**	**3.2**	**50.308**	**166.0**	**28.3**	**27.6**	**49**

Site US-4 Storm Event Water Quality Data

Sampling Date	Stage (m)	Estimated Q (m3/s)	Total N (mg/L)	Total P (ug/L)	TSS (mg/L)	E. Coli (cfu)	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	TEMP (C)	TDS (mg/L)
03/19/2002	0.03	0.03	-	-	-	240	7.4	0.223	11.7	11.0	10.3	150
04/08/2002	0.03	0.03	1.4	111	11.3	341	8.0	0.476	11.0	7.6	10.6	310
04/20/2002	0.14	0.27	1.0	188	94.2	13760	7.7	0.178	295.0	8.1	18.5	120
04/27/2002	0.05	0.06	1.6	164	7.8	410	8.0	0.611	9.9	8.4	13.6	390
05/07/2002	0.03	0.03	3.2	1015	11.8	8160	7.6	0.168	13.5	7.5	18.8	110
05/08/2002	0.18	0.40	1.0	177	36.7	9050	7.6	0.237	46.9	8.2	16.4	150
05/09/2002	0.16	0.34	1.2	94	7.2	3500	7.4	0.419	11.0	8.0	14.6	270
05/13/2002	0.15	0.30	1.4	58	10.0	2626	7.6	0.470	8.3	7.9	13.1	310
05/17/2002	0.32	0.95	2.1	147	33.9	4374	7.4	0.218	372.0	7.9	16.0	140
05/17/2002	0.18	0.40	4.6	96	25.2	2356	7.5	0.341	14.9	7.9	14.9	220
07/12/2002	0.10	0.17	3.3	130	125.8	48384	7.8	0.149	301.0	4.4	21.8	100
07/18/2002	0.10	0.17	2.3	610	70.2	34657	7.7	0.154	912.0	6.3	22.6	100
# of Samples	**12**	**12**	**11**	**11**	**11**	**12**	**12**	**12**	**12**	**12**	**12**	**12**
Mean	**0.12**	**0.26**	**2.1**	**254**	**39.5**	**10655**	**7.6**	**0.304**	**167.3**	**7.8**	**15.9**	**198**
Minimum	**0.03**	**0.03**	**1.0**	**58**	**7.2**	**240**	**7.4**	**0.149**	**8.3**	**4.4**	**10.3**	**100**
Maximum	**0.32**	**0.95**	**4.6**	**1015**	**125.8**	**>48384**	**8.0**	**0.611**	**912.0**	**11.0**	**22.6**	**390**
Median	**0.12**	**0.22**	**1.6**	**147**	**25.2**	**3937**	**7.6**	**0.230**	**14.2**	**7.9**	**15.4**	**150**
Stand. Dev.	**0.09**	**0.26**	**1.2**	**293**	**40.1**	**15261**	**0.2**	**0.155**	**272.2**	**1.5**	**3.9**	**99**
Coeff Var.	**69.63**	**99.43**	**55.1**	**116**	**101.7**	**143**	**2.7**	**51.144**	**162.7**	**19.3**	**24.7**	**50**

Site IF-1 Storm Event Water Quality Data

Sampling Date	Stage (m)	Estimated Q (m3/s)	Total N (mg/L)	Total P (ug/L)	TSS (mg/L)	E. Coli (cfu)	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	TEMP (C)	TDS (mg/L)
03/19/2002	0.45	0.59	-	-	-	74	6.6	0.654	5.3	8.7	13.6	420
04/08/2002	0.46	0.62	2.0	20	3.7	399	6.9	0.558	5.4	6.0	13.5	360
04/20/2002	0.75	1.42	2.0	23	5.2	7540	6.5	0.632	6.0	4.2	14.0	400
04/27/2002	0.45	0.59	2.0	6	1.2	100	6.7	0.649	3.8	4.2	13.9	420
05/07/2002	0.38	0.45	2.4	11	4.5	630	7.0	0.667	5.6	4.4	14.1	430
05/08/2002	0.76	1.45	2.1	118	41.9	2590	6.4	0.417	14.7	4.1	13.9	270
05/09/2002	0.66	1.14	2.4	62	9.9	1460	6.7	0.478	7.7	4.5	14.0	310
05/13/2002	0.60	0.97	2.3	40	2.6	466	6.8	0.515	4.6	4.1	14.0	330
05/17/2002	0.70	1.26	4.1	137	-	852	6.6	0.446	10.7	2.8	14.0	290
07/12/2002	0.60	0.97	2.3	208	100.4	786	6.2	0.629	4.1	3.2	15.1	400
07/18/2002	0.43	0.55	2.1	33	0.5	40	6.4	0.652	4.0	3.6	15.0	420
# of Samples	**11**	**11**	**10**	**10**	**9**	**11**	**11**	**11**	**11**	**11**	**11**	**11**
Mean	**0.57**	**0.91**	**2.4**	**66**	**18.9**	**1358**	**6.6**	**0.572**	**6.5**	**4.5**	**14.1**	**368**
Minimum	**0.38**	**0.45**	**2.0**	**6**	**0.5**	**40**	**6.2**	**0.417**	**3.8**	**2.8**	**13.5**	**270**
Maximum	**0.76**	**1.45**	**4.1**	**208**	**100.4**	**7540**	**7.0**	**0.667**	**14.7**	**8.7**	**15.1**	**430**
Median	**0.60**	**0.97**	**2.2**	**37**	**4.5**	**630**	**6.6**	**0.629**	**5.4**	**4.2**	**14.0**	**400**
Stand. Dev.	**0.14**	**0.37**	**0.6**	**67**	**33.2**	**2180**	**0.2**	**0.093**	**3.4**	**1.6**	**0.5**	**59**
Coeff Var.	**24.41**	**40.64**	**26.5**	**102**	**175.6**	**161**	**3.3**	**16.304**	**51.4**	**35.2**	**3.5**	**16**

Site IF-2 Storm Event Water Quality Data

Sampling Date	Stage (m)	Estimated Q (m3/s)	Total N (mg/L)	Total P (ug/L)	TSS (mg/L)	E. Coli (cfu)	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	TEMP (C)	TDS (mg/L)
03/19/2002	0.76	-	-	-	-	20	6.6	0.652	3.7	9.0	13.6	420
04/08/2002	0.38	-	2.2	50	5.6	373	6.9	0.573	5.7	6.1	13.2	370
04/20/2002	0.55	-	2.5	381	159.4	241920	6.9	0.615	61.2	6.0	18.2	390
04/27/2002	0.45	-	2.1	21	6.9	63	6.8	0.649	4.4	5.4	14.0	420
05/07/2002	0.42	-	2.3	14	6.5	110	6.9	0.667	8.5	6.7	14.4	430
05/08/2002	0.95	-	1.4	199	31.1	11199	6.7	0.281	28.1	6.2	15.9	180
05/09/2002	1.02	-	1.8	133	19.8	8164	6.7	0.449	13.3	5.7	15.1	290
05/13/2002	0.60	-	1.9	78	15.1	4196	6.9	0.512	30.4	5.7	13.9	330
05/17/2002	0.86	-	4.4	281	64.7	12976	7.0	0.376	26.6	5.8	16.3	240
05/17/2002	1.06	-	1.8	86	29.9	5702	6.8	0.540	14.6	5.1	15.3	350
07/12/2002	0.55	-	2.8	615	170.4	18416	7.0	0.849	58.5	3.5	22.3	540
07/18/2002	0.31	-	2.1	26	16.4	244	6.4	0.658	6.0	4.3	15.0	420
# of Samples	**12**	-	**11**	**11**	**11**	**12**	**12**	**12**	**12**	**12**	**12**	**12**
Mean	**0.66**	-	**2.3**	**171**	**47.8**	**25282**	**6.8**	**0.568**	**21.8**	**5.8**	**15.6**	**365**
Minimum	**0.31**	-	**1.4**	**14**	**5.6**	**20**	**6.4**	**0.281**	**3.7**	**3.5**	**13.2**	**180**
Maximum	**1.06**	-	**4.4**	**615**	**170.4**	**>241920**	**7.0**	**0.849**	**61.2**	**9.0**	**22.3**	**540**
Median	**0.58**	-	**2.1**	**86**	**19.8**	**4949**	**6.8**	**0.594**	**14.0**	**5.7**	**15.1**	**380**
Stand. Dev.	**0.26**	-	**0.8**	**188**	**60.3**	**68494**	**0.2**	**0.151**	**20.2**	**1.3**	**2.5**	**96**
Coeff Var.	**39.72**	-	**34.4**	**110**	**126.2**	**271**	**2.6**	**26.523**	**92.7**	**23.1**	**16.1**	**26**

Site OF-1 Storm Event Water Quality Data

Sampling Date	Stage (m)	Estimated Q (m3/s)	Total N (mg/L)	Total P (ug/L)	TSS (mg/L)	E. Coli (cfu)	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	TEMP (C)	TDS (mg/L)
03/19/2002	-	-	-	-	-	5	7.3	0.693	3.6	11.5	11.3	440
04/08/2002	0.12	0.99	2.2	90	16.8	216	7.2	0.574	24.9	6.8	12.9	370
04/20/2002	0.19	1.95	2.7	395	524.8	241917	7.0	0.579	202.0	3.8	17.6	370
04/27/2002	0.17	1.67	2.0	111	34.3	410	7.2	0.593	14.9	7.6	14.1	380
05/07/2002	0.12	0.95	2.3	68	26.1	2560	7.5	0.590	13.0	9.1	16.1	380
05/08/2002	0.36	4.79	1.8	388	78.2	46110	7.2	0.288	135.0	7.7	16.2	190
05/09/2002	0.25	2.67	1.8	211	48.8	26130	7.0	0.402	29.2	4.7	15.8	260
05/13/2002	0.23	2.37	2.2	112	27.6	14540	7.0	0.523	23.0	5.7	13.9	330
05/17/2002	0.47	7.31	1.8	217	77.6	39726	7.0	0.396	84.5	5.6	16.3	260
05/17/2002	0.27	2.99	2.9	336	68.0	48384	7.0	0.497	36.3	5.2	15.9	320
07/12/2002	0.15	1.29	2.5	317	159.6	6152	7.1	0.520	263.0	3.8	21.3	330
07/18/2002	0.09	0.57	1.9	35	33.0	492	7.1	0.581	17.9	7.0	18.2	370
# of Samples	**11**	**11**	**11**	**11**	**11**	**12**	**12**	**12**	**12**	**12**	**12**	**12**
Mean	**0.22**	**2.50**	**2.2**	**207**	**99.5**	**35553**	**7.1**	**0.520**	**70.6**	**6.5**	**15.8**	**333**
Minimum	**0.09**	**0.57**	**1.8**	**35**	**16.8**	**5**	**7.0**	**0.288**	**3.6**	**3.8**	**11.3**	**190**
Maximum	**0.47**	**7.31**	**2.9**	**395**	**524.8**	**241917**	**7.5**	**0.693**	**263.0**	**11.5**	**21.3**	**440**
Median	**0.19**	**1.95**	**2.2**	**211**	**48.8**	**10346**	**7.1**	**0.549**	**27.1**	**6.2**	**16.0**	**350**
Stand. Dev.	**0.11**	**1.99**	**0.4**	**133**	**146.6**	**67649**	**0.1**	**0.110**	**85.0**	**2.3**	**2.6**	**68**
Coeff Var.	**51.80**	**79.37**	**17.4**	**64**	**147.3**	**190**	**2.0**	**21.234**	**120.4**	**34.6**	**16.4**	**20**

Site OF-2 Storm Event Water Quality Data

Sampling Date	Stage (m)	Estimated Q (m3/s)	Total N (mg/L)	Total P (ug/L)	TSS (mg/L)	E. Coli (cfu)	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	TEMP (C)	TDS (mg/L)
03/19/2002	0.75	0.68	-	-	-	988	7.6	0.480	5.1	11.0	11.0	310
04/08/2002	0.70	0.65	1.7	43	40.8	620	7.6	0.448	14.8	8.1	12.4	290
04/20/2002	1.22	0.51	2.7	449	324.0	23100	7.2	0.178	97.1	7.2	17.9	120
04/27/2002	0.63	0.68	1.8	31	12.8	520	7.5	0.469	12.2	8.6	14.0	300
05/07/2002	0.60	2.04	1.9	93	20.7	13740	7.6	0.464	12.6	8.3	16.2	300
05/08/2002	1.75	12.35	1.6	326	23.3	27000	7.0	0.203	44.4	8.5	16.0	130
05/09/2002	1.30	3.79	1.8	192	49.6	14670	7.1	0.382	25.9	6.5	15.6	250
05/13/2002	1.00	2.89	1.7	103	13.0	4962	7.2	0.311	11.8	7.9	13.9	200
05/17/2002	1.70	9.57	2.2	180	53.3	14540	7.1	0.194	37.4	8.1	15.9	130
05/17/2002	1.25	9.57	2.4	172	33.2	5510	7.1	0.263	18.1	7.5	14.8	170
07/12/2002	0.57	0.31	2.4	325	-	8212	7.3	0.513	235.0	4.4	21.3	330
07/18/2002	0.53	0.18	1.9	38	42.0	452	7.2	0.579	17.7	7.0	18.3	370
# of Samples	**12**	**12**	**11**	**11**	**10**	**12**	**12**	**12**	**12**	**12**	**12**	**12**
Mean	**1.00**	**3.60**	**2.0**	**177**	**61.3**	**9526**	**7.3**	**0.374**	**44.3**	**7.8**	**15.6**	**242**
Minimum	**0.53**	**0.18**	**1.6**	**31**	**12.8**	**452**	**7.0**	**0.178**	**5.1**	**4.4**	**11.0**	**120**
Maximum	**1.75**	**12.35**	**2.7**	**449**	**324.0**	**27000**	**7.6**	**0.579**	**235.0**	**11.0**	**21.3**	**370**
Median	**0.88**	**1.36**	**1.9**	**172**	**37.0**	**6861**	**7.2**	**0.415**	**17.9**	**8.0**	**15.7**	**270**
Stand. Dev.	**0.44**	**4.36**	**0.4**	**138**	**93.4**	**9112**	**0.2**	**0.139**	**65.0**	**1.5**	**2.8**	**88**
Coeff Var.	**43.78**	**120.93**	**17.9**	**78**	**152.5**	**96**	**3.2**	**37.117**	**146.5**	**19.8**	**17.7**	**36**

Site SDS Storm Event Water Quality Data

Sampling Date	Stage (m)	Estimated Q (m3/s)	Total N (mg/L)	Total P (ug/L)	TSS (mg/L)	E. Coli (cfu)	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	TEMP (C)	TDS (mg/L)
03/19/2002	0.36	0.61	-	-	-	1046	7.5	0.422	6.1	10.8	10.8	270
04/08/2002	0.35	0.57	1.4	36	3.6	1989	7.8	0.361	9.6	8.5	11.9	230
04/20/2002	-	-	2.2	452	215.4	32820	7.4	0.167	79.7	7.7	18.0	110
04/27/2002	0.35	0.57	1.4	15	1.9	119	7.6	0.391	5.6	8.4	13.8	250
05/07/2002	0.34	0.54	1.9	111	66.2	17220	7.6	0.399	10.1	7.9	16.0	260
05/08/2002	-	-	-	-	4.1	6760	6.9	0.184	22.2	8.0	15.9	120
05/09/2002	-	-	1.6	121	16.8	3840	7.1	0.242	8.9	7.7	14.7	160
05/13/2002	0.62	2.05	1.7	98	10.4	5702	7.2	0.272	3.4	7.8	14.1	180
05/17/2002	-	-	-	-	-	-	6.6	0.153	30.5	7.5	15.6	100
05/17/2002	-	-	-	-	-	-	6.9	0.200	12.0	7.4	14.4	130
# of Samples	**5**	**5**	**6**	**6**	**7**	**8**	**10**	**10**	**10**	**10**	**10**	**10**
Mean	**0.40**	**0.87**	**1.7**	**139**	**45.5**	**8687**	**7.3**	**0.279**	**18.8**	**8.2**	**14.5**	**181**
Minimum	**0.34**	**0.54**	**1.4**	**15**	**1.9**	**119**	**6.6**	**0.153**	**3.4**	**7.4**	**10.8**	**100**
Maximum	**0.62**	**2.05**	**2.2**	**452**	**215.4**	**32820**	**7.8**	**0.422**	**79.7**	**10.8**	**18.0**	**270**
Median	**0.35**	**0.57**	**1.7**	**105**	**10.4**	**4771**	**7.3**	**0.257**	**9.9**	**7.9**	**14.6**	**170**
Stand. Dev.	**0.12**	**0.66**	**0.3**	**159**	**78.2**	**11135**	**0.4**	**0.105**	**22.9**	**1.0**	**2.1**	**66**
Coeff Var.	**29.94**	**76.18**	**18.2**	**115**	**172.0**	**128**	**5.1**	**37.620**	**121.9**	**12.2**	**14.2**	**37**

Site JS Storm Event Water Quality Data

Sampling Date	Stage (m)	Estimated Q (m3/s)	Total N (mg/L)	Total P (ug/L)	TSS (mg/L)	E. Coli (cfu)	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	TEMP (C)	TDS (mg/L)
07/12/2002	0.26	0.02	2.0	81	7.2	62	6.6	0.466	5.8	1.1	17.6	300
07/18/2002	0.30	0.02	1.9	67	0.8	126	6.7	0.470	3.1	2.8	17.2	310
# of Samples	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**
Mean	**0.28**	**0.02**	**2.0**	**74**	**4.0**	**94**	**6.7**	**0.468**	**4.5**	**2.0**	**17.4**	**305**
Minimum	**0.26**	**0.02**	**1.9**	**67**	**0.8**	**62**	**6.6**	**0.466**	**3.1**	**1.1**	**17.2**	**300**
Maximum	**0.30**	**0.02**	**2.0**	**81**	**7.2**	**126**	**6.7**	**0.470**	**5.8**	**2.8**	**17.6**	**310**
Median	**0.28**	**0.02**	**2.0**	**74**	**4.0**	**94**	**6.7**	**0.468**	**4.5**	**2.0**	**17.4**	**305**
Stand. Dev.	**0.03**	**0.00**	**0.1**	**10**	**4.5**	**45**	**0.0**	**0.003**	**1.9**	**1.2**	**0.2**	**7**
Coeff Var.	**10.10**	**23.91**	**3.6**	**13**	**113.1**	**48**	**0.7**	**0.604**	**42.9**	**61.2**	**1.3**	**2**

APPENDIX C

Pollution Load Data

Site US-1 Storm Event Pollution Load Data

Date	Estimated Q (m3/s)	Daily Load TN (kg/day)	Daily Load TP (kg/day)	Daily Load TSS (kg/day)	Daily Load TDS (kg/day)
03/19/02	0.09	-	-	-	4651
04/20/02	0.46	36	7.41	657	2802
04/27/02	0.04	4	0.40	60	479
05/07/02	0.02	2	0.32	27	164
05/08/02	1.12	165	17.27	7004	5820
05/09/02	0.36	44	2.39	401	6527
05/13/02	0.02	2	0.10	16	148
05/17/02	0.83	165	11.51	1222	0
05/17/02	0.58	105	4.79	1092	9970
07/12/02	0.36	44	8.70	668	2797
07/18/02	0.18	14	3.90	185	1437

Site US-2 Storm Event Pollution Load Data

Date	Estimated Q (m3/s)	Daily Load TN (kg/day)	Daily Load TP (kg/day)	Daily Load TSS (kg/day)	Daily Load TDS (kg/day)
03/19/02	0.22	-	-	-	30053
04/20/02	2.27	884	252.63	49857	88400
04/27/02	0.28	105	25.19	11595	11463
05/07/02	0.08	44	8.76	280	9975
05/08/02	3.90	741	175.54	54380	30323
05/09/02	1.31	237	43.82	6890	16942
05/13/02	0.27	47	6.83	730	5146
05/17/02	6.44	2115	64.02	42921	55669
05/17/02	2.10	489	37.67	1829	21732
07/12/02	1.90	-	254.66	53719	55753
07/18/02	0.61	142	41.63	1745	47303

Site US-3 Storm Event Pollution Load Data

Date	Estimated Q (m3/s)	Daily Load TN (kg/day)	Daily Load TP (kg/day)	Daily Load TSS (kg/day)	Daily Load TDS (kg/day)
03/19/02	0.14	-	-	-	6109
04/08/02	0.27	28	5.52	265	8287
04/20/02	8.11	2032	515.10	119560	301354
04/27/02	0.27	25	2.95	230	11049
05/07/02	0.42	110	24.81	918	6220
05/08/02	13.95	1567	341.05	58328	48205
05/09/02	0.14	18	2.90	459	3234
05/13/02	2.49	344	48.33	3845	66591
05/17/02	14.60	3027	436.34	60154	252218
05/17/02	5.66	1810	117.41	18393	200567
07/12/02	3.95	137	182.68	20932	204878
07/18/02	0.42	146	19.50	446	7318

Site US-4 Storm Event Pollution Load Data

Date	Estimated Q (m3/s)	Daily Load TN (kg/day)	Daily Load TP (kg/day)	Daily Load TSS (kg/day)	Daily Load TDS (kg/day)
03/19/02	0.03	-	-	-	353
04/08/02	0.03	3	0.26	27	730
04/20/02	0.27	24	4.46	2236	2848
04/27/02	0.06	8	0.83	40	1976
05/07/02	0.03	8	2.39	28	259
05/08/02	0.40	35	6.12	1270	5190
05/09/02	0.34	35	2.73	209	7829
05/13/02	0.30	37	1.53	263	8160
05/17/02	0.95	172	12.06	2780	11482
05/17/02	0.40	159	3.32	872	7612
07/12/02	0.17	47	1.86	1802	1433
07/18/02	0.17	33	8.74	1006	1433

Site IF-1 Baseflow Pollution Load Data

Date	Estimated Q (m3/s)	Daily Load TN (kg/day)	Daily Load TP (kg/day)	Daily Load TSS (kg/day)	Daily Load TDS (kg/day)
04/04/02	0.43	92	0.44	37	15093
04/18/02	0.41	-	-	-	14755
05/20/02	0.84	340	4.56	297	25326
06/11/02	0.55	-	-	-	18073
06/20/02	0.51	-	-	-	17102
06/27/02	0.49	97	1.01	1287	15977
07/11/02	0.49	-	-	-	15556
08/01/02	0.41	67	1.86	25	14404
08/23/02	0.30	-	-	-	11843
09/03/02	0.30	54	0.64	44	11585
09/17/02	0.30	-	-	-	10813
10/01/02	0.26	37	0.78	71	9842
10/22/02	0.19	-	-	-	7201
11/07/02	0.28	51	0.92	34	11178
11/22/02	0.22	-	-	-	9056
12/06/02	0.23	46	1.63	734	8069
12/19/02	0.19	-	-	-	7365
01/08/03	0.22	45	0.51	21	8339
01/20/03	0.16	-	-	-	6097
02/10/03	0.14	20	0.48	14	6842
03/16/03	0.30	54	0.44	31	11560

Site IF-1 Storm Event Pollution Load Data

Date	Estimated Q (m3/s)	Daily Load TN (kg/day)	Daily Load TP (kg/day)	Daily Load TSS (kg/day)	Daily Load TDS (kg/day)
03/19/02	0.59	-	-	-	21586
04/08/02	0.62	107	1.07	197	19208
04/20/02	1.42	246	2.82	638	49114
04/27/02	0.59	103	0.31	62	21586
05/07/02	0.45	92	0.42	173	16565
05/08/02	1.45	264	14.82	5262	33909
05/09/02	1.14	237	6.12	978	30609
05/13/02	0.97	193	3.36	218	27697
05/17/02	1.26	448	14.95	-	31656
07/12/02	0.97	193	17.46	8427	33572
07/18/02	0.55	100	1.57	24	19976

Site IF-2 Baseflow Pollution Load Data

Date	Estimated Q (m3/s)	Daily Load TN (kg/day)	Daily Load TP (kg/day)	Daily Load TSS (kg/day)	Daily Load TDS (kg/day)
04/04/02	0.43	88.3	0.48	103.1	15093
04/18/02	0.41	-	-	-	14755
05/20/02	0.84	318.4	5.57	1874.1	25326
06/11/02	0.55	-	-	-	18073
06/20/02	0.51	-	-	-	17102
06/27/02	0.49	100.9	1.14	248.1	15977
07/11/02	0.49	-	-	-	16397
08/01/02	0.41	63.2	2.53	256.5	14755
08/23/02	0.30	-	-	-	11585
09/03/02	0.30	54.1	0.49	113.3	11585
09/17/02	0.30	-	-	-	10813
10/01/02	0.26	38.9	0.60	354.8	9842
10/22/02	0.19	-	-	-	7201
11/07/02	0.28	51.0	0.75	116.6	11178
11/22/02	0.22	-	-	-	9056
12/06/02	0.23	50.4	1.25	617.2	7867
12/19/02	0.19	-	-	-	7365
01/08/03	0.22	41.5	0.49	52.8	8339
01/20/03	0.16	-	-	-	6349
02/10/03	0.14	13.0	-	153.6	6960
03/16/03	0.30	56.6	0.39	151.9	11585

Site JS Baseflow Pollution Load Data

Date	Estimated Q (m3/s)	Daily Load TN (kg/day)	Daily Load TP (kg/day)	Daily Load TSS (kg/day)	Daily Load TDS (kg/day)
06/11/02	0.02	-	-	-	549
06/20/02	0.01	-	-	-	368
07/11/02	0.01	-	-	-	322
08/01/02	0.02	4	0.15	2	559
08/23/02	0.03	-	-	-	707
09/03/02	0.03	5	0.05	3	751
09/17/02	0.04	-	-	-	999
10/01/02	0.02	3	0.04	4	444
10/22/02	0.02	-	-	-	471
11/07/02	0.03	5	0.08	1	751
11/22/02	0.02	-	-	-	696
12/06/02	0.02	4	0.05	4	383
12/19/02	0.01	-	-	-	311
01/08/03	0.02	5	0.04	1	530
01/20/03	0.02	-	-	-	428
02/10/03	0.02	2	0.04	3	563
03/16/03	0.03	4	0.09	2	615

Site JS Storm Event Pollution Load Data

Date	Estimated Q (m3/s)	Daily Load TN (kg/day)	Daily Load TP (kg/day)	Daily Load TSS (kg/day)	Daily Load TDS (kg/day)
07/12/02	0.02	3	0.11	10	404
07/18/02	0.02	4	0.13	2	587

Site OF-1 Baseflow Pollution Load Data

Date	Estimated Q (m3/s)	Daily Load TN (kg/day)	Daily Load TP (kg/day)	Daily Load TSS (kg/day)	Daily Load TDS (kg/day)
04/04/02	0.51	92	1.28	440	17162
04/18/02	0.64	-	-	-	20542
05/20/02	2.33	805	8.85	724	68408
06/11/02	0.40	-	-	-	11813
06/20/02	0.36	-	-	-	11217
06/27/02	0.23	47	0.65	781	7080
07/11/02	0.30	-	-	-	9681
08/01/02	0.30	44	2.30	932	9943
08/23/02	0.21	-	-	-	7410
09/03/02	0.22	39	1.04	359	7520
09/17/02	0.18	-	-	-	5769
10/01/02	0.18	26	0.61	240	6072
10/22/02	0.21	-	-	-	6827
11/07/02	0.34	51	1.46	113	13078
11/22/02	0.26	-	-	-	10155
12/06/02	0.23	41	0.88	818	6489
12/19/02	0.25	-	-	-	8561
01/08/03	0.36	69	0.81	312	12527
01/20/03	0.25	-	-	-	8503
02/10/03	0.23	1.00	0.86	550	8833
03/16/03	0.43	92	0.74	819	14537

Site OF-1 Storm Event Pollution Load Data

Date	Estimated Q (m3/s)	Daily Load TN (kg/day)	Daily Load TP (kg/day)	Daily Load TSS (kg/day)	Daily Load TDS (kg/day)
03/19/02	-	-	-	-	-
04/08/02	0.99	189	7.72	1440	31722
04/20/02	1.95	455	66.63	88527	62414
04/27/02	1.67	289	16.04	4956	54901
05/07/02	0.95	188	5.57	2136	31106
05/08/02	4.79	745	160.62	32373	78655
05/09/02	2.67	415	48.67	11256	59968
05/13/02	2.37	450	22.89	5640	67437
05/17/02	7.31	1137	137.06	49012	164216
05/17/02	2.99	750	86.85	17576	82710
07/12/02	1.29	278	35.29	17768	36738
07/18/02	0.57	94	1.73	1633	18309

Site OF-2 Baseflow Pollution Load Data

Date	Estimated Q (m3/s)	Daily Load TN (kg/day)	Daily Load TP (kg/day)	Daily Load TSS (kg/day)	Daily Load TDS (kg/day)
04/04/02	0.28	49	0.49	135	7584
04/18/02	0.24	-	-	-	7071
05/20/02	2.18	904	7.72	810	48981
06/11/02	0.37	-	-	-	10496
06/20/02	0.20	-	-	-	6165
06/27/02	0.13	23	0.33	361	3853
07/11/02	0.15	-	-	-	4888
08/01/02	0.09	14	0.73	239	3068
08/23/02	0.11	-	-	-	3719
09/03/02	0.08	16	0.52	121	2809
09/17/02	0.07	-	-	-	2290
10/01/02	0.04	5	0.11	110	1468
10/22/02	0.04	-	-	-	1336
11/07/02	0.65	107	2.53	383	24759
11/22/02	0.62	-	-	-	24221
12/06/02	0.54	107	3.11	4946	16270
12/19/02	0.57	-	-	-	19573
01/08/03	0.71	147	1.35	758	24344
01/20/03	0.54	-	-	-	18362
02/10/03	0.05	7	0.35	42	1892
03/16/03	0.20	41	0.46	267	6668

Site OF-2 Storm Event Pollution Load Data

Date	Estimated Q (m3/s)	Daily Load TN (kg/day)	Daily Load TP (kg/day)	Daily Load TSS (kg/day)	Daily Load TDS (kg/day)
03/19/02	0.68	-	-	-	18203
04/08/02	0.65	94	2.42	2296	16319
04/20/02	0.51	119	19.75	14249	5277
04/27/02	0.68	108	1.82	752	17615
05/07/02	2.04	342	16.38	3646	52846
05/08/02	12.35	1670	347.75	24854	138673
05/09/02	3.79	589	62.95	16261	81961
05/13/02	2.89	434	25.70	3244	49905
05/17/02	9.57	1855	148.85	44076	107503
05/17/02	9.57	2014	142.23	27455	140581
07/12/02	0.31	64	8.75	-	8881
07/18/02	0.18	29	0.58	637	5612

Site SDS Baseflow Pollution Load Data

Date	Estimated Q (m3/s)	Daily Load TN (kg/day)	Daily Load TP (kg/day)	Daily Load TSS (kg/day)	Daily Load TDS (kg/day)
04/04/02	0.47	71	0.46	4	10919
04/18/02	0.35	-	-	-	8105
05/20/02	1.27	521	15.37	299	25184
06/11/02	0.35	-	-	-	8705
06/20/02	0.22	-	-	-	5805
06/27/02	0.16	29	0.60	40	4250

Site SDS Storm Event Pollution Load Data

Date	Estimated Q (m3/s)	Daily Load TN (kg/day)	Daily Load TP (kg/day)	Daily Load TSS (kg/day)	Daily Load TDS (kg/day)
03/19/02	0.61	-	-	-	14202
04/08/02	0.57	69	1.78	178	11361
04/27/02	0.57	69	0.74	94	12348
05/07/02	0.54	88	5.14	3065	12038
05/13/02	2.05	301	17.34	1841	31855

APPENDIX D

Pre Reservoir Drainage
Water Quality Data

Site	Date	Stage (m)	TN (mg/L)	TP (ug/L)	TSS (mg/L)	E. coli (cfu)	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	TEMP (C)	TDS (mg/L)
IF-1	02/07/02	0.49	-	-	-	20	7.0	0.730	1.1	7.5	13.7	470
IF-2	02/07/02	0.75	-	-	-	31	7.0	0.734	3.1	8.5	13.7	470
OF-1	02/07/02	0.04	-	-	-	31	7.3	0.656	4.5	9.4	9.6	420
OF-2	02/07/02	0.62	-	-	-	31	7.7	0.505	3.9	10.8	10.0	320
SDS	02/07/02	0.38	-	-	-	20	7.8	0.436	3.5	10.5	10.4	280
IF-1	02/14/02	0.42	-	-	-	20	7.0	0.695	6.8	9.3	13.9	450
IF-2	02/14/02	0.83	-	-	-	<10	7.1	0.702	3.5	10.7	14.2	450
OF-1	02/14/02	0.55	-	-	-	<10	8.0	0.683	21.3	15.0	9.6	440
OF-2	02/14/02	0.67	-	-	-	<10	8.0	0.552	7.3	11.3	10.3	350
SDS	02/14/02	0.32	-	-	-	10	7.9	0.489	-3.3	11.1	10.7	320
IF-1	02/21/02	0.47	2.2	9	0.2	10	7.2	0.707	2.5	9.0	14.0	450
IF-2	02/21/02	0.79	2.2	10	1.6	20	7.4	0.705	2.3	11.1	14.2	450
OF-1	02/21/02	0.09	2.1	1	1.2	<10	7.8	0.676	3.8	13.5	10.6	430
OF-2	02/21/02	0.57	1.8	10	-0.2	20	8.0	0.528	4.7	11.3	11.0	340
SDS	02/21/02	0.30	1.6	20	2.0	<10	8.0	0.453	7.1	11.2	11.1	290
IF-1	02/28/02	0.42	2.4	9	2.2	10	6.8	0.706	1.9	9.2	14.1	450
IF-2	02/28/02	0.73	2.4	1	-0.4	30	6.9	0.709	4.4	12.4	14.6	450
OF-1	02/28/02	0.07	2.0	-5	4.2	<10	7.8	0.693	9.3	14.1	7.6	440
OF-2	02/28/02	0.53	1.8	2	1.8	<10	7.8	0.552	4.0	11.6	9.9	350
SDS	02/28/02	0.33	1.8	12	1.0	20	7.8	0.519	-0.1	11.4	10.1	330
IF-1	03/07/02	0.41	2.5	3	4.0	<10	6.7	0.749	2.7	9.2	13.6	480
IF-2	03/07/02	0.70	2.3	-2	1.4	10	6.7	0.752	3.6	9.3	13.6	480
OF-1	03/07/02	0.39	2.1	-10	3.1	10	7.3	0.715	8.1	12.9	10.2	460
OF-2	03/07/02	0.64	1.6	-1	-1.8	10	7.7	0.549	5.3	11.8	10.7	350
SDS	03/07/02	0.33	1.5	13	1.7	20	7.6	0.421	6.2	11.9	11.0	270
IF-1	03/14/02	0.43	2.5	36	4.9	10	6.6	0.728	2.5	10.8	14.0	470
IF-2	03/14/02	0.65	2.5	9	2.0	10	6.7	0.731	3.0	11.9	14.1	470
OF-1	03/14/02	0.07	2.1	28	55.1	<10	7.6	0.711	25.6	15.3	12.0	460
OF-2	03/14/02	0.52	1.8	6	1.9	10	7.6	0.544	6.3	12.1	12.0	350

APPENDIX E

Automatic Water Sampler
& Data Logger Data

Sampling Date: November 12, 2002 Baseflow
Water Chemistry monitored every 30 minutes for 24 hours
TN, TP, & TSS collected every 2 hours for 18 hours

TIME	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	Temp °C	TDS (mg/L)	TN (mg/L)	TP (ug/L)	TSS (mg/L)
13:01	6.5	0.761	5.8	1.3	15.0	490			
13:31	6.5	0.761	4.9	3.8	15.0	490			
14:01	6.5	0.760	4.0	3.8	15.0	490			
14:31	6.5	0.764	4.0	3.8	15.0	490			
15:01	6.5	0.764	4.0	3.7	15.0	490	2.3	32	9.6
15:31	6.5	0.761	4.1	3.7	15.0	490			
16:01	6.5	0.761	4.2	3.7	15.0	490			
16:31	6.5	0.761	4.4	3.6	15.0	490			
17:01	6.5	0.763	4.3	3.6	15.0	490	2.2	41	3.8
17:31	6.5	0.759	4.3	3.6	15.0	490			
18:01	6.5	0.769	4.3	3.6	15.0	490			
18:31	6.5	0.767	4.4	3.6	15.0	490			
19:01	6.5	0.762	4.6	3.6	15.0	490	2.1	44	4.2
19:31	6.5	0.762	4.5	3.6	15.0	490			
20:01	6.5	0.759	4.6	3.6	15.0	490			
20:31	6.5	0.767	4.6	3.6	15.0	490			
21:01	6.5	0.758	4.7	3.6	15.0	490	2.2	46	3.0
21:31	6.5	0.765	4.8	3.6	15.0	490			
22:01	6.5	0.762	4.9	3.6	15.0	490			
22:31	6.5	0.762	4.9	3.7	15.0	490			
23:01	6.5	0.760	4.9	3.7	15.0	490	2.1	47	3.0
23:31	6.5	0.760	5.0	3.7	15.0	490			
0:01	6.5	0.766	5.0	3.7	15.0	490			
0:31	6.5	0.767	5.0	3.7	15.0	490			
1:01	6.5	0.760	5.0	3.7	15.0	490	2.2	43	1.4
1:31	6.5	0.763	5.1	3.7	15.0	490			
2:01	6.5	0.759	5.1	3.7	15.0	490			
2:31	6.5	0.768	5.2	3.7	15.0	490			
3:01	6.5	0.757	5.1	3.7	15.0	480	2.2	45	3.4
3:31	6.5	0.761	5.2	3.7	15.0	490			
4:01	6.5	0.763	5.2	3.7	15.0	490			
4:31	6.5	0.761	5.2	3.7	15.0	490			
5:01	6.5	0.760	5.2	3.7	15.0	490	2.0	83	1.8
5:31	6.5	0.759	5.2	3.7	15.0	490			
6:01	6.5	0.760	5.2	3.7	15.0	490			
6:31	6.5	0.759	5.2	3.7	15.0	490			
7:01	6.5	0.761	5.3	3.7	15.0	490	2.0	54	2.6
7:31	6.5	0.760	5.3	3.7	15.0	490			
8:01	6.5	0.760	5.3	3.7	15.0	490			
8:31	6.5	0.767	5.3	3.7	15.0	490			
9:01	6.5	0.759	5.3	3.7	15.0	490			
9:31	6.5	0.765	5.3	3.7	15.0	490			
10:01	6.5	0.756	5.4	3.7	15.0	480			
10:31	6.5	0.763	5.3	3.7	15.0	490			
11:01	6.5	0.762	5.4	3.7	15.0	490			
11:31	6.5	0.759	5.5	3.7	15.0	490			
12:01	6.5	0.757	5.5	3.7	15.0	480			
12:31	6.5	0.757	5.4	3.7	15.0	480			
13:01	6.5	0.760	5.4	3.7	15.0	490			

Sampling Date: December 30, 2002 Storm Event
Water Chemistry monitored every 30 minutes for 48 hours
TN and TP sampled every hour for first 7 hours, then every 2 hours for 16 hours
TSS sampled every 4 hours for 24 hours

TIME	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	Temp ^{o}C	TDS (mg/L)	TN (mg/L)	TP (ug/L)	TSS (mg/L)
16:38	6.3	0.960	6.5	3.5	14.4	600	1.8	49	61.4
17:08	6.3	0.970	3.0	5.6	14.4	600			
17:38	6.3	0.970	2.4	5.6	14.4	600	2.1	105	
18:08	6.3	0.980	2.4	5.6	14.4	600			
18:38	6.3	0.970	2.6	5.5	14.4	620	2.1	42	
19:08	6.3	0.980	2.8	5.5	14.4	600			
19:38	6.3	0.970	3.3	5.4	14.4	600	2.3	43	
20:08	6.3	0.980	3.3	5.4	14.4	600			
20:38	6.3	0.987	5.3	5.3	14.4	630	2.1	39	6.7
21:08	6.4	0.980	8.2	5.3	14.4	600			
21:38	6.4	0.960	10.4	5.3	14.4	600	1.9	24	
22:08	6.4	0.940	13.4	5.2	14.4	600			
22:38	6.4	0.930	14.6	5.2	14.4	590	1.9	83	
23:08	6.4	0.993	16.1	5.5	14.3	640			
23:38	6.4	0.981	20.3	5.4	14.3	630	2.4	88	
0:08	6.4	0.974	22.9	5.4	14.3	620			
0:38	6.4	0.981	23.2	5.3	14.4	630			57.2
1:08	6.4	0.978	24.4	5.3	14.3	630			
1:38	6.4	0.977	23.0	5.4	14.3	630	2.4	155	
2:08	6.4	0.983	21.1	5.3	14.4	630			
2:38	6.3	0.973	24.0	5.3	14.3	620			
3:08	6.3	0.948	23.1	5.3	14.3	610			
3:38	6.3	0.924	22.1	5.3	14.4	590	2.2	73	
4:08	6.3	0.905	22.7	5.3	14.3	580			
4:38	6.3	0.898	21.0	5.3	14.3	570			34.8
5:08	6.3	0.893	20.8	5.3	14.3	570			
5:38	6.3	0.892	20.8	5.2	14.3	570	2.2	92	
6:08	6.3	0.893	19.5	5.2	14.3	570			
6:38	6.3	0.896	20.1	5.2	14.3	570			
7:08	6.3	0.898	19.3	5.2	14.3	570			
7:38	6.3	0.902	19.1	5.2	14.3	580	2.2	90	
8:08	6.3	0.906	17.6	5.2	14.3	580			
8:38	6.3	0.910	18.4	5.3	14.3	580			22.0
9:08	6.4	0.917	17.9	5.2	14.3	590			
9:38	6.4	0.923	17.8	5.2	14.3	590	2.1	65	
10:08	6.4	0.926	17.3	5.2	14.3	590			
10:38	6.4	0.930	16.7	5.2	14.3	600			
11:08	6.4	0.934	17.2	5.2	14.3	600			
11:38	6.4	0.935	17.0	5.2	14.3	600	2.0	51	
12:08	6.4	0.937	18.2	5.2	14.3	600			
12:38	6.4	0.940	16.8	5.2	14.3	600			16.4
13:08	6.4	0.941	16.5	5.2	14.3	600			
13:38	6.4	0.943	16.9	5.2	14.3	600	2.1	50	
14:08	6.4	0.944	17.5	5.2	14.3	600			
14:38	6.4	0.946	16.5	5.1	14.3	610			
15:08	6.4	0.948	17.2	5.1	14.3	610			
15:38	6.4	0.948	16.3	5.1	14.3	610	2.3	72	
16:08	6.4	0.952	17.0	5.1	14.3	610			

Sampling Date: December 31, 2002 Storm Event
Water Chemistry monitored every 30 minutes for 48 hours
TN and TP sampled every hour for first 7 hours, then every 2 hours for 16 hours
TSS sampled every 4 hours for 24 hours

TIME	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	Temp ^{o}C	TDS (mg/L)	TN (mg/L)	TP (ug/L)	TSS (mg/L)
16:38	6.4	0.950	17.5	5.1	14.3	610			12.2
17:08	6.4	0.951	16.8	5.1	14.3	610			
17:38	6.4	0.955	17.2	5.0	14.3	610			
18:08	6.4	0.951	16.9	5.1	14.3	610			
18:38	6.4	0.951	17.9	5.1	14.3	610			
19:08	6.4	0.953	17.3	5.1	14.3	610			
19:38	6.4	0.949	18.1	5.1	14.3	610			
20:08	6.4	0.948	17.3	5.1	14.3	610			
20:38	6.4	0.953	17.3	5.1	14.3	610			
21:08	6.4	0.950	17.5	5.1	14.3	610			
21:38	6.4	0.950	17.8	5.1	14.3	610			
22:08	6.4	0.949	17.6	5.1	14.3	610			
22:38	6.4	0.952	18.1	5.1	14.3	610			
23:08	6.4	0.949	18.4	5.1	14.3	610			
23:38	6.4	0.948	18.7	5.1	14.3	610			
0:08	6.4	0.949	19.1	5.1	14.3	610			
0:38	6.4	0.951	18.6	5.2	14.3	610			
1:08	6.4	0.949	18.7	5.2	14.3	610			
1:38	6.4	0.949	18.6	5.2	14.3	610			
2:08	6.4	0.949	19.1	5.2	14.3	610			
2:38	6.4	0.950	18.8	5.2	14.3	610			
3:08	6.4	0.949	19.0	5.2	14.3	610			
3:38	6.4	0.950	19.4	5.2	14.2	610			
4:08	6.4	0.950	19.6	5.2	14.2	610			
4:38	6.4	0.949	20.0	5.3	14.2	610			
5:08	6.4	0.947	20.7	5.3	14.3	610			
5:38	6.4	0.949	20.0	5.3	14.2	610			
6:08	6.4	0.947	20.1	5.3	14.3	610			
6:38	6.4	0.949	20.3	5.3	14.2	610			
7:08	6.4	0.951	20.7	5.3	14.2	610			
7:38	6.4	0.952	21.0	5.3	14.2	610			
8:08	6.4	0.950	21.0	5.3	14.2	610			
8:38	6.4	0.949	21.3	5.3	14.2	610			
9:08	6.4	0.951	21.7	5.3	14.2	610			
9:38	6.4	0.950	21.9	5.3	14.2	610			
10:08	6.4	0.947	22.0	5.2	14.2	610			
10:38	6.4	0.950	22.4	5.2	14.2	610			
11:08	6.4	0.951	22.5	5.2	14.2	610			
11:38	6.4	0.950	22.9	5.2	14.2	610			
12:08	6.4	0.948	23.1	5.2	14.2	610			
12:38	6.4	0.949	23.7	5.2	14.2	610			
13:08	6.4	0.951	25.0	5.2	14.2	610			
13:38	6.4	0.948	24.2	5.2	14.2	610			
14:08	6.4	0.949	24.6	5.2	14.2	610			
14:38	6.4	0.947	25.1	5.2	14.2	610			
15:08	6.4	0.946	25.1	5.2	14.2	610			
15:38	6.4	0.948	25.5	5.2	14.2	610			
16:08	6.4	0.945	25.8	5.2	14.2	600			
16:38	6.4	0.946	26.3	5.2	14.2	610			

Sampling Date: April 7, 2003 Storm Event
Water Chemistry monitored every 30 minutes for 24 hours
TN, TP, & TSS collected every 2 hours for 22 hours

TIME	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	Temp °C	TDS (mg/L)	TN (mg/L)	TP (mg/L)	TSS (mg/L)
12:07	6.4	0.853	18.1	5.2	13.7	550	3.3	24	1.3
12:37	6.4	0.850	5.0	6.7	13.7	540			
13:07	6.4	0.848	0.3	6.8	13.7	540			
13:37	6.4	0.847	0.0	6.9	13.7	540			
14:07	6.4	0.848	0.8	6.9	13.8	540	2.6	31	1.2
14:37	6.4	0.844	3.4	6.9	13.7	540			
15:07	6.4	0.837	6.9	6.9	13.7	540			
15:37	6.4	0.830	10.2	7.0	13.7	530			
16:07	6.4	0.825	20.5	7.0	13.7	530	2.7	37	4.2
16:37	6.3	0.820	28.1	7.1	13.7	520			
17:07	6.3	0.818	32.3	7.1	13.7	520			
17:37	6.3	0.816	43.2	7.2	13.6	520			
18:07	6.3	0.807	52.0	7.2	13.6	520	2.7	48	7.6
18:37	6.3	0.792	64.6	7.2	13.6	510			
19:07	6.3	0.774	77.5	7.2	13.6	500			
19:37	6.3	0.756	89.4	7.2	13.5	480			
20:07	6.3	0.740	96.7	7.2	13.5	470	2.4	57	10.6
20:37	6.3	0.729	102.0	7.3	13.5	470			
21:07	6.3	0.726	108.0	7.3	13.5	460			
21:37	6.3	0.724	118.0	7.3	13.5	460			
22:07	6.3	0.721	127.0	7.3	13.5	460	2.2	50	9.2
22:37	6.3	0.720	135.0	7.3	13.5	460			
23:07	6.3	0.717	127.0	7.4	13.5	460			
23:37	6.3	0.710	136.0	7.4	13.5	450			
0:07	6.3	0.706	151.0	7.3	13.5	450	2.2	43	8.2
0:37	6.3	0.701	150.0	7.3	13.4	450			
1:07	6.3	0.697	151.0	7.3	13.4	450			
1:37	6.3	0.695	124.0	7.3	13.4	440			
2:07	6.3	0.692	123.0	7.3	13.4	440	2.0	49	7.2
2:37	6.3	0.693	128.0	7.3	13.4	440			
3:07	6.3	0.695	136.0	7.3	13.4	440			
3:37	6.3	0.697	143.0	7.3	13.4	450			
4:07	6.3	0.702	147.0	7.3	13.4	450	2.4	50	6.4
4:37	6.3	0.707	151.0	7.2	13.4	450			
5:07	6.3	0.712	157.0	7.2	13.4	460			
5:37	6.3	0.719	162.0	7.2	13.4	460			
6:07	6.3	0.725	167.0	7.1	13.3	460	2.0	45	4.6
6:37	6.3	0.731	171.0	7.1	13.4	470			
7:07	6.3	0.737	176.0	7.1	13.4	470			
7:37	6.3	0.743	182.0	7.1	13.3	480			
8:07	6.3	0.746	186.0	7.0	13.4	480	2.0	35	4.2
8:37	6.3	0.751	191.0	7.0	13.3	480			
9:07	6.3	0.753	191.0	7.0	13.4	480			
9:37	6.3	0.756	195.0	7.0	13.4	480			
10:07	6.3	0.759	201.0	7.0	13.4	490	2.3	39	3.6
10:37	6.3	0.762	204.0	7.0	13.4	490			
11:07	6.3	0.765	209.0	7.0	13.4	490			
11:37	6.3	0.767	212.0	6.9	13.4	490			
12:07	6.3	0.769	217.0	6.9	13.4	490			

Sampling Date: April 26, 2003 Storm Event
Water Chemistry monitored every 30 minutes for 70 hours
TN, TP, & TSS collected every 4 hours for 44 hours

TIME	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	Temp ^{o}C	TDS (mg/L)	TN (mg/L)	TP (ug/L)	TSS (mg/L)
15:45	6.0	0.839	42.0	5.0	13.8	540	2.1	21	*
16:15	6.2	0.840	16.9	5.7	13.8	540			
16:45	6.3	0.835	8.6	5.7	13.8	530			
17:15	6.3	0.833	6.1	5.7	13.8	530			
17:45	6.3	0.832	5.1	5.7	13.8	530			
18:15	6.3	0.832	4.8	5.6	13.8	530			
18:45	6.3	0.832	4.6	5.7	13.8	530			
19:15	6.3	0.837	4.5	5.7	13.8	540			
19:45	6.3	0.828	4.6	5.7	13.8	530	2.2	25	*
20:15	6.3	0.829	4.5	5.7	13.8	530			
20:45	6.3	0.837	4.4	5.6	13.8	540			
21:15	6.3	0.839	4.4	5.7	13.8	540			
21:45	6.3	0.835	4.4	5.6	13.8	530			
22:15	6.3	0.830	4.4	5.7	13.8	530			
22:45	6.3	0.839	4.4	5.7	13.8	540			
23:15	6.3	0.833	4.7	5.6	13.8	530			
23:45	6.3	0.827	4.7	5.6	13.8	530	2.3	27	*
0:15	6.3	0.837	4.6	5.6	13.8	540			
0:45	6.3	0.834	4.6	5.5	13.8	530			
1:15	6.3	0.842	4.9	5.5	13.8	540			
1:45	6.3	0.851	4.6	5.3	13.8	540			
2:15	6.3	0.845	4.6	5.1	13.8	540			
2:45	6.3	0.850	4.6	4.8	13.8	540			
3:15	6.3	0.856	4.6	4.5	13.8	550			
3:45	6.3	0.862	4.7	4.3	13.8	550	2.2	45	*
4:15	6.3	0.852	4.7	4.4	13.8	550			
4:45	6.3	0.857	4.7	4.6	13.8	550			
5:15	6.3	0.849	4.8	4.9	13.8	540			
5:45	6.3	0.852	4.8	5.2	13.8	540			
6:15	6.3	0.849	4.9	5.5	13.8	540			
6:45	6.3	0.849	5.0	5.6	13.8	540			
7:15	6.3	0.853	5.3	5.6	13.8	550			
7:45	6.3	0.848	5.6	5.7	13.9	540	2.0	49	*
8:15	6.3	0.826	6.0	5.7	13.9	530			
8:45	6.3	0.801	7.0	5.9	13.8	510			
9:15	6.3	0.781	8.1	6.1	13.8	500			
9:45	6.3	0.780	8.4	6.3	13.8	500			
10:15	6.3	0.772	8.9	6.4	13.8	490			
10:45	6.2	0.766	8.9	6.4	13.8	490			
11:15	6.2	0.757	9.3	6.5	13.7	480			
11:45	6.2	0.753	9.4	6.5	13.7	480	1.7	43	*
12:15	6.2	0.745	9.6	6.6	13.7	480			
12:45	6.2	0.739	9.7	6.6	13.7	470			
13:15	6.2	0.731	9.8	6.5	13.7	470			
13:45	6.2	0.723	10.0	6.5	13.7	460			
14:15	6.2	0.718	9.8	6.5	13.7	460			
14:45	6.2	0.712	9.8	6.5	13.7	460			
15:15	6.2	0.703	9.9	6.5	13.7	450			

Sampling Date: April 27, 2003 Storm Event
Water Chemistry monitored every 30 minutes for 70 hours
TN, TP, & TSS collected every 4 hours for 44 hours

TIME	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	Temp ^{o}C	TDS (mg/L)	TN (mg/L)	TP (ug/L)	TSS (mg/L)
15:45	6.2	0.704	9.7	6.5	13.7	450	1.6	38	*
16:15	6.2	0.700	9.7	6.5	13.6	450			
16:45	6.2	0.694	9.7	6.5	13.7	440			
17:15	6.2	0.699	9.7	6.5	13.7	450			
17:45	6.2	0.691	9.7	6.5	13.7	440			
18:15	6.2	0.688	9.8	6.5	13.7	440			
18:45	6.2	0.693	9.9	6.5	13.7	440			
19:15	6.2	0.690	9.9	6.4	13.7	440			
19:45	6.2	0.690	9.8	6.4	13.7	440	1.8	29	*
20:15	6.2	0.697	9.7	6.4	13.6	450			
20:45	6.2	0.700	9.6	6.3	13.7	450			
21:15	6.2	0.705	9.8	6.3	13.7	450			
21:45	6.2	0.711	10.0	6.3	13.7	450			
22:15	6.2	0.712	9.9	6.2	13.7	460			
22:45	6.2	0.711	9.7	6.2	13.7	460			
23:15	6.2	0.720	9.6	6.2	13.7	460			
23:45	6.2	0.718	9.6	6.2	13.7	460	1.6	28	*
0:15	6.2	0.724	9.6	6.2	13.7	460			
0:45	6.2	0.733	9.7	6.1	13.7	470			
1:15	6.2	0.737	9.6	6.1	13.7	470			
1:45	6.2	0.740	9.6	6.1	13.7	470			
2:15	6.2	0.740	9.5	6.1	13.7	470			
2:45	6.2	0.735	9.6	6.1	13.7	470			
3:15	6.2	0.737	9.7	6.1	13.7	470			
3:45	6.2	0.738	9.6	6.1	13.7	470	1.7	54	*
4:15	6.2	0.739	10.2	6.2	13.7	470			
4:45	6.2	0.741	11.4	6.2	13.7	470			
5:15	6.2	0.732	12.1	6.2	13.7	470			
5:45	6.2	0.739	13.1	6.2	13.7	470			
6:15	6.2	0.743	12.8	6.2	13.7	480			
6:45	6.2	0.734	12.3	6.2	13.6	470			
7:15	6.2	0.736	12.5	6.1	13.7	470			
7:45	6.2	0.736	12.3	6.1	13.6	470	1.7	57	*
8:15	6.2	0.740	12.3	6.2	13.6	470			
8:45	6.2	0.748	12.4	6.2	13.6	480			
9:15	6.2	0.746	12.9	6.3	13.6	480			
9:45	6.2	0.749	13.5	6.3	13.6	480			
10:15	6.2	0.733	13.8	6.3	13.6	470			
10:45	6.2	0.723	14.3	6.3	13.6	460			
11:15	6.2	0.710	14.9	6.4	13.6	450			
11:45	6.2	0.704	15.6	6.4	13.6	450	1.4	52	*
12:15	6.2	0.695	15.5	6.4	13.6	450			
12:45	6.2	0.687	16.1	6.3	13.6	440			
13:15	6.2	0.680	15.7	6.3	13.6	440			
13:45	6.2	0.687	15.9	6.4	13.6	440			
14:15	6.2	0.682	16.0	6.4	13.6	440			
14:45	6.2	0.689	15.9	6.4	13.6	440			
15:15	6.2	0.690	15.7	6.4	13.5	440			

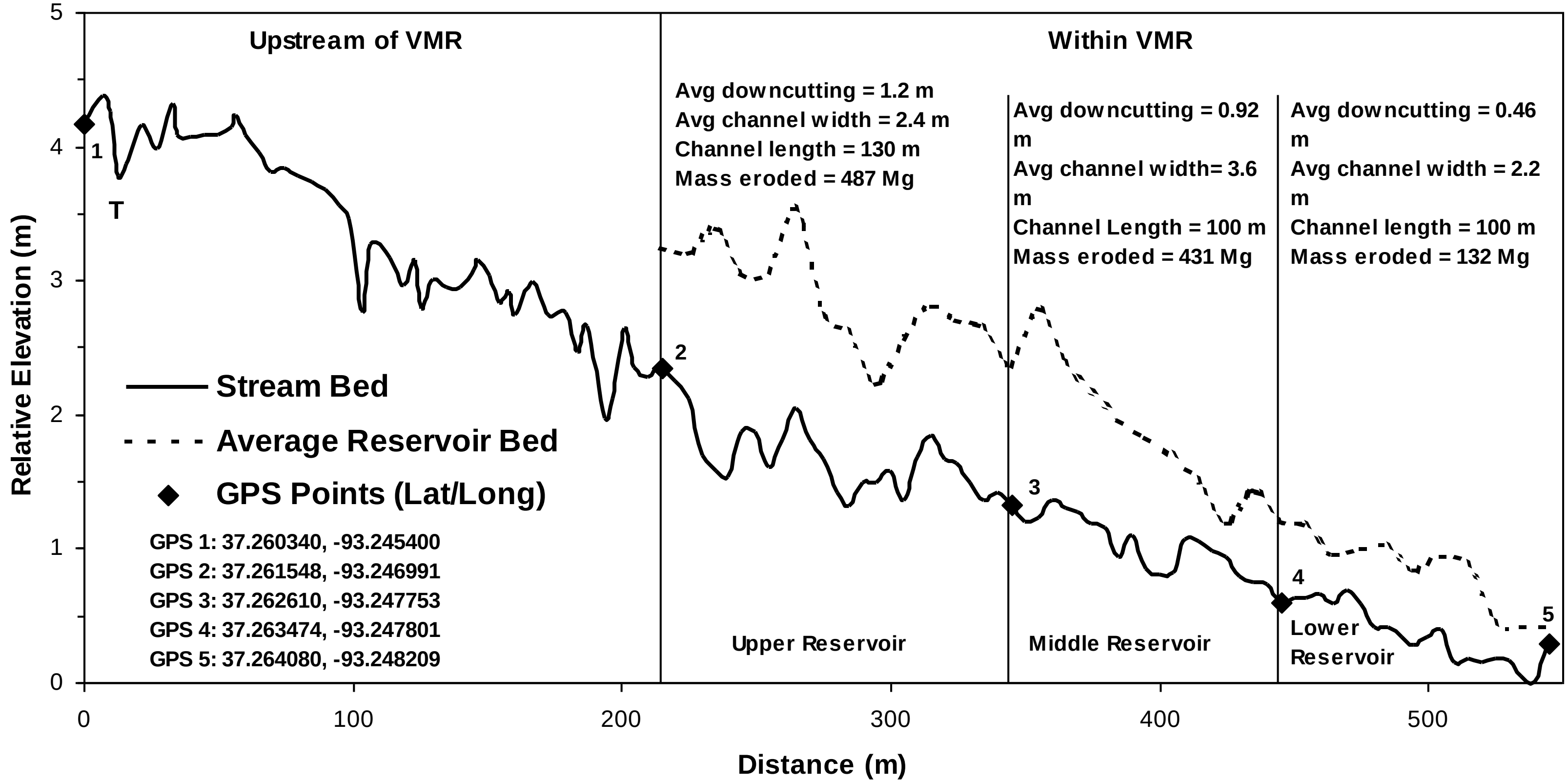
Sampling Date: April 28, 2003 Storm Event
Water Chemistry monitored every 30 minutes for 70 hours
TN, TP, & TSS collected every 4 hours for 44 hours

TIME	pH	COND (mS/cm)	TURB (NTU)	DO (mg/L)	Temp ^{o}C	TDS (mg/L)	TN (mg/L)	TP (ug/L)	TSS (mg/L)
15:45	6.2	0.692	15.6	6.4	13.5	440			
16:15	6.2	0.695	16.1	6.4	13.5	440			
16:45	6.2	0.686	15.9	6.4	13.5	440			
17:15	6.2	0.686	16.1	6.4	13.5	440			
17:45	6.2	0.681	16.2	6.4	13.5	440			
18:15	6.2	0.679	15.9	6.4	13.5	430			
18:45	6.2	0.680	15.9	6.4	13.5	440			
19:15	6.2	0.676	15.7	6.4	13.5	430			
19:45	6.2	0.679	15.9	6.4	13.5	430			
20:15	6.2	0.686	15.9	6.4	13.5	440			
20:45	6.2	0.689	15.7	6.3	13.5	440			
21:15	6.2	0.689	15.8	6.3	13.5	440			
21:45	6.2	0.692	15.5	6.3	13.5	440			
22:15	6.2	0.703	15.7	6.3	13.5	450			
22:45	6.2	0.708	15.8	6.3	13.5	450			
23:15	6.2	0.710	15.7	6.3	13.5	450			
23:45	6.2	0.713	15.4	6.3	13.5	460			
0:15	6.2	0.719	15.8	6.3	13.5	460			
0:45	6.2	0.721	15.5	6.3	13.5	460			
1:15	6.2	0.722	15.6	6.3	13.5	460			
1:45	6.2	0.728	15.6	6.3	13.5	470			
2:15	6.2	0.738	15.9	6.2	13.5	470			
2:45	6.2	0.731	15.8	6.2	13.5	470			
3:15	6.2	0.738	15.6	6.2	13.5	470			
3:45	6.2	0.735	15.7	6.2	13.5	470			
4:15	6.2	0.744	15.7	6.2	13.5	480			
4:45	6.2	0.743	16.0	6.2	13.5	480			
5:15	6.2	0.748	16.0	6.1	13.5	480			
5:45	6.2	0.750	15.8	6.1	13.5	480			
6:15	6.2	0.754	15.9	6.1	13.5	480			
6:45	6.2	0.748	16.0	6.1	13.5	480			
7:15	6.2	0.752	16.1	6.1	13.5	480			
7:45	6.2	0.766	16.2	6.1	13.5	490			
8:15	6.2	0.759	16.1	6.1	13.5	490			
8:45	6.2	0.760	16.1	6.1	13.5	490			
9:15	6.2	0.764	16.2	6.1	13.5	490			
9:45	6.2	0.762	16.3	6.1	13.5	490			
10:15	6.2	0.770	16.5	6.1	13.5	490			
10:45	6.2	0.778	16.6	6.1	13.5	500			
11:15	6.2	0.770	15.9	6.1	13.5	490			
11:45	6.2	0.777	16.3	6.1	13.6	500			
12:15	6.2	0.771	16.3	6.1	13.5	490			
12:45	6.2	0.776	16.0	6.1	13.5	500			
13:15	6.2	0.782	16.2	6.0	13.5	500			
13:45	6.2	0.783	15.0	6.0	13.5	500			
14:15	6.2	0.784	16.3	6.0	13.5	500			

APPENDIX F

Valley Mill Reservoir
Channel Survey

Longitudinal Profile of Sanders Spring Channel and Reservoir Bed from Site IF-1 to Shallow Pool within Valley Mill Reservoir



Bed elevation at 0 distance (GPS point 1) is approximately 1205.2 ft., 0.15 ft. above the spillway elevation of 1205.05 ft. determined by Landmark Surveying and Consulting, LLC on March 27, 2003. The spillway is located approximately 75 m downstream of GPS point 5. "**T**" marks the tributary confluence with Sanders Spring.

APPENDIX G

Precipitation Data for
Springfield, MO
During Study Period

Daily Precipation Data for Springfield, MO Reported in cm (Source: NOAA, 2003A)
Note: T = Trace Rainfall

Day	MAR 02	APR 02	MAY 02	JUNE 02	JULY 02	AUG 02	SEP 02	OCT 02	NOV 02	DEC 02	JAN 03	FEB 03	MAR 03
1	1.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	T
2	0.89	0.03	0.36	0.00	1.32	1.75	0.00	T	0.38	0.00	0.05	0.00	0.00
3	0.00	0.00	T	0.00	0.00	0.00	0.00	0.00	0.13	0.71	0.00	T	0.00
4	0.00	0.00	0.00	T	0.00	0.00	T	0.03	0.03	1.22	0.00	0.00	0.00
5	0.00	0.00	0.00	0.74	0.00	0.00	0.00	0.00	0.81	0.00	0.00	T	T
6	0.00	0.00	0.23	0.00	0.00	T	0.00	0.58	0.00	0.00	0.00	0.25	0.00
7	T	1.96	7.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.03	0.69	3.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.36	0.05	1.02	T	0.00	0.00	0.00	T	0.00	0.00	0.00	0.36	0.00
10	0.00	0.00	0.13	0.08	0.30	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	T	0.00	T	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	T	3.53	1.45	1.12	0.18	0.00	0.28	0.00	0.13	0.00	0.00	0.71
13	0.00	0.97	0.18	T	0.76	0.10	0.00	0.00	0.00	0.79	0.00	0.64	0.74
14	0.00	0.00	0.00	T	0.00	0.08	0.20	0.00	1.07	0.00	0.00	2.08	0.00
15	0.30	0.00	T	T	0.00	0.00	T	0.00	0.03	0.00	0.00	0.48	0.00
16	T	0.48	1.35	T	0.05	0.00	0.00	0.61	0.00	0.00	0.41	0.08	0.00
17	T	0.00	3.23	0.00	0.00	4.14	0.10	0.00	0.00	0.51	0.00	0.00	0.00
18	1.40	0.41	0.00	0.00	0.71	0.00	0.00	0.28	0.00	T	T	1.75	0.03
19	1.40	0.69	0.00	0.00	4.22	0.00	1.12	0.38	0.00	0.00	0.00	0.69	2.74
20	T	2.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46
21	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	T	0.00	T	T
22	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	T	0.71	0.00
23	T	0.13	0.71	0.00	0.38	2.84	0.00	T	0.00	2.59	0.00	2.21	0.00
24	1.12	0.30	1.73	0.00	0.00	1.68	0.00	1.47	0.00	0.89	0.00	T	0.00
25	2.03	0.89	0.00	0.18	0.00	0.00	0.00	1.42	0.00	0.00	0.00	0.00	0.41
26	T	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	T	T	T	0.00
27	0.00	0.33	T	0.08	0.00	0.00	0.00	0.58	0.00	0.03	0.00	0.18	0.00
28	0.00	0.00	0.97	T	0.00	0.00	0.00	2.26	0.00	0.00	0.10	0.05	2.16
29	0.00	0.00	0.00	0.00	0.23	0.00	0.00	0.15	0.00	0.00	0.03	-	0.00
30	0.00	0.08	0.00	0.00	0.03	0.00	0.00	0.23	0.00	0.48	T	-	0.00
31	0.00	-	0.00	-	0.00	0.00	-	T	-	0.00	0.20	-	0.00
Total	**8.59**	**10.69**	**24.03**	**2.51**	**9.19**	**10.85**	**1.42**	**8.28**	**2.44**	**7.34**	**1.09**	**9.47**	**7.24**