A BASELINE STUDY OF SEDIMENT AND NITROGEN FLUX IN A PRE-URBANIZED WATERSHED, PARKER COUNTY, TEXAS

by

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At times our own light goes out and is rekindled by a spark from another person. Each of us has cause to think with deep gratitude of those who have lighted the flame within us.
~ Albert Schweitzer

This manuscript is dedicated to the memory of my grandparents, Joyal and Vergie Dunford, for their undying belief that I could accomplish anything I chose to undertake.

Just after starting this project, I experienced the loss of three loved ones during the span of five months. These losses and other personal circumstances resulted in my "light going out" which led to what seemed like an interminable and insurmountable delay in my ability to complete my work. Without the continual support and encouragement of many faculty, family, and friends, I do not think it would have been possible for me to rekindle my own flame. Thus, this thesis could not have been written without the scholarship, love, and friendship of these individuals and I would like to pay tribute to those who were most instrumental in providing the spark necessary to see this project through to completion.

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A thing long expected takes the form of the unexpected when at last it comes.
~ Mark Twain

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CHAPTER I: INTRODUCTION AND LITERATURE REVIEW

Water is the most critical resource issue of our lifetime and our children's lifetime. The health of our waters is the principal measure of how we live on the land.
~ Luna Leopold

The competing demands on water have affected not only its supply and future availability, but also its quality. Mitigating the effects of high demand on the quality of both surface water and groundwater will require a long-term commitment to conservation and limits on development. Representing a more acute risk to water quality, though, is contamination that results from such human activities as industry, agriculture, and urbanization. In Texas, human activity has affected water quality in all 15 river basins, in the eight coastal basins where rivers drain into the Gulf of Mexico, and in all major aquifers, including some that are sources of drinking water (Texas Center for Policy Studies, 2000).

History of Water Quality Legislation

Federal legislation. It was not until the 1940s and 1950s that Congress began to address water pollution legislatively. Initial efforts in this area, like the Federal Water Pollution Control Act of 1948, did not address pollution prevention plans or the development of water quality standards. Instead, they focused on funding water treatment plants, identifying polluted bodies of water, and locating the polluters for legal action. Comprehensive legislation to protect water quality did not occur until the 1960s. Rachel Carson's 1962 bestseller *Silent Spring*, bolstered by articles and scientific reports detailing pollution problems, provided the impetus for the nation's first water quality legislation (Dzurick, 1990).

One result was the 1965 Water Quality Act, which established the Water Pollution Control Administration within the Department of the Interior. With the creation of this new federal agency, water quality was for the first time treated as an environmental concern. The 1965 law was soon followed by the 1966 Clean Water Act, which provided construction grants for wastewater treatment facilities. The Clean Water Act of 1972 forms the basis today for water quality protection for surface water in streams, rivers, and lakes, as well as for groundwater. The Clean Water Act set water quality standards for major rivers and lakes and required discharge permits for both public and private facilities. The act was strengthened in 1977 in an effort to address the most visible causes of water pollution. It explicitly prohibited the discharge into waterways of hazardous substances, including industrial waste, sewage, accidental spills, toxics, and other point sources. As a result, hundreds of billions of dollars were spent on the cleanup of pollution primarily caused by sewage and industrial wastewater discharges.

However, at the same time as this money was being spent, it became apparent that these efforts were insufficient. In addition to pollution from point sources, pollution from land and from human activity, primarily agriculture, was preventing the cleanup goals from being met in spite of the vast expenditures. The 1987 amendments to the Water Quality Act were the first concerted effort by the federal government to address pollution from non-point sources, including agricultural fields and feedlots, urban streets, and runoff channeled through municipal storm-water systems. The law required states to develop a non-point source management plan.

Early in the twentieth century, contamination of the water supply and outbreaks of disease led to questions about how we purify our water and how we protect our drinking water supplies. The federal Safe Drinking Water Act of 1974 created national drinking water standards to limit a range of substances that can adversely affect human health. These maximum-contaminant levels set by the Environmental Protection Agency (EPA) are based on the health effects of a single contaminant. They do not consider the cumulative impact of a combination of contaminants on human health, because little is known about the possible synergistic effects (EPA, 1991). The 1986 amendments to the Safe Drinking Water Act accelerated the EPA's schedule for bringing contaminants under regulation and expanded the number of contaminants covered. In 1996 Congress passed additional amendments to the Safe Drinking Water Act. These amendments provide an increased emphasis on protecting local sources of drinking water by requiring a source water assessment program to identify potential contaminants of all major water sources.

State legislation. Along with Congress, the Texas legislature has recognized the need to protect water quality. In 1991 the legislature adopted the Clean Rivers Act, which directed the river authorities to conduct a regional assessment of water quality for each major river basin, with the Texas Natural Resource Conservation Commission (TNRCC) overseeing the effort. It should be noted that TNRCC is currently known as the Texas Commission on Environmental Quality (TCEQ). The Clean Rivers Act supports the TCEQ's overall efforts to move water pollution management to a river basin or "watershed" approach. In 1997 the legislature amended the Clean Rivers Act by limiting funding to the monitoring and assessment of water quality to support site-specific water quality standards and wastewater discharge permitting. The data generated through such monitoring and assessment programs is utilized to develop new and modify existing water quality standards.

There are three different types of water quality standards set by state and federal regulations: (1) Stream standards, also referred to as surface water quality standards; (2) effluent standards (set for wastewaters); and (3) drinking water standards, which also cover groundwater used as a public water supply. Today, the TCEQ is the primary agency responsible for water quality management in Texas, although it shares the responsibility with other state agencies. Under the Clean Water Act and Chapter 26 of the Texas Water Code, the TCEQ has the sole authority to develop and amend surface water quality standards for the state that are implemented via agency permitting programs.

National Water-Quality Assessment (NAWQA) Program

Monitoring and assessing the quality of the nation's waters is of paramount importance due to the inherent link to the health of humans and aquatic organisms, and to the corollary costs incurred by federal, state, and local agencies in managing, conserving, and regulating the use of land and water. Thus, in 1991, the U. S. Congress approved funding for the U. S. Geological Survey (USGS) to establish the National Water-Quality Assessment Program (NAWQA). The NAWQA Program was designed to facilitate the collaboration of the USGS and other government agencies in researching and quantifying the spatial and temporal variability associated with water quality and ascertaining the effect of various human activities and natural factors on the quality of the nation's streams and aquifers. Knowledge obtained through the NAWQA program will enable resource managers and policy makers at all levels of government to make informed decisions in prioritizing, managing, restoring, and protecting the quality of the nation's waters in different hydrologic regimes and land-use settings.

The NAWQA Program is responsible for assessing and quantifying the water quality conditions of more than 50 of the largest river basins and aquifers in the United States. These "Study Units" collectively comprise about one-half of the United States and include drinking water sources utilized by approximately 70 percent of the U.S. population (USGS, 1999). At any given time, comprehensive assessments are conducted on one-third of the Study Units. In order to evaluate changes in water quality conditions, each Study Unit is slated for reassessment every ten years. The NAWQA Program not only utilizes data collected by the USGS, but also data collected by other federal, state, and local agencies. Due to the need to standardize the data collected by different agencies, the NAWQA Program specifies and mandates the use of "nationally consistent study designs and methods of sampling and analysis" (USGS, 1999). Such standardization provides the foundation to make valid comparisons among watersheds and enables generalizations to be made regarding the human and natural factors that affect water quality conditions on a local, regional, and national scale.

Total Maximum Daily Loads (TMDLs)

As stipulated in the Clean Water Act, Texas must designate how water bodies will be utilized and must establish and enforce a comprehensive set of water quality standards. There are four components to surface water quality standards: (1) Designated uses; (2) chemical, physical, and biological criteria to support those uses; (3) assessment of the impact of discharge on those criteria; and (4) abatement of discharges that cause the criteria to be exceeded (Houck, 1999). State water quality standards must be reviewed by the EPA to ensure that they are in compliance with the Clean Water Act goals of "fishable and swimmable quality waters."

Moreover, in an attempt to stay abreast of potential changes in watershed conditions, every three years, states are required to evaluate and revise their water quality standards as needed. In considering applications for wastewater discharge permits, TCEQ and/or the EPA use these water quality standards to develop limits on the amount and type of contaminants that will be allowed in the discharge. Texas is required to routinely monitor all water bodies to ascertain whether these water quality standards are being met and to produce a water quality inventory.

The water quality inventory also serves as the basis of the Clean Water Act 303(d) list, which identifies all impaired water bodies that fail to meet their designated uses. In brief, section 303(d) of the Clean Water Act requires states to complete three steps:

- Identify waters that are and will remain polluted after applying current technology standards;
- Prioritize these waters according to the severity of their pollution; and
- Establish "total maximum daily loads" (TMDLs) for these waters at levels necessary to meet applicable water quality standards, taking seasonal variations into account and establishing a margin of safety to reflect lack of certainty about discharges and water quality (Houck, 1999).

States are required to submit their inventories and TMDLs to the EPA for approval. In essence, the state is required to implement "watershed action plans" to restore those impaired water bodies identified in the 303(d) list. The basis for the watershed action plans is the establishment of TMDLs for all pollutants that thwart the attainment of water quality standards. A TMDL is an estimate of the maximum amount of a certain kind of pollutant a body of water can receive and still meet water quality standards. TMDLs may result in stricter discharge standards or even enforcement actions against a source of pollution.

Surface Water Pollution

According to the TNRCC's 1996 Water Quality Inventory, only 69 percent of the number of river miles with specific state standards fully supported the uses for which they were designated by the state. Of the 4,431 miles of rivers and streams that did not fully meet their designated use in 1996, 3,855 miles did not meet safe swimming conditions, 1,304 miles did not meet standards for aquatic life, and 12 miles could not fully support boating and non-contact recreation uses. Between 1994 and 1996, overall use support in reservoirs declined from 98 to 78 percent, indicating a substantial decline in reservoir water quality. The decline in overall use support was caused by lower levels of dissolved oxygen, higher levels of metals and organic substances, and elevated fecal coliform bacteria densities. Finally, the issuance of consumption advisories and aquatic life closures by the Texas Department of Health increased the number of reservoirs determined to yield fish that could not be safely consumed. Some 336,600 acres of reservoirs were covered by fish-consumption advisories, while 500 acres of reservoirs were also determined to yield fish unsafe for consumption and were subject to aquatic life closures (TNRCC, 1996).

The most frequently violated water quality standards in streams and rivers were those for pathogens, low dissolved oxygen, and toxics such as metals and pesticides. Impairment of reservoir use was related to elevated levels of metals and high levels of pathogens and pesticides (TNRCC, 1994). According to the 1996 Water Quality Inventory, 521.5 miles of streams and rivers, 22,240 acres of reservoirs, and 0.7 miles of bays and estuaries have such high toxicity levels that they do not meet their designated use for aquatic life (TNRCC, 1996).

Sources of Pollution

The sources of water pollution typically fall into one of two categories: point source pollution and non-point source pollution. Point source pollution refers to pollutants discharged from a discrete and confined location or point, such as an industry or municipal wastewater treatment plant. Non-point source pollution refers to pollutants that cannot be identified from one discrete location or point because they are diffuse and intermittent. Examples of pollutants washed into water bodies in runoff are oil and grease from urban streets, nitrogen from fertilizers and pesticides, and animal wastes from agricultural land. Different sources of pollution can have different effects on reservoirs, rivers, and bays. For example, the TNRCC determined that the major sources of pollution in Texas reservoirs and bays were non-point sources and that the major source of pollution in Texas streams and rivers was wastewater discharges from cities (TNRCC, 1996).

Point source pollution.

Since the passage of the 1972 Clean Water Act, most water pollution control efforts have focused on point source pollution. After the establishment of the 1977 Clean Water Act, all municipal and industrial dischargers have been required to obtain a National Pollutant Discharge Elimination System, or NPDES, permit from the EPA. Despite its name, the NPDES permit does not eliminate pollution; instead, it is designed to control pollution by setting limits on the quality of the discharged wastewater. In 1998, the EPA awarded the NPDES program to the TNRCC. Previously, most industrial and municipal dischargers had to obtain both a state and a federal wastewater permit. Under the NPDES program, the state establishes basic effluent limits for all facilities to protect surface water quality standards.

Non-point source pollution. The impact of non-point source pollution on water quality is significant: the EPA estimates that non-point source pollution accounts for 65 percent of pollution in rivers, 76 percent in lakes, and 45 percent in estuaries in the United States (World Resources Institute, 1992). As stated earlier, the 1987 amendments to the Water Quality Act were the first comprehensive attempt by the federal government to control non-point source pollution from urban streets and sewers as well as from agricultural activities. The law requires states to conduct an assessment of waters contaminated by non-point source pollution and to devise best management pollution abatement plans to help clean up these waters. According to the TNRCC, of the 142 segments that do not meet their designated uses, 62 have been identified as not meeting their use because of non-point source pollution, while 42 segments have been identified as being affected by both point source and non-point source pollution, and only 37 segments are impaired solely because of point or natural sources (TNRCC, 1997).

Non-point source pollution occurs mainly through storm water runoff. When it rains, runoff from urban parking lots, streets, and construction sites, suburban lawns, roofs, and driveways, and rural farmlands enters waterways. This runoff often contains harmful substances such as heavy metals, pesticides, sediment, and excess nutrients. The effects of non-point source pollution seldom show up overnight. Instead, it often goes unnoticed for years, ultimately making it all the more difficult to control. Since urban runoff and agriculture have been identified consistently as the main sources of the majority of non-point source pollutants, it comes as no surprise that sediment and nutrients from fertilizers represent the top two pollutants in naturally occurring surface water, respectively (EPA, 1998).

Sediment. Sediment is comprised of soil particles of varying sizes carried by rainwater into streams, lakes, rivers, and bays. By volume, sediment remains the most significant pollutant, accounting for 40% of all water contamination (EPA, 1998). One of the most important physical characteristics of surface water is the suspended sediment concentration, which is determined largely by the amount of sediment carried by the water body. Sediment yield is the total sediment outflow from a watershed or drainage basin measured for a specific period and at a defined cross section in a stream channel, and is usually measured in milligrams per liter (mg/l). Sediment yield is normally determined by sediment sampling and relating the results to stream flow discharge. Streams discharging large quantities of sediment are those that drain areas undergoing natural geologic erosion or accelerated human-induced erosion caused by disturbances in drainage areas, such as agricultural cultivation, grazing of livestock, logging operations, and urban construction. As a general rule, the transport of sediment increases with increasing flow.

Transported fluvial sediments are moved either in suspension (suspended load) or along the channel bed (bed load). Part of the suspended load is called the wash load. The wash load is made up only of silt and clay, whereas the suspended load also includes sand-sized particles (Nordin, 1963, Reid & Frostick, 1987). The suspended load includes those grains whose settling velocity is more than matched by the upward component of turbulence and so remain within the flow, having no contact with the bed for an unspecified but significant fraction of time. The wash load is often assumed to remain suspended in the flow due to the presence of clay particles with settling velocities of less than 10^{-6} m/s. The bed load is derived by disturbing the channel sediments and generally consists of sand, gravel, or rocks and is transported along the stream bottom by traction, rolling, sliding, or saltation.

Although it is convenient to distinguish these three modes of transport, it is important to bear in mind that particles that are carried as bed load in one reach or at one flow may become suspended either downstream, where flow conditions are different, or in a single reach as a flood wave waxes. However, as a general rule, clays and fine to medium silts (particles < 32 μm) will almost always move as suspended load, and pebbles and coarser gravels (> 4 mm) will generally travel as bed load. Coarse silts, sands, and granules (32 μm - 4 mm) may switch from one mode to another depending upon local flow conditions.

Another potential source of sediment of considerable importance is the channel bank (Thorne & Lewin, 1982). According to Reid & Frostick (1994), the degree to which a stream bank will contribute material depends upon cohesion and, therefore, upon the clay content of the channel wall. Schumm (1961) found an inverse relationship between the fractional amount of silt and clay and the width to depth ratio of ephemeral channels in the western part of the United States. Those banks which had higher shear strength through higher clay content had channels which were less wide and more incised.

Suspended sediment is the largest fraction carried by rivers and streams. Clay particles dominate suspended sediment loads and are often made available by the weathering and erosion processes that operate on the hillslopes of a drainage basin, and are subsequently carried to the channel system by overland flow. Therefore, much of the suspended load may be entrained before water enters the river's first-order tributaries. Sediment concentrations in overland flow have been reported as high as 60% (Gerson, 1977), though values as high as this may reflect, in part, human activities in accelerating the erosion process and tend to occur in semi-arid environments. As noted earlier, besides hillslope sources, the channel bed and banks also provide fine particles. In fact, the suspended sediment load is significant, if not necessarily spectacular, even at low flows, and concentrations of several hundred mg/l (<0.1%) are often reported for perennial streams in humid temperate environments during the long periods that intervene between floods. Unlike bed load, which may contribute to total sediment transport for much less than 1% of the time in some streams, suspended sediment load almost never falls to zero values, at least in perennial streams.

In terms of water quality, suspended sediment is more important because it restricts sunlight from reaching photosynthetic plants (measured as turbidity), and it can affect aquatic ecosystems adversely by smothering benthic communities and by covering gravels that are often important spawning habitat for fish. The lower the turbidity, the deeper light can penetrate into a body of water and, hence, the greater the opportunity for photosynthesis and higher oxygen levels. Turbidity is caused by suspended clays, silts, organic matter, plankton, and other inorganic and organic particles. Turbidity is easily measured and can sometimes be used to predict suspended-sediment concentrations.

In addition, suspended sediment carries many nutrients and heavy metals that adversely affect water quality. Suspended sediment consists of fine-grained clay minerals that can carry pollutants adsorbed on their surfaces and are transported with the sediment particles. Consequently, the movement of contaminants can only be understood through knowledge of the movement of particles.

Nitrogen. Nitrogen is a widely distributed element found most commonly as nitrogen gas in the atmosphere, nitrate in soils and groundwater, and in biomass in the form of amino acids, peptides, and proteins. Nitrogen is important to all life and is an essential element for plant growth. Despite 78% by volume of the atmosphere being gaseous dinitrogen (N_2), the availability of nitrogen from this source is restricted due to its low chemical reactivity. Atmospheric nitrogen cannot be utilized directly by most organisms and its availability is only made possible through an extremely complex nitrogen cycle (Figure 1). Atmospheric nitrogen is converted into nitrates mainly by free-living or symbiotic bacteria (*Rhizobium*, *Azobacter*, cyanobacteria) through a process called nitrogen fixation. These nitrogen-fixing bacteria have the nitrogenase enzyme that combines gaseous nitrogen with hydrogen to produce ammonia (NH_3). It should be noted, however, that the fraction of nitrogen fixed by such organisms relative to that originating from the decay of organic matter, fertilized runoff, and other external sources, is quite low (Manahan, 2000; Ward & Trimble, 2004). Lightning also converts some aerial nitrogen gas into forms that return to earth as nitrate ions in rainfall and other types of precipitation.

As can be seen in Figure 1, ammonia plays a major role in the nitrogen cycle. Excretion by animals and anaerobic decomposition of dead organic matter by bacteria produce ammonia. Ammonia, in turn, is converted by nitrification bacteria into nitrites (NO_2^-) and then into nitrates (NO_3^-). This process is known as nitrification. Nitrification bacteria are aerobic. The bacteria that convert ammonia into nitrites are known as nitrite bacteria (*Nitrosomonas*) and the bacteria that convert nitrites into nitrates are known as nitrate bacteria (*Nitrobacter*). The nitrates thus formed may be absorbed through the roots of plants and utilized as a nutrient for growth.

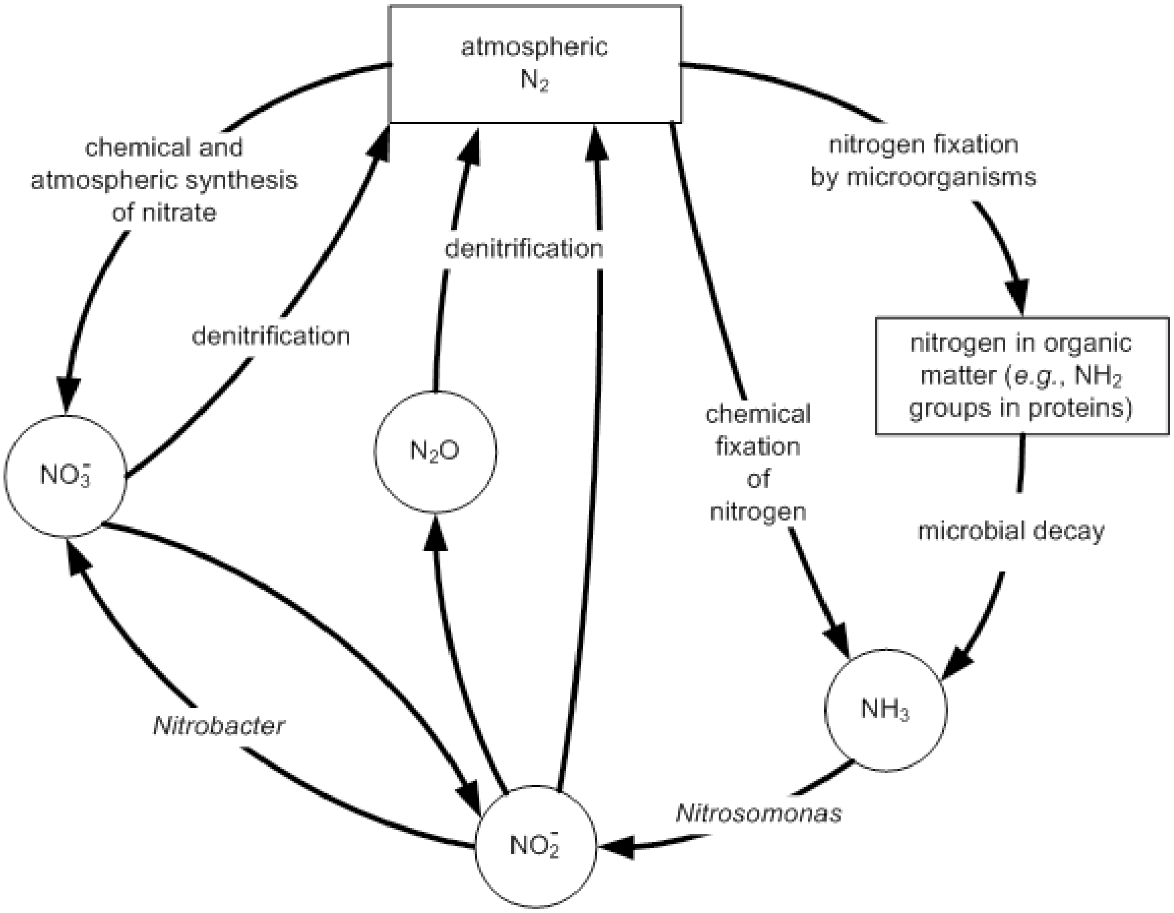


Figure 1. The nitrogen cycle (after Manahan, 2000).

The processes discussed so far remove nitrogen from the atmosphere and pass it through the ecosystem. How then does nitrogen return to the atmosphere as dinitrogen? This is accomplished through a process called denitrification that reduces nitrates to nitrogen gas. Once again, the operative agents are aerobic and anaerobic bacteria living in the soil and the oceans. However, the conversion to dinitrogen is incomplete and this leads to the formation of nitrous oxide (N_2O), the second most abundant nitrogen containing species in the atmosphere (Howard, 1998).

In recent years, humans have significantly altered the nitrogen cycle. By using synthetic fertilizers, cultivating nitrogen-fixing crops, and burning fossil fuels, humans now convert more nitrogen to ammonia and nitrates than all natural land processes combined (Cunnigham & Cunnigham, 2002). Ammonium ions readily bind to soils, especially to humic substances and clays. Nitrate and nitrite ions, due to their negative charge, bind less readily since there are less positively charged ion-exchange sites in soil than negative (Brady & Weil, 1999). After rain or irrigation, leaching, or the removal of soluble ions, such as nitrate and nitrite, into groundwater can occur.

Nitrogen becomes a concern to stream ecology and water quality when nitrogen in the soil is converted to nitrate (NO_3^-). Nitrate is very mobile and moves with water in the soil. The concern of nitrates and water quality is generally directed at groundwater. However, nitrates can also enter surface water such as ponds, streams, and rivers as a result of heavy rains generating surface runoff. According to the USGS (2005), two of the major problems associated with excess levels of nitrogen in the environment are:

(1) Where groundwater recharges stream flow, nitrate-enriched groundwater can contribute to eutrophication causing overstimulation of growth of aquatic plants and algae. Excessive growth of these organisms, in turn, can clog water intakes, use up dissolved oxygen as they decompose, and block light to deeper waters. This seriously affects the respiration of fish and aquatic invertebrates, leads to a decrease in animal and plant diversity, and affects the use of the water for fishing, swimming, and boating.

(2) Too much nitrate in drinking water can be harmful to young infants or young livestock. In the digestive system, nitrate is reduced to nitrite, which binds with hemoglobin in the blood and restricts the transfer of oxygen from the lungs. This condition is known as methemoglobinemia or blue-baby syndrome.

Storm Runoff and Streamflow

Streams are the routes by which the precipitation excess on the continents is returned to the oceans completing the global hydrologic cycle (Figure 2). Various processes and pathways determine how excess water becomes streamflow. Event flow or storm runoff is water that flows directly into a channel and quickly produces streamflow. Other pathways have a detention storage time, and weeks or months can pass before excess precipitation enters a stream channel. This water is referred to as baseflow. Therefore, the magnitude of water flowing into the various pathways determines the ultimate shape and size of a streamflow hydrograph. A streamflow hydrograph is the graphical relationship of stream discharge (m^3/s) plotted against time (Figure 3).

Storm runoff. The sum of channel interception, surface runoff or overland flow, and subsurface flow or interflow, is called storm runoff. The most direct pathway is channel interception and is defined as precipitation that falls directly on the stream channel and associated saturated areas. Channel interception often, but not always, produces the initial rise in the streamflow hydrograph and ceases after precipitation stops. Surface runoff, or overland flow, is water that flows over the soil surface and occurs on a sloping surface that is either 1) saturated

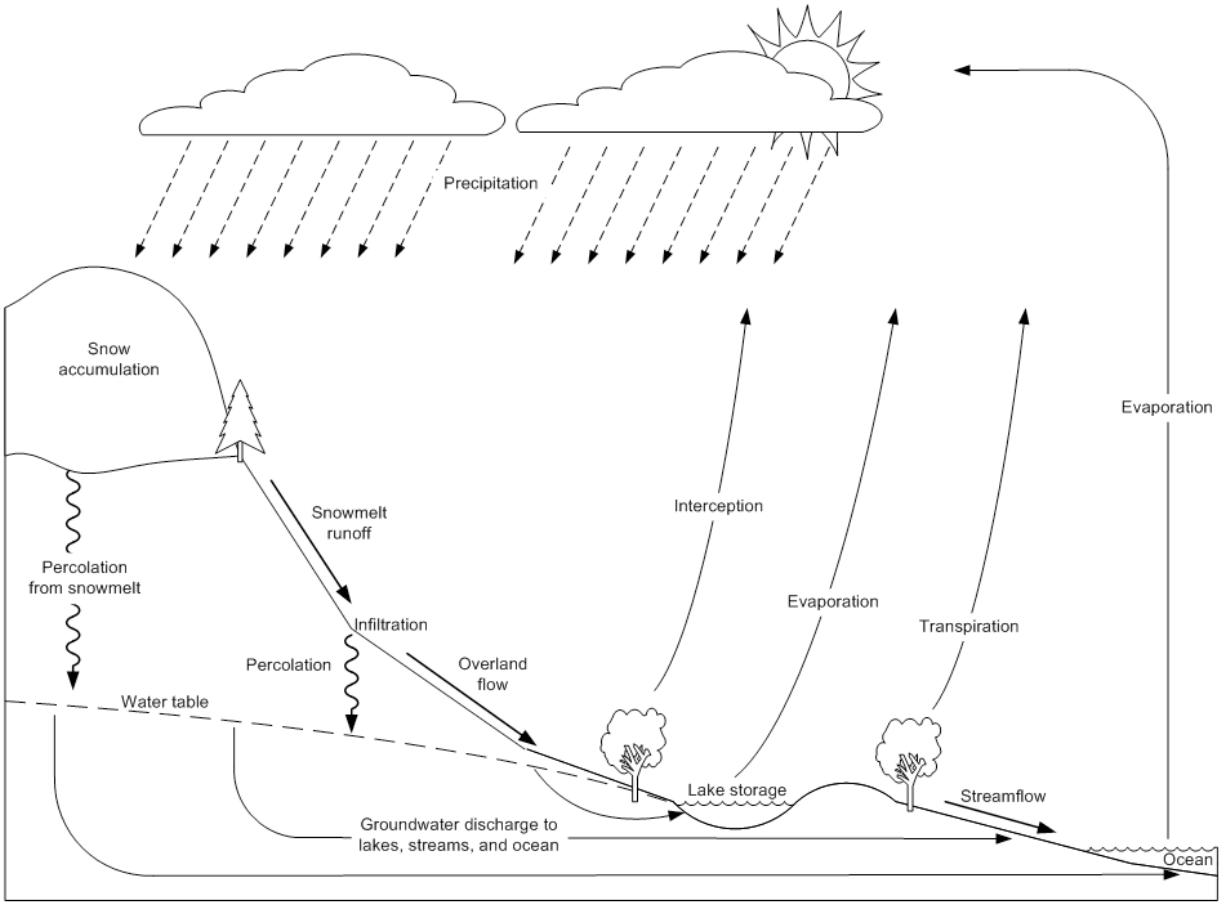


Figure 2. Schematic diagram of the hydrologic cycle (after Dunne & Leopold, 1978).

from above or 2) saturated from below. Hortonian overland flow is surface runoff that results from saturation from above, including that which occurs on impermeable surfaces. Saturation from above results from the precipitation rate exceeding the infiltration capacity. Saturation overland flow is overland flow that occurs due to saturation from below and consists of direct water input to the saturated area plus the return flow contributed by the “break-out” of ground water from upslope. Overall, both methods of surface runoff represent a quick flow response that reaches the outlet of a watershed second only to channel interception. Overland flow in one part of a watershed can infiltrate at some downslope location before reaching a stream channel. This pathway results in flow reaching the channel later than surface runoff, but quicker than

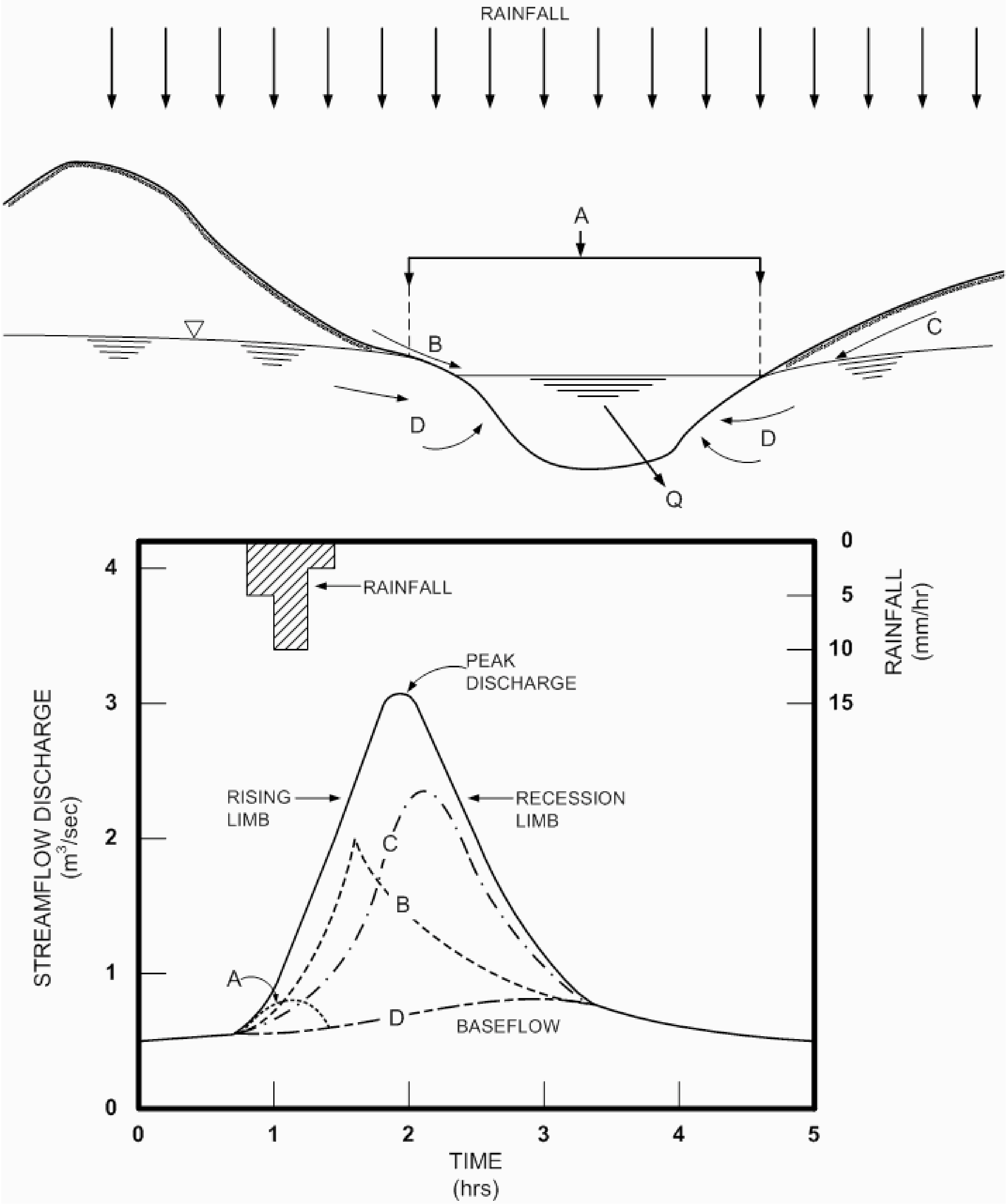


Figure 3. Watershed pathways of flow and resultant streamflow hydrograph (after Brooks, et. al, 1997). A = channel interception; B = surface runoff or overland flow; C = subsurface flow or interflow; D = groundwater or baseflow; Q = streamflow discharge.

groundwater (Brooks, et. al, 1997). Subsurface flow, or interflow, is that part of precipitation that infiltrates into the soil surface but arrives at the stream channel over a short enough period of time to be considered part of the storm hydrograph.

Baseflow. Once rainfall reaches the ground it can infiltrate into the soil. Infiltrated water that reaches the water table as recharge is stored in the groundwater reservoir. While freshly infiltrated precipitation is entering the groundwater reservoir, other groundwater, known as baseflow, is discharging into the stream. Because of the long and convoluted pathways involved, groundwater flow, or baseflow, does not respond quickly to moisture input and therefore is not associated with a specific storm event.

Streamflow. Although the four major pathways of flow can be conceptually visualized, measuring each pathway and separating one from the others is impossible physically. The actual pathway from rainfall to streamflow usually involves a combination of surface and subsurface flows. The total streamflow hydrograph depicts an integrated response of a watershed to a given quantity of moisture input with a given set of watershed conditions. Most hydrograph studies do not attempt to separate the various pathways of flow. Rather, the streamflow response is evaluated by separating the stormflow component from the slow-responding baseflow.

Many factors determine the magnitude of stormflow volume and peak flow; some are fixed and some vary in time for a given watershed. Watershed characteristics that are fixed and have a pronounced influence on stormflow response include soil type, size and shape of the watershed, elevation, channel and watershed slopes, topography, drainage density, and presence of wetlands or lakes. Factors affecting stormflow response that vary with time can be separated into meteorological and watershed factors. Meteorological factors that can vary and influence stormflow response includes type of precipitation, rainfall intensity and duration, rainfall amount, areal distribution of rainfall over the watershed, direction of storm movement, and antecedent precipitation and resulting soil moisture. Watershed factors that can vary and influence stormflow response include vegetation type and extent, soil surface conditions, and land use. All of the above factors exert some influence on stormflow response. It is difficult to separate and quantify the contributions of individual factors. However, computer simulation models have been developed to study and quantify the various meteorological and watershed factors affecting stormflow (USGS, 2005; Brooks, et. al, 1997).

Context and Justification of Study

In response to this background, the National Competitive Grants Program of the United States Geological Survey (USGS) and the National Institutes for Water Resources established three major research priorities related to non-point source pollution. These research priorities focus on questions of regional or national significance and enhance understanding of watershed processes by addressing 1) issues related to Total Maximum Daily Load (TMDL) development and compliance; 2) source water quality and availability; and/or 3) integrated watershed decision support tools. The problem of assessing non-point source sediment and nutrient loads on a watershed scale including transport pathways and influence of changes in land use is an example of the type of problem that needs to be addressed according to the program mentioned above.

Purpose. The present study reports the results of a 13-month field investigation into the dynamics of pollutant flux in response to storm runoff on a pre-urbanized watershed in Parker County, Texas. The overarching purpose of this study is to monitor the sediment and nitrogen flux in this watershed in order to develop a historical record. Mary's Creek lies in a watershed that has been utilized historically as grazing and pastureland. There are plans underway to urbanize this watershed over the next ten years. As this land is converted, the watershed will undergo many changes. Water quality is strongly influenced by chemical and biological reactions that occur as water moves over and through the land surface toward streams. Since water quality standards are becoming ever more stringent, it is vital to know when problems are arising or getting worse. Thus, water quality issues provide scientific and practical motivation for studying stream response to water-input events.

Continual water quality monitoring will allow researchers to judge whether or not the pollutant flux is changing in response to the proposed land use changes. Continual monitoring is also important because of the inherent complexity and variability of environmental systems. Changes in complex systems can be very subtle and may not become apparent for some time. Establishment of a baseline through long-term monitoring will provide essential information on how systems are changing and how fast, and allows for the development of more effective best management practices to safeguard the integrity of the watershed.

Objectives. The specific objectives of this study are therefore:

1) To establish a baseline of sediment and nitrogen flux prior to slated land use changes;
2) To quantify the export of sediment and nitrogen from the watershed to determine whether levels pose any significant threats;
3) To determine the spatial and temporal variability of sediment and nitrogen flux at the watershed scale.

CHAPTER II: STUDY SITE AND METHODS

Any river is really the summation of the whole valley. To think of it as nothing but water is to ignore the greater part.
~ Hal Borland

Study Site

Location. A 13-month field study was conducted to establish a baseline of sediment and nitrogen flux at two sites on Mary's Creek, a small tributary of the Clear Fork of the Trinity River, located on the Walsh Ranch in Parker County, Texas (Figures 4-6). Mary's Creek rises three miles north of Willow Park in eastern Parker County (at 32^{o} 48' N, 97^{o} 38'W). It was named in memory of Mary Lee Bone, an Indian woman who drowned in the creek in the nineteenth century. Mary's Creek flows southeastward for 14.5 miles, passing through nearly level to rolling terrain, surfaced with shallow to deep clay and loam soils that supports grass. Mary's Creek drains predominantly pre-urbanized land that historically has been used as pasture and rangeland for cattle. The intermittent stream joins the Clear Fork of the Trinity River in southwestern Tarrant County (at 32^{o} 42' N, 97^{o} 26'W) just inside the city of Fort Worth. The Walsh Ranch is located approximately 18 miles (29 kilometers) west of Texas Christian University and 2.1 miles north-northeast of Aledo. The roughly 7,275 acre (2,944 hectare) Walsh Ranch lies within the Lower West Fork Trinity River watershed. The type of vegetation on the Walsh Ranch is mainly grasses and oak trees scattered along the bank of Mary's Creek. The site was selected based on a number of criteria including manageable size and proximity to TCU. However, the site primarily was chosen because of the opportunity to establish a baseline of sediment and nitrogen flux in a pre-urbanized watershed prior to the conversion of the land comprising the Walsh Ranch to urban land uses. Within 10 to 15 years, the Walsh Ranch is slated for conversion to a multi-use urban/suburban complex, including residential, commercial, industrial, and recreational areas. Continual monitoring of this watershed will provide a detailed account of the effect of land use changes on the pollutant flux.

Figure 4. Location of the Walsh Ranch within the Trinity River basin and Parker County.

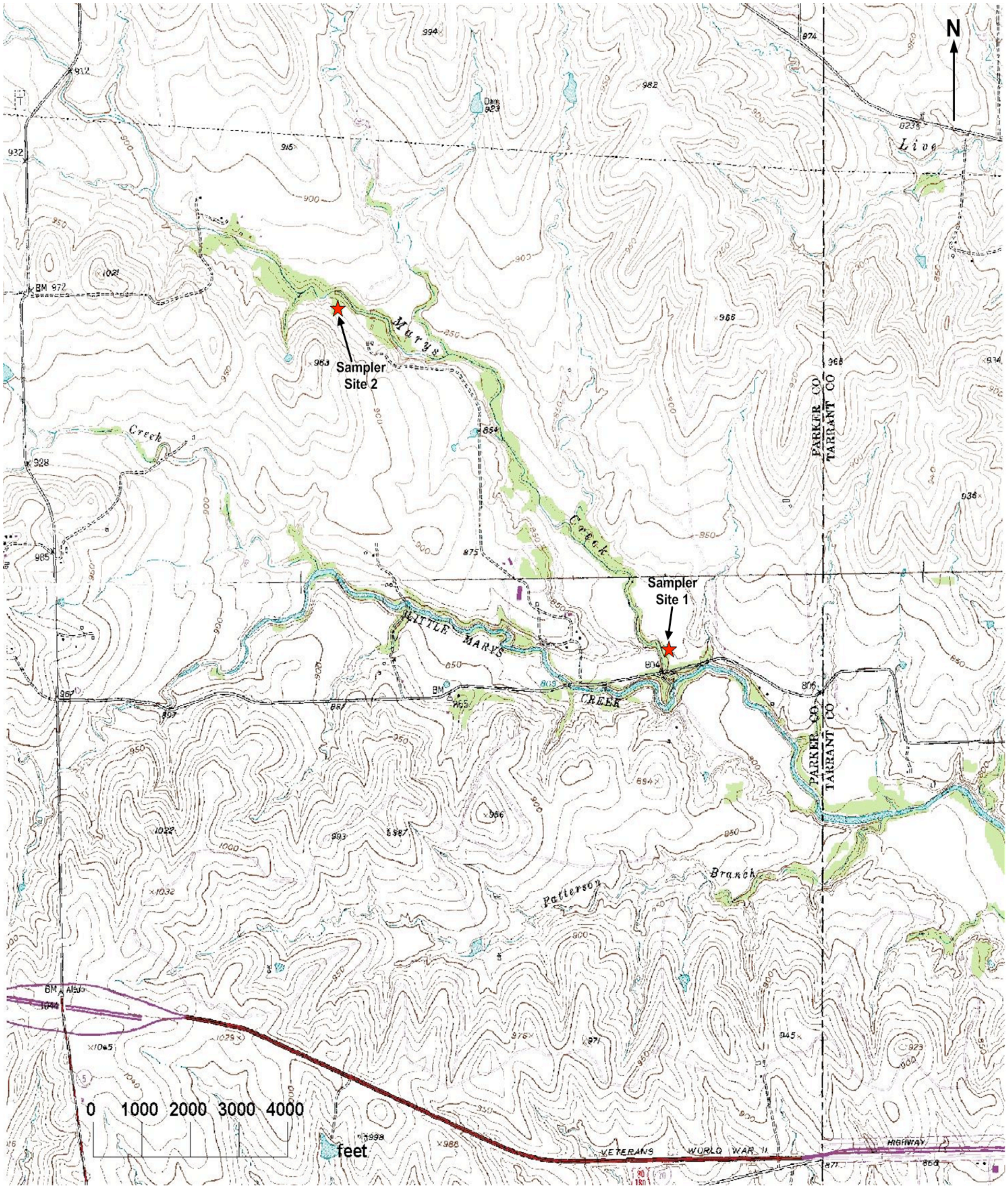


Figure 5. USGS topographic Aledo and Springtown SE quadrangle maps (joined) with sites delineated.

Sampler 1 - Outlet

Sampler 2 - Headwater

Figure 6. Automated water samplers at both sites on Mary's Creek.

Climate. The climate in Parker County is subtropical, with dry winters and hot, humid summers. The county characteristically experiences rapid changes in temperature, typified by marked extremes and wide daily and annual variation. Average high and low temperatures range from 95.2° F (35.11° C) in July to 29.0° F (-1.67° C) in January. The mean annual precipitation also varies considerably, from less than 20.59 inches (522.99 millimeters) to more than 48.99 inches (1,244.35 millimeters), with the average being 34.70 inches (881.38 millimeters). Most of the precipitation falls in May and June and in September and October. Precipitation is lowest in the winter, falling either as rain, freezing rain, sleet, or snow. However, the average accumulation of snow is less than an inch; snow usually melts as it falls. Late afternoon or evening showers are frequent in the months of April and May. June experiences very hot days, but the spells of hot weather are broken by thunderstorms. July and August are characterized by very hot days with little variation in daily weather patterns. August is one of the driest months of the year. Rainfall increases during the months of September and October. However, thunderstorm activity in the fall is not as frequent as in the spring, and drops off sharply after October (USDA, 1977; Table 1).

Geology and soils. The geologic formations exposed in Parker County range from recent to Pennsylvanian in age. The older stratigraphic units are exposed near the western limits of the county. Younger bedrock units are exposed in sequence in a generally eastward direction. Cretaceous rocks consist mainly of interbedded sandstone, limestone, marl, and clay of the Trinity, Fredericksburg, and Washita groups (Hendricks, 1957). Formations of these groups are located to the east of the Pennsylvanian-aged rocks and underlie most of the county. The Aledo, Bolar, and Denton soils were derived from the limestone and marl.

Table 1. Climatological data for Parker County, Texas
30 Year Normals (1971-2000)
(after National Weather Service, 2006)

	Normal				
				Degree Days	
	Maximum (°F)	Minimum (°F)	Precipitation (in.)	Heating	Cooling
Jan	54.2	29.0	1.50	726	0
Feb	59.5	33.9	2.36	520	7
Mar	67.8	41.3	2.79	330	6
Apr	75.8	49.6	2.84	126	56
May	82.7	59.5	4.76	26	216
Jun	90.1	67.4	3.93	1	414
Jul	95.2	71.3	2.11	0	566
Aug	95.2	70.1	2.60	0	547
Sep	88.0	62.8	2.85	7	319
Oct	78.1	51.4	4.19	84	77
Nov	65.6	40.4	2.61	373	13
Dec	56.9	31.7	2.16	642	1
Ann	75.8	50.7	34.70	2835	2222

The study area is gently sloping to sloping and undulating and is covered with very shallow to deep loamy soils over limestone or clay loam. Mary’s Creek drains mainly soils from the Aledo-Venus-Bolar association. This association is found in open prairies on uplands and occupies 30% of the county. The association is comprised of 26% Aledo soils, 24% Venus soils, 4% Bolar soils, and 46% soils of minor extent including Brackett, Denton, Frio, Krum, Lamar, Maloterre, and Purves (USDA Soil Conservation Service, 1977; Figures 7-8).

In a representative profile of the moderately alkaline Aledo soil, the upper 4” of the surface layer is dark grayish-brown, calcareous clay loam. The next 12” is grayish-brown, calcareous, very gravelly clay loam. The underlying material is fractured indurated limestone. Aledo soils are well drained. Runoff is rapid. Permeability is moderate, and the available water capacity is very low. Aledo soils are in hydrologic soil group C. Bolar soils are grayish-brown calcareous clay loams underlain by indurated limestone bedrock. These moderately alkaline

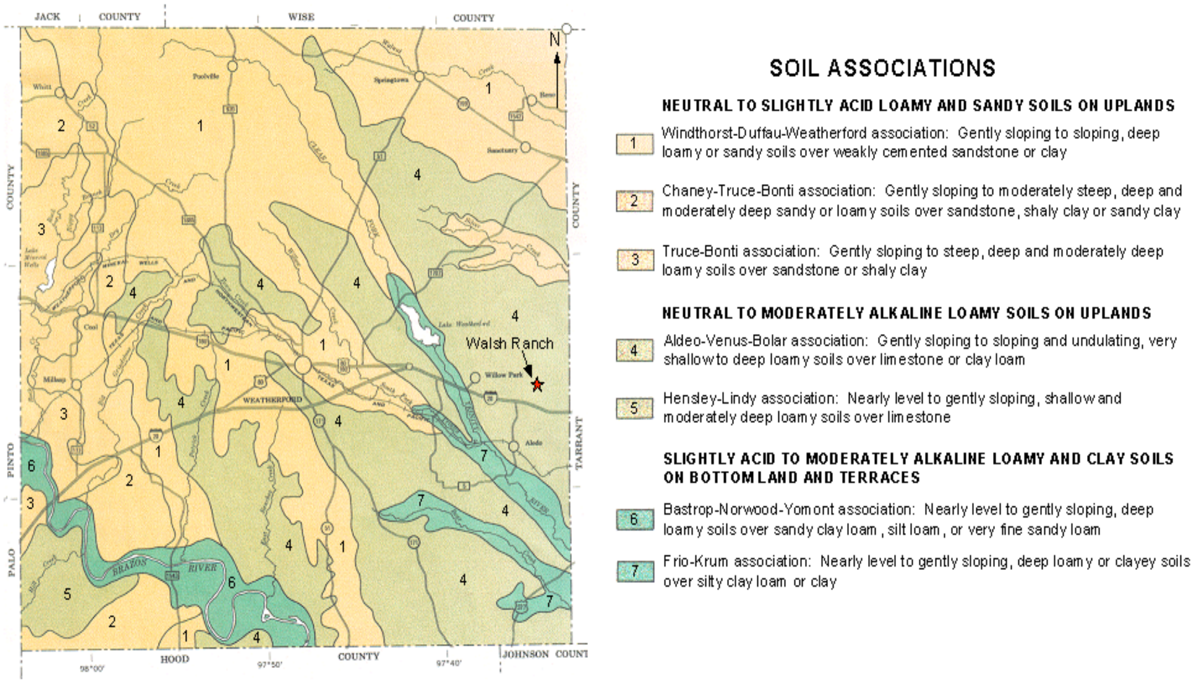


Figure 7. General soil map of Parker County, Texas (after United States Department of Agriculture Soil Conservation Service, 1977).

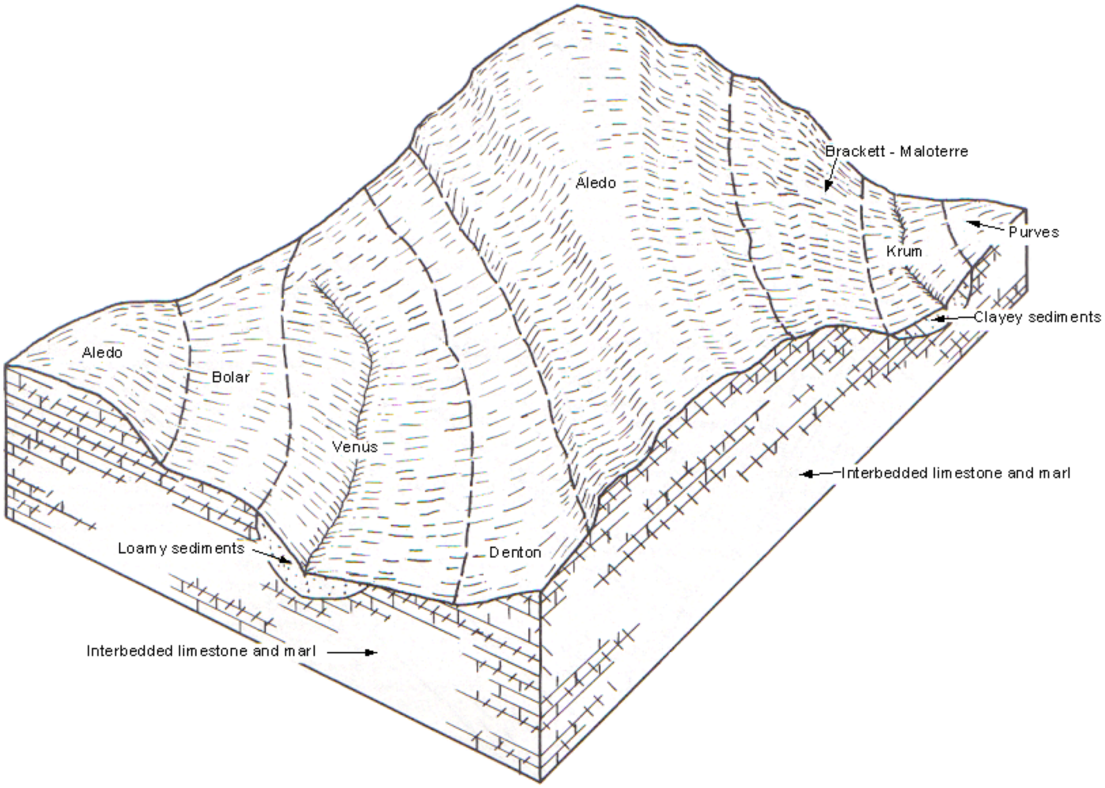


Figure 8. Pattern of soils in the Aledo-Venus-Bolar association (after United States Department of Agriculture Soil Conservation Service, 1977).

soils are well-drained. Runoff is medium. Permeability is moderate and the available water capacity is medium. Bolar soils are also in hydrologic soil group C. Venus soils are brown, calcareous clay loams underlain by light brown, calcareous clay loam containing common films and threads of calcium carbonate. These moderately alkaline soils are well drained. Runoff is medium. Permeability is moderate and the available water capacity is high. Venus soils are in hydrologic soil group B.

Watershed profile. Parker County contains a portion of three watersheds: Lower West Fork Trinity, Middle Brazos-Palo Pinto, and Upper West Fork Trinity. In Parker County, 20-30% of the surface waters have been assigned to an impaired or threatened use category, with a total of 30-40 impaired watersheds being reported (EPA, 2006). As noted earlier, Mary's Creek and the Walsh Ranch lie within the Lower West Fork Trinity River watershed (Figure 9). In conjunction with states, tribes, private organizations, and other federal agencies, the EPA developed an index of water quality indicators in the mid to late 90's to report information on the "health" of aquatic resources in the United States.

Based on the first index of water quality indicators, the Lower West Fork Trinity received a score of 4, indicating less serious problems, but high vulnerability (EPA, 1998). The index of watershed indicators identified several areas of serious concern: fish and wildlife consumption advisories, urban and agricultural runoff potential, population change, and hydrologic modification. In 2000, the Lower West Fork Trinity watershed received a score of 1, indicating better quality, and low vulnerability. However, it is interesting to note that the EPA indicators in this later report still identified the same areas of serious concern: urban and agricultural runoff, population change, and hydrologic modification (EPA, 2000). According to the Clean Water Act

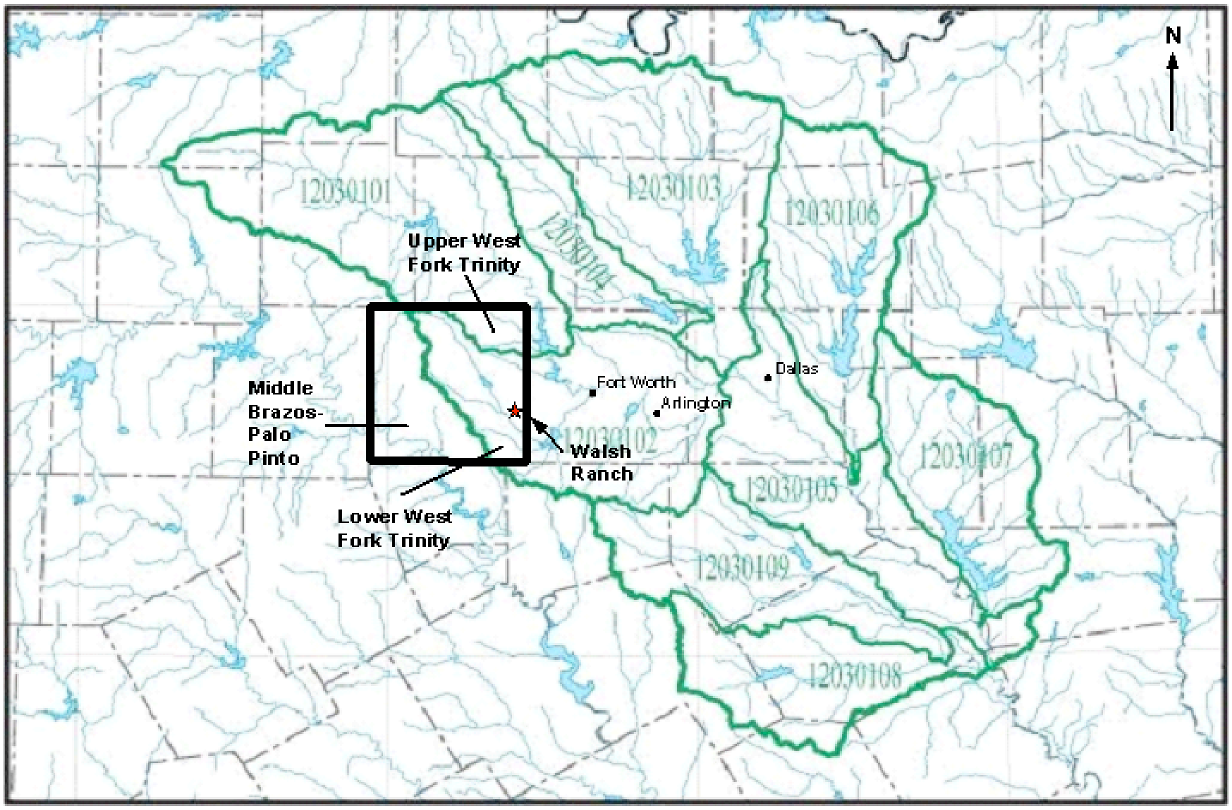


Figure 9. Upper Trinity watershed map depicting watersheds located in Parker County, including the Walsh Ranch located in the Lower West Fork Trinity watershed (after United States Geological Survey, 2006).

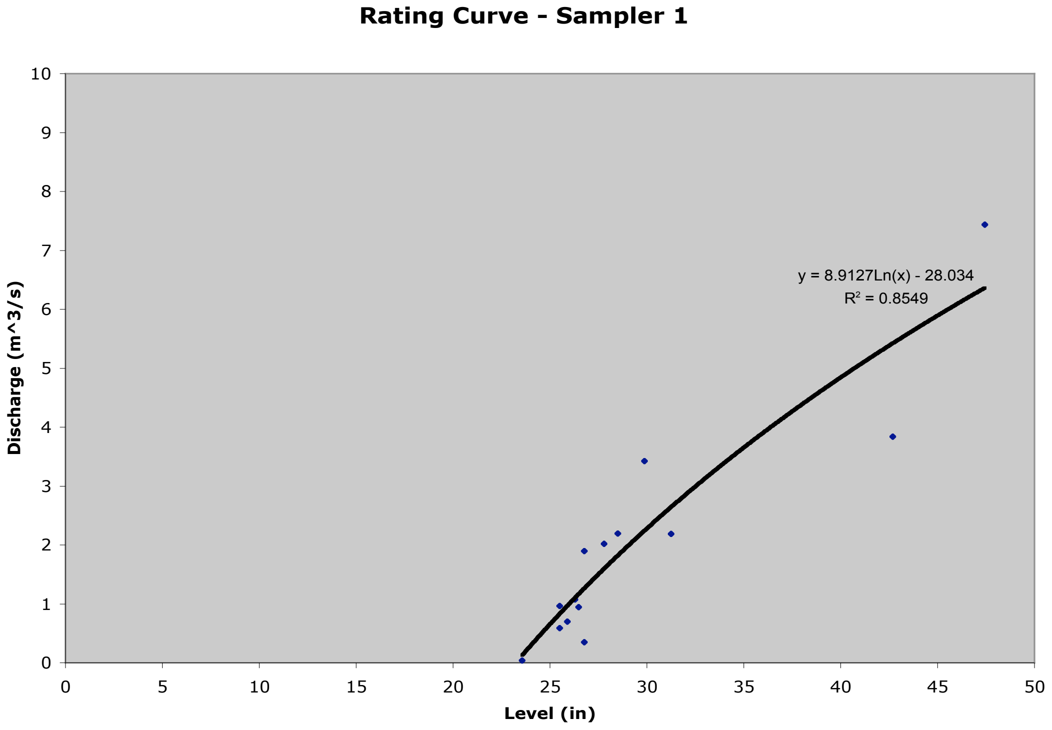
Status Report, the leading pollutants/stressors of rivers, streams, and creeks in the Lower West Fork Trinity watershed are pesticides, low dissolved oxygen/organic enrichment, pathogens, and metals. The leading source of water quality problems to these same surface waters is non-point source pollution (Green Media Toolshed, 2005; EPA, 2006). Because of these impairments, the Lower West Fork Trinity watershed continues to remain on the EPA's Section 303(d) list.

Methods

Field methods. The study site was monitored for 13 months, from January, 2001 through January, 2002. In order to establish a baseline level of pollutant flux, gauging stations were set up at two points on Mary's Creek (Figures 4-6). Automated Sigma 900 MAX water samplers were installed at each site and were programmed to take samples during storm events. The samplers were also fitted with flow meters to measure water level. These stages were then regressed against measured discharge of various magnitude to produce a stage-discharge rating curve for each site (Figure 10). Discharge was measured by calculating the cross-sectional area of the stream and measuring the stream velocity at each site during sampling with an American Sigma portable velocity meter. An external tipping-bucket rain gauge was also attached to the water sampler at Site #2. Although using rain data collected from one site to extrapolate for the entire basin may not be appropriate because it does not allow for spatial and temporal variability in rainfall between the two sampling sites and could lead to faulty inferences, the gauge was placed at Sampling Site #2 because of the number of trees surrounding Sampling Site #1. It was determined that a rain gauge at Site #1 would not yield accurate data due to the amount of interception that would occur due to tree coverage. Stage height and the rain depth were measured every 5 minutes, and water samples were taken from each site every 15 minutes during storm events.

Baseflow water samples were taken at both sites periodically during low-flow conditions. These samples were collected manually by simply plunging a clean plastic bottle into the flow and returning the bottle to the hydrology lab for analysis. When these grab samples were collected, discharge was once again computed at each site by measuring the velocity.

<u>Laboratory methods</u>. Before collecting samples, all bottles were washed with distilled water to prevent accidental contamination. When samples were collected in the field, they were brought back to TCU's hydrology laboratory and were stored in a refrigerator at a temperature



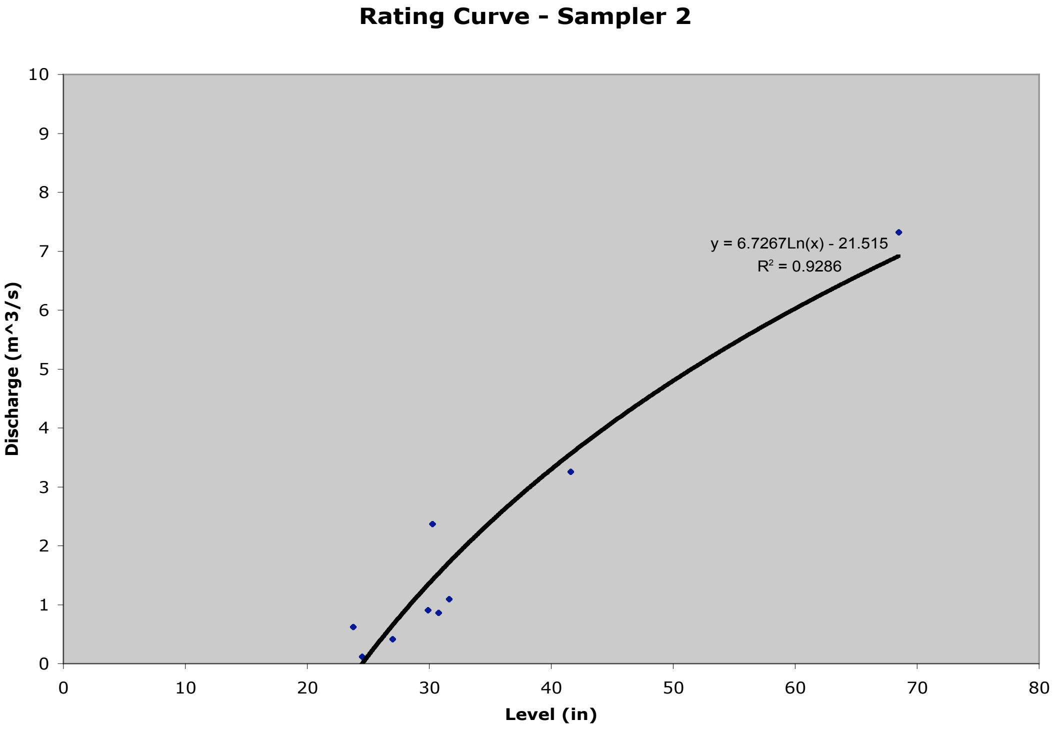


Figure 10. Stage-discharge rating curves for both sites on Mary's Creek.

below 4°C to prevent possible nutrient degradation. To further prevent the deterioration of the nutrients, 1 milliliter of sulfuric acid was added to each sample bottle containing 500 milliliters of water.

Water samples retrieved from the water samplers were filtered and analyzed for total suspended solids (TSS). Some water samples were analyzed for ammonia nitrogen (NH_3-N) and nitrate nitrogen (NO_3-N). The TSS analyses were performed according to Standard Methods #209C (Total Suspended Solids Dried at 103-105°C). Prepared LaMotte reagents were used to perform the analyses of NH_3-N and NO_3-N. Actual concentrations were measured using a Smart Colorimeter. These methods of analysis are approved by the EPA and are based on the Standard Methods #417B (Nesslerization Method) and #418C (Cadmium Reduction Method).

CHAPTER III: RESULTS AND DISCUSSION

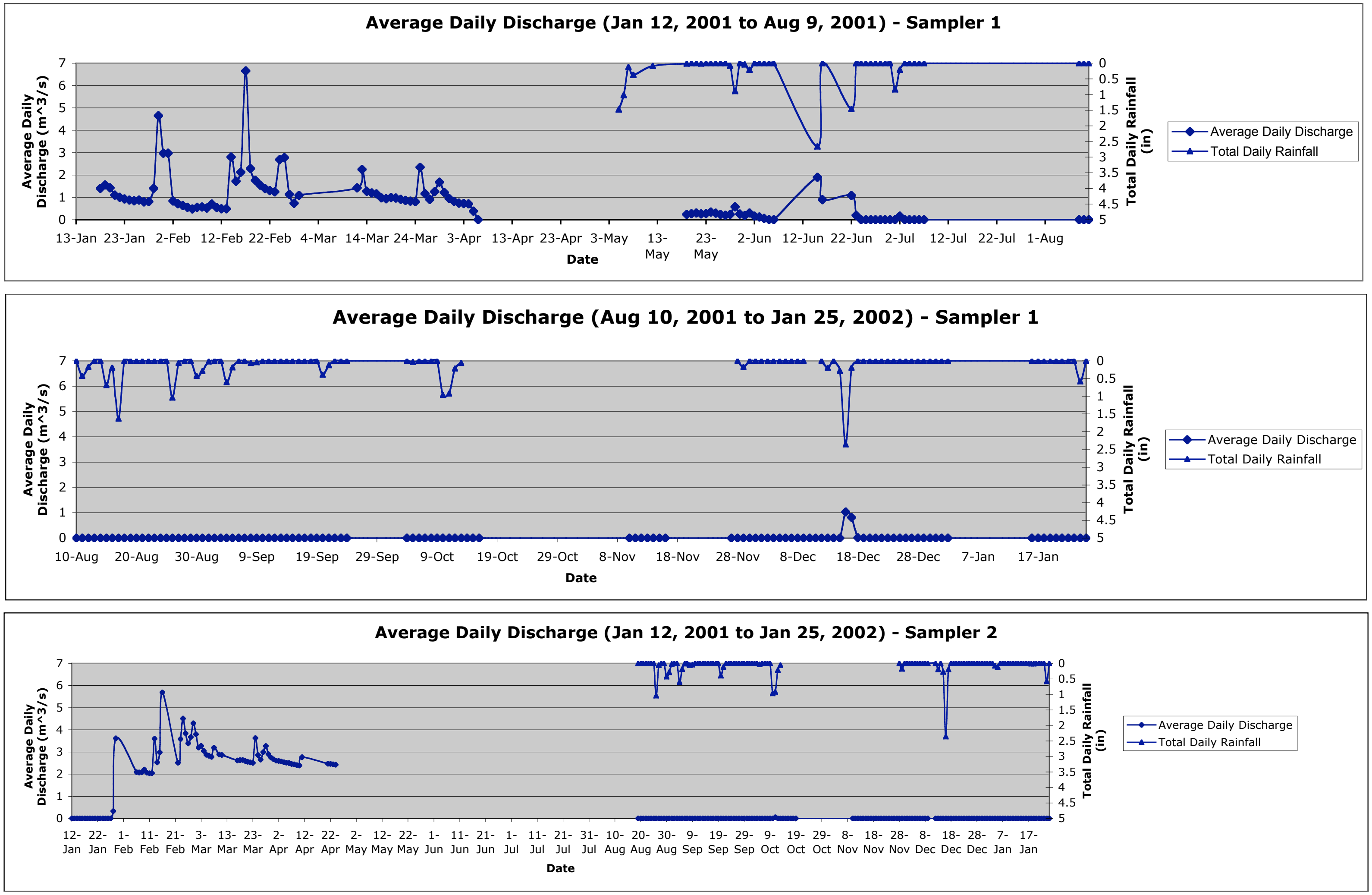
It is of the highest importance in the art of detection to be able to recognize out of a number of facts which are incidental and which are vital.
~ Sir Arthur Conan Doyle

Hydrological Response of the Basin

The field-monitoring period lasted from January 12, 2001 to January 25, 2002. A total of twenty-two storm events were used for hydrograph analysis: eighteen of these recorded storm events were common to both sampling sites and an additional four storm events were recorded only at the second sampling site. The average daily discharge record for both sampling sites is shown in Figure 11. The major storms and their hydrological characteristics are summarized in Table 2.

As can be seen in Figure 11, the average daily discharge for the two sampling sites gives an initial indication of the responsiveness of the two sub-basins. The most significant period, hydrologically, occurred from January 2001 to April 2001 when there were numerous rainfall events and both water samplers were functioning. There was very little to no flow at either site from August 2001 through January 2002. In fact, based on the distribution of rainfall events during the time frame of this study, the Walsh Ranch experienced two distinct precipitation regimes; sub-humid (January to April) and semi-arid (May to December). It should be noted that this is not a typical precipitation regime for Parker County and reflects a year marked by drought.

Due to a computer malfunction, rainfall data was lost for the months of January 2001 through April 2001. Rainfall data was obtained from the Southern Regional Climate Center that



Average Daily Discharge (Jan 12, 2001 to Aug 9, 2001) - Sampler 1

Average Daily Discharge (Aug 10, 2001 to Jan 25, 2002) - Sampler 1

Average Daily Discharge (Jan 12, 2001 to Jan 25, 2002) - Sampler 2

Figure 11. Average daily discharge records for both sites on Mary's Creek.

Table 2. Hydrological characteristics of the sub-basins during storm events

Sampler 1

Date of Storm Event	Total Rain	Rain Duration	Maximum Rain Intensity				Peak Discharge	Runoff Coefficient	Runoff Depth	Centroid Lag-to-Peak	Time of Rise
	(in)	(hrs)		(in/hr)			(m^3/s)	(%)	(in)	(hrs)	(hrs)
			5 min	15 min	30 min	60 min					
18-Jan-01	No Data	No Data	No Data	No Data	No Data	No Data	1.99	No Data	0.03	No Data	8.25
25-Jan-01	No Data	No Data	No Data	No Data	No Data	No Data	1.67	No Data	0.01	No Data	0.59
28-Jan-01	No Data	No Data	No Data	No Data	No Data	No Data	8.55	No Data	0.35	No Data	17.00
13-Feb-01	No Data	No Data	No Data	No Data	No Data	No Data	8.91	No Data	0.34	No Data	6.50
15-Feb-01	No Data	No Data	No Data	No Data	No Data	No Data	13.57	No Data	0.67	No Data	18.67
23-Feb-01	No Data	No Data	No Data	No Data	No Data	No Data	15.38	No Data	0.27	No Data	7.33
11-Mar-01	No Data	No Data	No Data	No Data	No Data	No Data	4.97	No Data	0.11	No Data	13.67
14-Mar-01	No Data	No Data	No Data	No Data	No Data	No Data	1.40	No Data	0.004	No Data	5.75
18-Mar-01	No Data	No Data	No Data	No Data	No Data	No Data	1.49	No Data	0.004	No Data	0.58
24-Mar-01	No Data	No Data	No Data	No Data	No Data	No Data	4.94	No Data	0.16	No Data	8.92
27-Mar-01	No Data	No Data	No Data	No Data	No Data	No Data	2.23	No Data	0.07	No Data	6.59
23-May-01	None	None	None	None	None	None	1.60	None	0.004	None	0.67
28-May-01	0.97	24.67	3.36	2.36	1.76	N/A	0.94	0.05	0.05	7.21	7.75
30-May-01	0.25	1.5	0.48	0.28	0.26	0.21	0.54	0.03	0.01	1.18	2.17
14-Jun-01	2.66	1.5	5.28	4.64	3.96	2.56	4.91	0.05	0.14	1.81	2.16
21-Jun-01	1.46	0.25	4.32	2.88	2.72	N/A	2.29	0.04	0.06	3.42	3.34
1-Jul-01	0.17	3.08	0.24	0.24	0.18	N/A	0.56	0.04	0.01	0.71	1.16
16-Dec-01	2.74	37.08	1.68	0.96	0.7	0.5	3.21	0.04	0.10	4.75	3.67

Sampler 2

Date of Storm Event	Total Rain	Rain Duration	Maximum Rain Intensity				Peak Discharge	Runoff Coefficient	Runoff Depth	Centroid Lag-to-Peak	Time of Rise
	(in)	(hrs)		(in/hr)			(m^3/s)	(%)	(in)	(hrs)	(hrs)
			5 min	15 min	30 min	60 min					
13-Feb-01	No Data	No Data	No Data	No Data	No Data	No Data	7.82	No Data	0.30	No Data	6.09
15-Feb-01	No Data	No Data	No Data	No Data	No Data	No Data	9.60	No Data	0.46	No Data	19.25
23-Feb-01	No Data	No Data	No Data	No Data	No Data	No Data	11.59	No Data	0.64	No Data	4.50
27-Feb-01	No Data	No Data	No Data	No Data	No Data	No Data	4.48	No Data	0.12	No Data	3.75
3-Mar-01	No Data	No Data	No Data	No Data	No Data	No Data	3.51	No Data	0.02	No Data	9.42
8-Mar-01	No Data	No Data	No Data	No Data	No Data	No Data	6.67	No Data	0.07	No Data	5.25
24-Mar-01	No Data	No Data	No Data	No Data	No Data	No Data	5.43	No Data	0.20	No Data	8.17
27-Mar-01	No Data	No Data	No Data	No Data	No Data	No Data	3.76	No Data	0.09	No Data	6.25
11-Oct-01	0.91	3.09	2.16	1.68	1.08	0.63	0.46	0.01	0.01	1.75	0.83

has a rainfall gauging station 4.2 miles south-southeast of Aledo in Parker County, with the hopes of using this data in lieu of the rainfall data that was lost. Unfortunately, the correlation and regression of the existing onsite rainfall with the offsite rainfall yielded results that had too much scatter to be able to use the offsite rainfall data in lieu of or to “predict” the lost onsite rainfall data (Appendix C).

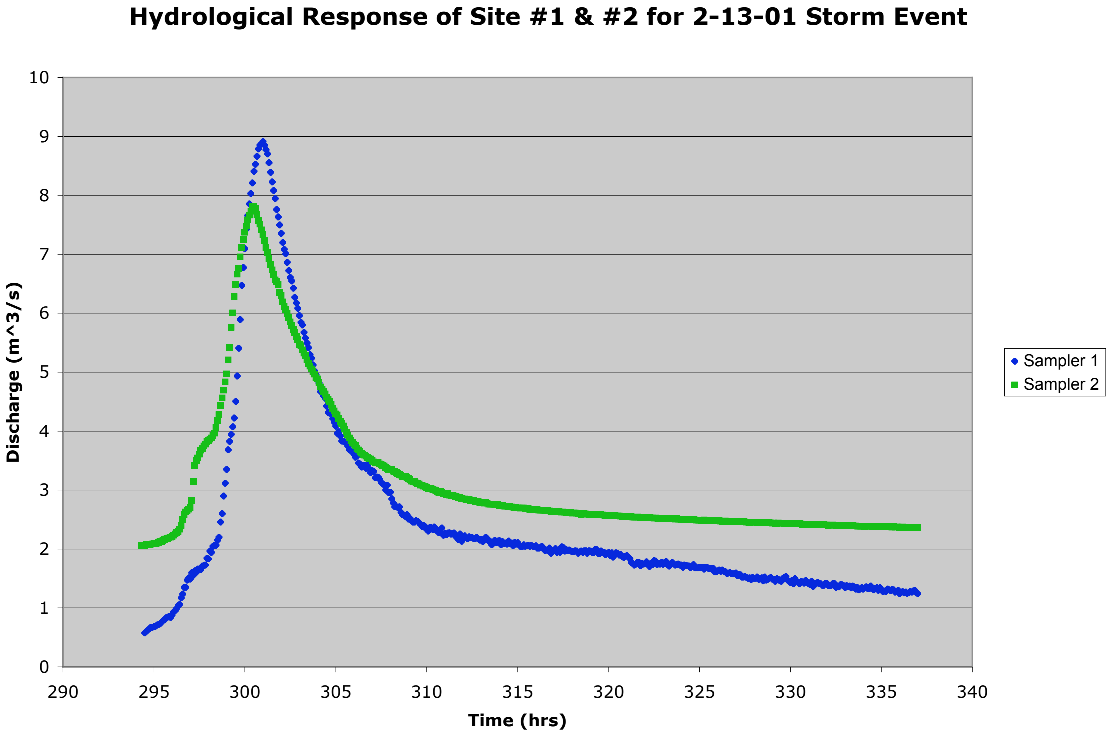
Since most of the discharge occurred during the months of January to April for which there is no onsite rainfall data, it is difficult to quantify the hydrologic response of Mary’s Creek relative to the storm events. In addition, there was only one storm for Sampling Site #2 for which there was rainfall data and discharge. Despite these limitations, comparisons can be made between the discharge regimes for the two sampling sites using the storm hydrographs. It should be noted that the lack of data for Sampling Site #2 was due to the need to remove the pressure transducer from Site #2 to replace the damaged pressure transducer at Sampling Site #1. It was deemed more important to obtain the data from the outlet (Site #1) than from upstream (Site #2) while waiting for the new replacement transducer to be ordered and delivered.

Because a storm hydrograph comprises both stormflow and baseflow, and this study was designed to examine only storm runoff, it was necessary to separate these two components using a technique called “graphical hydrograph separation.” There are several methods that can be used to separate stormflow from baseflow. However, it should be noted that all of these techniques are “arbitrary and have little or nothing to do with the processes by which stormflow is generated, but if one method is employed consistently, then usable results are obtained” (Dunne & Leopold, 1978, p. 287). To this end, a constant-slope baseflow separation method designed for watershed basins that are smaller than 20 square miles was selected to graphically separate the two components of stormflow and baseflow on the storm hydrographs (Appendix E). This method involves drawing a line from the point of initial hydrograph rise that slopes upward at the constant rate of .05 cubic feet per second. This constant sloping line is extended until it intersects the hydrograph. The area under each storm hydrograph and the baseflow line was calculated by averaging the data points using the equation $(Q1+Q2)/2*t$, where “Q” is discharge in cubic meters per second and “t” is the time in seconds between the two discharge data points. The difference between the two curves yielded the volume of the actual runoff.

To further understand how meteorologic factors and drainage-basin characteristics affected the shape of the storm hydrographs, other important hydrological variables were calculated including maximum rainfall intensities, runoff coefficients, centroid lag-to-peak, and time of rise. Maximum rainfall intensities were computed for 5, 15, 30, and 60 minute durations. These were computed by taking the maximum amount of rainfall that occurred in the stipulated time period and converting it to a rate in inches per hour. Runoff coefficients were calculated for seven of the storms by dividing the runoff volume by the total volume of rainfall, which was obtained by multiplying the measured rain depth by the area of the basin. Centroid lag-to-peak is a commonly used measure of basin response time. The centroid lag-to-peak is defined as the time between the center of mass of the rainfall and the peak runoff rate. Due to the occurrence of multi-peaked hydrographs and the spatial and temporal variability of the rainfall, the centroid lag-to-peak was often a challenge to calculate. The duration of the hydrograph rise is called the time of rise. Time of rise is defined as the difference between the time of peak discharge and the beginning of the effective water input. Generally, the peak discharge occurs when or soon after water input ceases.

A comparison of storm hydrographs reveals that the two sampling sites have very similar responses to rainfall events (Figures 12-14). This is not surprising since both sites are located within the boundaries of the Walsh Ranch and are subject to very similar land use regimes (pasture and rangeland for cattle) as well as similar soil and geologic properties. Table 3 summarizes and compares the key quantitative components of the discharge regime of both sites. In response to the rain events that occurred on February 13, 15, and 23, Sampling Site #1 had a larger peak discharge than Sampling Site #2; whereas, for the March 24 and 27 rain events, the peak discharge was greater for Sampling Site #2. This is probably due to a “threshold effect” generated by a retention pond immediately upstream of Sampling Site #1 near the basin outlet. From the data in Table 3, it can be speculated that for smaller discharges (~$5m^3/s$ or less), large volumes of runoff are stored in the retention pond resulting in a lower peak discharge for Sampling Site #1 as compared to Sampling Site #2. Larger discharges ($>5m^3/s$) exceed the storage capacity of the retention pond and all of the runoff travels as stormflow to the outlet at Sampling Site #1, resulting in a larger peak discharge than observed at Sampling Site #2.

In all but one (February 15) of the storm events depicted in Figures 12-14, Sampling Site #1 had a longer time of rise than Sampling Site #2. In all five events, the average discharge was greater for Site #2 than Site #1. This is not surprising given that the baseline discharge for Site #2 was greater than the baseline discharge for Site #1. Moreover, the greater average discharge for Site #2 may also be due in part to its smaller drainage area. Thus, the precipitation has less distance to travel as runoff before entering Mary’s Creek. Smaller drainage areas also have less storage capacity and more water will enter the creek as storm runoff rather than later as baseflow. In Figure 12, it should be noted that the hydrological response to the February 15



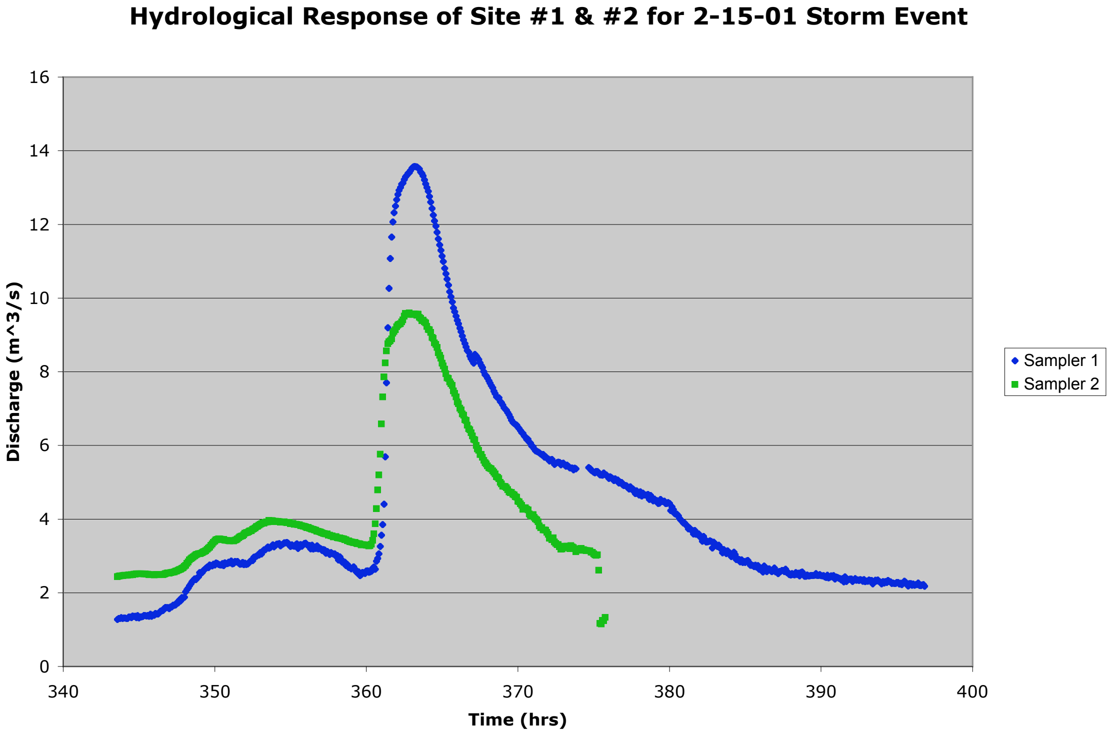
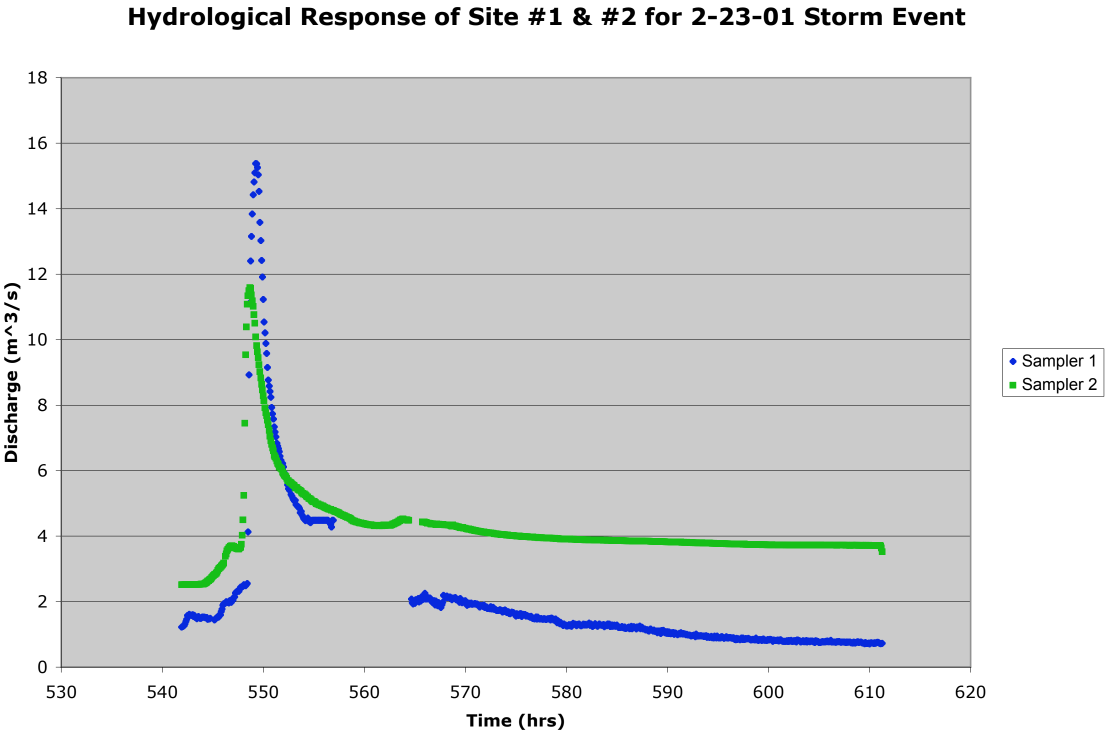


Figure 12. Comparison of hydrological response of both sites on Mary's Creek for February 13 and February 15, 2001 storm events.



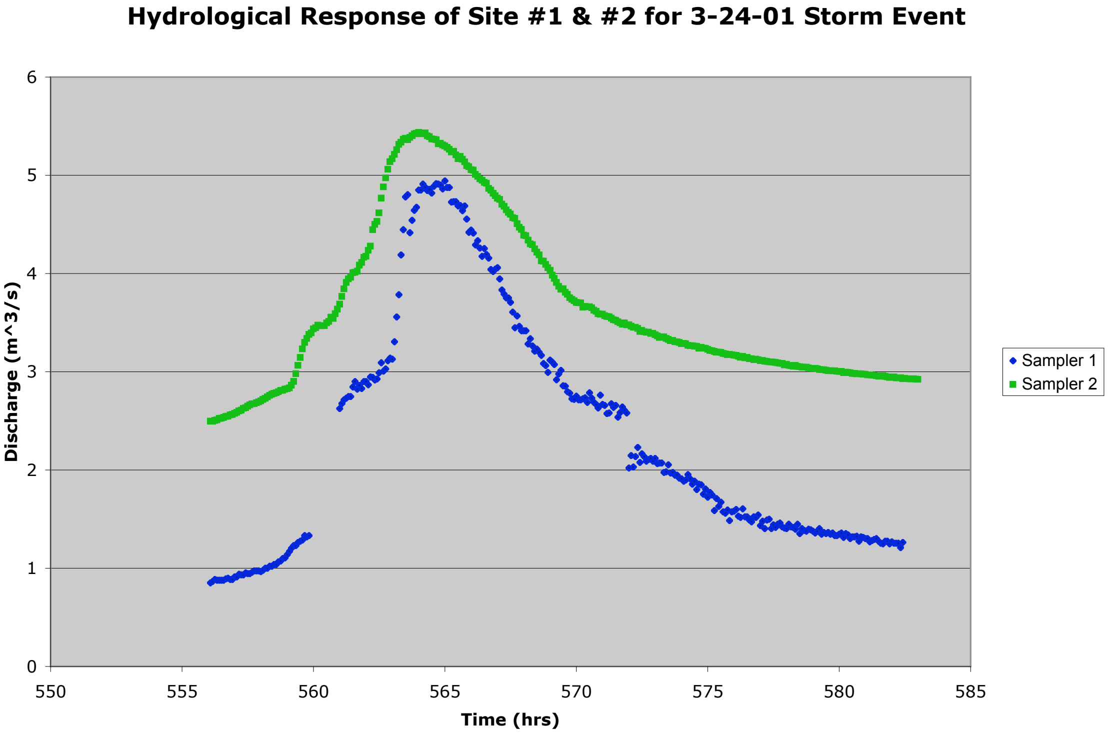


Figure 13. Comparison of hydrological response of both sites on Mary's Creek for February 23 and March 24, 2001 storm events.

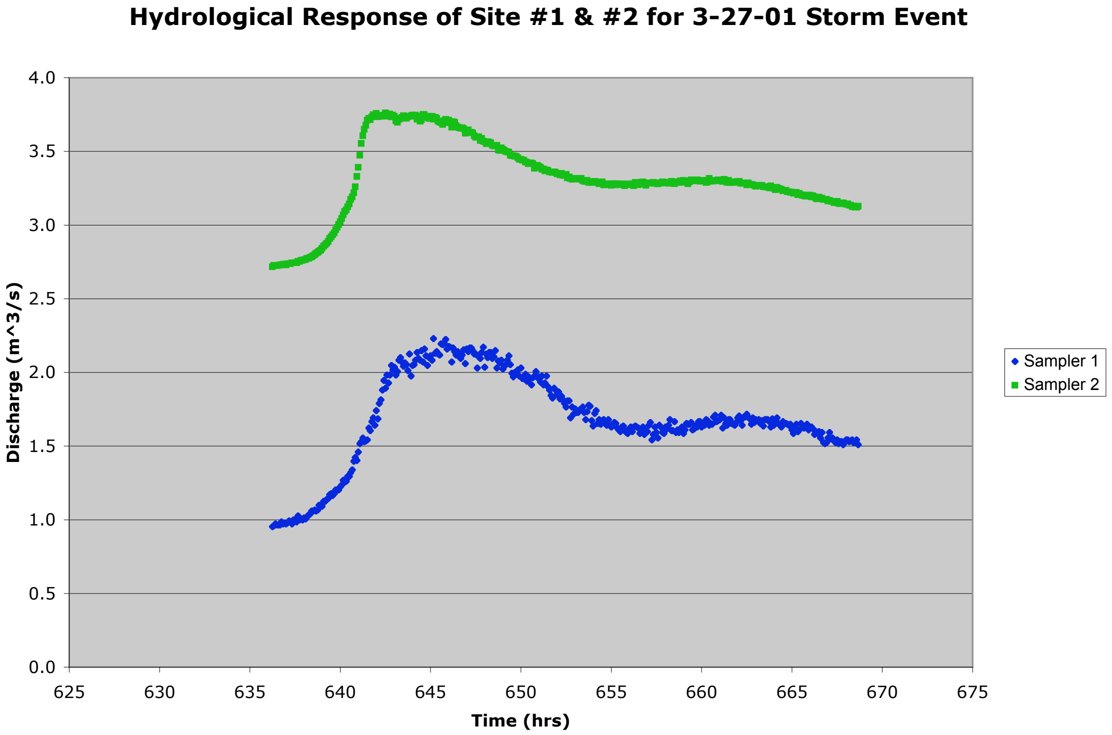


Figure 14. Comparison of hydrological response of both sites on Mary's Creek for March 27, 2001 storm events.

Table 3. Comparison of hydrological response of both sites to selected storm events

Sampler 1				
Date of Storm Event	**Average Discharge**	**Peak Discharge**	**Runoff Depth**	**Time of Rise**
	(m^3/s)	**(m^3/s)**	**(in)**	**(hrs)**
2/13/01	2.51	8.91	0.34	6.50
2/15/01	4.40	13.57	0.67	18.67
2/23/01	3.60	15.38	0.27	7.33
3/24/01	2.35	4.94	0.16	8.92
3/27/01	1.74	2.23	0.07	6.59
Averages	**2.92**	**9.01**	**0.30**	**9.60**
Sampler 2				
Date of Storm Event	**Average Discharge**	**Peak Discharge**	**Runoff Depth**	**Time of Rise**
	(m^3/s)	**(m^3/s)**	**(in)**	**(hrs)**
2/13/01	3.56	7.82	0.30	6.09
2/15/01	4.50	9.60	0.46	19.25
2/23/01	3.93	11.59	0.64	4.50
3/24/01	3.64	5.43	0.20	8.17
3/27/01	3.34	3.76	0.09	6.25
Averages	**3.79**	**7.64**	**0.34**	**8.85**

storm event for Sampling Site #2 is incomplete due to the pressure transducer being dislodged due to the intensity of the stormflow.

The maximum rainfall intensity calculations show that three storms (May 28, June 14, and June 21) exceeded the normal 2-year 30-minute and only one storm (June 14) exceeded the 2-year 1-hour rainfall intensities for Parker County, 1.4 to 1.6 in/30 minutes and 1.6 to 1.8 in/hour, respectively (Dunne & Leopold, 1978; Figure 15). Therefore, these three storms represent large magnitude, low frequency events and the remaining storms, albeit the majority, were relatively low magnitude, high frequency events. Large magnitude, low frequency storms typically are an important cause of large amounts of runoff and erosion. However, the soil moisture content can also affect the response of a basin to a storm event since infiltration rates decrease as the soil water content increases. Thus, previous storms or irrigation can increase the runoff from an area. This study did not take antecedent soil moisture into account and represents a flaw in the methodology and limits the interpretation of the hydrological response of the sub-basins to storm events.

As can be seen in Figure 16, the runoff coefficients reported in this study are unusually low in comparison to the expected 10-15% for this region (Reed, et. al, 1997). Smaller basins typically have larger runoff coefficients. The runoff coefficients for this study may be lower due to a larger than average storage capacity for a basin this size. This implies that the majority of the streamflow in Mary’s Creek travels to the creek via delayed routes as baseflow. Moreover, it is evident that the June 14 and December 16 storms produced the most runoff and the May 30 and July 1 storms produced the least runoff. Because of differences in storm intensity and duration and antecedent moisture content of the soil, it is common for storms generating similar

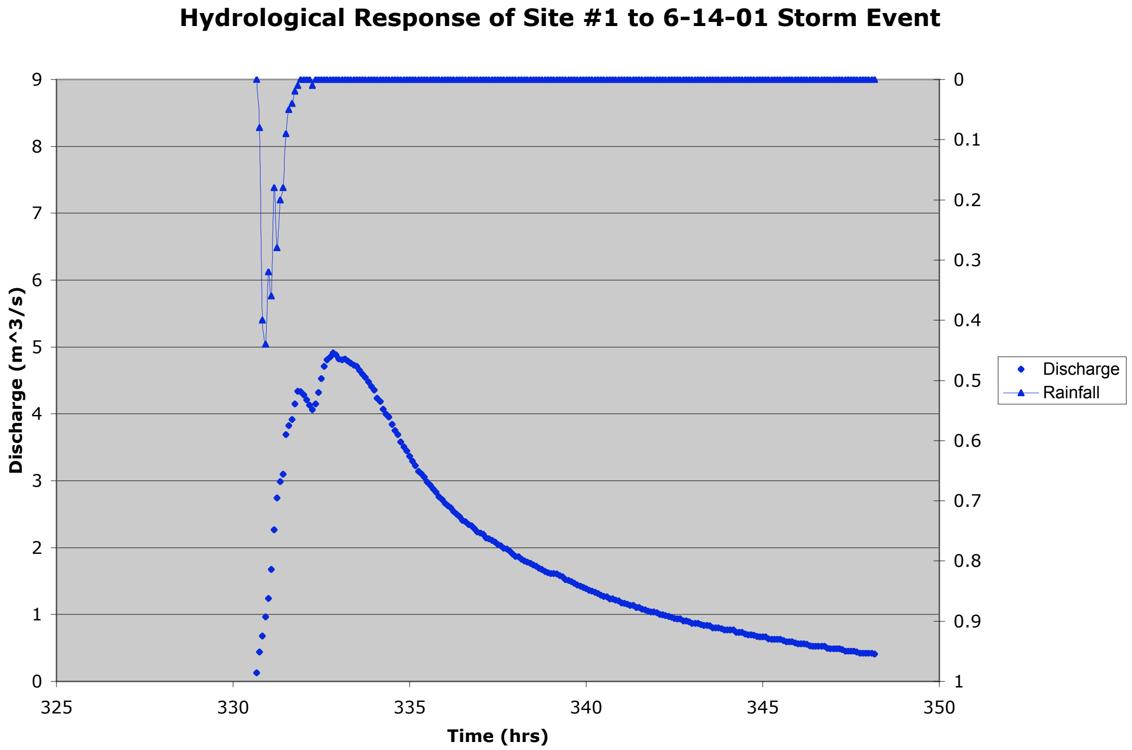


Figure 15. Hydrograph for the June 14, 2001 storm that exceeded the 2-year 1-hour rainfall intensities for Parker County, TX.

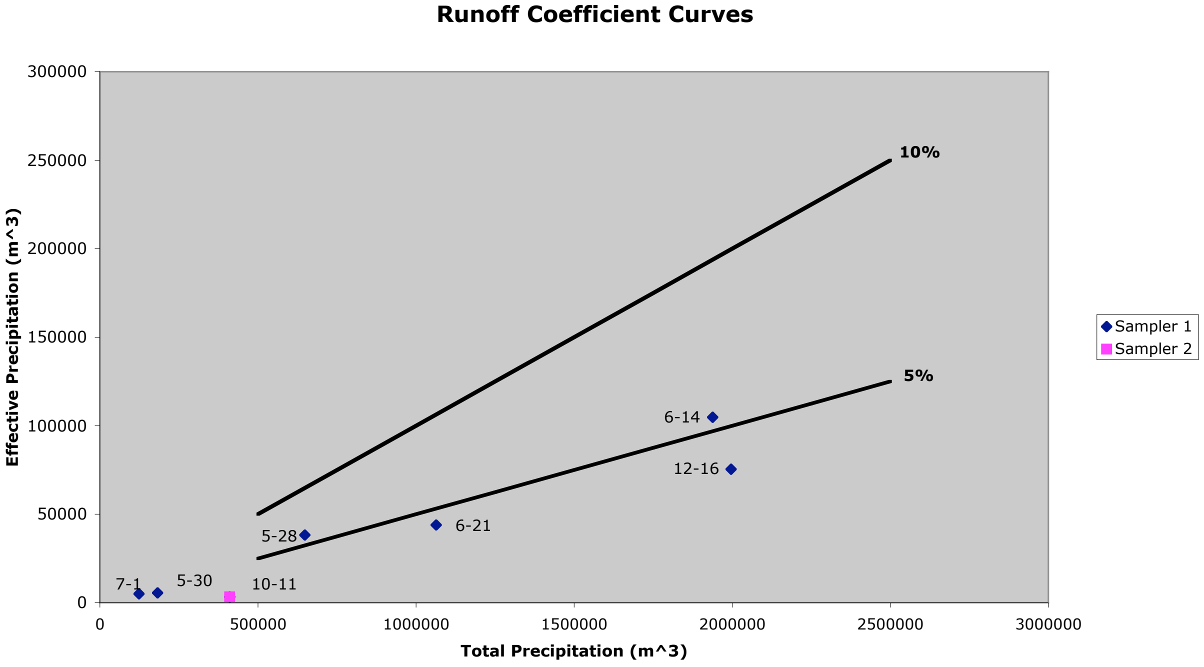


Figure 16. Distribution of the runoff coefficients and relationship between rainfall and runoff in the Mary's Creek watershed.

amounts of rainfall to produce significantly different amounts of storm runoff and for storms generating different amounts of rainfall to produce similar amounts of runoff.

However, this is not the relationship revealed by the data in this study. As shown in Figure 16, storms generating similar amounts of rainfall also produced extremely similar amounts of runoff. What does this mean? These results most likely can be attributed to a small dataset; seven storms do not adequately reveal the true relationship between total precipitation and effective precipitation in this basin.

Based on calculated centroid lag-to-peak times and sub-basin size, the predominant runoff-producing mechanism on the Walsh Ranch appears to be a combination of Hortonian overland flow and saturation overland flow (Figure 17). Once rainfall intensity exceeds the infiltration capacity, runoff rises rapidly to a sharp peak at the end of rainfall, followed by a rapid decline as soon as the rainfall intensity decreases. If there are any succeeding bursts of rainfall,

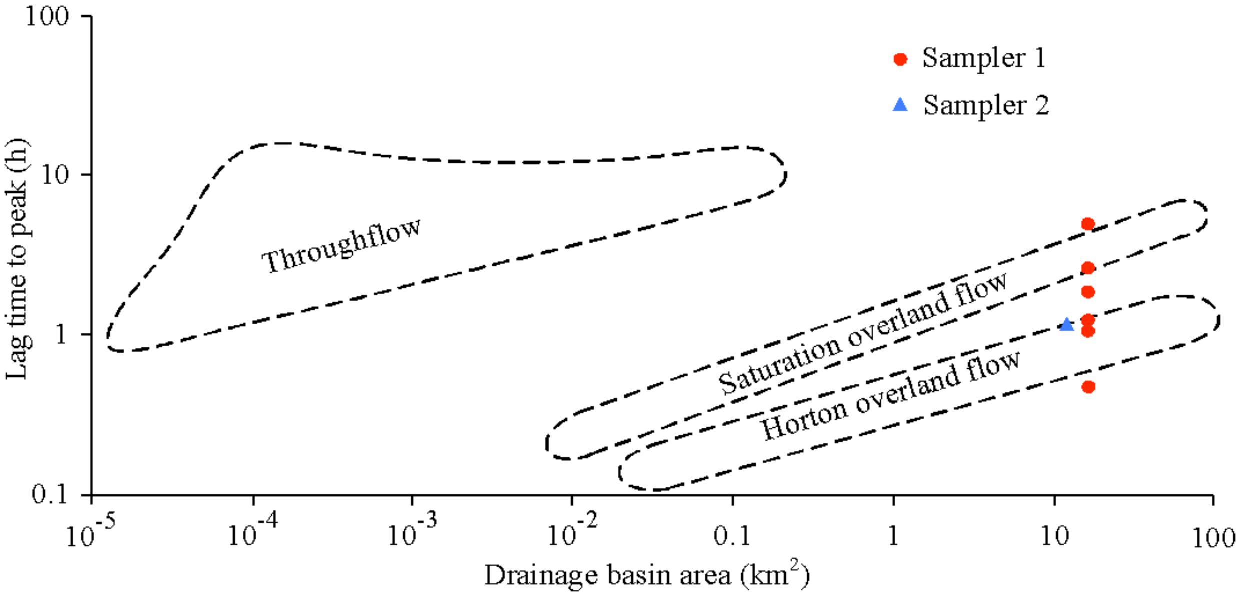


Figure 17. Ranges of peak lag time associated with various response mechanisms (after Dingman, 2002).

the process is repeated. This accounts for the rapid hydrological response of the creek and the multi-peaked hydrographs.

Given that the Walsh Ranch is comprised of the Aledo-Venus-Bolar soil association, it is not surprising to find Hortonian overland flow operating as a predominant runoff mechanism. As mentioned in Chapter 2, the Aledo-Venus-Bolar soil association contains a lot of clay soils with relatively low permeability. As such, even moderate rainfall inputs will exceed infiltration capacity and the clay soils will serve as an impervious cover, thus producing runoff in the form of Hortonian overland flow. Dunne and Leopold (1978) indicate that Hortonian overland flow commonly occurs on areas devoid of vegetation or possessing only a thin cover, such as semi-arid rangelands and cultivated fields in regions with high rainfall intensity. This is a valid description of the climatological, geological, and land use characteristics of the Walsh Ranch. However, it should be pointed out that the area contributing Hortonian overland flow may be only a small portion of the basin according to the partial-area concept of storm runoff (Betson, 1964).

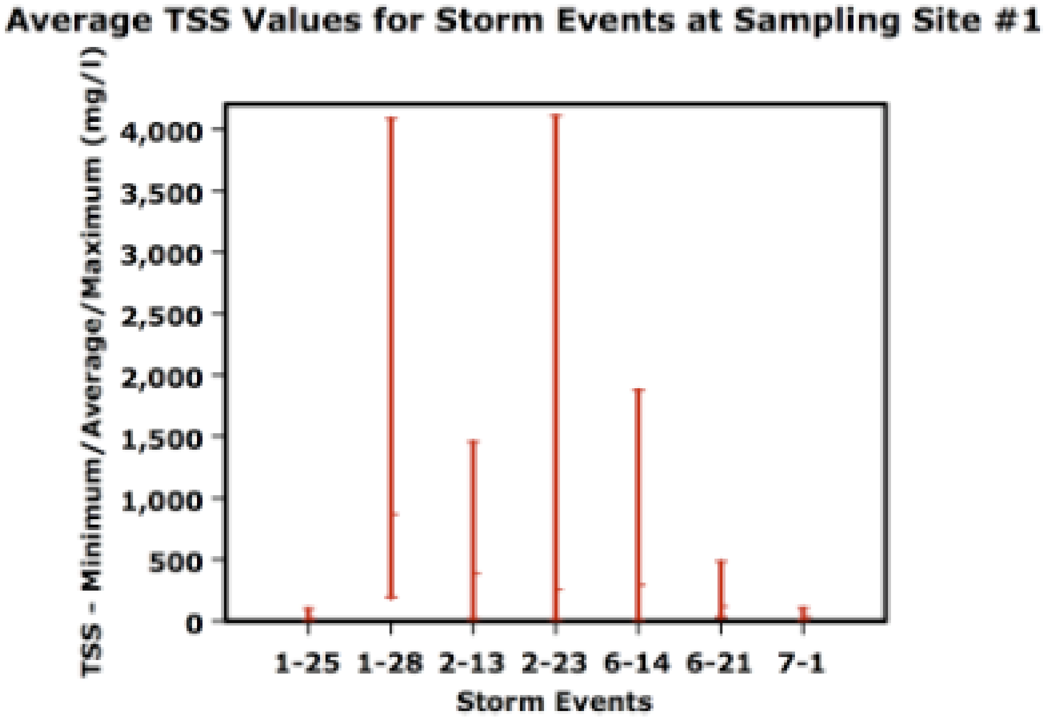
Indeed, results of a study of runoff generation in the hillslope hollow between Sampling Sites #1 and #2 on the Walsh Ranch, revealed that the process controlling the runoff from that area was saturation overland flow (Johnson, 2003). Some of the calculated centroid lag-to-peak times in this study also indicate that saturation overland flow was operating as the response mechanism. This data underscores the complexity of stream hydrologic response even within a relatively small watershed. The response mechanism in operation likely will vary within the watershed and from storm to storm due to the variability in key watershed characteristics; most importantly, the spatial and temporal variability associated with antecedent soil moisture content and rainfall intensity and duration.

It is evident from the average time of rise calculations that Mary's Creek is a "flashy" creek, meaning that the water level is quick to rise and quick to fall. Average time of rise for Sampling Site #1 and #2 was 6.38 hours and 7.06 hours, respectively. This is not very surprising given that, in general, streams from smaller basins will be flashier than those from larger ones. Moreover, the high clay content of the soil and the intense, short duration storm events characteristic of this region are factors that also typically produce flashy stream responses (Gordon, et. al, 2004).

Sediment Flux

In this 13-month field study, a total of 245 samples were collected during both baseline and stormflow conditions in order to quantify sediment flux from the basin.

Spatial and temporal variations. Sediment concentrations at both sampling sites on Mary's Creek during both storm events and non-storm periods are shown in Figures 18 and 19. In Figure 18, total suspended solid (TSS) values were averaged for each storm event and graphed with the corresponding maximum and minimum values observed at both sampling sites. The actual TSS storm data values are given in Appendix D. Over the course of this study period, 136 TSS samples were collected across seven storm events at Sampling Site #1 and 79 TSS samples were collected across four storm events at Sampling Site #2. The average TSS across all storm events at Sampling Site #1 was 271.43 mg/l with a maximum and minimum value of 4,100.6



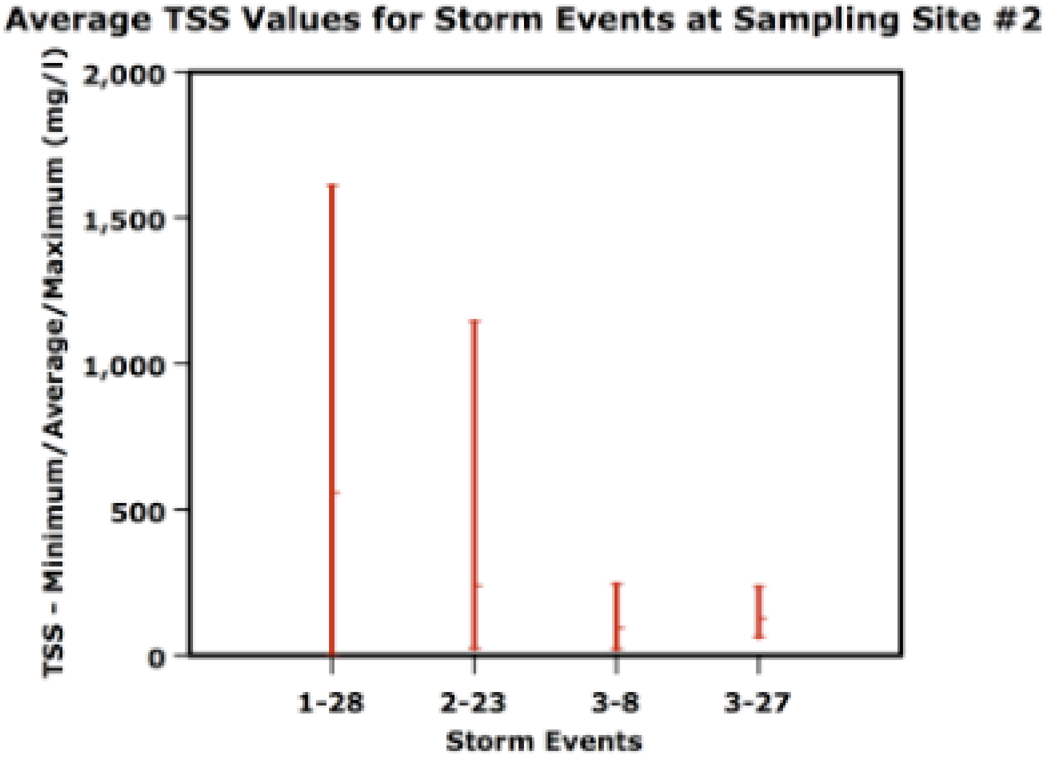


Figure 18. Average TSS values for storm events at both sites on Mary's Creek.

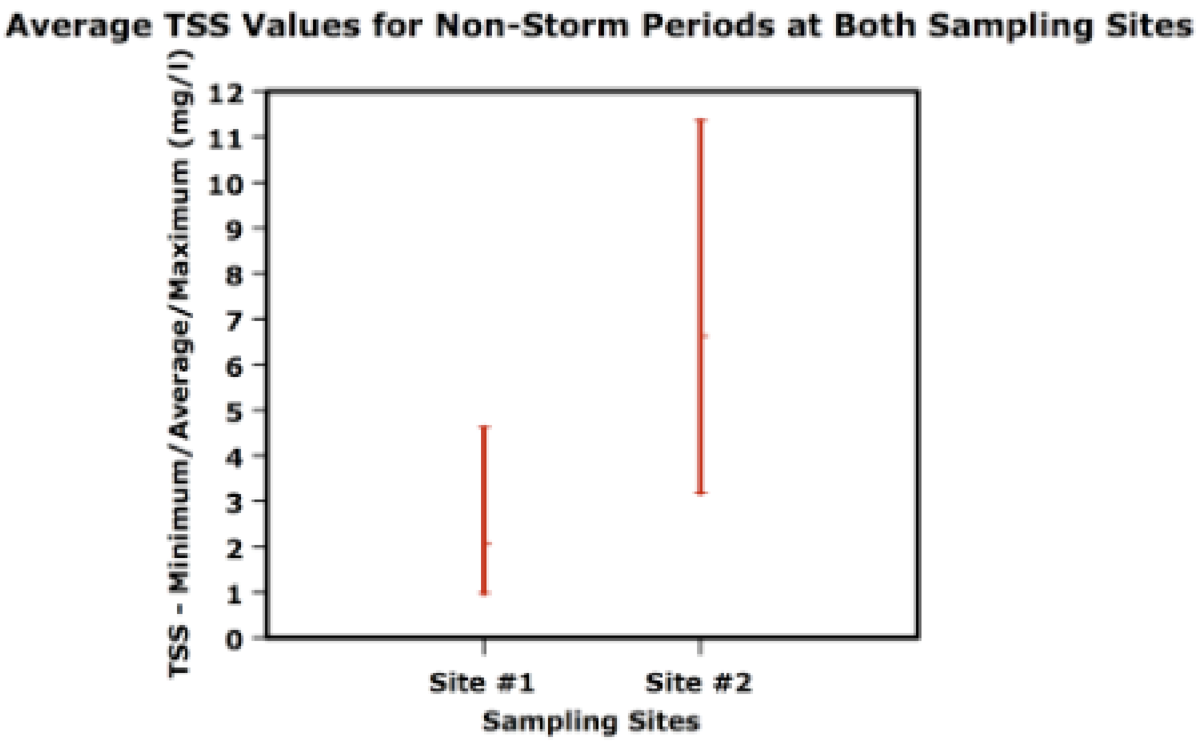


Figure 19. Average TSS values for non-storm periods at both sites on Mary's Creek.

mg/l and 5 mg/l, respectively. Average TSS values for storm events at Sampling Site #2 was 294.64 mg/l with a maximum and minimum value of 1,610 and 0 mg/l, respectively.

The overall average TSS value at Site #2 was higher than at Site #1. This is somewhat unexpected given that Site #2 is the upstream site and Site #1 is the outlet. It is reasonable to expect that additional sediment would be delivered to Mary's Creek from contributing areas located between the upstream site and the outlet. Indeed, it is fairly common to see such a suspended sediment buildup along the conveyance route. On the other hand, given the bank instability at both sites, especially at Sampling Site #2, it is not surprising to discover a higher average TSS value associated with that particular site. Evidence of slumping from the higher, concave bank at Site #2 was observed following several storm events. The clay content of the soil and the lack of ground cover and trees along the bank at Site #2 were contributing factors to the bank instability. It should also be noted that although the average TSS value at Site #2 was greater than at Site #1, the difference was found to be not statistically significant using the non-parametric Mann-Whitney U test (Appendix F). However, the difference in overall average TSS storm event values between the two sites may be misleading due to the limited number of samples collected during storm events at Sampling Site #2 because the pressure transducer had to be removed from this site to replace the damaged pressure transducer at Site #1. As mentioned earlier, samples from seven different storm events were collected at Site #1; whereas, at Site #2 samples were collected from four different storm events. Thus, the TSS concentrations may be underestimated for the upstream site due to relatively sparse and inconclusive data.

As can be seen in Figure 18, there are only two storm events (January 28 and February 23) common to both sites for which there is TSS data. This primarily was due to the need to relocate the pressure transducer from the second site to replace the damaged pressure transducer at the first site, as was previously noted. Thus, it is difficult to make comparisons between sites regarding sediment flux in relation to stormflow. Average TSS values were greater at Site #1 than at Site #2 for the January 28, 2001 storm event, 866.67 and 557.91 mg/l, respectively. In comparison, average TSS values for Site #1 and Site #2 for the February 23, 2001 storm event were comparable, 255.41 and 240.05 mg/l, respectively. However, the maximum TSS values were greater at Site #1 for both storm events. For the January 28, 2001 storm event, maximum TSS values for Sites #1 and #2 were 4,080 and 1,610 mg/l, respectively. For the February 23 storm event, maximum TSS values for Sites #1 and #2 were 4,100.6 and 1,144.7 mg/l, respectively. Although sediment samples from Site #2 were obtained and analyzed for the January 28, 2001 storm event, it should be pointed out that no hydrologic data were analyzed from this storm event due to the transducer being ripped out early in the duration of the storm. Moreover, a depth-integrating sediment sampler was not used in this study. Thus, the reported TSS values do not take into account vertical and lateral patterns of sediment concentration and velocity. Therefore, the pattern of sediment discharge revealed in this study may not be representative of the cross section at both sampling sites.

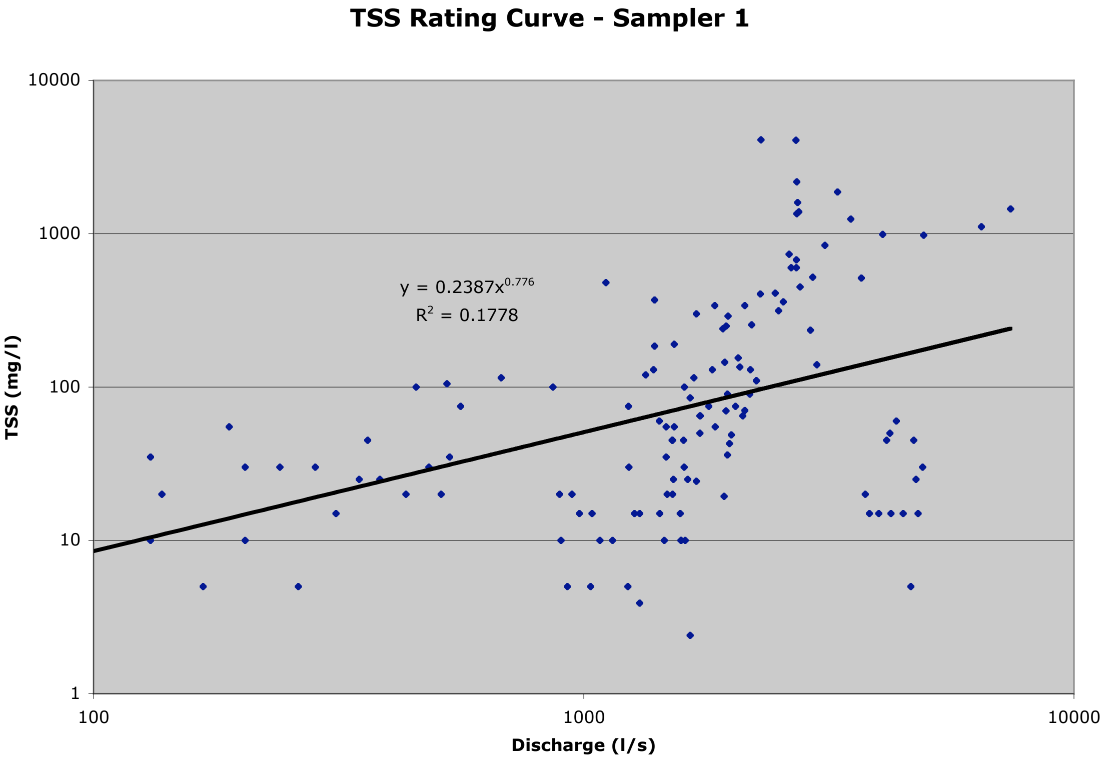
A total of 15 grab samples were collected during baseline or non-storm periods at each sampling site. These TSS values were generally low, ranging between 0.97 and 11.36 mg/l across both sampling sites. Interestingly, the TSS non-storm values at the outlet (Site #1) were lower than those upstream (Site #2); which corresponds to the observed overall average TSS storm event values discussed above. The average TSS non-storm value at Site #1 was 2.07 mg/l as compared to 6.62 mg/l at Site #2 (Figure 19). As mentioned in the preceding hydrologic response section, there is a retention pond located immediately upstream from Sampling Site #1. The lower TSS values at the outlet may be due to the effects of the retention pond on flow velocity and, subsequently, settling velocities of the suspended sediment. However, the difference may likely be related to sporadic localized inputs of sediment. It is possible that the higher TSS values at Site #2 may be due to higher cattle traffic along the banks and in the creek itself. Site #2 was located near a large grazing area for the cattle and evidence of cattle traffic along the banks and in the creek was observed on several occasions. In addition, Site #2 provides easier access for the cattle to enter the creek.

TSS rating curves. TSS rating curves were generated for both sampling sites to depict the relationship between stream discharge and suspended sediment. All suspended sediment data obtained at the sampling sites were used to produce the rating curves, with the exception of the

TSS data obtained during non-storm periods. As can be seen in Figure 20, the overall scatter in data points is generally high for both sampling sites. There is a weak direct power relationship between discharge and TSS for Site #1; whereas, there is a weak inverse power relationship between discharge and TSS for Site #2. For both sampling sites, the r^2 value is low due to the wide scatter in data points. This scatter may be attributed to the relatively small number of data points, the effects of the retention pond on both discharge and TSS values at Sampling Site #1, and the sporadic and isolated inputs of sediment at both sampling sites.

Separating and plotting the TSS values by precipitation regime reveals some interesting patterns (Figure 21). In terms of TSS values for Sampling Site #1, seasonal variation can be seen. There is a stronger relationship between discharge and TSS during the sub-humid as opposed to the semi-arid precipitation regime. The higher sediment production during the wet season may be attributed to heavier and more intense rainfall and, thus, sporadic and localized inputs of sediment (i.e., slumping). It is also certainly possible that the wetter season results in a more rigorous and extensive saturation overland flow response. According to the variable source-area concept, within a given watershed, the extent of areas saturated from below varies spatially and temporally reflecting the overall watershed wetness. Thus, these variable source-areas or saturation wedges may be tapping into additional sediment sources within the basin.

During the sub-humid precipitation regime, the TSS values for Sampling Site #2 show quite a bit more scatter than for those for Sampling Site #1. It is interesting to note that the majority of the outlying TSS values for both sites occurred during the January 28, 2001 storm event. These large TSS values are surprisingly associated with relatively low flows. One possible explanation is that the January 28, 2001 storm event resulted in slumping of the stream



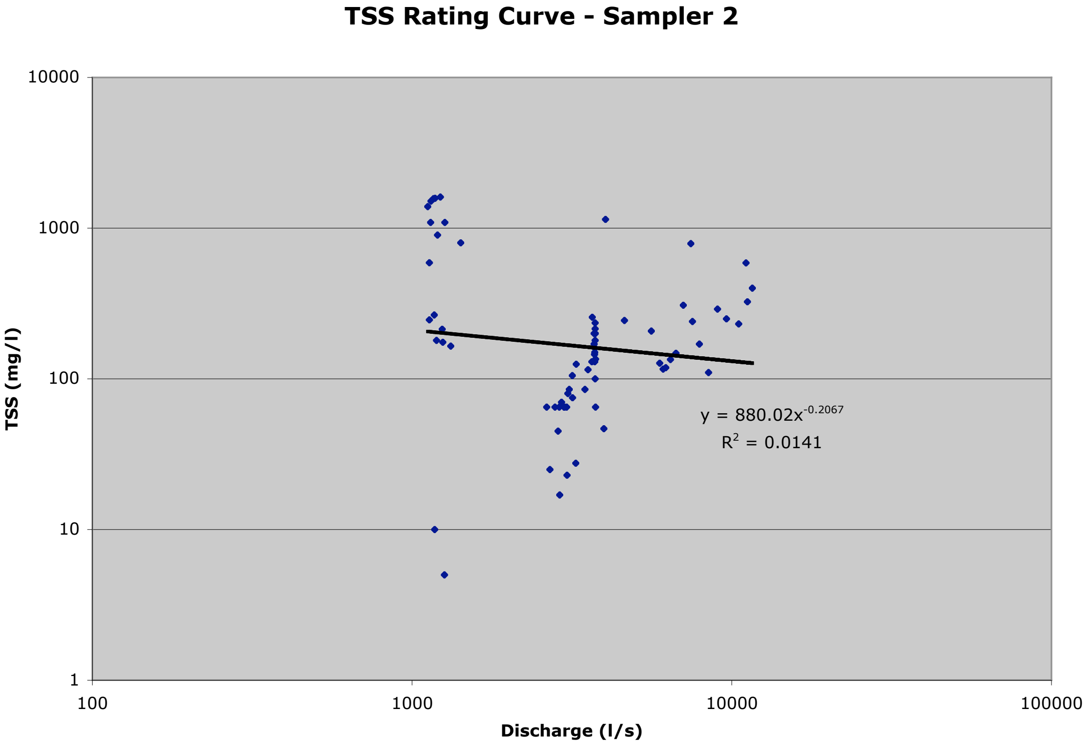
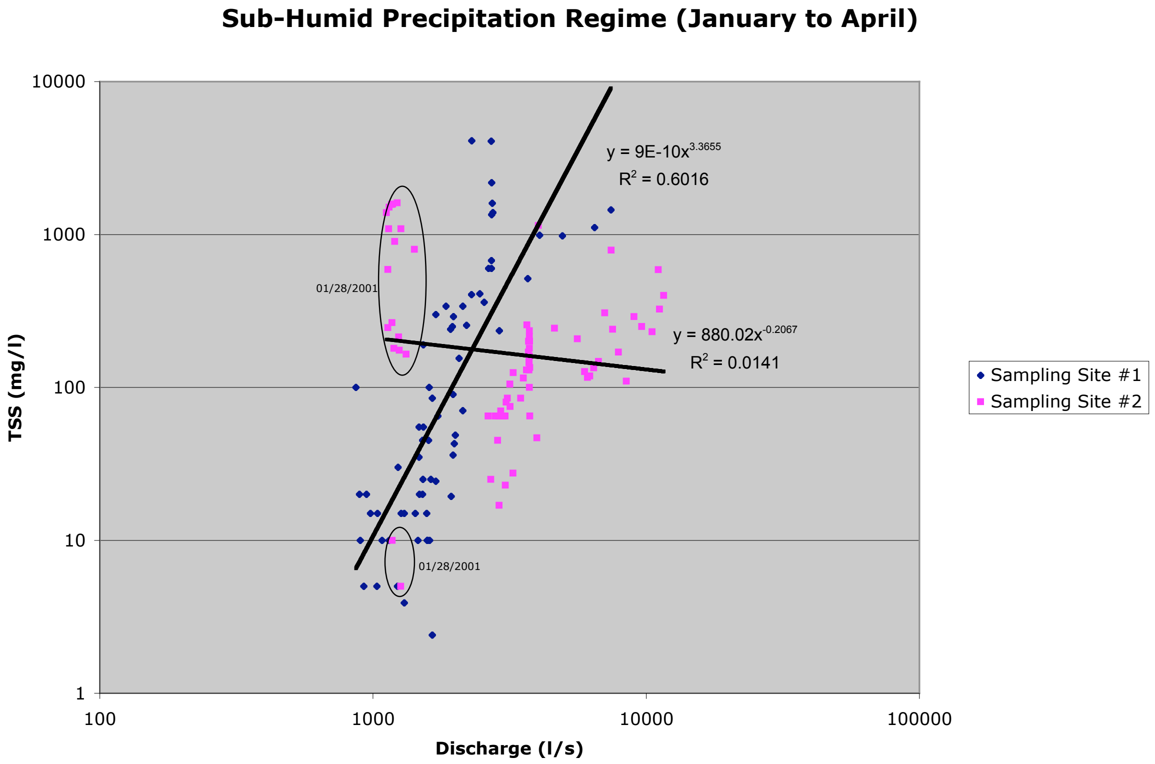
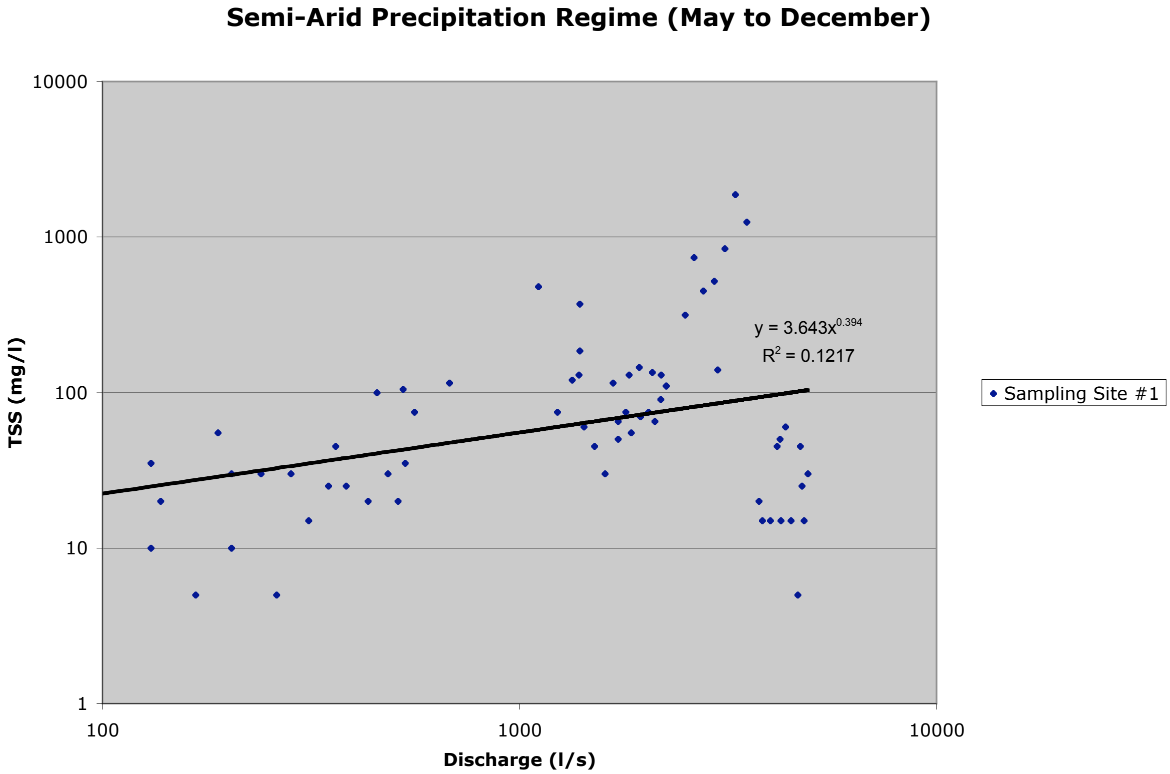


Figure 20. TSS rating curves for both sites on Mary’s Creek.



Sub-Humid Precipitation Regime (January to April)



Semi-Arid Precipitation Regime (May to December)

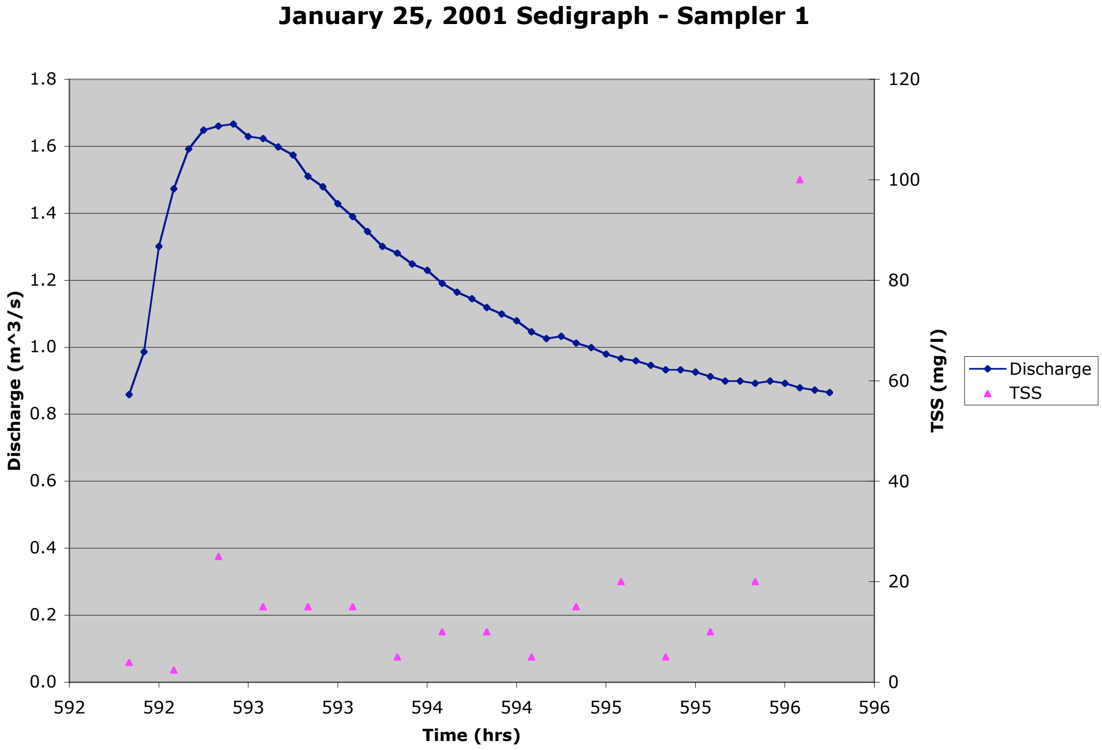
Figure 21. Seasonal TSS rating curves for both sites on Mary's Creek.

banks. A related explanation is that patterns of sediment discharge often do not necessarily coincide with runoff patterns (Gordon, et al., 2004). Erosion is commonly highest at the beginning of a storm event because the sediment is more readily available. This sediment is washed into the stream with the first flush of runoff. As the sediment supply is exhausted, the concentration declines rapidly. As a result, it is not unusual for large sediment concentrations to be associated with lower discharges during the rising limb of the hydrograph. Similarly, when the stage level peaks and begins to fall, sediment concentrations drop substantially and smaller sediment concentrations are often observed for larger discharges. This hysteresis effect will be addressed in more detail in the next section.

The highest TSS values occurred during the sub-humid precipitation regime, when the most intensive and biggest storm events took place. A comparison of the highest TSS values at Site #1 (4,100.6 mg/l) and Site #2 (1,610 mg/l) suggests a higher erosion rate at the outlet site. This is surprising given the greater bank instability observed at the upstream site. However, the higher TSS values may not necessarily be related to higher erodibility of the bank and channel at Site #1, but instead may be due to a buildup of sediment between the two sampling sites resulting in increased sediment delivery. The TSS values for the semi-arid precipitation regime are much more scattered than those for the sub-humid period. Again, this is probably due to the fact that less frequent and lower magnitude storms took place during this period and less sediment was entrained in the storm runoff. Unfortunately, the highest sediment concentrations occurred during the months of January, February, and March when rainfall data was lost due to a computer malfunction. Consequently, a comparison of sediment concentration and rainfall intensity and duration cannot be done.

Sedigraphs and hysteresis plots. To further analyze the sediment flux in Mary's Creek in response to storm events, sedigraph and hysteresis plots were constructed. The sedigraph plots examine discharge and total suspended solids as a function of time. The hysteresis plots examine total suspended solids as a function of discharge. These plots are shown in Figures 22-32 and form the foundation of a more detailed understanding of sediment behavior at both sampling sites. As can be seen in the sedigraphs, the total suspended solid concentration peaks before the discharge for all storms except the January 25 and June 14 storms at Sampling Site # 1 and the March 27 storm at Sampling Site #2. A sediment lead indicates the mobilization of sediment already stored in the channel: whereas, a sediment lag is the result of the mobilization of sediment distal to the basin. Since the majority of the sedigraphs and hysteresis plots for both sampling sites reveal the presence of sediment lead, this overall pattern suggests that Mary's Creek and its watershed is a sediment supply-limited system. The amount carried in the basin discharge is dependent on the suspended sediment availability. This is perfectly illustrated in Figure 27. The large positive hysteresis loop represents the first flush of sediment in the channel that is followed by an exhaustion of sediment and a negative hysteresis loop.

Comparing the sedigraphs of the only two storm events (January 28 and February 23) common to both sites reveals similar hydrologic and sediment response patterns between the headwater and outlet of Mary's Creek. As can be seen in Figure 23 and Figure 29, TSS concentrations peaked before discharge at both sites in response to the January 28 storm event. However, the TSS concentration peaked 7.34 hours before the discharge peaked at Sampling Site #1 as compared to 2.66 hours before the discharge peaked at Sampling Site #2. It is interesting to note that TSS values peaked at the outlet (Site #1) 2.09 hours in advance of the peak in TSS



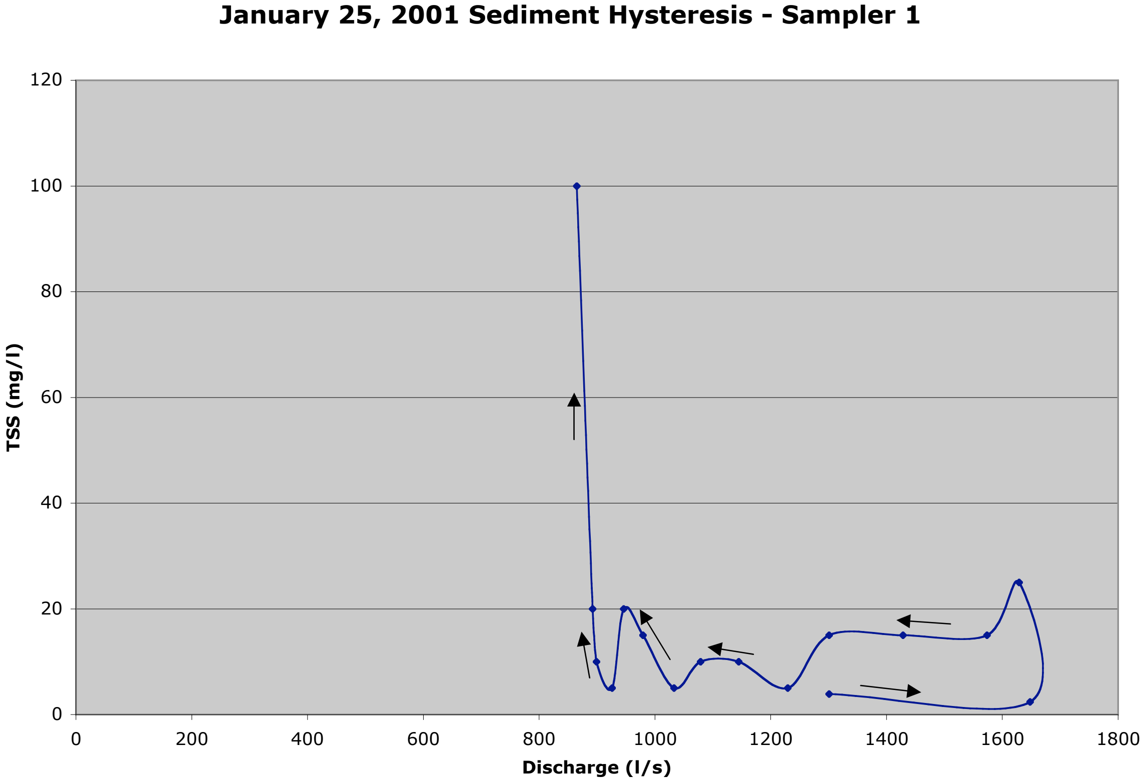
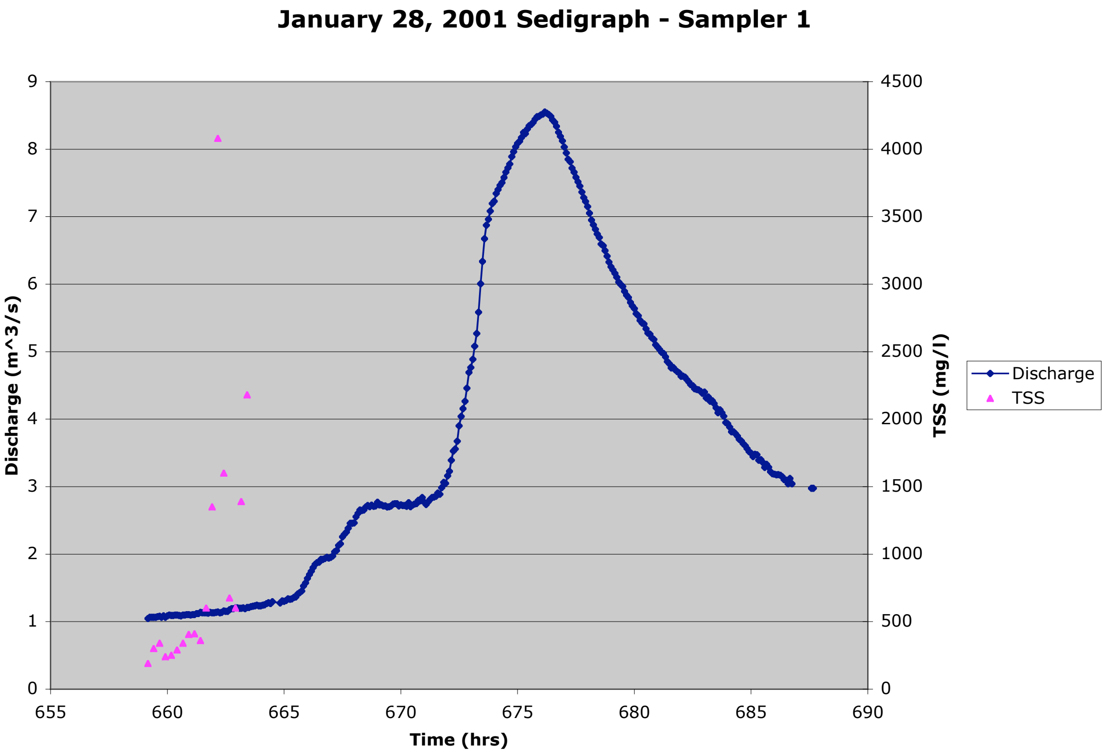


Figure 22. January 25, 2001 storm sedigraph and hysteresis plots for site #1.



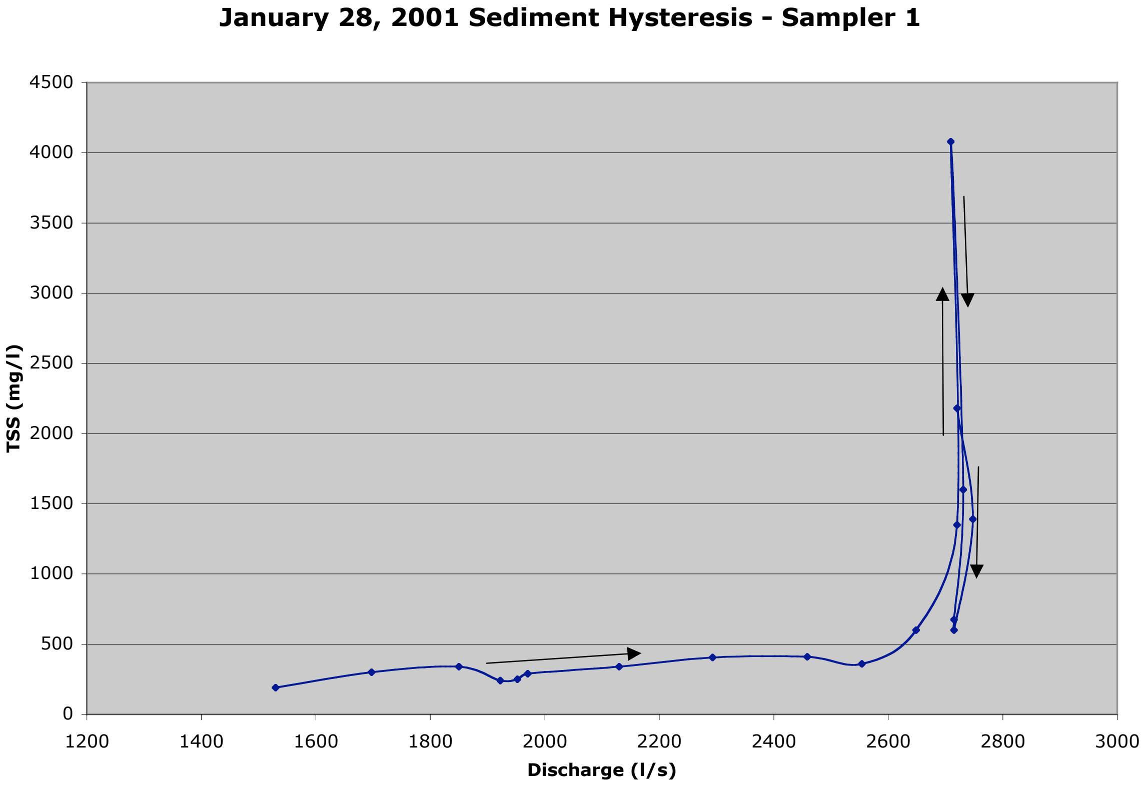
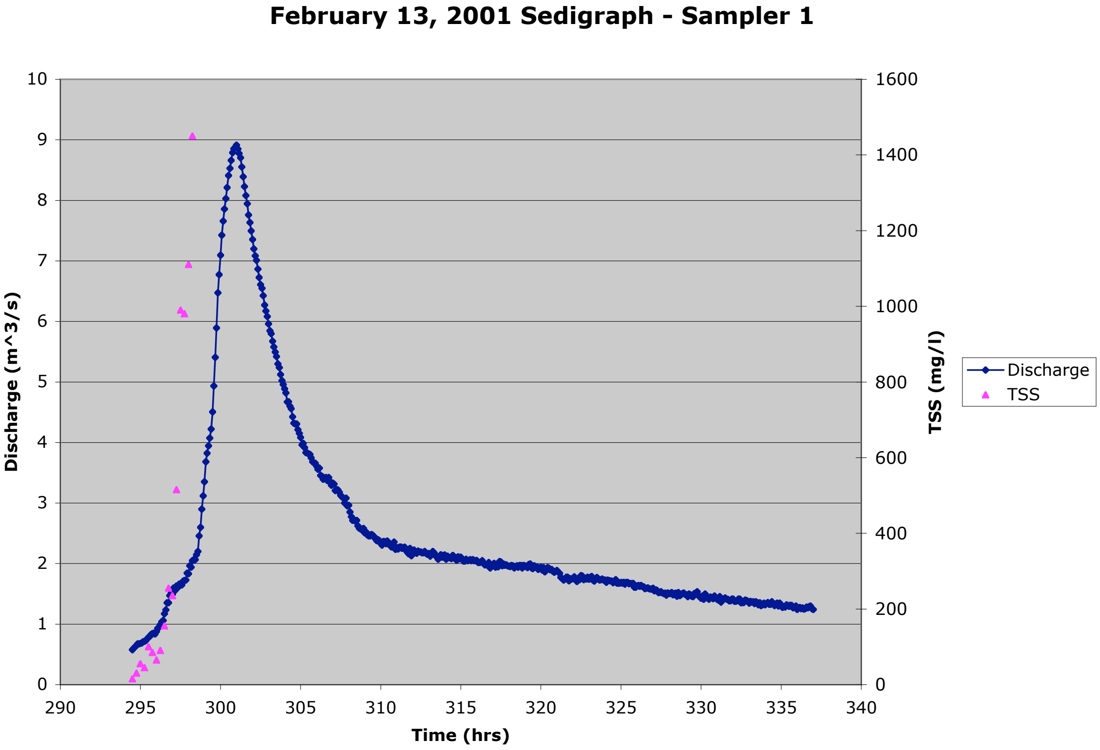


Figure 23. January 28, 2001 storm sedigraph and hysteresis plots for site #1.



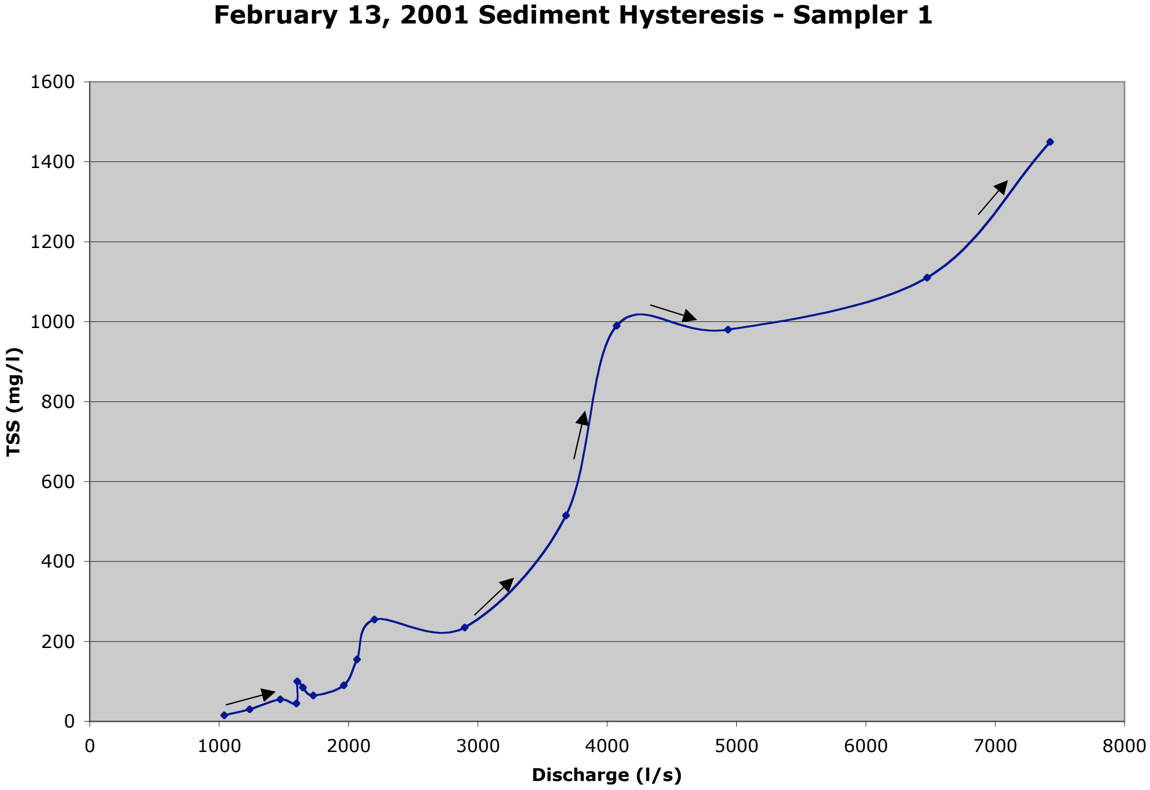
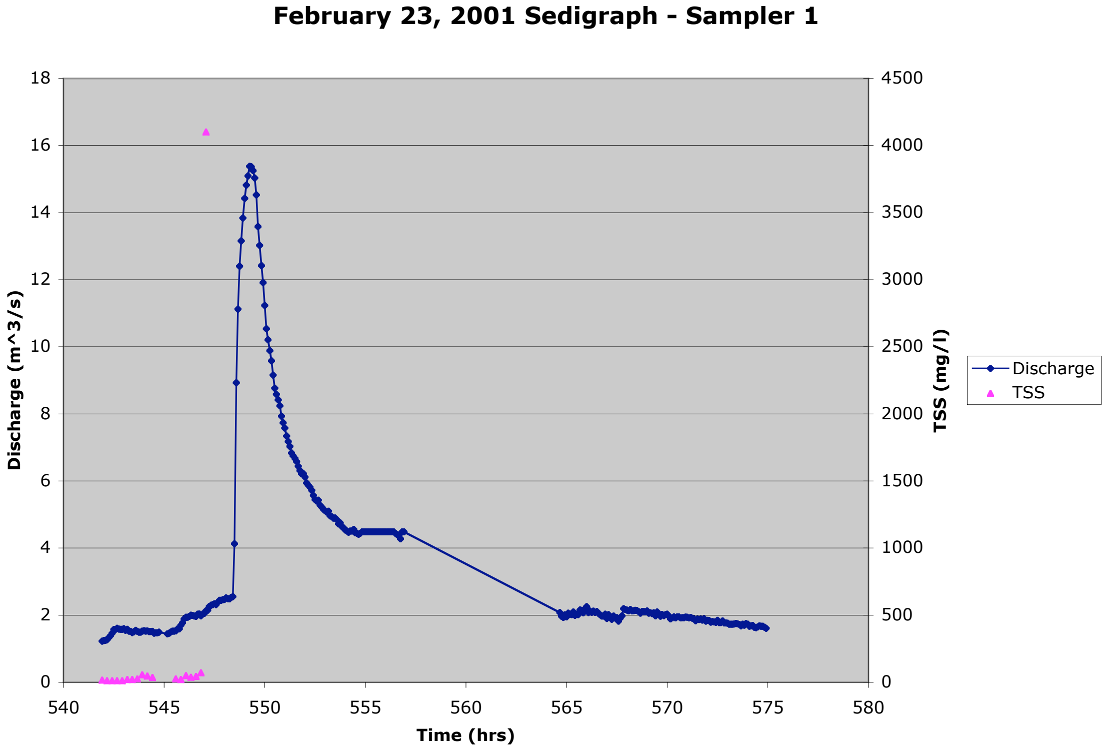


Figure 24. February 13, 2001 storm sedigraph and hysteresis plots for site #1.



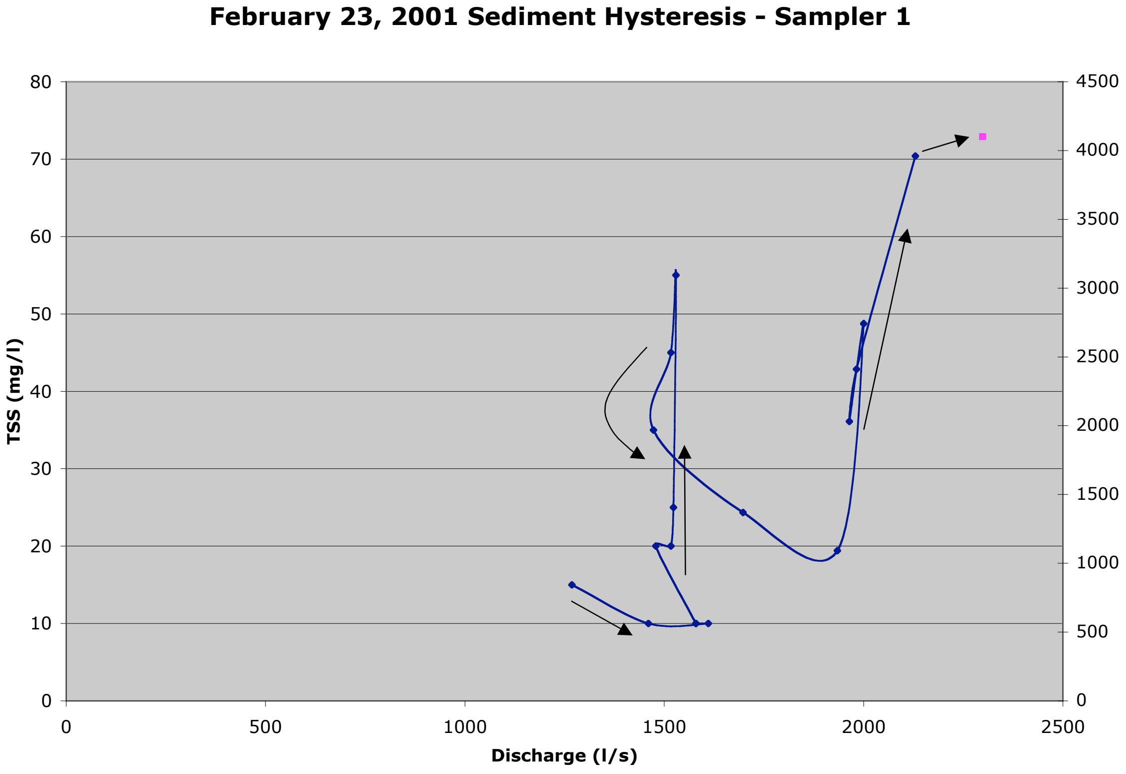
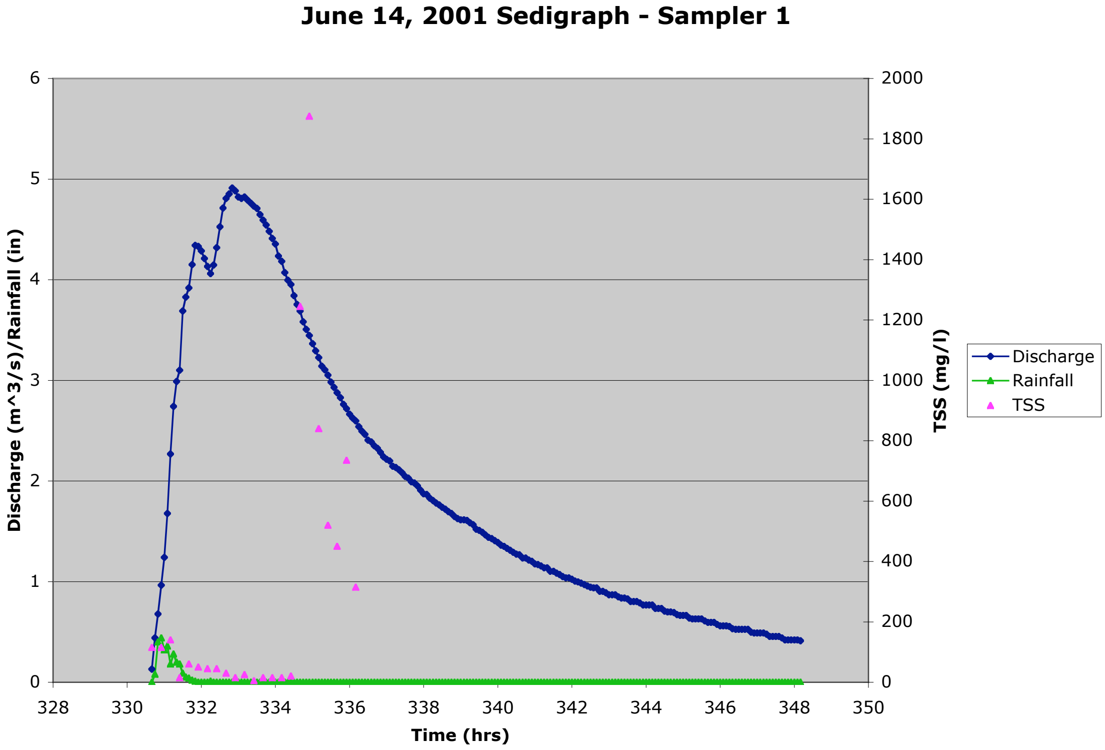


Figure 25. February 23, 2001 storm sedigraph and hysteresis plots for site #1.



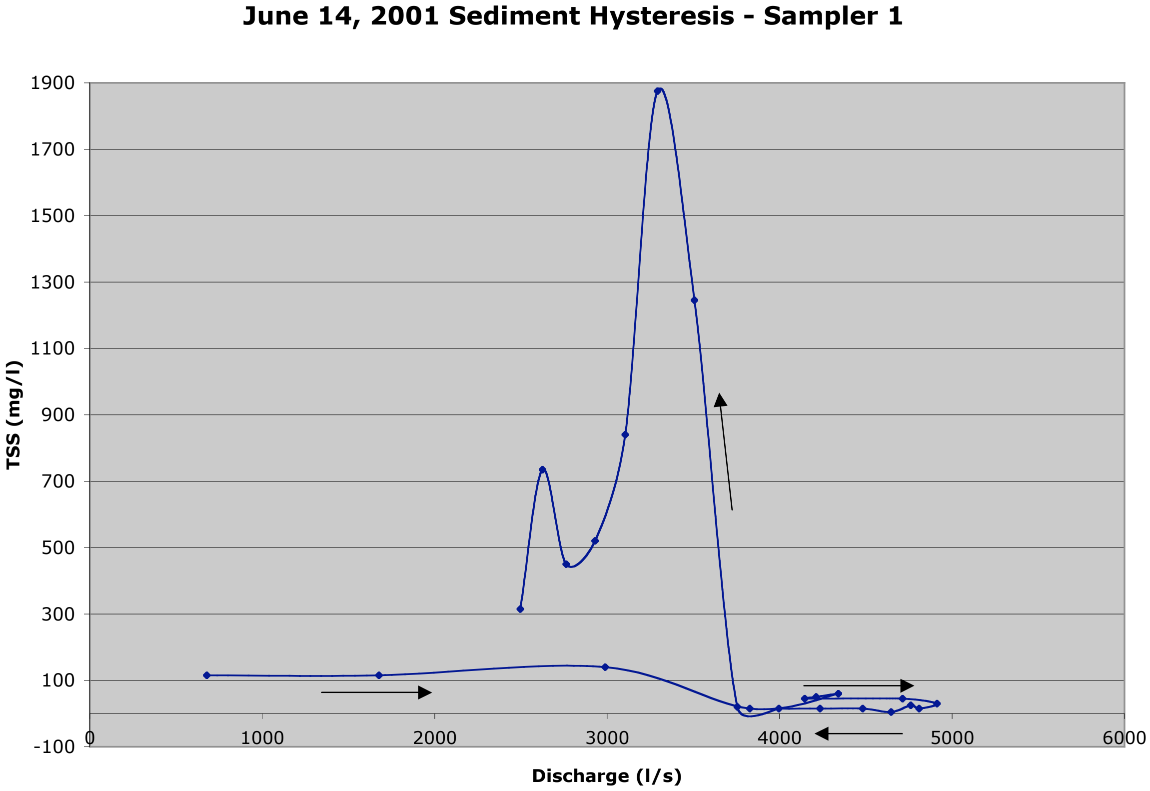
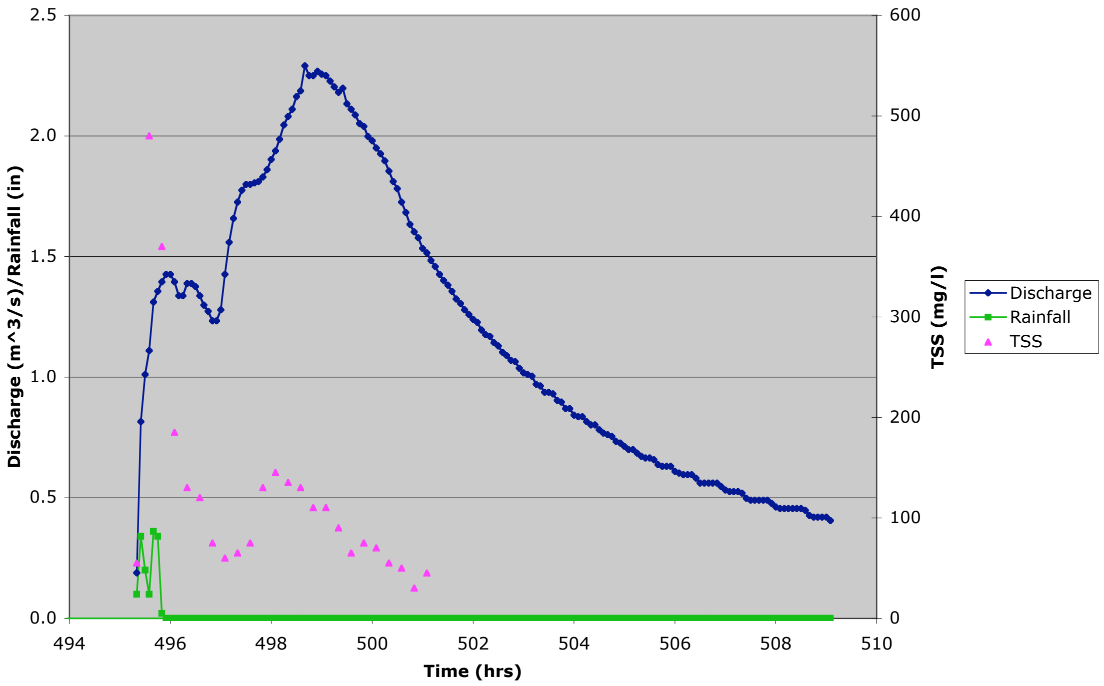


Figure 26. June 14, 2001 storm sedigraph and hysteresis plots for site #1.

June 21, 2001 Sedigraph - Sampler 1



June 21, 2001 Sediment Hysteresis - Sampler 1

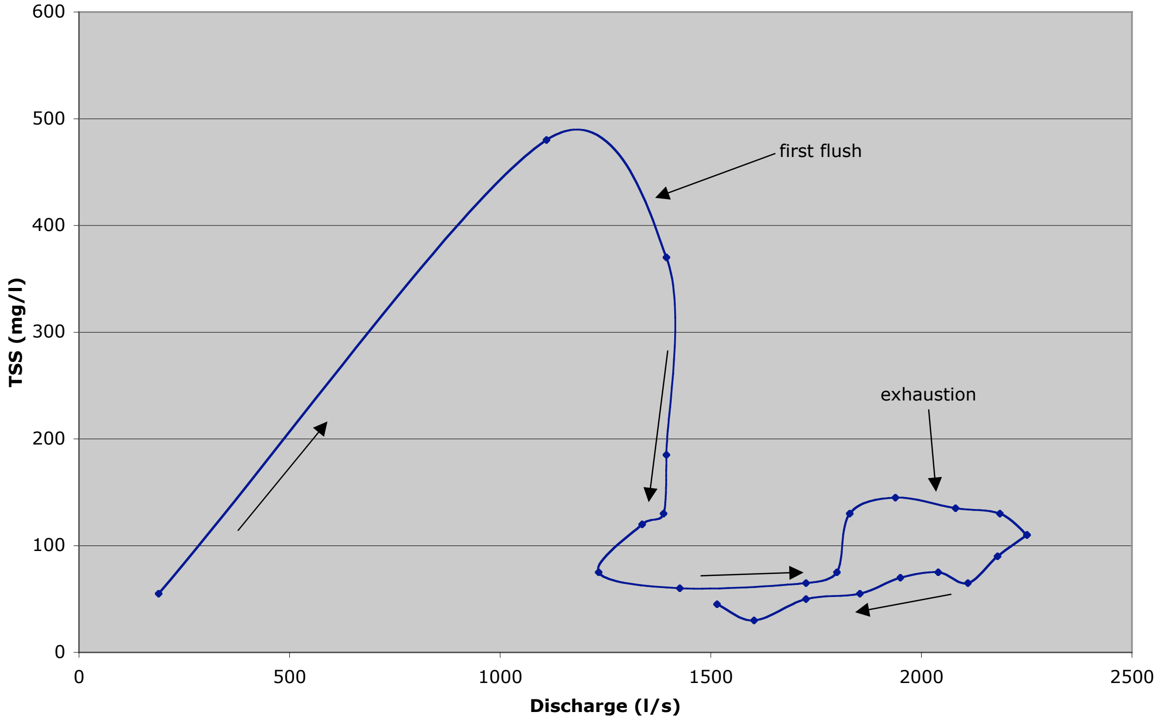
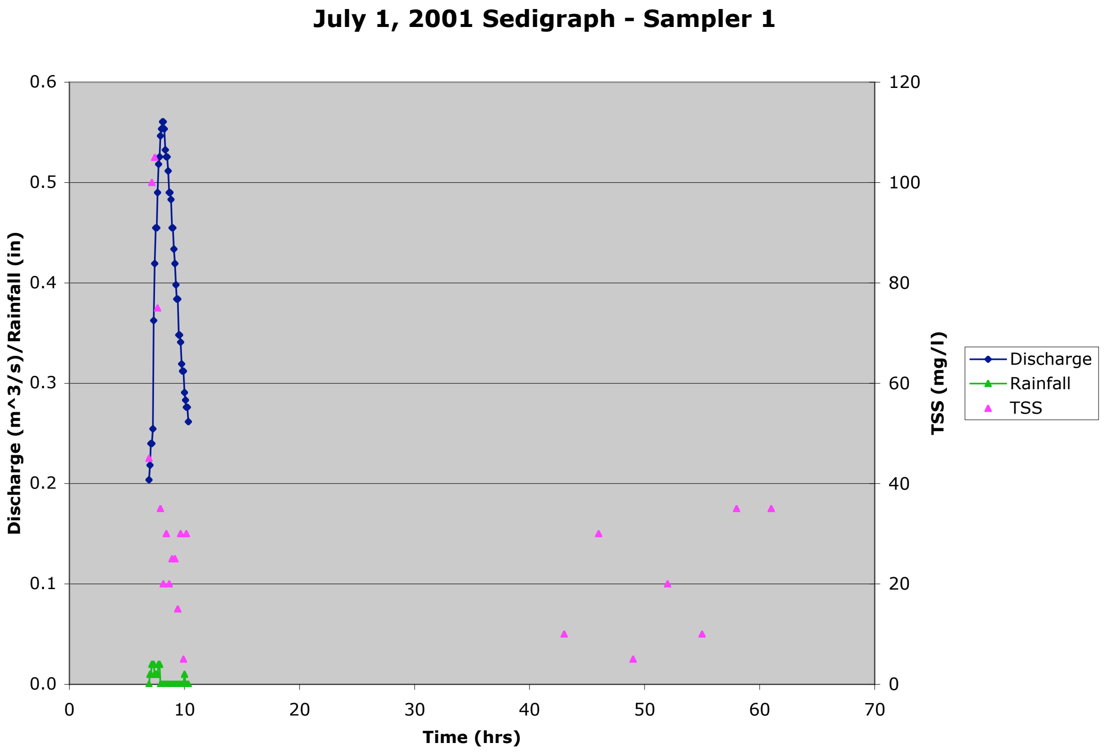
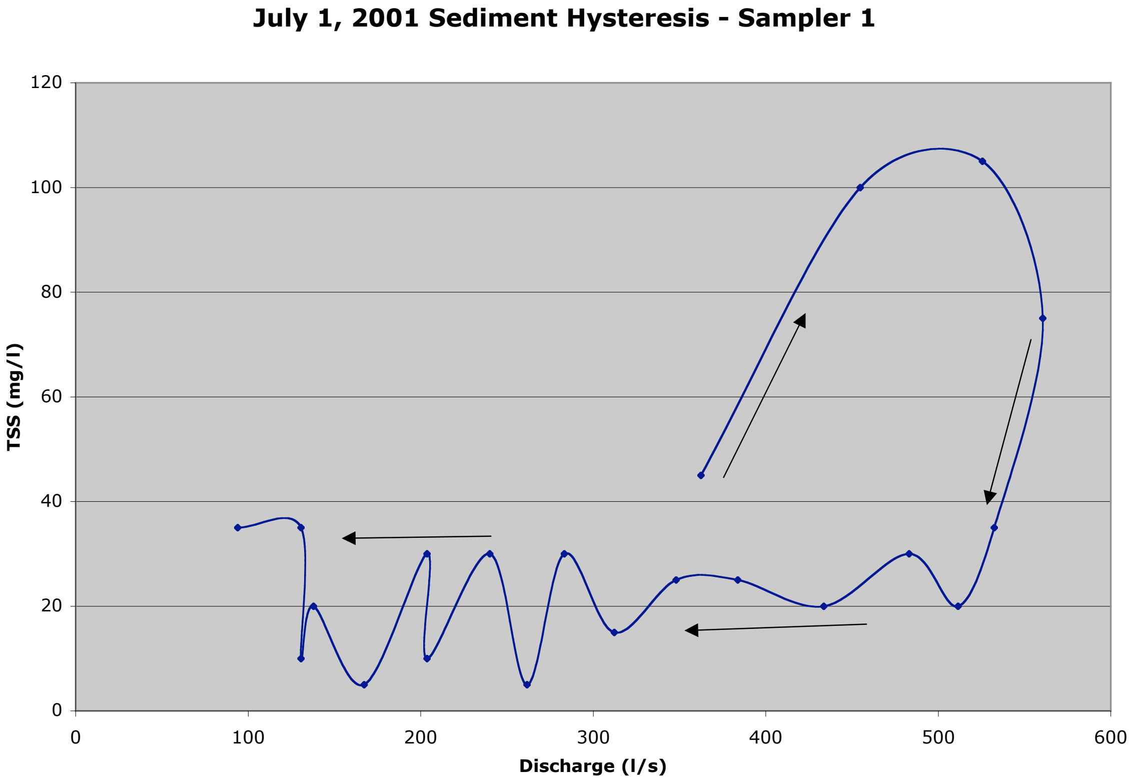


Figure 27. June 21, 2001 storm sedigraph and hysteresis plots for site #1.

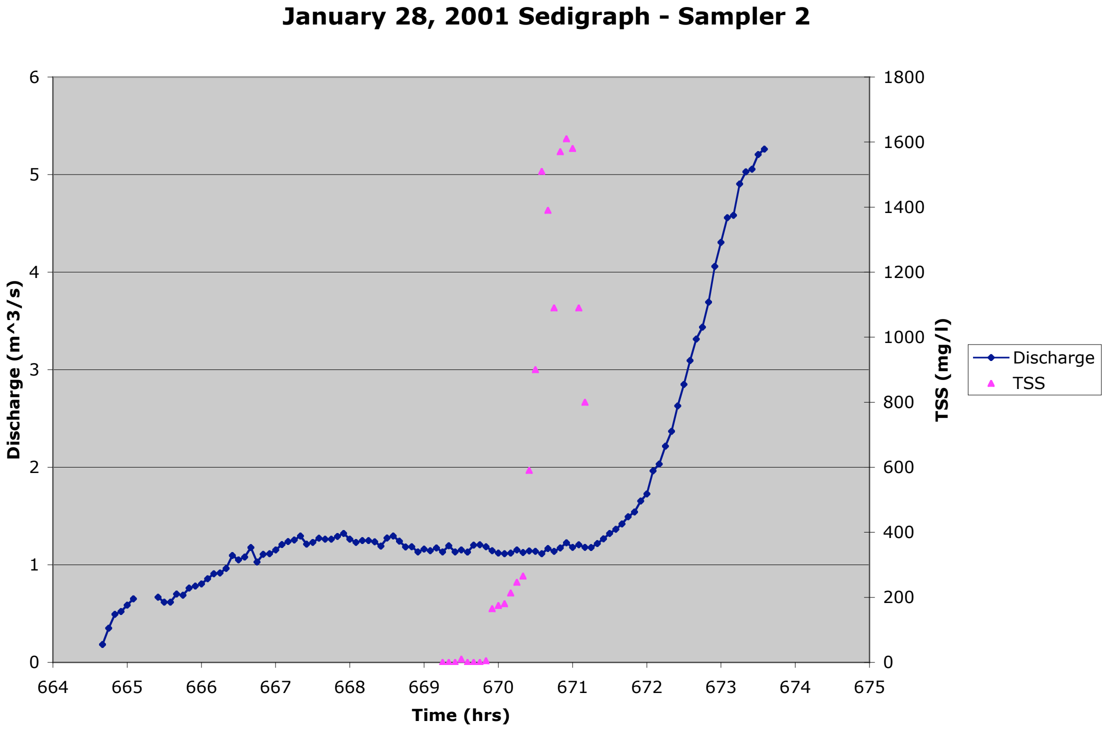


July 1, 2001 Sedigraph - Sampler 1



July 1, 2001 Sediment Hysteresis - Sampler 1

Figure 28. July 1, 2001 storm sedigraph and hysteresis plots for site #1.



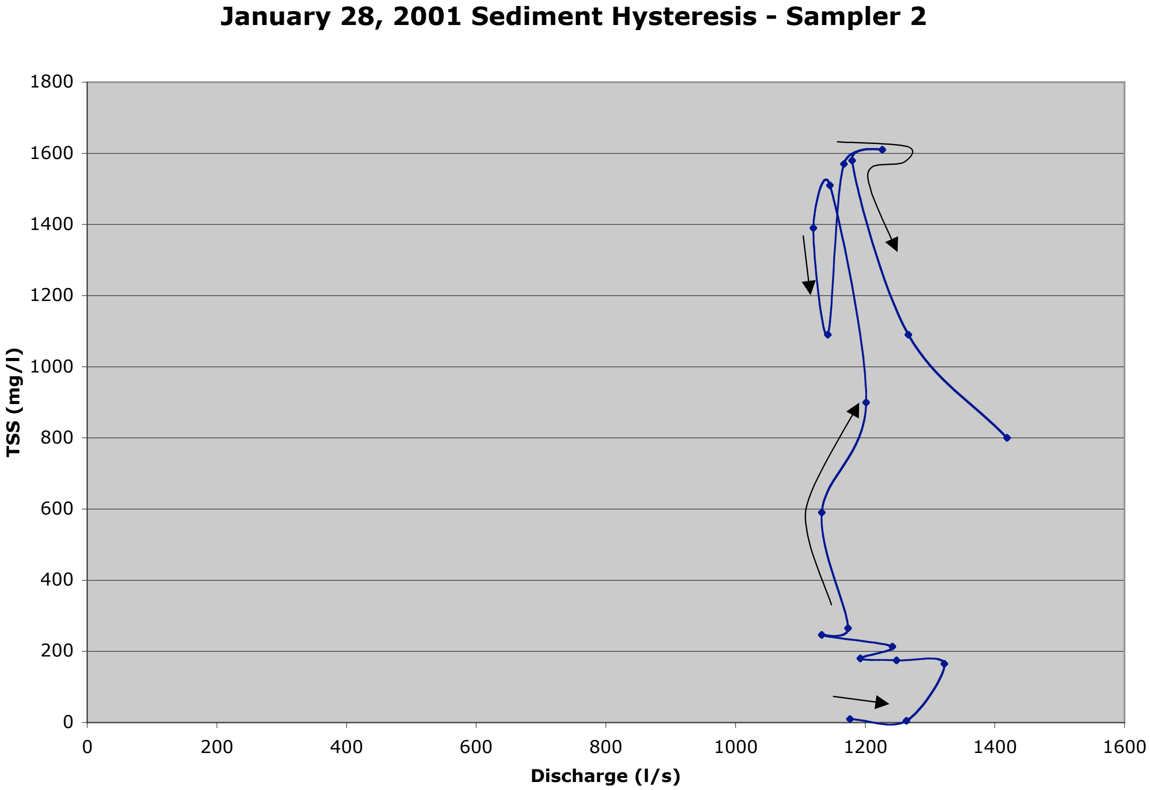
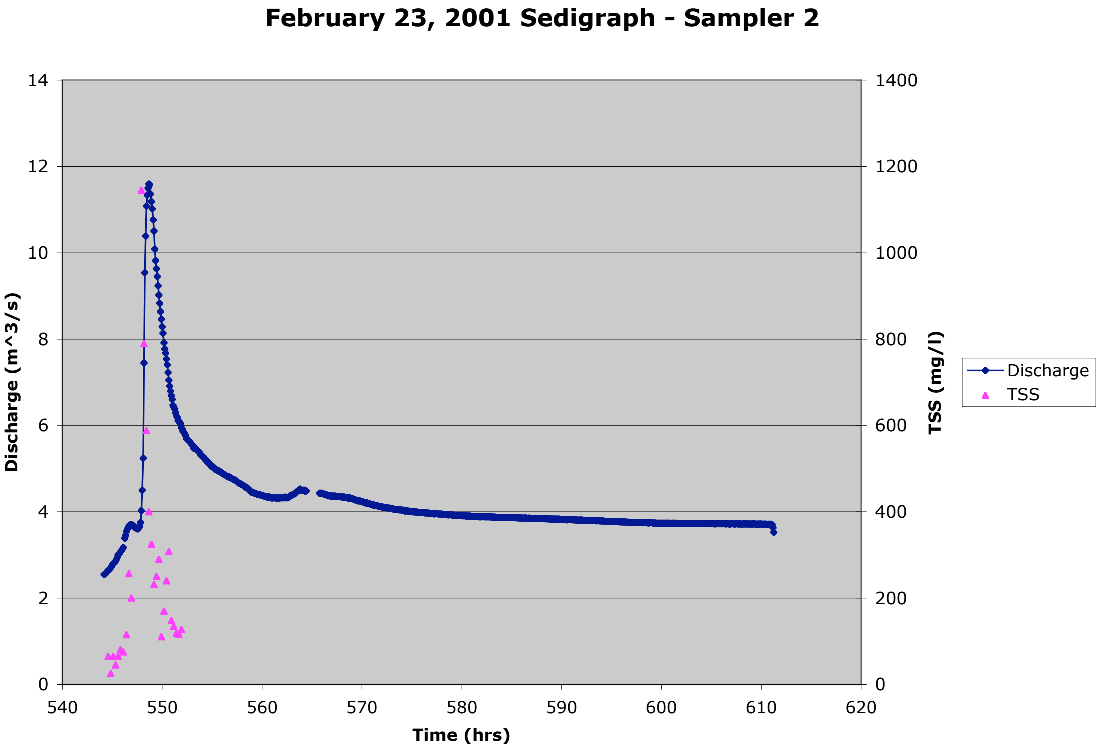


Figure 29. January 28, 2001 storm sedigraph and hysteresis plots for site #2.



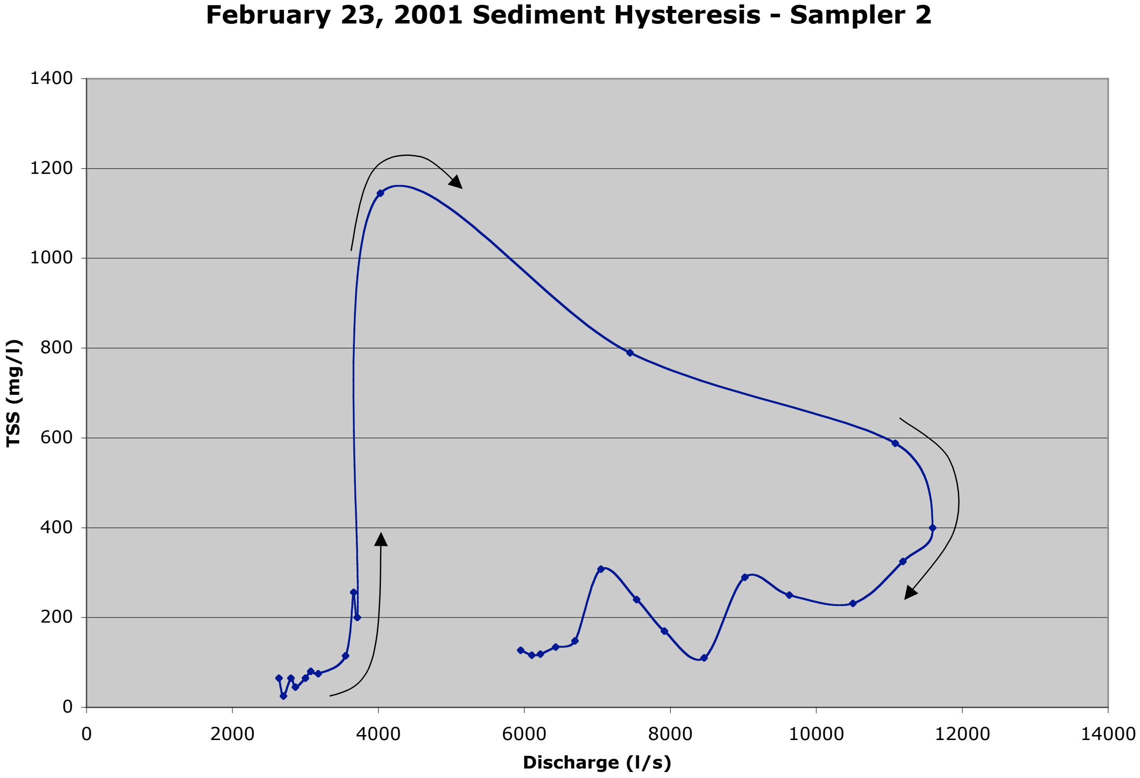
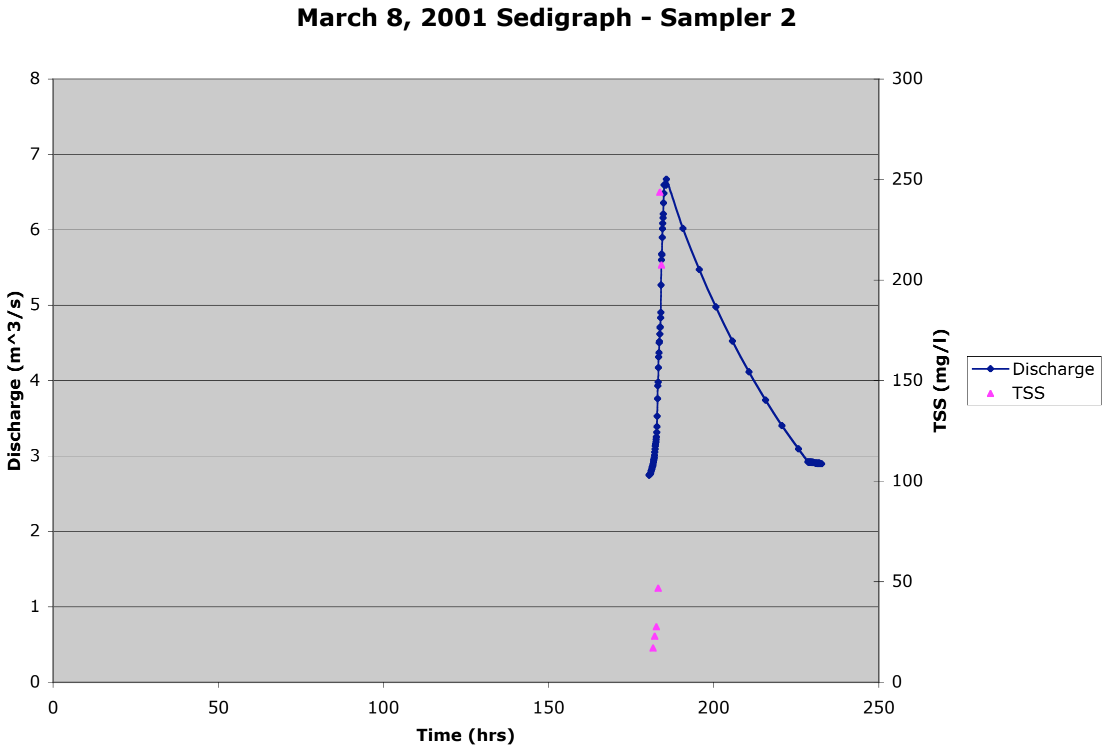


Figure 30. February 23, 2001 storm sedigraph and hysteresis plots for site #2.



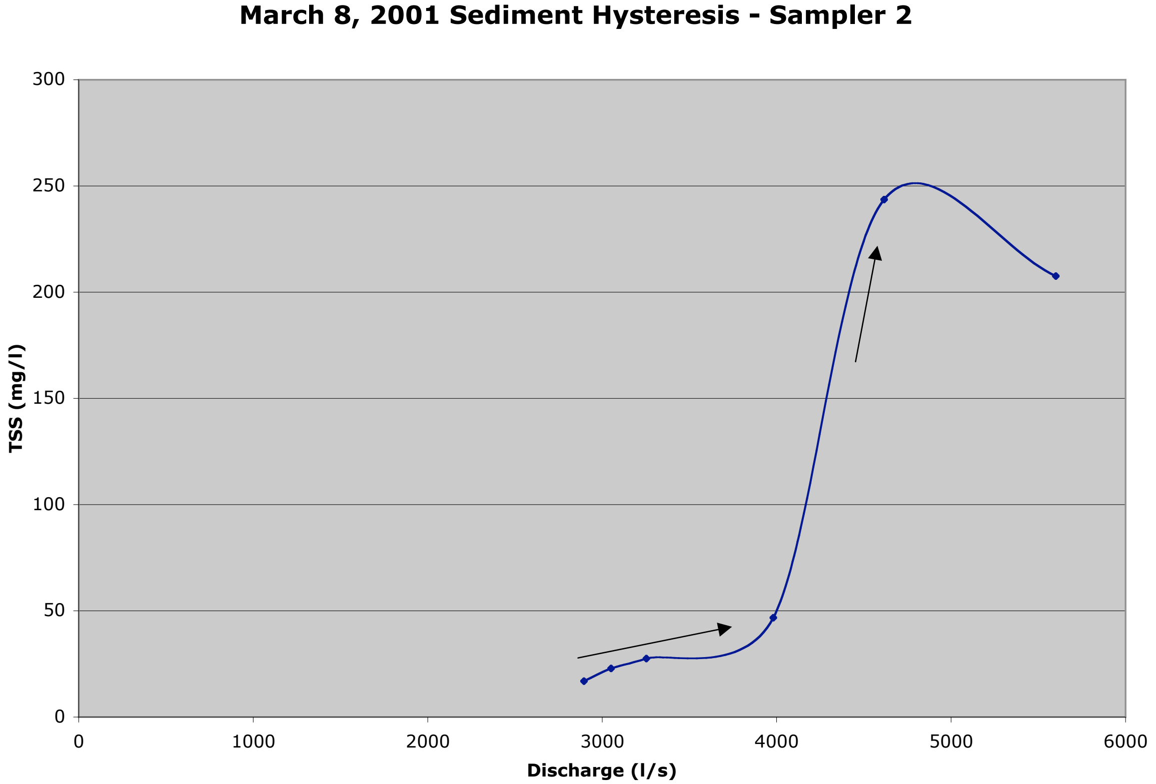
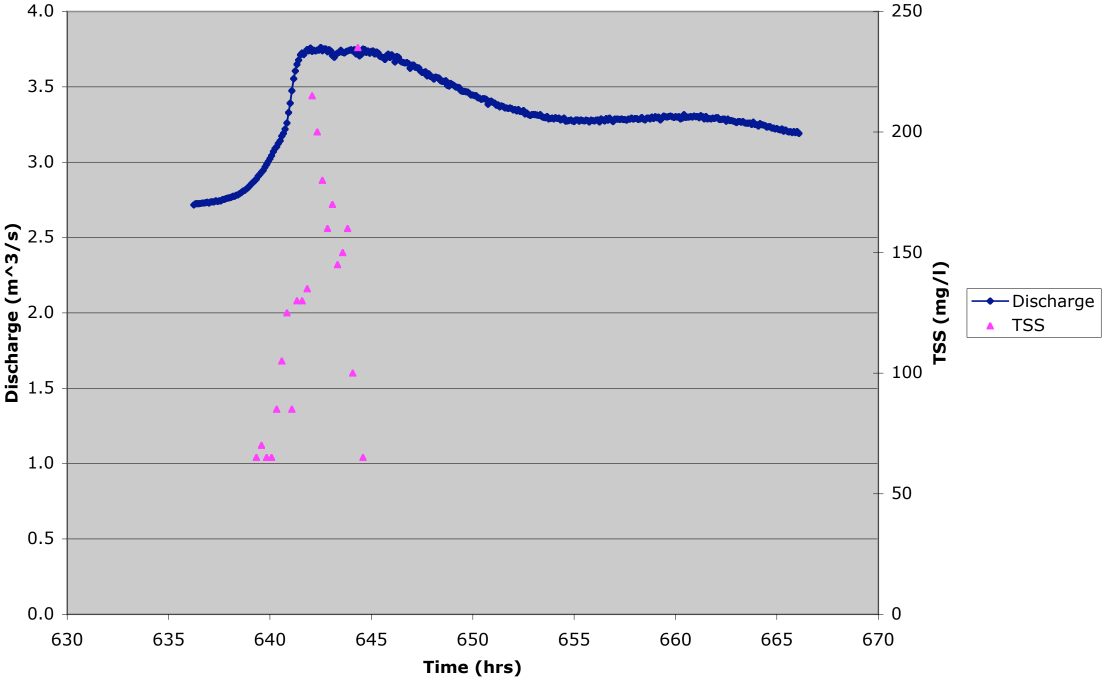


Figure 31. March 8, 2001 storm sedigraph and hysteresis plots for site #2.

March 27, 2001 Sedigraph - Sampler 2



March 27, 2001 Sediment Hysteresis - Sampler 2

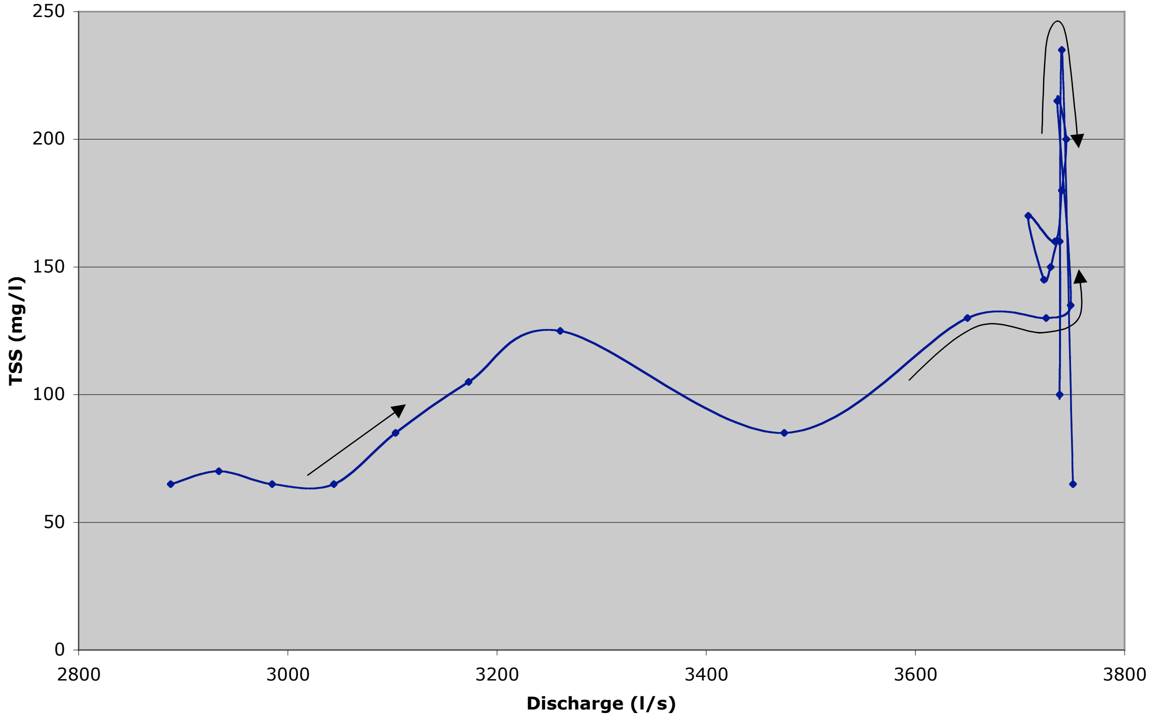


Figure 32. March 27, 2001 storm sedigraph and hysteresis plots for site #2.

values at the headwater (Site #2). However, peak discharge values at Site #2 occurred 2.59 hours in advance of peak discharge values at Site #1. Quantitatively, peak TSS values were greater at Site #1 than at Site #2, 4,080 mg/l and 1,610 mg/l, respectively.

Figure 25 and Figure 30 reveal similar results for the February 23 storm event. TSS concentrations peaked before discharge at both sites, 1.92 hours before discharge for Site #1 and 0.75 hours before discharge for Site #2. Once again, TSS values peaked at the outlet (Site #1) before peaking at the headwater (Site #2). This time the peak in TSS (4,100.6 mg/l) at Site #1 occurred 0.59 hours in advance of the peak in TSS (1,144.7 mg/l) at Site #2. In addition, Site #2 once again experienced peak discharge 0.58 hours before peak discharge occurred at Site #1.

Thus, qualitatively, the hydrologic and sediment response of the headwater and basin are the same for both the January 28 and February 23 storm events. However, there is a difference in the response quantitatively. Although these two storms allow comparisons to be made between both sampling sites, the data for these two storms are incomplete. The hydrologic and sediment responses to these two storms cannot be compared to the corresponding rainfall data since that data was lost due to a computer malfunction. In addition, a complete sediment record was not obtained since these storms ran through the middle of the night and the automatic samplers only can take a maximum of six hours of samples (at 15-minute intervals) before all 24 bottles are filled and need to be replaced.

The most complete rainfall, discharge, and suspended sediment records were obtained from the storms of June 14 and June 21 (Figures 26-27) at Sampling Site #1. As illustrated in both the June 14 and June 21 sedigraphs, peaks in discharge strongly parallel peaks in rainfall.

The double-peaked hydrograph corresponds to the fairly discrete periods during the storm event that were characterized by increased rainfall intensity. This demonstrates the variability of the creek's response to the intensity of meteorologic events. Furthermore, the rapid response of Mary's Creek (as indicated by the steep slope of the rising limb) to the initial influx of rain is yet another indicator of the "flashiness" of the creek. However, in the June 14 sedigraph, the peak in TSS lags behind both peaks in discharge and rainfall. Whereas, in the June 21 sedigraph, the peak in TSS occurred slightly before the initial peak in discharge and slightly after the initial peak in rainfall. As mentioned earlier, the June 14 storm is one of three storm events in which TSS peaks occurred after discharge peaks. The June 14 storm event produced 2.66 inches of rainfall in 10 minutes and the June 21 storm event produced 1.46 inches of rainfall in 35 minutes.

As mentioned earlier, discharge and instantaneous sediment concentration may not have a predictable relation during a single storm flow. The tendency for sediment concentration to have different values at identical stream discharges is referred to as a "hysteresis" effect. This effect can be seen in the sediment hysteresis plots for both sampling sites on Mary's Creek (Figures 22-32). In response to both the January 28 and the February 23 storm events, both sites produced a tremendous initial discharge of sediment corresponding with the initial rise in the hydrograph. This indicates a flushing of sediment that was previously in the basin in response to the initial influx of water. Once again, this is consistent with the characteristics of a "flashy" creek.

Despite this similarity, an in-depth analysis of the hysteresis plots for both storms reveals some subtle differences in the sediment response patterns for the headwater and outlet sites. During the January 28 storm event at Sampling Site #1, sediment concentration slightly increased and varied very little with increasing discharge until the discharge rose to over 2,600 l/s. At this point, the sediment concentration jumped from 600 mg/l to 4,080 mg/l within 30 minutes. After the peak at 4,080 mg/l, TSS values dropped substantially to 1,600 mg/l and continued to decrease to 600 mg/l before TSS values began to rise a second time. This negative hysteresis loop indicates a depletion in sediment supply. This drop in TSS values occurred even as discharge continued to increase. This raises the question as to whether or not these sudden dramatic spikes in sediment load are the result of these critical discharges tapping into some other sediment source.

At Sampling Site #2, sediment concentration progressively rose while discharge remained fairly constant, predominantly fluctuating between 1,100 and 1,200 l/s. The rise in sediment concentration was continuous until it reached 1,510 mg/l and then collapsed when the discharge dropped from 1,145 l/s to 1,120 l/s forming a negative hysteresis loop. TSS values peaked a second time when discharge recovered to 1,142 l/s. After the second peak in sediment concentration, TSS values continually decreased even though discharge continued to increase.

The sediment concentration response to the February 23 storm event differed from the January 28 storm event at both sampling sites. At the outlet (Site #1), TSS values initially decreased as discharge increased. Ninety-five minutes into the storm, TSS values began to rise, but this rise occurred while discharge remained virtually constant. This initial rise peaked at 55 mg/l and then decreased to 35 mg/l as the discharge decreased briefly before increasing once again forming a small, open negative hysteresis loop. TSS values continued to fall throughout the subsequent increase in discharge until peaking a second time at 48.75 mg/l. Then TSS values dropped once again in response to a small and brief decrease in discharge before peaking a third time at 4,100.6 mg/l as discharge continued to increase, forming a second small, closed negative hysteresis loop.

Conversely, at the headwater (Site #2), TSS values fluctuated slightly in response to increasing discharge before peaking at 1,144.7 mg/l. After peaking, TSS values fell as discharge increased. Four hours and 20 minutes into the storm, discharge consistently decreased, yet TSS values once again fluctuated up and down. The hysteresis plot forms a huge positive open loop resulting from significant increases in TSS with increasing discharge, followed by relatively quick sediment depletion occurring after the peak discharge.

TSS load and sediment yield. In discussing sediment transport, it is important to distinguish between concentration, which is typically expressed as the weight of sediment per unit volume of water (mg/l), and load, which is the rate of discharge of the sediment. Sediment load is defined as the product of sediment concentration and discharge of water. In this study, TSS loads were calculated from the measured sediment concentrations and discharge values only for the duration of the sampling, not necessarily for the entire storm event. As with water discharge, it is often useful to compare sediment loads in different rivers, creeks, and streams on a per-unit-drainage-area basis. This quantity is called sediment yield and is calculated by dividing the sediment load by the basin area. Table 4 summarizes the calculated values of the TSS loads and sediment yield for each storm event for Sampling Site #1 and Sampling Site #2, respectively. It should be noted that the majority of the TSS concentration values represent the first flush of the basin and do not represent the entire sediment response over the duration of the hydrograph.

Table 4. TSS load and yield values for storm events at both sites

Storm Event	Discharge (l/s)	TSS (mg/l)	TSS Load (mg/s)	TSS Load (kg)	TSS Load (t)	TSS Yield (t/ha)	TSS Yield (t/km^2)
Sampler 1							
25-Jan-01	18874.62	276.30	299445.22	230.57	0.23057	0.00008	0.00804
28-Jan-01	43473.06	15600.00	40425175.48	16857.13	16.85713	0.00588	0.58756
13-Feb-01	46978.52	6175.00	31075815.89	23122.74	23.12274	0.00806	0.81401
23-Feb-01	31766.79	4597.45	10290860.73	5020.33	5.02033	0.00175	0.17499
14-Jun-01	82896.45	6705.00	20873535.48	18432.35	18.43235	0.00642	0.64247
21-Jun-01	40517.56	2855.00	4590311.77	4100.60	4.10060	0.00143	0.14293
1-Jul-01	6760.85	705.00	271947.78	243.27	0.24327	0.00008	0.00848
Total	**271267.85**	**36913.75**	**107827092.35**	**68006.99**	**68.00699**	**0.02370**	**2.37848**
Sampler 2							
Storm Event	**Discharge (l/s)**	**TSS (mg/l)**	**TSS Load (mg/s)**	**TSS Load (kg)**	**TSS Load (t)**	**TSS Yield (t/ha)**	**TSS Yield (t/km^2)**
28-Jan-01	22848.68	13389.86	15994025.85	13883.79	13.88379	0.00782	0.78174
23-Feb-01	170595.55	6481.25	47336712.03	42263.33	42.26333	0.02380	2.37969
8-Mar-01	26252.47	565.30	2681753.57	1890.50	1.89050	0.00106	0.10645
27-Mar-01	79921.78	2840.00	10196182.47	9066.86	9.06686	0.00511	0.51052
Total	**299618.48**	**23276.41**	**76208673.92**	**67104.48**	**67.10448**	**0.03779**	**3.7784**

Drainage area of Sampling Site #1: 28.69 km^2 (2,869 ha) Drainage area of Sampling Site #2: 17.76 km^2 (1,776 ha)

These results show a great deal of variability in sediment flux at both sampling sites. Due to a computer malfunction, total rainfall amounts were only obtained for three of the storm events listed in Table 4; 2.66”, 1.46”, and 0.17” for the June 14, June 21, and July 1 storm events, respectively. From this limited rainfall data, it appears that higher amounts of rainfall generate higher levels of sediment discharge. For example, the June 14 storm event yielded 18 tons of sediment, the June 21 storm event yielded 4 tons of sediment, and the July 1 storm event yielded 0.24 tons of sediment.

It is interesting to compare the data for the January 28 and the February 23 storm events for both sites. Sediment flux was essentially the same at both sampling sites for the January 28 storm event, 16.86 tons and 13.88 tons at Site #1 and Site #2, respectively. However, sediment flux was quite different for the February 23 storm event where Site #1 produced 5 tons of sediment and Site #2 produced 42 tons of sediment. These results illustrate the impact of spatial variability of the basin, particularly the impact of differences in erodibility at the headwater and the outlet sites. As was previously noted, evidence of slumping was observed to have occurred on several occasions at Site #2. Slumping probably accounts for the difference in sediment flux for the February 23 storm event. The difference in discharge for both sites for the February 23 storm event should also be noted. Discharge for Site #1 was 31,766 l/s, whereas the discharge for Site #2 was 170,596 l/s. The greater discharge at Site #2 would produce a higher erosion rate due to the more turbulent flow.

Table 5 summarizes the sediment loads during non-storm periods. This table shows that higher discharge levels typically are associated with higher sediment loads. A seasonal effect on discharge also is readily apparent. During the sub-humid precipitation regime (January to April), there was flow in Mary's Creek at both sites. This baseflow was sufficiently elevated to increase the sediment load carried in the flow. When there was flow in the channel during non-storm periods, the headwater transported almost 4.5 times more sediment than the outlet. It is interesting to compare these results with those obtained during storm events. During storms, the outlet (Sampling Site #1) carried 1.4 times more sediment than the headwater (Sampling Site #2). In general, TSS loads during non-storm periods were much lower than during storm events.

During the semi-arid precipitation regime (May to December), there was no flow in Mary's Creek at either site. It is interesting to compare the TSS levels of both sites during this drier season. TSS levels at Sampling Site #1 remained fairly constant; however, TSS levels at

Table 5. TSS loads during non-storm periods at both sites					
Sampler 1					
Sampling Date	**Discharge**	**TSS**	**TSS Load**	**TSS Load**	**TSS Load**
	(l/s)	**(mg/l)**	**(mg/s)**	**(g/s)**	**(kg/day)**
23-Jan-01	865	2.34	2024.10	2.02	174.88
7-Feb-01	845	2.87	2425.15	2.43	209.53
22-Feb-01	1254	4.62	5793.48	5.79	500.56
17-Mar-01	966	3.79	3661.14	3.66	316.32
21-Apr-01	N/A*	1.85	N/A*	N/A*	N/A*
18-May-01	247	2.11	521.17	0.52	45.03
14-Jun-01	0	1.93	0	0	0
21-Jun-01	0	1.58	0	0	0
19-Aug-01	0	1.66	0	0	0
21-Sep-01	0	1.58	0	0	0
4-Oct-01	0	1.76	0	0	0
10-Nov-01	0	1.32	0	0	0
27-Nov-01	0	1.45	0	0	0
12-Dec-01	0	1.29	0	0	0
16-Jan-01	0	0.97	0	0	0
Total	**4177.00**	**31.12**	**14425.04**	**14.43**	**1246.32**
Average	**298.36**	**2.07**	**1030.36**	**1.03**	**89.02**
Sampler 2					
Sampling Date	**Discharge**	**TSS**	**TSS Load**	**TSS Load**	**TSS Load**
	(l/s)	**(mg/l)**	**(mg/s)**	**(g/s)**	**(kg/day)**
23-Jan-01	0	3.17	0	0	0
7-Feb-01	2084	7.92	16505.28	16.51	1426.06
22-Feb-01	2527	6.84	17284.68	17.28	1493.40
17-Mar-01	2627	11.36	29842.72	29.84	2578.41
21-Apr-01	2471	8.53	21077.63	21.08	1821.11
18-May-01	0	7.28	0	0	0
14-Jun-01	0	6.71	0	0	0
21-Jun-01	0	5.65	0	0	0
19-Aug-01	0	9.49	0	0	0
21-Sep-01	0	7.06	0	0	0
4-Oct-01	0	6.61	0	0	0
10-Nov-01	0	4.38	0	0	0
27-Nov-01	0	5.82	0	0	0
12-Dec-01	0	4.67	0	0	0
16-Jan-01	0	3.74	0	0	0
Total	**9709**	**99.23**	**63632.68**	**63.63**	**5497.86**
Average	**647.27**	**6.62**	**5647.35**	**5.65**	**487.93**
*** = transducer damaged, no reading**					

Sampling Site #2 was not only considerably higher than those at Site #1, but the TSS levels exhibited much more variability. As suggested earlier, these higher TSS levels are likely due to the influence of cattle traffic in and out of the channel at Site #2.

Sediment load rating curves were generated for both sampling sites to depict the relationship between stream discharge and sediment load. All suspended sediment data obtained at the sampling sites were used to produce the rating curves, with the exception of the TSS data obtained during non-storm periods. As can be seen in Figure 33, there is a moderately strong, direct, power relationship between discharge and sediment load for Site #1; whereas, there is a much weaker direct, power relationship between discharge and sediment load for Site #2. However, a detailed analysis of Figure 33 reveals some interesting trends and patterns.

In terms of Sampling Site #2, a cluster of data points can be seen to the left of the main mass of data points. All of the points in this cluster came from the data for the January 28 storm event. As mentioned previously, this storm event produced large TSS values associated with relatively small amounts of discharge. As such, the January 28 storm event represents an aberrant response pattern relative to the response patterns that were produced for the other three storm events at Site #2. As alluded to earlier, this response pattern may be explained by slumping. Figure 34 shows the same sediment load rating curves with the data points for the January 28 storm event removed for Sampling Site #2. The resulting trendlines are very similar in slope indicating that the headwater and outlet of Mary's Creek are responding similarly to storm events with regard to discharge and sediment load. The r^2 value for Sampling Site #2 increased from 0.1739 to 0.667 signifying a much stronger correlation between discharge and sediment load.

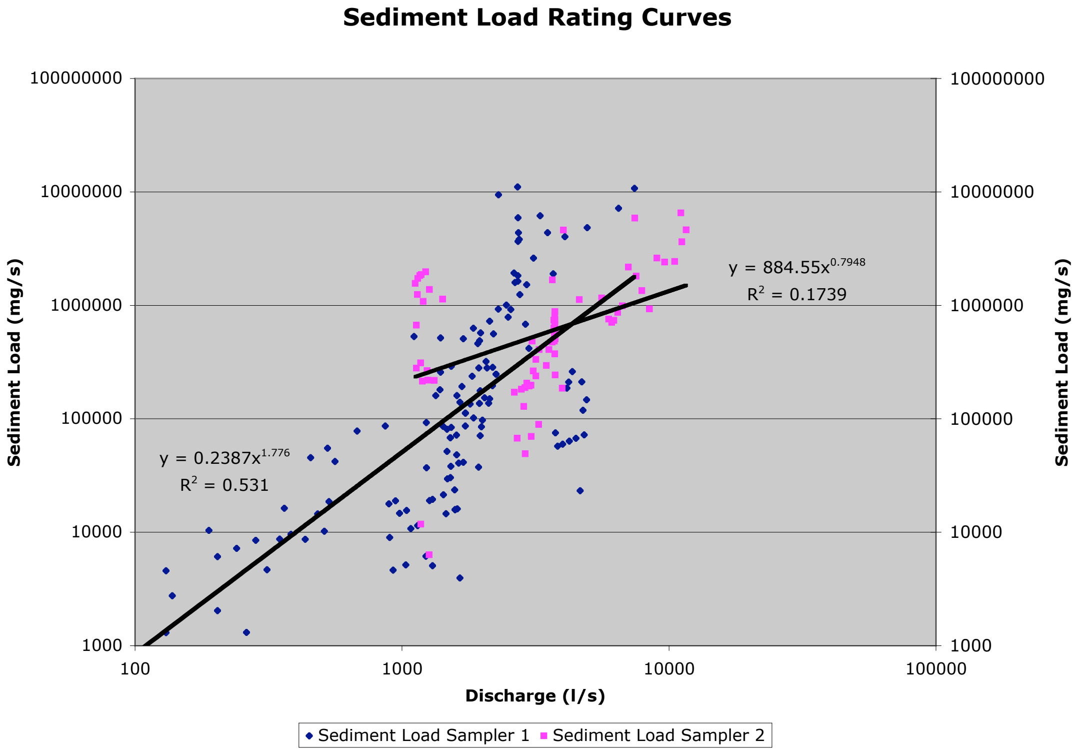


Figure 33. Sediment load rating curves for both sites on Mary's Creek.

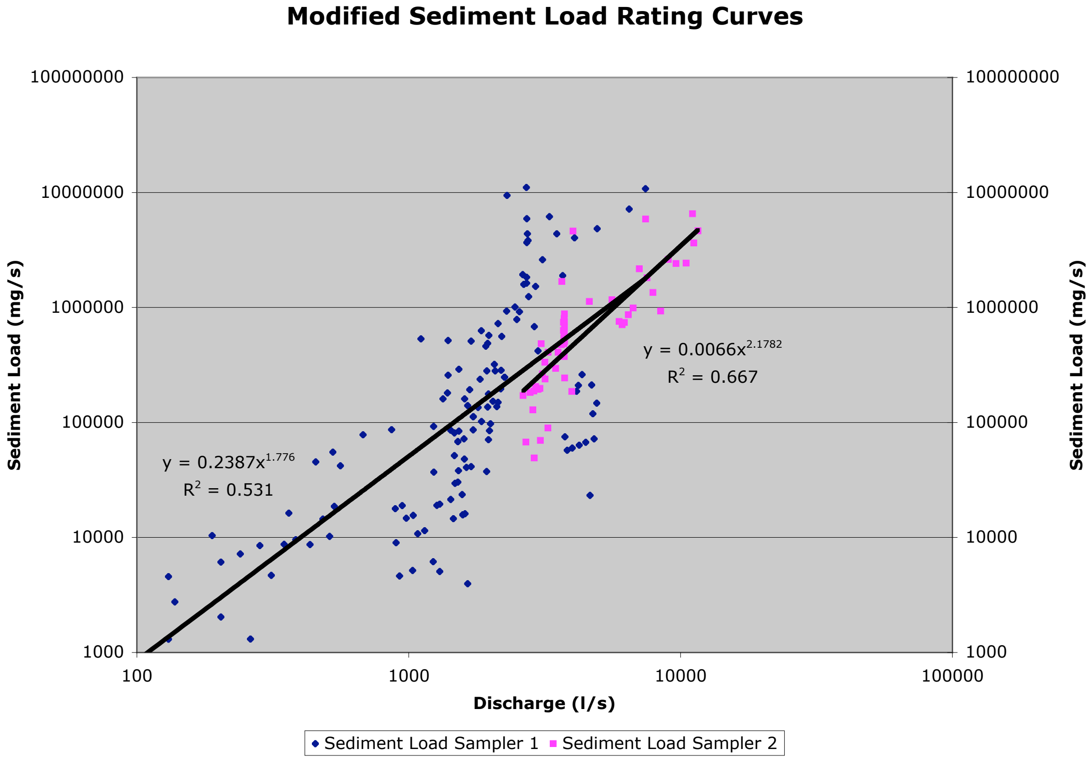
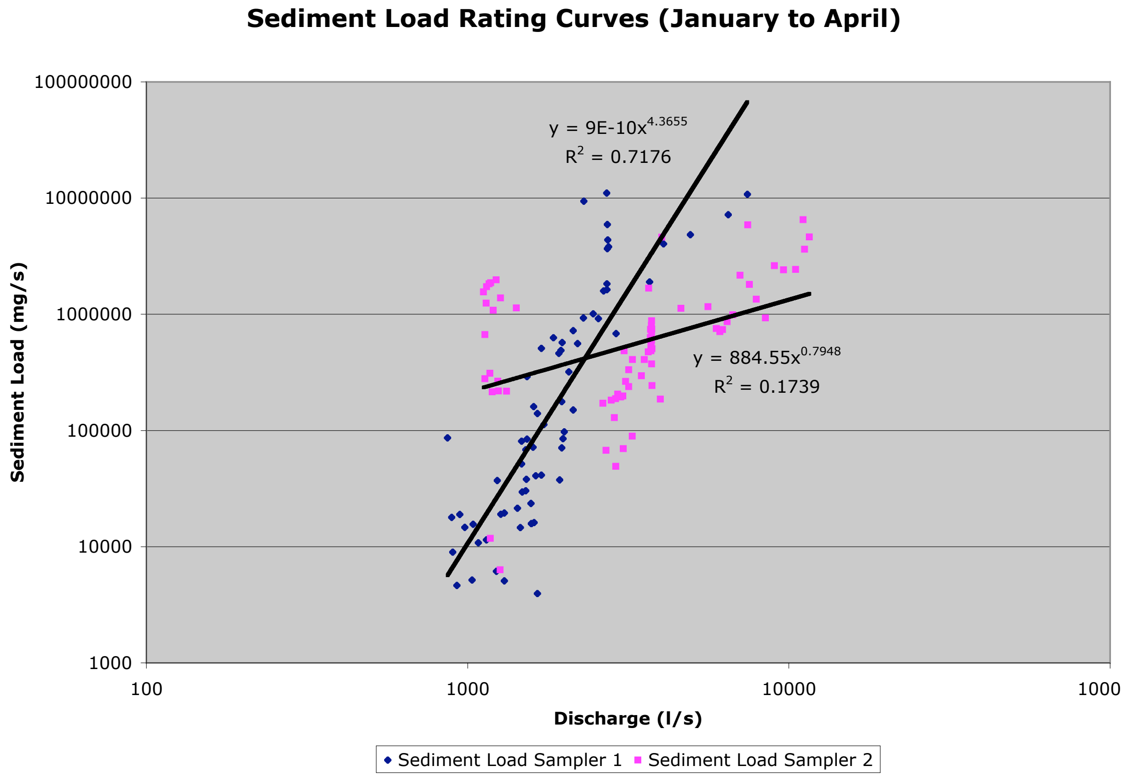


Figure 34. Modified sediment load rating curves for both sites on Mary's Creek. Data points removed for January 28 storm event at sampling site #2.

In terms of sediment load, once again seasonal variation can be seen (Figure 35). There is a stronger relationship between discharge and sediment load during the sub-humid as opposed to the semi-arid precipitation regime for Sampling Site #1. Separating the data by these two different rainfall patterns increases the r^2 value from 0.531 to 0.7176 in the wetter part of the year and to 0.6342 in the drier part of the year. It should be noted the January 28 storm was included in the plot for Sampling Site #2. The storms occurring between January and April produced significantly more sediment than the storms occurring between May and December. This result most likely is due to heavier and more intense rainfall, and thus, more turbulent discharge with greater erosive capability.

The erosion tolerance level is normally set up at a maximum value of approximately 12.35 t/ha/yr (Miller & Gardiner, 1998). Although, this study took place over a 13-month period, not all storms were monitored during that period of time. Thus, the erosion tolerance level for the two sampling sites must be estimated by adding up the values in Table 4. The outlet transported a total of 0.02370 t/ha and the headwater transported a total of 0.03779 t/ha based on the seven monitored storm events at Sampling Site #1 and the four monitored storm events at Sampling Site #2. It is highly unlikely that the sediment load at either site would reach, let alone, exceed the annual tolerable erosion level.

The method used above to calculate sediment yield is based strictly on measured data from actual monitored storms. Although this may be the most obvious way to calculate sediment yield for the basin, it underestimates the amount of sediment transported since not all storms were monitored during the year and since many of the sediment values represent only the first flush of sediment rather than the entire sediment response over the duration of the hydrograph.



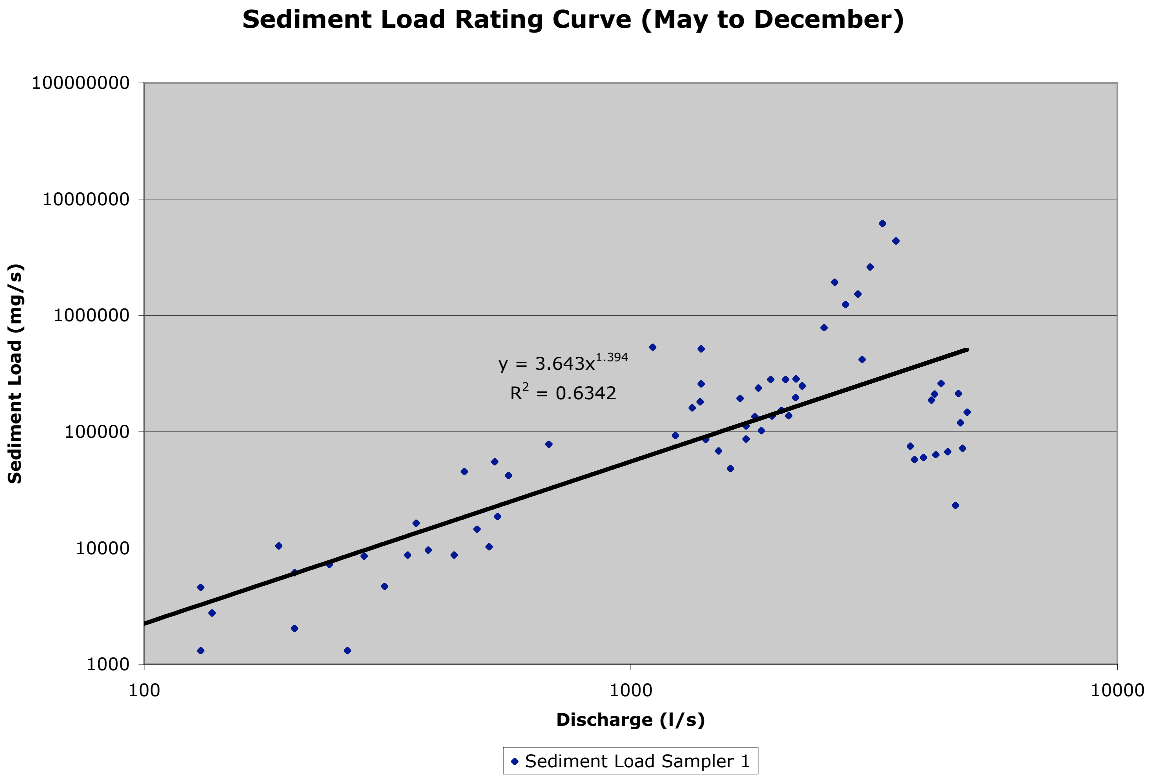


Figure 35. Seasonal sediment load rating curves for both sites on Mary's Creek.

Therefore, for comparative purposes, another method of calculating sediment yield was also used.

This method involved overlaying the data derived from the flow duration log for Sampling Site #1 (Figure 36) with the rating curve produced by combining the sediment load data for both sampling sites (Figure 37). The results are given in Table 6. According to this method, sediment flux in the basin was 0.32175 t/ha/yr. Although this value is an order of magnitude larger than the sediment yield value calculated using the first method, it is still far below the annual tolerable level of 12.35 t/ha/yr. Thus, according to sediment yield calculations from both methods, the sediment load being transported out of this basin does not exceed critical limits. That being said, the spatial and temporal variability of rainfall, discharge, and soil erosion must be kept in mind.

Nitrogen Flux

In this 13-month field study, a total of 118 samples were collected during baseline and stormflow conditions at Sampling Site #1 in order to gain some preliminary understanding of the nitrogen flux at the outlet of this basin in terms of ammonia-nitrogen and nitrate-nitrogen.

Temporal variation. Ammonia-nitrogen and nitrate-nitrogen concentrations at Sampling Site #1 during storm events and non-storm periods are shown in Figures 38 and 39. In Figure 38, ammonia-nitrogen (NH_3-N) and nitrate-nitrogen (NO_3-N) values were averaged for each storm event and graphed with corresponding maximum and minimum values observed at the outlet. The actual NH_3-N and NO_3-N values are given in Appendix D. Forty-seven NH_3-N and 47 NO_3-N samples were collected for two storm events at Sampling Site #1. The average NH_3-N

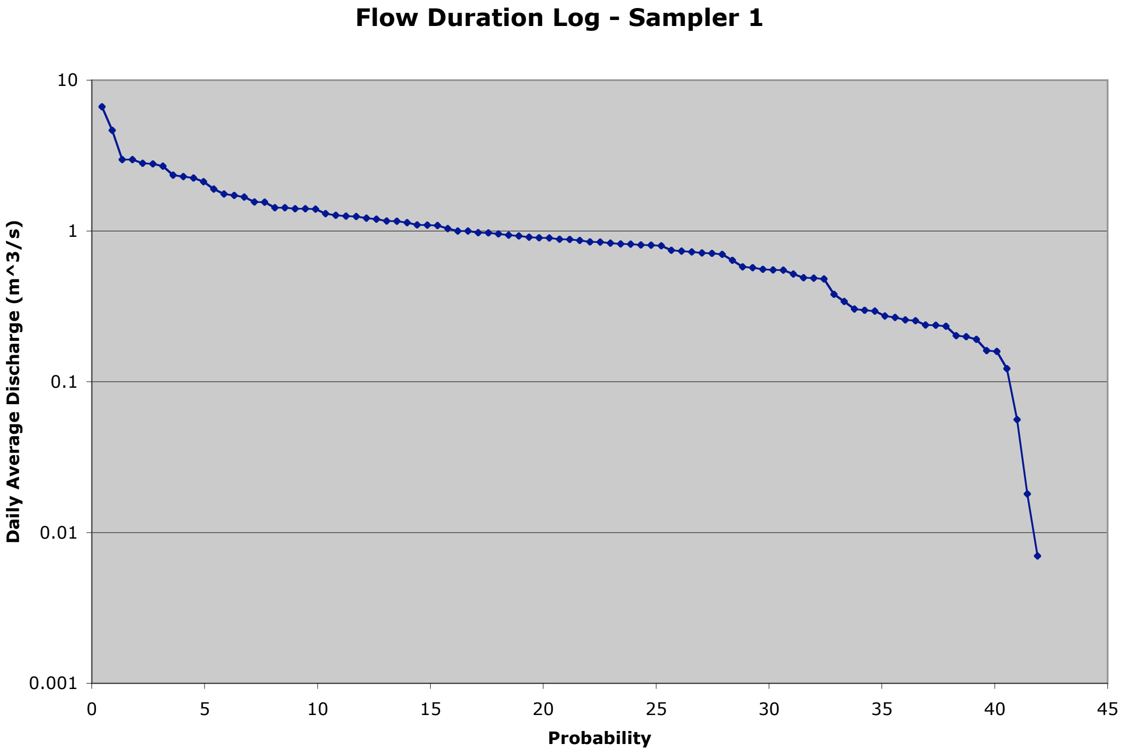


Figure 36. Flow duration log for site #1 on Mary's Creek.

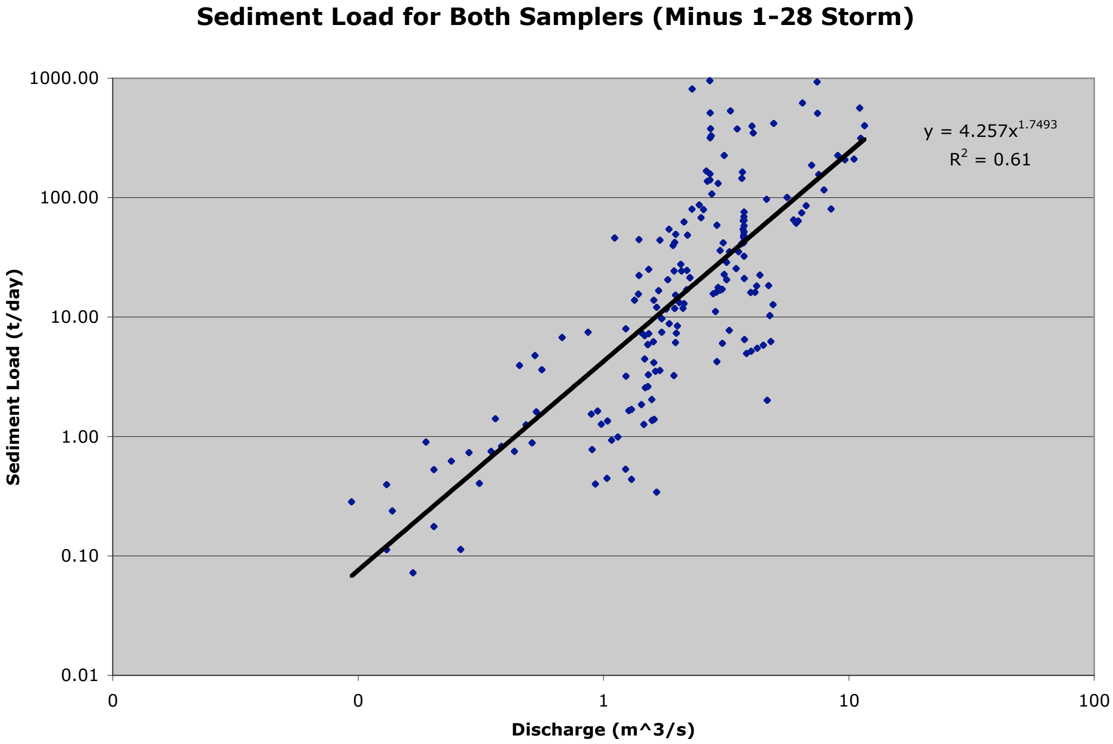


Figure 37. Sediment load rating curve for both sites on Mary's Creek. Data points removed for January 28 storm event at sampling site #2.

Table 6. Sediment yield calculations based on flow duration log and sediment load rating curve

Lower Bound of % Time Increment	Time in Increment (delta %)	Median of Time Increment (%)	Mean Daily Discharge (cfm)	Instantaneous Sediment Discharge (tons/day)	Mean Sediment Discharge for Time Increment
0.02	0.02	0.01	8	161.8	0.0
0.1	0.08	0.06	7	128.1	0.1
0.2	0.1	0.15	6.75	120.2	0.1
0.5	0.3	0.35	6	97.8	0.3
1	0.5	0.75	4	48.1	0.2
2	1	1.5	2.9	27.4	0.3
3	1	2.5	2.7	24.2	0.2
5	2	4	2	14.3	0.3
9	4	7	1.4	7.7	0.3
15	6	12	1.09	4.9	0.3
25	10	20	0.8	2.9	0.3
35	10	30	0.28	0.5	0.0
45	10	40	0.001	0.0	0.0
55	10	50	0.001	0.0	0.0
65	10	60	0.001	0.0	0.0
75	10	70	0.001	0.0	0.0
85	10	80	0.001	0.0	0.0
95	10	90	0.001	0.0	0.0
99	4	97	0.001	0.0	0.0
99.8	0.8	99.4	0.001	0.0	0.0
	99.8			**Mean tons/day**	**2.529**
				Mean tons/year	**923.101**
				t/ha/yr	**0.32175**

y = 4.257x^1.7493 equation for sediment load rating curve   Drainage area = 2,869 ha

concentration across both storm events was 0.19 mg/l with a maximum and a minimum value of 0.97 mg/l and 0 mg/l, respectively. The average NO_3-N concentration across both storm events was 1.01 mg/l with a maximum and a minimum value of 2.01 mg/l and 0.28 mg/l, respectively.

As can be seen in Figure 38, both storm events for which NH_3-N and NO_3-N samples were collected occurred in June. Unfortunately, NH_3-N and NO_3-N testing reagents and colorimeter were not obtained until March and sampling did not begin until June. June was followed by a very low-flow to no-flow regime and no more NH_3-N and NO_3-N storm event

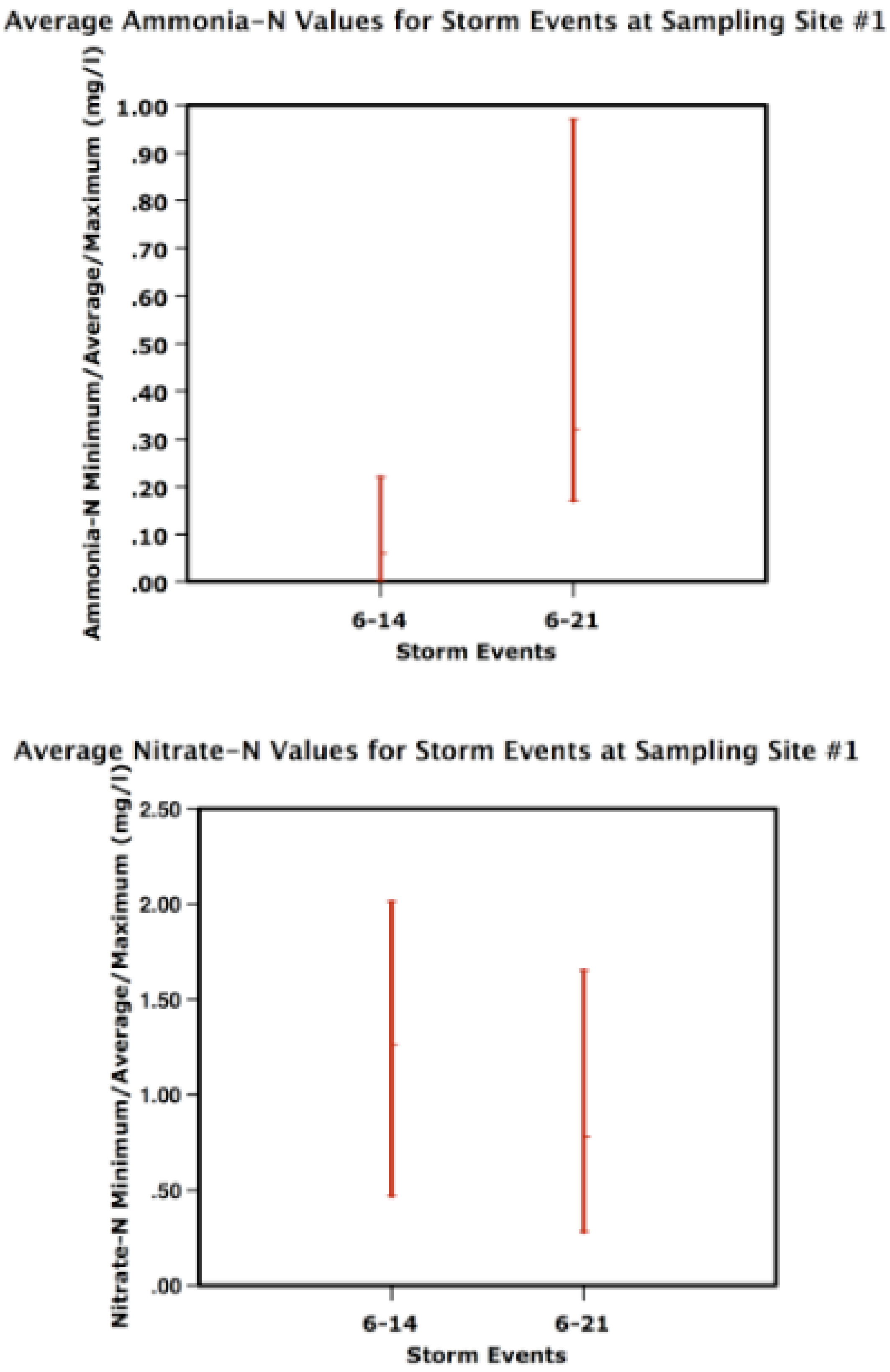


Figure 38. Average NH_3-N and NO_3-N values for storm events at site #1 on Mary's Creek.

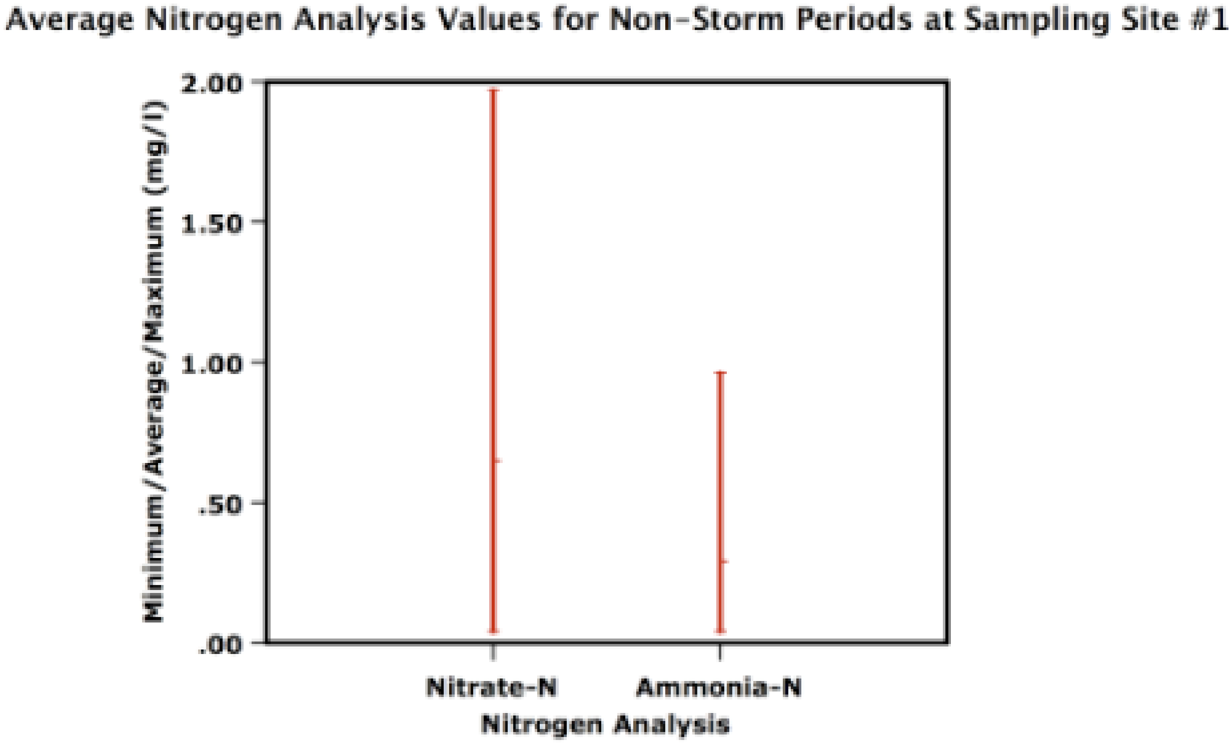


Figure 39. Average NH_3-N and NO_3-N values for non-storm periods at site #1 on Mary's Creek.

samples were collected. For this reason, analysis of temporal variation is limited to the comparison between the two June storm events. Ammonia-nitrogen concentration values were higher for the June 21 storm event, but the nitrate-nitrogen concentration values were higher for the June 14 storm event (Table 7).

Table 7. Nitrogen concentrations at site #1

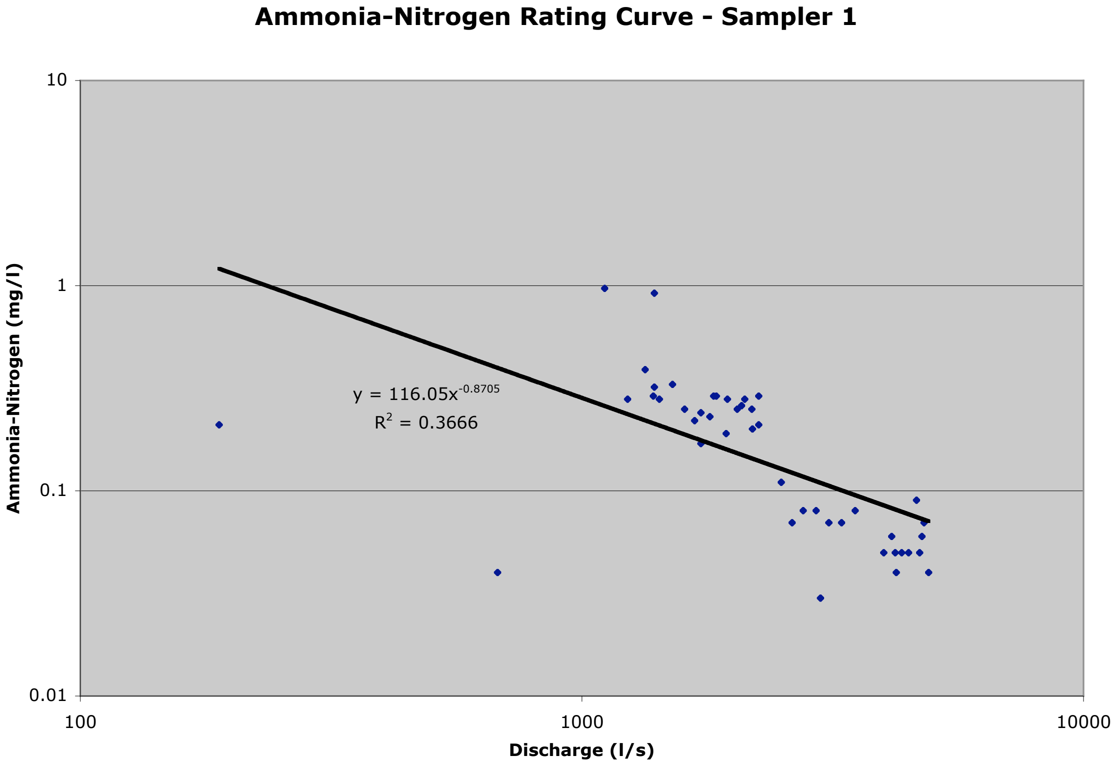
	June 14, 2001	June 21, 2001
Ammonia-Nitrogen		
Mean (mg/l)	0.06	0.32
Maximum (mg/l)	0.22	0.97
Minimum (mg/l)	0	0.17
Nitrate-Nitrogen		
Mean (mg/l)	1.26	0.78
Maximum (mg/l)	2.01	1.65
Minimum (mg/l)	0.47	0.28

According to TCEQ (2007), the screening level for NH_3-N in freshwater streams is 0.33 mg/l. Only 4 of the 47 NH_3-N samples exceeded the 0.33 mg/l. Based on the TCEQ's binomial method for determining screening level concerns, 4 exceedances out of 47 samples indicates no concern. Thus, NH_3-N levels do not appear to be problematic at Sampling Site #1 based on these two storm events. In terms of nitrate-nitrogen, the screening level is 1.95 mg/l based on the criteria developed by TCEQ. Once again, using the binomial method for determining screening level concerns indicates that 1 sample out of 47 represents no concern. As such, NO_3-N levels also do not appear to be problematic at Sampling Site #1 based on these two storm events.

In addition to the storm event samples, a total of 12 grab samples were collected between March 2001 and January 2002 during non-storm periods at Sampling Site #1. These samples were also analyzed for ammonia-nitrogen and nitrate-nitrogen concentrations. The average NH_3-N non-storm value was 0.29 mg/l and the average NO_3-N non-storm value was 0.65 mg/l (Figure 39). Ammonia-nitrogen concentration values ranged from 0.96 mg/l to 0.04 mg/l and nitrate-nitrogen concentration values ranged from 1.97 mg/l to 0.04 mg/l. Three of the 12 NH_3-N non-storm period samples exceeded TCEQ's screening level guidelines. However, according to TCEQ's exceedance guidelines, these elevated non-storm period concentration levels are of no concern and do not pose a problem at the outlet of Mary's Creek. It is suggested that these higher ammonia-nitrogen concentration levels are most likely the result of no-flow in the creek during the hot and dry summer coupled with the continued use of the creek by cattle. When there is discharge in Mary's Creek, the NH_3-N levels drop to acceptable levels. Only one of the 12 NO_3-N non-storm period concentration values exceeded TCEQ's screening level guidelines and is of no concern according to TCEQ's exceedance guidelines. In summary, it appears that neither NH_3-N nor NO_3-N concentration levels during storm events and/or non-storm periods represent a water quality problem at the outlet of Mary's Creek.

That being said, caution must be exercised in interpreting these results. It must be reiterated that the storm event values represent only two storm events that occurred in the same month of the year collected at one sampling site. Therefore, it was difficult to make spatial and seasonal comparisons. However, one temporal pattern was observed. NH_3-N concentration levels tended to be higher during the hotter and drier months when the creek was not flowing, but was a series of disconnected puddles; whereas, NO_3-N concentration levels tended to be lower during these same time periods and conditions. These results represent a preliminary snapshot of the nitrogen concentrations in Mary's Creek.

Nitrogen rating curves. Ammonia-nitrogen and nitrate-nitrogen rating curves were generated to depict the relationship between stream discharge and nitrogen concentrations. All nitrogen concentration data obtained at Sampling Site #1 were used to produce the rating curves, with the exception of the data obtained during non-storm periods. As can be seen in Figure 40, there is a weak to moderate, inverse relationship ($r^2 = 0.3666$) between discharge and ammonia-nitrogen concentration values. This is not surprising due to the dilution effect of a large volume of water in relation to a very small volume of NH_3-N. However, although the r^2 value is very low (0.0595), there is a direct, positive relationship between discharge and nitrate-nitrogen concentration values. This is somewhat surprising since it would be expected to show a dilution effect as well. However, storm runoff could lead to an increase in the delivery of nitrate-nitrogen to the creek from the surrounding land area. Once again, caution must be exercised in



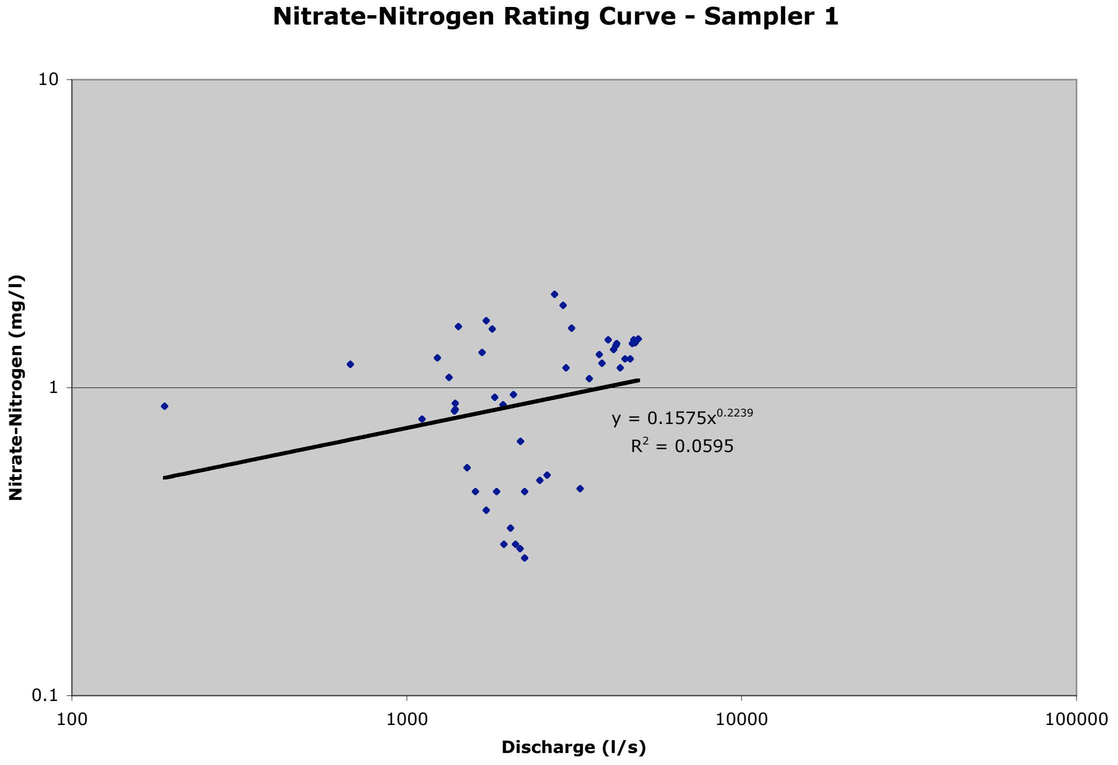


Figure 40. NH_3-N and NO_3-N rating curves for site #1 on Mary's Creek.

interpreting these limited and preliminary results. More sampling throughout the year and at other sites on Mary's Creek needs to be conducted before any valid generalizations can be made.

Nitrogen loads. Ammonia-nitrogen and nitrate-nitrogen loads were calculated for the two storm events in June and are summarized in Table 8. A comparison of the standardized NH_3-N and NO_3-N loads (kg/mm/hr) with the corresponding runoff coefficients indicates that higher runoff did not produce higher NH_3-N or NO_3-N loads. Ammonia-nitrogen and nitrate-nitrogen loads during non-storm periods are summarized in Table 9. Both average NH_3-N and NO_3-N loads were higher during storm events than during non-storm periods. However, during storm events, average NH_3-N loads were lower than average NO_3-N loads.

Table 8. Ammonia-nitrogen and nitrate nitrogen load values during storm events at site #1

NH_3-N

Storm Event	Total Rain	Sampling Duration	Ammonia-N Load			Runoff Coefficient	Average Load	
	(mm)	(hrs)	(kg)	(kg/mm)	(kg/mm/hr)	(%)	(g/s)	(g/s/mm)
14-Jun-01	67.56	1.50	4.26	0.06	0.04	0.05	0.20	0.003
21-Jun-01	37.08	0.25	10.82	0.29	1.17	0.04	0.49	0.013

NO_3-N

Storm Event	Total Rain	Sampling Duration	Nitrate-N Load			Runoff Coefficient	Average Load	
	(mm)	(hrs)	(kg)	(kg/mm)	(kg/mm/hr)	(%)	(g/s)	(g/s/mm)
14-Jun-01	67.56	1.50	94.83	1.40	0.94	0.05	4.42	0.065
21-Jun-01	37.08	0.25	26.42	0.71	2.85	0.04	1.19	0.032

Ammonia-nitrogen and nitrate-nitrogen load rating curves were generated to depict the relationship between stream discharge and nitrogen load. All nitrogen concentration data obtained at Sampling Site #1 was used to produce the rating curves with the exception of the

Table 9. Ammonia-nitrogen and nitrate-nitrogen loads during non-storm periods at site #1

NH_3-N

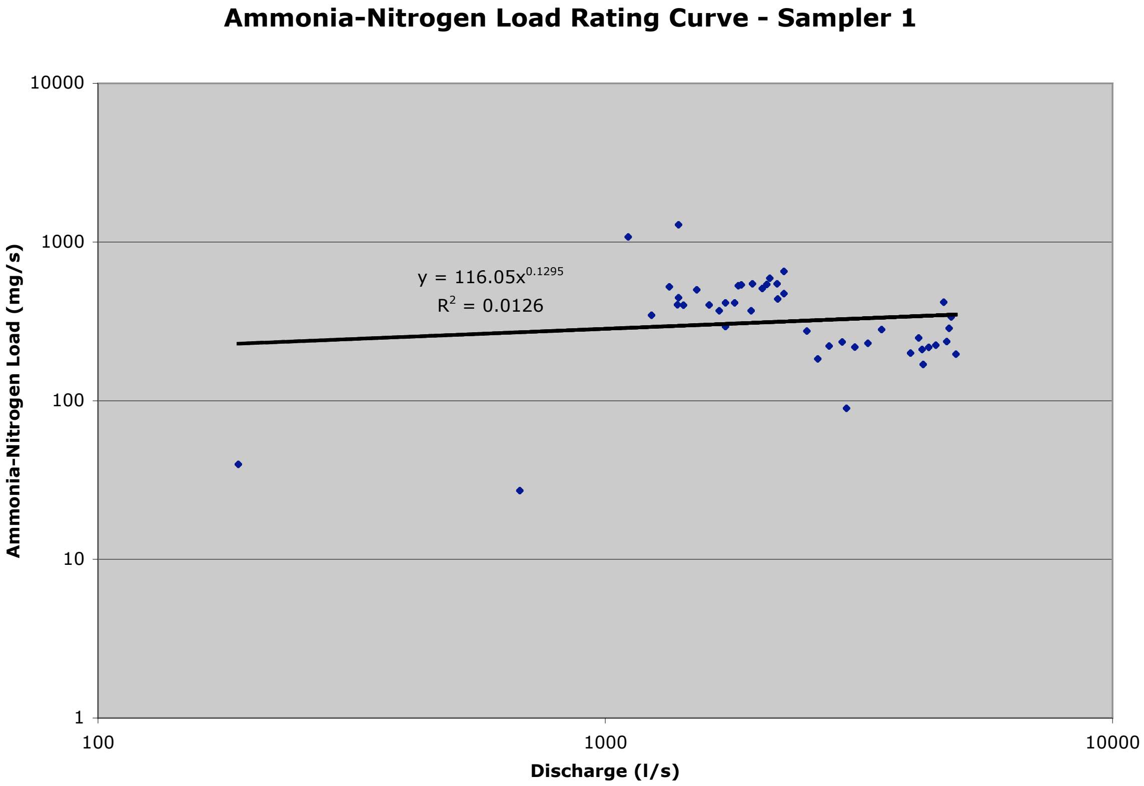
Sampling Date	Discharge (l/s)	NH_3-N (mg/l)	NH_3-N Load (mg/s)	NH_3-N Load (g/s)	NH_3-N Load (kg/day)
17-Mar-01	966	0.55	531.30	0.53	45.90
21-Apr-01	N/A*	0.09	N/A*	N/A*	N/A*
18-May-01	247	0.10	24.70	0.02	2.13
14-Jun-01	0	0.04	0	0	0
21-Jun-01	0	0.20	0	0	0
19-Aug-01	0	0.21	0	0	0
21-Sep-01	0	0.96	0	0	0
4-Oct-01	0	0.63	0	0	0
10-Nov-01	0	0.18	0	0	0
27-Nov-01	0	0.22	0	0	0
12-Dec-01	0	0.19	0	0	0
16-Jan-01	0	0.11	0	0	0
Total	**1213.00**	**3.48**	**556.00**	**0.556**	**48.04**
Average	**110.27**	**0.29**	**50.55**	**0.05**	**4.37**

NO_3-N

Sampling Date	Discharge (l/s)	NO_3-N (mg/l)	NO_3-N Load (mg/s)	NO_3-N Load (g/s)	NO_3-N Load (kg/day)
17-Mar-01	966	1.06	1023.96	1.02	88.47
21-Apr-01	N/A*	0.49	N/A*	N/A*	N/A*
18-May-01	247	0.63	155.61	0.16	13.44
14-Jun-01	0	1.97	0	0	0
21-Jun-01	0	0.90	0	0	0
19-Aug-01	0	0.62	0	0	0
21-Sep-01	0	0.68	0	0	0
4-Oct-01	0	0.04	0	0	0
10-Nov-01	0	0.27	0	0	0
27-Nov-01	0	0.07	0	0	0
12-Dec-01	0	0.99	0	0	0
16-Jan-01	0	0.13	0	0	0
Total	**1213**	**7.85**	**1179.57**	**1.18**	**101.91**
Average	**110.27**	**0.65**	**107.23**	**0.11**	**9.26**

*** = transducer damaged, no reading**

nitrogen data obtained during the non-storm periods. As can be seen in Figure 41, there is an extremely weak, positive relationship between discharge and NH_3-N load ($r^2 = 0.0126$). However, there is a strong, positive relationship between discharge and NO_3-N load



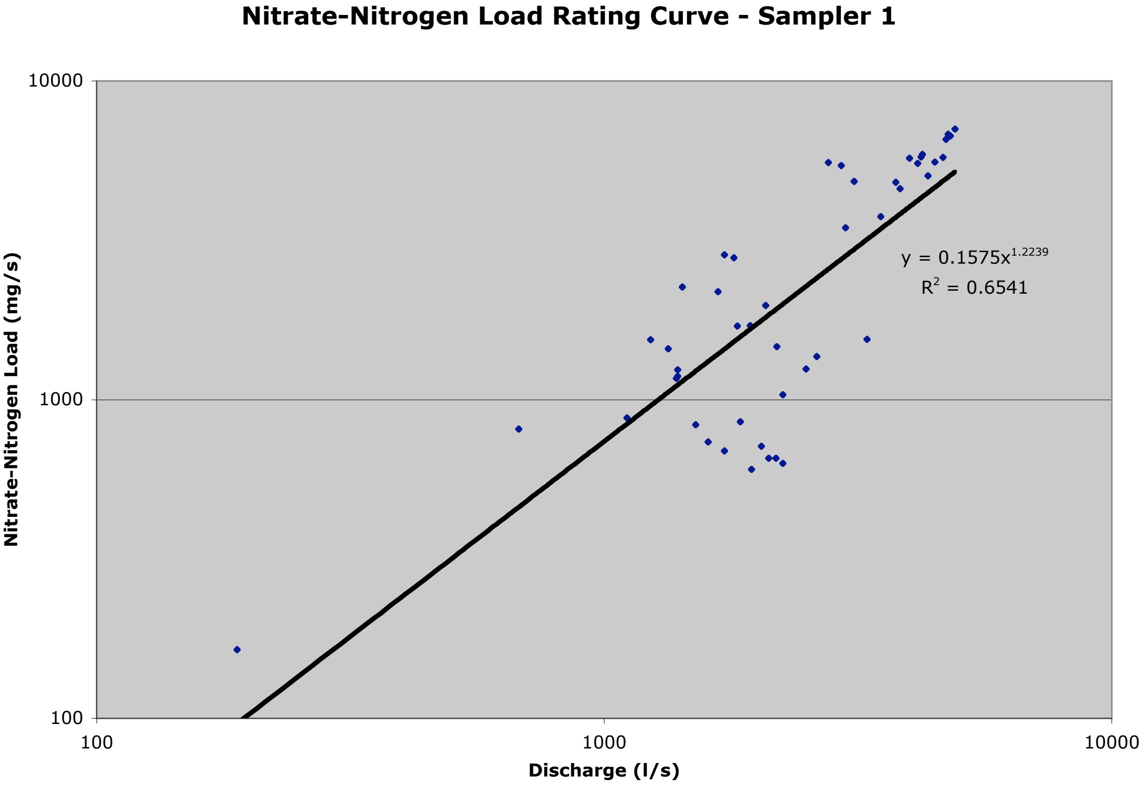


Figure 41. NH_3-N and NO_3-N load rating curves for site #1 on Mary's Creek.

($r^2 = 0.6541$). To obtain a more accurate and generalizable account of the nitrogen loads in relation to runoff, more data from additional storms throughout the year and from different sampling sites are needed.

CHAPTER IV: CONCLUSIONS AND RECOMMENDATIONS

We call upon the waters that rim the earth, horizon to horizon, that flow in our rivers and streams, that fall upon our gardens and fields, and we ask that they teach us and show us the way.
~ Chinook Indian Blessing Litany

This thesis has presented the results of a 13-month field investigation into the dynamics of pollutant flux in response to storm runoff on a pre-urbanized watershed in Parker County, Texas. The objectives of the research were:

1) To establish a baseline of sediment and nitrogen flux prior to slated land use changes;
2) To quantify the export of sediment and nitrogen from the watershed to determine whether levels pose any significant threats;
3) To determine the spatial and temporal variability of sediment and nitrogen flux at the watershed scale.

In general, the two sampling sites on Mary's Creek were found to have very similar responses to rainfall events as revealed by the hydrograph separations. Both the headwaters and basin outlet typically had "flashy" responses to rainfall input as indicated by the average time of rise calculations. The runoff coefficients for this study were unusually low given the basin size and the regional setting. The background streamflow in Mary's Creek appears to be maintained by baseflow, which is the portion of streamflow representing drainage from basin storage. The low runoff coefficients suggest a larger-than-average storage capacity of the watershed, which is not surprising given the land use in the basin. The use of the Walsh Ranch as grazing and pastureland instead of as crop production plays a vital role in the magnitude of the runoff produced, as well as the sediment yield of the basin. It is widely reported that runoff coefficients are dependant on the land use in the watershed (Dingman, 2002), with impervious surfaces resulting in higher runoff coefficients.

Based on calculated centroid lag-to-peak times and sub-basin size, the predominant runoff-producing mechanism on the Walsh Ranch was inferred to be a combination of Hortonian overland flow and saturation overland flow. This finding underscores the complexity of stream hydrologic response even within a relatively small watershed with relatively uniform land use. The runoff mechanism in operation will likely vary within the watershed and from storm to storm due to the variability in key watershed characteristics, most importantly, the spatial and temporal variability associated with antecedent soil moisture content and rainfall intensity and duration.

Overall average TSS values were found to be higher at the headwater site than at the outlet site. This difference was most likely the result of greater bank instability at the headwater site resulting in sporadic and localized inputs of sediment through the process of bank slumping. However, it was also suggested that the lower TSS values at the outlet may be due to the effects of a retention pond (located just upstream from the outlet) on flow velocity, and, subsequently, settling velocities of the suspended sediment. Another proposed explanation was that the headwater site had higher TSS values simply due to the higher cattle traffic along the banks and in the creek itself at that site. Sedigraph and hysteresis plots revealed an overall response pattern of sediment lead, indicating the mobilization of sediment already stored in the channel. This suggests that Mary’s Creek and its watershed is a sediment supply-limited system, a finding again consistent with land use patterns. The amount carried in the basin discharge is dependent on the suspended sediment availability. According to sediment yield calculations based on two different methods, the sediment load being transported out of this basin was found to be well below tolerable limits.

A preliminary analysis of nitrogen concentration levels revealed an overall consistent response pattern. Ammonia-nitrogen levels tended to decrease as discharge increased; whereas, nitrate-nitrogen levels increased as discharge increased. Ammonia-nitrogen and nitrate-nitrogen concentration levels rarely exceeded TCEQ's screening level guidelines and were determined to be of no concern.

Determining the spatial and temporal variability of sediment and nitrate flux was difficult due to the number of limiting factors and conditions previously discussed. However, seasonal variation in TSS values was observed. There was a stronger relationship between discharge and TSS during the sub-humid precipitation regime (January to April) as opposed to the semi-arid precipitation regime (May to December). Because nitrogen concentration samples were only collected at Sampling Site #1, spatial variability could not be addressed. Moreover, the ability to ascertain any patterns of temporal variability of nitrogen was hindered since the storm event samples were all obtained in June. Although nitrogen grab samples were collected from March to January, the majority of those months were characterized by a no-flow regime. Despite these obstacles, one pattern of temporal variability was observed: NH_3-N levels tended to be higher during the hotter and drier months when the creek was not flowing; whereas, NO_3-N levels tended to be lower during these same time periods and conditions.

The overarching purpose of this study was to monitor the sediment and nitrogen flux in this watershed in order to develop a baseline and historical record. Mary's Creek lies in a watershed that has been utilized historically as grazing and pastureland. As mentioned earlier, this land use plays a vital role in controlling the amount of runoff produced as well as the nature and magnitude of the pollutant flux. Land use actually governs the overall runoff response and pollutant flux. There are plans underway to urbanize this watershed over the next ten years. The conversion of agricultural or rural land to highly urbanized land causes dramatic changes and can pose significant risk to the health of local water bodies and can jeopardize the intended use of these water bodies.

During the construction phase of development, there will be a large increase in sediment production, which most likely will be accompanied by a moderate increase in runoff. Following the construction phase, the sediment yield will drop to a lower level, but the magnitude of the runoff and peak discharge rates will increase even more due to the impervious surfaces of buildings, parking lots, and streets. As peak runoff rates increase, pollutant transport and total pollutant loading to the water body will increase. Sediment and nutrients are common urban runoff pollutants. In addition to nutrients, these sediments can carry and deposit metals and other pollutants. Moreover, the increased runoff may change the morphology of the stream channel through the processes of erosion and deposition, causing the channel to become wider and shallower. These changes may result in an increase in the intensity and frequency of flooding. Figure 42 illustrates the effect of land use on sediment yield and channel condition.

Each of these changes in the hydrology of a watershed can result in physical and chemical changes that directly affect the biological health and beneficial uses of the water body. Since water quality standards are becoming ever more stringent, it is vital to know when problems are arising or getting worse. Therefore, continued water quality monitoring on Mary's

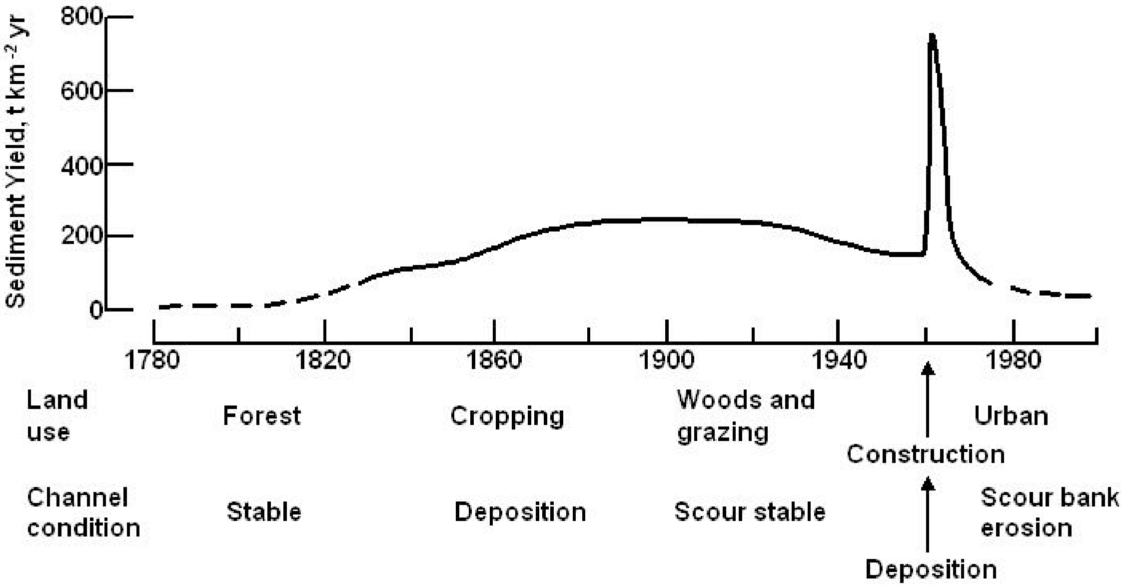


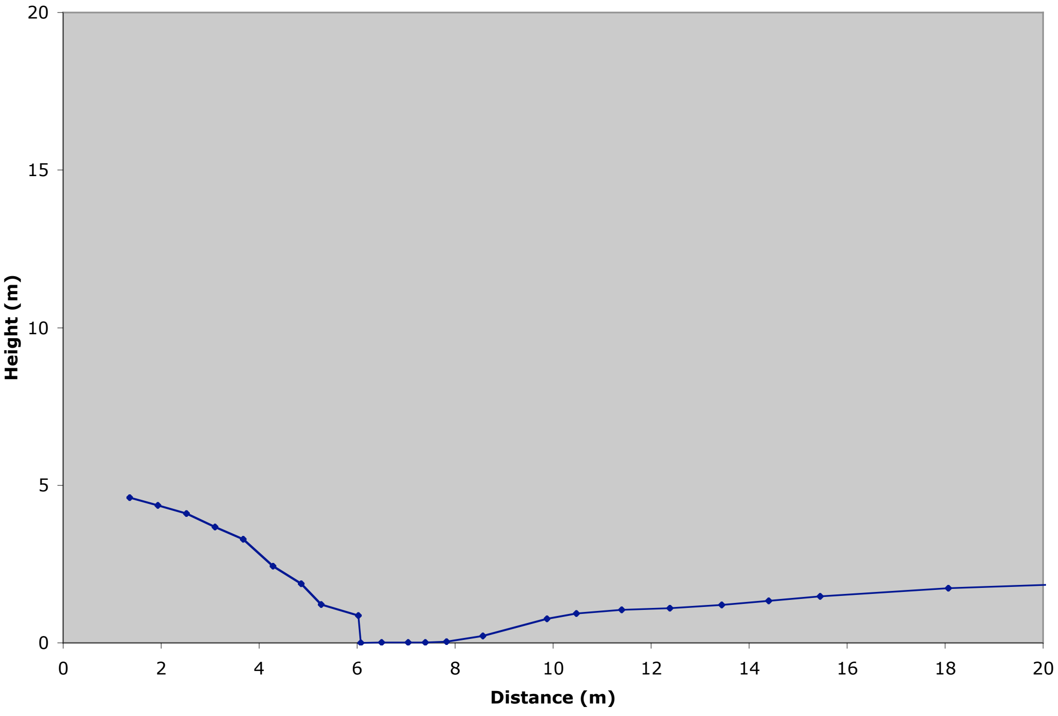
Figure 42. Schematic sequence of land use changes, sediment yield, and channel behavior (after Wolman, 1967).

Creek is strongly recommended because it will allow researchers and city planners to judge how the runoff and pollutant flux is changing in response to the land use changes. Continual monitoring is also important because of the inherent complexity and variability of environmental systems. Changes in complex systems can be very subtle and may not become apparent for some time. The establishment of a preliminary baseline through the monitoring conducted for this study may provide essential information on how systems are changing and how fast, and allows for the development of more effective best management practices to safeguard the integrity of the watershed.

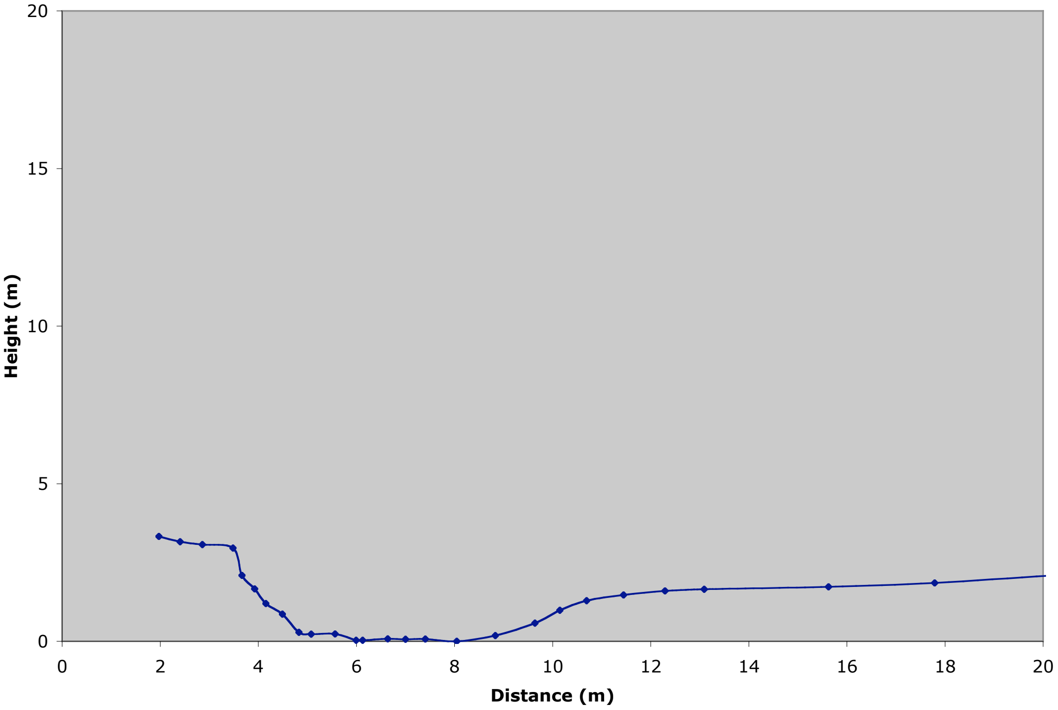
APPENDIX A: CROSS-SECTIONAL SURVEYS

Survey Data & Calculations							
11/15/01							
Sampler 1				**Sampler 2**			
	X	**Z**	**Absolute**		**X**	**Z**	**Absolute**
	34.348	-2.614	3.848		34.523	-1.945	2.959
	31.307	-2.884	3.578		32.199	-1.932	2.972
	28.51	-3.238	3.224		29.5	-2.031	2.873
	25.591	-3.789	2.673		27.475	-2.12	2.784
	23.059	-4.128	2.334		25.074	-2.498	2.406
	20.754	-4.588	1.874		22.398	-2.651	2.253
	18.067	-4.725	1.737		20.159	-2.822	2.082
	15.451	-4.98	1.482		17.79	-3.056	1.848
	14.4	-5.134	1.328	On gravel	15.624	-3.176	1.728
2 ft into bar	13.441	-5.256	1.206		13.092	-3.255	1.649
	12.385	-5.359	1.103		12.29	-3.308	1.596
	11.4	-5.41	1.052		11.448	-3.433	1.471
	10.478	-5.534	0.928		10.695	-3.616	1.288
	9.877	-5.696	0.766		10.149	-3.918	0.986
Edge of water	8.567	-6.243	0.219	Edge of water	9.639	-4.325	0.579
	7.825	-6.426	0.036		8.834	-4.721	0.183
	7.391	-6.448	0.014		8.044	-4.904	0
h=1.85	7.04	-6.453	0.009		7.404	-4.834	0.07
h=2.15	6.502	-6.454	0.008		6.999	-4.841	0.063
At bank	6.073	-6.462	0		6.639	-4.829	0.075
	6.023	-5.592	0.87		6.129	-4.869	0.035
	5.263	-5.244	1.218	Edge ledge	5.994	-4.874	0.03
	4.856	-4.583	1.879	On ledge	5.567	-4.671	0.233
	4.28	-4.031	2.431		5.076	-4.679	0.225
	3.679	-3.177	3.285	2nd ledge	4.828	-4.62	0.284
Sampler	3.096	-2.792	3.67		4.49	-4.043	0.861
	2.516	-2.355	4.107		4.156	-3.706	1.198
	1.93	-2.096	4.366		3.926	-3.238	1.666
	1.361	-1.85	4.612		3.665	-2.812	2.092
					3.484	-1.947	2.957
					2.861	-1.835	3.069
					2.404	-1.744	3.16
					1.975	-1.58	3.324
				H	**V**	**S**	
Channel bed	2.026	-1.8	0.337				
Sampler 1	10.479	-2.137	0	8.453	0.337	0.039867503	
				H	**V**	**S**	
Channel bed	2.895	-1.847	0.265				
Sampler 2	8.748	-2.112	0	5.853	0.265	0.045275927	

Survey - Sampler 1



Survey - Sampler 2



APPENDIX B: RATING CURVE DATA AND CALCULATIONS

Rating Curve Data & Calculations			
Sampler 1			
Area	**m/s**	**Stage**	**Q (m^3/s)**
1.92	1.052	27.8	2.01984
1.975	1.11	28.51	2.19225
1.711	0.562	25.5	0.961582
1.792	0.527	26.471	0.944384
1.711	0.343	25.5	0.586873
3.654	1.05	42.684	3.8367
1.815	0.194	26.762	0.35211
2.248	0.973	31.24	2.187304
2.124	1.611	29.869	3.421764
1.782	0.603	26.3	1.074546
1.819	1.042	26.762	1.895398
1.743	0.401	25.89	0.698943
1.544	0.027	23.57	0.041688
4.647	1.6	47.44	7.4352

Rating Curve Data & Calculations

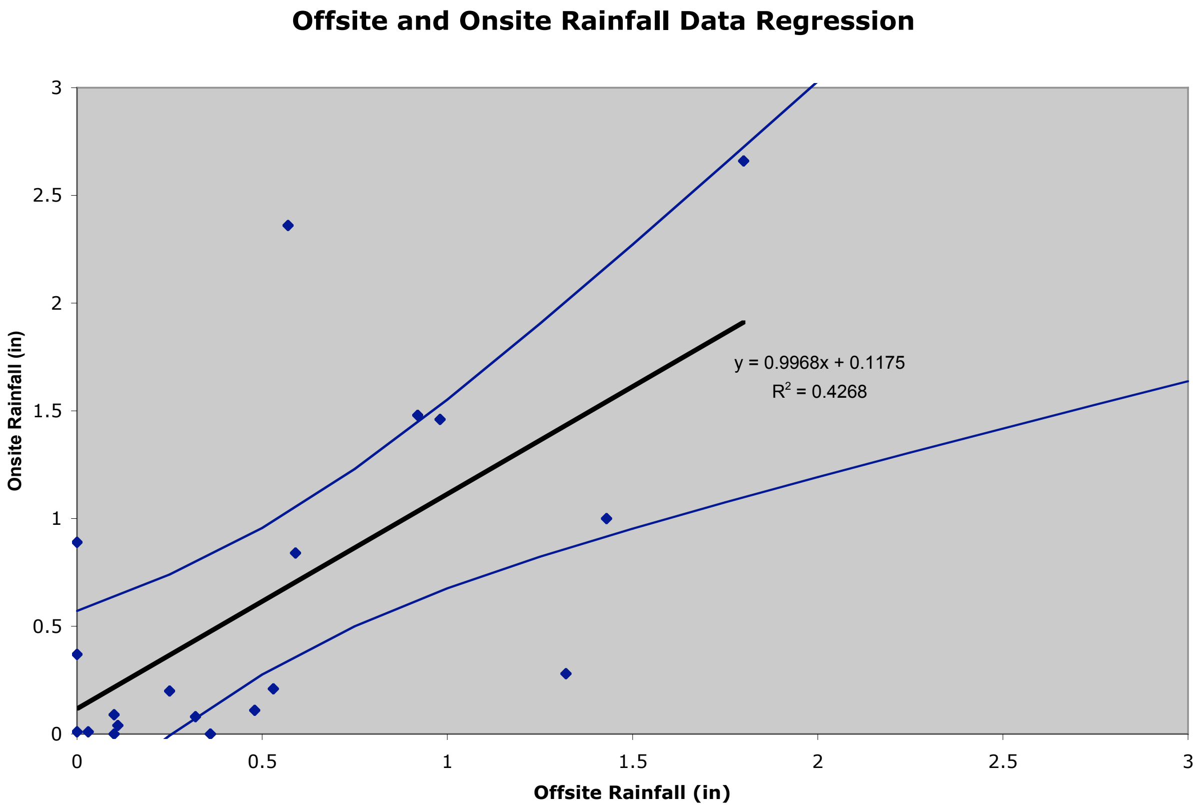
Sampler 2

Area	m/s	Stage	C.F.	Corr. Stage	Q (m^3/s)	
		3.385	19.843	23.228	0	nf
		3.318	19.843	23.161	0	nf
		3.115	19.843	22.958	0	nf
		2.708	19.843	22.551	0	nf
		1.083	19.843	20.926	0	nf
		3.318	19.843	23.161	0	nf
		2.911	19.843	22.754	0	nf
		2.97	19.843	22.813	0	nf
		3.25	19.843	23.093	0	nf
		3.385	19.843	23.228	0	nf
		3.521	19.843	23.364	0	nf
2.338	0.051	4.672	19.843	24.515	0.119238	
2.672	0.154	24.099	2.91	27.009	0.411488	
2.214	0.28	20.849	2.91	23.759	0.61992	
3.046	0.297	26.974	2.91	29.884	0.904662	
4.732	0.688	38.688	2.91	41.598	3.255616	
3.164	0.273	27.85	2.91	30.76	0.863772	
3.269	0.334	28.734	2.91	31.644	1.091846	
3.156	0.751	23.964	6.299	30.263	2.370156	
9.744	0.751			68.5	7.317744	
				0	0	
				0	0	
				0	0	
				0	0	
				0	0	
				0	0	
				0	0	
				0	0	
				0	0	
				0	0	
				0	0	
				0	0	
				0	0	
				0	0	
				0	0	
				0	0	
				0	0	
				0	0	
				0	0	

APPENDIX C: OFFSITE AND ONSITE RAINFALL CORRELATION AND REGRESSION

Rainfall Correlation & Regression Data

		Offsite	**Onsite**	**r**	**r^2**	**a**	**b**
		0.92	1.48	0.65	0.43	0.117	0.997
		1.43	1				
		0.48	0.11				
		0	0.37				
		0.1	0.09				
		0.03	0.01				
		0	0.01				
		0.32	0.08				
		0	0.89				
		0.11	0.04				
		1.8	2.66				
		0.98	1.46				
		0.1	0				
		0.59	0.84				
		0.53	0.21				
		0.36	0				
		0.25	0.2				
		1.32	0.28				
		0.57	2.36				
Regression Line Confidence Interval							
x	**CI**	**y+CI**	**y-CI**	**Slope**	0.99675678		
0.00	0.453	0.571	-0.336	**Intercept**	0.11747765		
0.25	0.374	0.741	-0.007	**Obs**	23		
0.50	0.340	0.956	0.276	**Std Err**	0.63872154		
0.75	0.365	1.230	0.500	**Ave x**	0.521		
1.00	0.438	1.552	0.676	**SSX**	5.19789474		
1.25	0.541	1.904	0.823	**t**	2.05953711		
1.50	0.659	2.272	0.953				
1.75	0.787	2.648	1.075				
2.00	0.919	3.030	1.192				
2.25	1.054	3.414	1.306				
2.50	1.192	3.801	1.418				
2.75	1.330	4.189	1.528				
3.00	1.470	4.578	1.637				


Offsite and Onsite Rainfall Data Regression
y = 0.9968x + 0.1175
R2 = 0.4268
Onsite Rainfall (in)
Offsite Rainfall (in)
0
0.5
1
1.5
2
2.5
3
0
0.5
1
1.5
2
2.5
3

APPENDIX D: RESEARCH DATA

SAMPLER 1 - RESEARCH DATA							
STORM EVENTS							
Date	**Time**	**Discharge**	**Baseflow**	**TSS**	**Nitrate-N**	**Ammonia-N**	**Storm**
		(m^3/s)	**(m^3/s)**	**(mg/l)**	**(mg/l)**	**(mg/l)**	
25-Jan-01	04:00p.m.	1.301	0.862	3.9			st-2
25-Jan-01	04:15p.m.	1.648	0.866	2.4			st-2
25-Jan-01	04:30p.m.	1.629	0.869	25			st-2
25-Jan-01	04:45p.m.	1.573	0.873	15			st-2
25-Jan-01	05:00p.m.	1.429	0.877	15			st-2
25-Jan-01	05:15p.m.	1.301	0.881	15			st-2
25-Jan-01	05:30p.m.	1.230	0.885	5			st-2
25-Jan-01	05:45p.m.	1.145	0.889	10			st-2
25-Jan-01	06:00p.m.	1.079	0.893	10			st-2
25-Jan-01	06:15p.m.	1.033	0.897	5			st-2
25-Jan-01	06:30p.m.	0.979	0.901	15			st-2
25-Jan-01	06:45p.m.	0.946	0.905	20			st-2
25-Jan-01	07:00p.m.	0.926	0.909	5			st-2
25-Jan-01	07:15p.m.	0.899	0.913	10			st-2
25-Jan-01	07:30p.m.	0.892	0.917	20			st-2
25-Jan-01	07:45p.m.	0.865	0.920	100			st-2
28-Jan-01	05:50p.m.	1.530	1.147	190			st-3
28-Jan-01	06:05p.m.	1.697	1.151	300			st-3
28-Jan-01	06:20p.m.	1.850	1.155	340			st-3
28-Jan-01	06:35p.m.	1.922	1.158	240			st-3
28-Jan-01	06:50p.m.	1.952	1.162	250			st-3
28-Jan-01	07:05p.m.	1.970	1.166	290			st-3
28-Jan-01	07:20p.m.	2.130	1.170	340			st-3
28-Jan-01	07:35p.m.	2.293	1.174	405			st-3
28-Jan-01	07:50p.m.	2.458	1.178	410			st-3
28-Jan-01	08:05p.m.	2.554	1.182	360			st-3
28-Jan-01	08:20p.m.	2.649	1.186	600			st-3
28-Jan-01	08:35p.m.	2.720	1.190	1350			st-3
28-Jan-01	08:50p.m.	2.709	1.194	4080			st-3
28-Jan-01	09:05p.m.	2.731	1.198	1600			st-3
28-Jan-01	09:20p.m.	2.715	1.202	675			st-3
28-Jan-01	09:35p.m.	2.715	1.206	600			st-3
28-Jan-01	09:50p.m.	2.748	1.210	1390			st-3
28-Jan-01	10:05p.m.	2.720	1.213	2180			st-3
13-Feb-01	08:20a.m.	1.039	0.606	15			st-4
13-Feb-01	08:35a.m.	1.236	0.610	30			st-4
13-Feb-01	08:50a.m.	1.473	0.614	55			st-4

13-Feb-01	09:05a.m.	1.598	0.618	45			st-4
13-Feb-01	09:20a.m.	1.605	0.621	100			st-4
13-Feb-01	09:35a.m.	1.648	0.625	85			st-4
13-Feb-01	09:50a.m.	1.728	0.629	65			st-4
13-Feb-01	10:05a.m.	1.964	0.633	90			st-4
13-Feb-01	10:20a.m.	2.065	0.637	155			st-4
13-Feb-01	10:35a.m.	2.200	0.641	255			st-4
13-Feb-01	10:50a.m.	2.900	0.645	235			st-4
13-Feb-01	11:05a.m.	3.682	0.649	515			st-4
13-Feb-01	11:20a.m.	4.073	0.653	990			st-4
13-Feb-01	11:35a.m.	4.935	0.657	980			st-4
13-Feb-01	11:50a.m.	6.473	0.661	1110			st-4
13-Feb-01	12:05p.m.	7.426	0.665	1450			st-4
23-Feb-01	02:10p.m.	1.269	1.227	15			st-6
23-Feb-01	02:25p.m.	1.460	1.231	10			st-6
23-Feb-01	02:40p.m.	1.611	1.235	10			st-6
23-Feb-01	02:55p.m.	1.580	1.239	10			st-6
23-Feb-01	03:10p.m.	1.580	1.243	10			st-6
23-Feb-01	03:25p.m.	1.479	1.247	20			st-6
23-Feb-01	03:40p.m.	1.517	1.250	20			st-6
23-Feb-01	03:55p.m.	1.523	1.254	25			st-6
23-Feb-01	04:10p.m.	1.530	1.258	55			st-6
23-Feb-01	04:25p.m.	1.517	1.262	45			st-6
23-Feb-01	04:40p.m.	1.473	1.266	35			st-6
23-Feb-01	05:50p.m.	1.697	1.279	24.35			st-6
23-Feb-01	06:05p.m.	1.934	1.283	19.4			st-6
23-Feb-01	06:20p.m.	2.000	1.287	48.75			st-6
23-Feb-01	06:35p.m.	1.964	1.291	36.1			st-6
23-Feb-01	06:50p.m.	1.982	1.295	42.85			st-6
23-Feb-01	07:05p.m.	2.130	1.299	70.4			st-6
23-Feb-01	07:20p.m.	2.299	1.303	4100.6			st-6
14-Jun-01	06:50p.m.	0.679	0.134	115	1.19	0.04	st-18
14-Jun-01	07:05p.m.	1.677	0.138	115	1.3	0.22	st-18
14-Jun-01	07:20p.m.	2.989	0.141	140	1.16	0.03	st-18
14-Jun-01	07:35p.m.	3.827	0.145	15	1.2	0	st-18
14-Jun-01	07:50p.m.	4.341	0.149	60	1.16	0.05	st-18
14-Jun-01	08:05p.m.	4.212	0.153	50	1.37	0.05	st-18
14-Jun-01	08:20p.m.	4.146	0.157	45	1.33	0.06	st-18
14-Jun-01	08:35p.m.	4.713	0.161	45	1.39	0.05	st-18
14-Jun-01	08:50p.m.	4.912	0.165	30	1.44	0.04	st-18
14-Jun-01	09:05p.m.	4.809	0.169	15	1.4	0.07	st-18
14-Jun-01	09:20p.m.	4.761	0.173	25	1.43	0.06	st-18
14-Jun-01	09:35p.m.	4.647	0.177	5	1.24	0.09	st-18
14-Jun-01	09:50p.m.	4.482	0.181	15	1.24	0.05	st-18
14-Jun-01	10:05p.m.	4.235	0.185	15	1.39	0.04	st-18
14-Jun-01	10:20p.m.	3.995	0.189	15	1.43	0.05	st-18
14-Jun-01	10:35p.m.	3.754	0.192	20	1.28	0	st-18
14-Jun-01	10:50p.m.	3.506	0.196	1245	1.07	0.08	st-18

14-Jun-01	11:05p.m.	3.293	0.200	1875	0.47	0.07	st-18
14-Jun-01	11:20p.m.	3.105	0.204	840	1.56	0.07	st-18
14-Jun-01	11:35p.m.	2.930	0.208	520	1.85	0.08	st-18
14-Jun-01	11:50p.m.	2.762	0.212	450	2.01	0.08	st-18
15-Jun-01	12:05a.m.	2.625	0.216	735	0.52	0.07	st-18
15-Jun-01	12:20a.m.	2.496	0.220	315	0.5	0.11	st-18
21-Jun-01	03:20p.m.	0.189	0.189	55	0.87	0.21	st-19
21-Jun-01	03:35p.m.	1.110	0.193	480	0.79	0.97	st-19
21-Jun-01	03:50p.m.	1.395	0.197	370	0.85	0.92	st-19
21-Jun-01	04:05p.m.	1.395	0.201	185	0.89	0.32	st-19
21-Jun-01	04:20p.m.	1.388	0.205	130	0.84	0.29	st-19
21-Jun-01	04:35p.m.	1.337	0.209	120	1.08	0.39	st-19
21-Jun-01	04:50p.m.	1.234	0.213	75	1.25	0.28	st-19
21-Jun-01	05:05p.m.	1.427	0.216	60	1.58	0.28	st-19
21-Jun-01	05:20p.m.	1.726	0.220	65	1.65	0.17	st-19
21-Jun-01	05:35p.m.	1.800	0.224	75	1.55	0.23	st-19
21-Jun-01	05:50p.m.	1.830	0.228	130	0.93	0.29	st-19
21-Jun-01	06:05p.m.	1.939	0.232	145	0.88	0.19	st-19
21-Jun-01	06:20p.m.	2.081	0.236	135	0.95	0.26	st-19
21-Jun-01	06:35p.m.	2.187	0.240	130	0.67	0.2	st-19
21-Jun-01	06:50p.m.	2.251	0.244	110	0.46	0.21	st-19
21-Jun-01	07:05p.m.	2.251	0.248	110	0.28	0.29	st-19
21-Jun-01	07:20p.m.	2.181	0.252	90	0.3	0.25	st-19
21-Jun-01	07:35p.m.	2.111	0.256	65	0.31	0.28	st-19
21-Jun-01	07:50p.m.	2.040	0.260	75	0.35	0.25	st-19
21-Jun-01	08:05p.m.	1.950	0.264	70	0.31	0.28	st-19
21-Jun-01	08:20p.m.	1.854	0.267	55	0.46	0.29	st-19
21-Jun-01	08:35p.m.	1.726	0.271	50	0.4	0.24	st-19
21-Jun-01	08:50p.m.	1.603	0.275	30	0.46	0.25	st-19
21-Jun-01	09:05p.m.	1.515	0.279	45	0.55	0.33	st-19
1-Jul-01	07:20a.m.	0.362	0.211	45			st-20
1-Jul-01	07:35a.m.	0.455	0.214	100			st-20
1-Jul-01	07:50a.m.	0.526	0.218	105			st-20
1-Jul-01	08:05a.m.	0.561	0.222	75			st-20
1-Jul-01	08:20a.m.	0.532	0.226	35			st-20
1-Jul-01	08:35a.m.	0.511	0.230	20			st-20
1-Jul-01	08:50a.m.	0.483	0.234	30			st-20
1-Jul-01	09:05a.m.	0.434	0.238	20			st-20
1-Jul-01	09:20a.m.	0.384	0.242	25			st-20
1-Jul-01	09:35a.m.	0.348	0.246	25			st-20
1-Jul-01	09:50a.m.	0.312	0.250	15			st-20
1-Jul-01	10:05a.m.	0.283	0.254	30			st-20
1-Jul-01	10:20a.m.	0.262	0.258	5			st-20
1-Jul-01	10:35a.m.	0.240	0.260	30			st-20
1-Jul-01	10:50a.m.	0.204	0.264	10			st-20
1-Jul-01	11:05a.m.	0.204	0.268	30			st-20
1-Jul-01	11:20a.m.	0.167	0.272	5			st-20
1-Jul-01	11:35a.m.	0.138	0.276	20			st-20

1-Jul-01	11:50a.m.	0.131	0.280	10			st-20
1-Jul-01	12:05p.m.	0.131	0.284	35			st-20
1-Jul-01	12:20p.m.	0.094	0.288	35			st-20
NON-STORM EVENTS							
23-Jan-01	1:20p.m.	0.865		2.34	**	**	gs
7-Feb-01	3:40p.m.	0.845		2.87	**	**	gs
22-Feb-01	3:45p.m.	1.254		4.62	**	**	gs
17-Mar-01	3:30p.m.	0.966		3.79	1.06	0.55	gs
21-Apr-01	1:55p.m.	N/A*		1.85	0 .49	0.09	gs
18-May-01	11:40a.m.	0.247		2.11	0.63	0.10	gs
14-Jun-01	1:25p.m.	0		1.93	1.97	0.04	gs
21-Jun-01	11:50a.m.	0		1.58	0.90	0.20	gs
19-Aug-01	7:15a.m.	0		1.66	0.62	0.21	gs
21-Sep-01	9:55a.m.	0		1.58	0.68	0.96	gs
4-Oct-01	11:45a.m.	0		1.76	0.04	0.63	gs
10-Nov-01	12:00p.m.	0		1.32	0.27	0.18	gs
27-Nov-01	4:35p.m.	0		1.45	0.07	0.22	gs
12-Dec-01	2:10p.m.	0		1.29	0.99	0.19	gs
16-Jan-02	1:40p.m.	0		0.97	0.13	0.11	gs
* = transducer damaged, no reading ** = reagents unavailable, no analysis done							

SAMPLER 2 - RESEARCH DATA

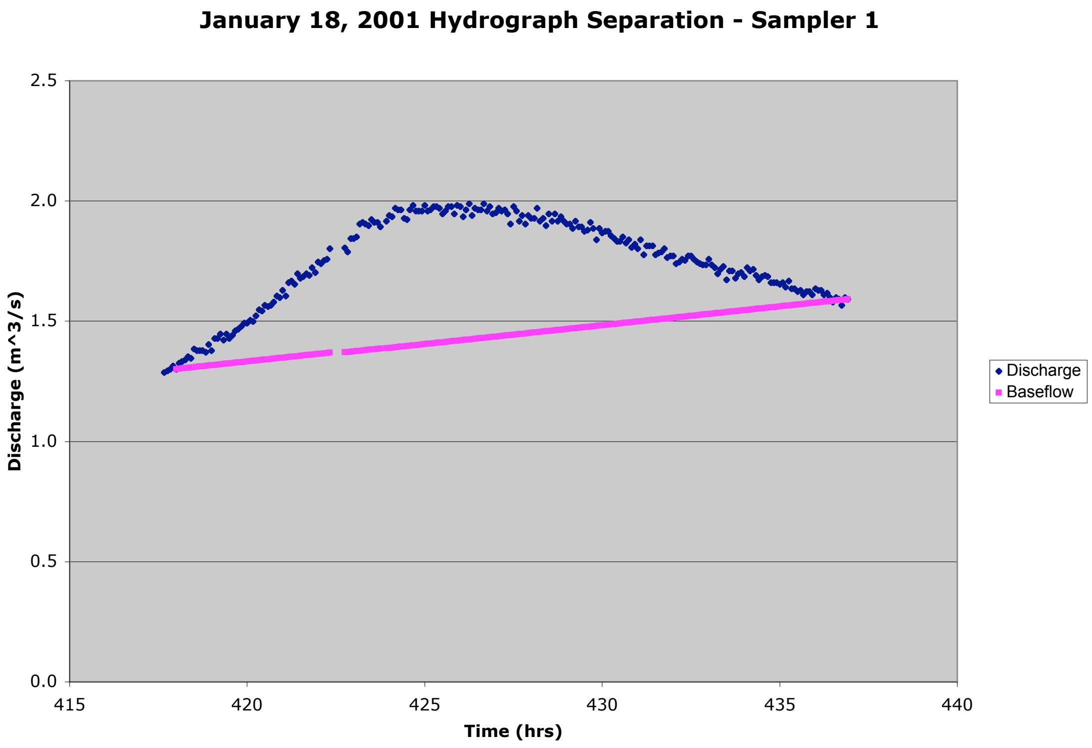
STORM EVENTS

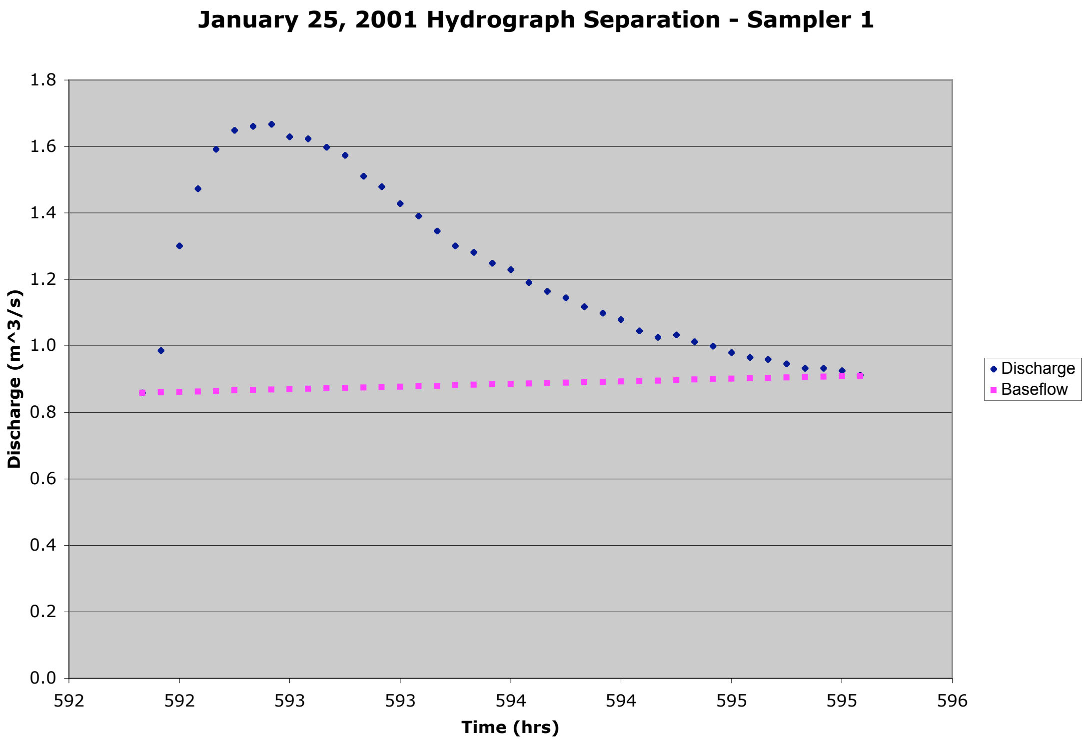
Date	Time	Discharge	Baseflow	TSS	Nitrate-N	Ammonia-N	Storm
		(m^3/s)	(m^3/s)	(mg/l)	(mg/l)	(mg/l)	
28-Jan-01	05:55p.m.	0.781	0.198	0			st-3
28-Jan-01	06:10p.m.	0.909	0.202	0			st-3
28-Jan-01	06:25p.m.	1.095	0.206	0			st-3
28-Jan-01	06:40p.m.	1.177	0.210	10			st-3
28-Jan-01	06:55p.m.	1.114	0.214	0			st-3
28-Jan-01	07:10p.m.	1.239	0.218	0			st-3
28-Jan-01	07:25p.m.	1.211	0.222	0			st-3
28-Jan-01	07:40p.m.	1.264	0.226	5			st-3
28-Jan-01	07:55p.m.	1.322	0.230	165			st-3
28-Jan-01	08:10p.m.	1.248	0.234	175			st-3
28-Jan-01	08:25p.m.	1.192	0.238	180			st-3
28-Jan-01	08:40p.m.	1.242	0.242	213.44			st-3
28-Jan-01	08:55p.m.	1.133	0.246	246.42			st-3
28-Jan-01	09:10p.m.	1.174	0.249	265			st-3
28-Jan-01	09:25p.m.	1.133	0.253	590			st-3
28-Jan-01	09:40p.m.	1.202	0.257	900			st-3
28-Jan-01	09:55p.m.	1.146	0.261	1510			st-3
28-Jan-01	10:10p.m.	1.120	0.265	1390			st-3
28-Jan-01	10:25p.m.	1.142	0.269	1090			st-3
28-Jan-01	10:40p.m.	1.167	0.273	1570			st-3
28-Jan-01	10:55p.m.	1.227	0.277	1610			st-3
28-Jan-01	11:10p.m.	1.180	0.281	1580			st-3
28-Jan-01	11:25p.m.	1.267	0.285	1090			st-3
28-Jan-01	11:40p.m.	1.419	0.289	800			st-3
23-Feb-01	04:35p.m.	2.637	2.558	65			st-6
23-Feb-01	04:50p.m.	2.699	2.561	25			st-6
23-Feb-01	05:05p.m.	2.801	2.565	65			st-6
23-Feb-01	05:20p.m.	2.862	2.569	45			st-6
23-Feb-01	05:35p.m.	2.999	2.573	65			st-6
23-Feb-01	05:50p.m.	3.072	2.577	80			st-6
23-Feb-01	06:05p.m.	3.175	2.581	75			st-6
23-Feb-01	06:25p.m.	3.550	2.585	115			st-6
23-Feb-01	06:40p.m.	3.661	2.589	256.25			st-6
23-Feb-01	06:55p.m.	3.710	2.593	200			st-6
23-Feb-01	07:55p.m.	4.026	2.609	1144.7			st-6
23-Feb-01	08:10p.m.	7.447	2.612	789.5			st-6
23-Feb-01	08:25p.m.	11.082	2.616	588.1			st-6
23-Feb-01	08:40p.m.	11.594	2.620	399.8			st-6
23-Feb-01	08:55p.m.	11.187	2.624	324.9			st-6
23-Feb-01	09:10p.m.	10.504	2.628	231.5			st-6
23-Feb-01	09:25p.m.	9.631	2.632	250			st-6
23-Feb-01	09:40p.m.	9.022	2.636	290			st-6

23-Feb-01	09:55p.m.	8.463	2.640	110			st-6
23-Feb-01	10:10p.m.	7.918	2.644	170			st-6
23-Feb-01	10:25p.m.	7.538	2.648	240			st-6
23-Feb-01	10:40p.m.	7.049	2.652	307.6			st-6
23-Feb-01	10:55p.m.	6.692	2.656	147.8			st-6
23-Feb-01	11:10p.m.	6.429	2.660	134.3			st-6
23-Feb-01	11:25p.m.	6.218	2.663	118.8			st-6
23-Feb-01	11:40p.m.	6.102	2.667	116.1			st-6
23-Feb-01	11:55p.m.	5.949	2.671	126.9			st-6
8-Mar-01	01:40p.m.	2.896	2.767	16.95	1	0.05	st-9
8-Mar-01	02:10p.m.	3.051	2.774	22.9	0.79	0.07	st-9
8-Mar-01	02:40p.m.	3.254	2.782	27.5	0.88	0.13	st-9
8-Mar-01	03:10p.m.	3.981	2.790	46.75	0.85	0.19	st-9
8-Mar-01	03:40p.m.	4.617	2.798	243.65	0.77	0.08	st-9
8-Mar-01	04:10p.m.	5.601	2.806	207.55	0.65	0.22	st-9
27-Mar-01	03:20p.m.	2.888	2.765	65			st-14
27-Mar-01	03:35p.m.	2.934	2.769	70			st-14
27-Mar-01	03:50p.m.	2.985	2.773	65			st-14
27-Mar-01	04:05p.m.	3.044	2.777	65			st-14
27-Mar-01	04:20p.m.	3.103	2.781	85			st-14
27-Mar-01	04:35p.m.	3.173	2.785	105			st-14
27-Mar-01	04:50p.m.	3.261	2.789	125			st-14
27-Mar-01	05:05p.m.	3.475	2.793	85			st-14
27-Mar-01	05:20p.m.	3.650	2.797	130			st-14
27-Mar-01	05:35p.m.	3.725	2.801	130			st-14
27-Mar-01	05:50p.m.	3.748	2.805	135			st-14
27-Mar-01	06:05p.m.	3.736	2.809	215			st-14
27-Mar-01	06:20p.m.	3.744	2.812	200			st-14
27-Mar-01	06:35p.m.	3.740	2.816	180			st-14
27-Mar-01	06:50p.m.	3.733	2.820	160			st-14
27-Mar-01	07:05p.m.	3.708	2.824	170			st-14
27-Mar-01	07:20p.m.	3.723	2.828	145			st-14
27-Mar-01	07:35p.m.	3.729	2.832	150			st-14
27-Mar-01	07:50p.m.	3.738	2.836	160			st-14
27-Mar-01	08:05p.m.	3.738	2.840	100			st-14
27-Mar-01	08:20p.m.	3.740	2.844	235			st-14
27-Mar-01	08:35p.m.	3.751	2.848	65			st-14
NON-STORM EVENTS							
23-Jan-01	2:55p.m.	0		3.17			gs
7-Feb-01	2:15p.m.	2.084		7.92			gs
22-Feb-01	5:40p.m.	2.527		6.84			gs
17-Mar-01	12:15p.m.	2.627		11.36			gs
21-Apr-01	11:15a.m.	2.471		8.53			gs
18-May-01	10:35a.m.	0		7.28			gs
14-Jun-01	11:30a.m.	0		6.71			gs
21-Jun-01	12:40p.m.	0		5.65			gs
19-Aug-01	8:45a.m.	0		9.49			gs
21-Sep-01	9:25a.m.	0		7.06			gs

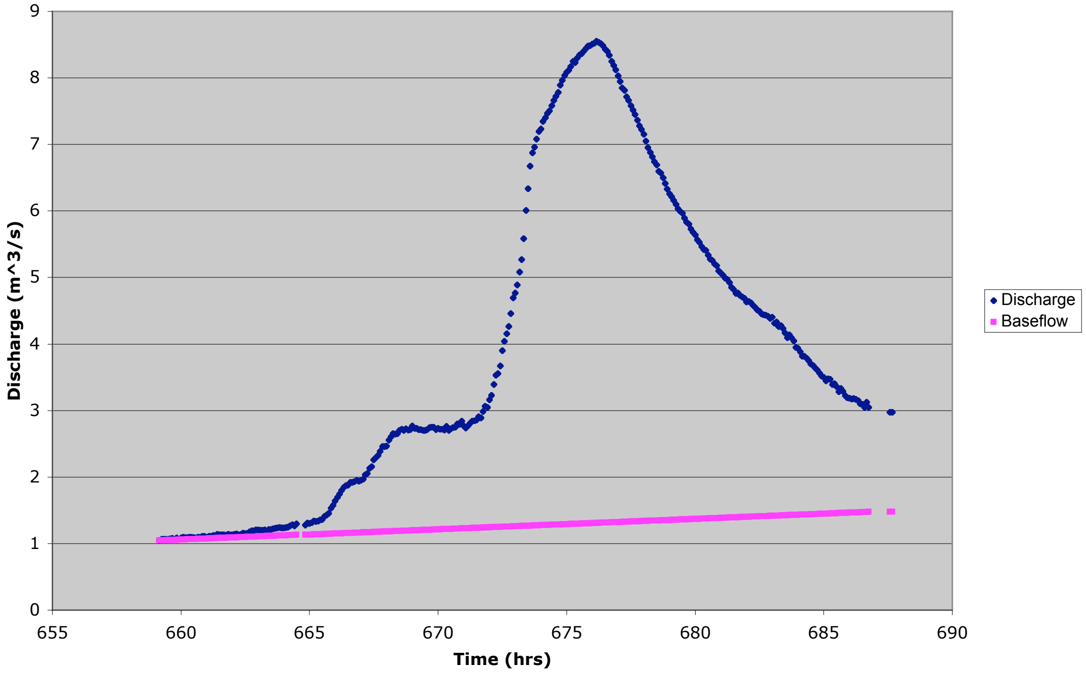
4-Oct-01	1:05p.m.	0		6.61			gs
10-Nov-01	12:30p.m.	0		4.38			gs
27-Nov-01	3:20p.m.	0		5.82			gs
12-Dec-01	3:25p.m.	0		4.67			gs
16-Jan-02	2:10p.m.	0		3.74			gs

APPENDIX E: GRAPHICAL HYDROGRAPH SEPARATIONS

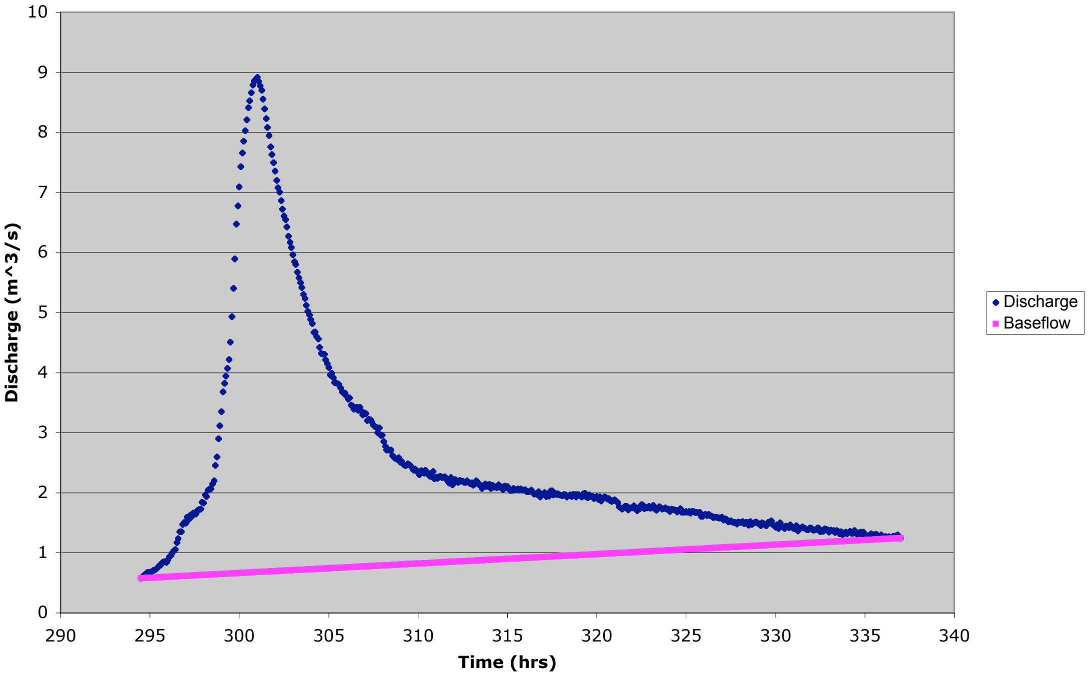


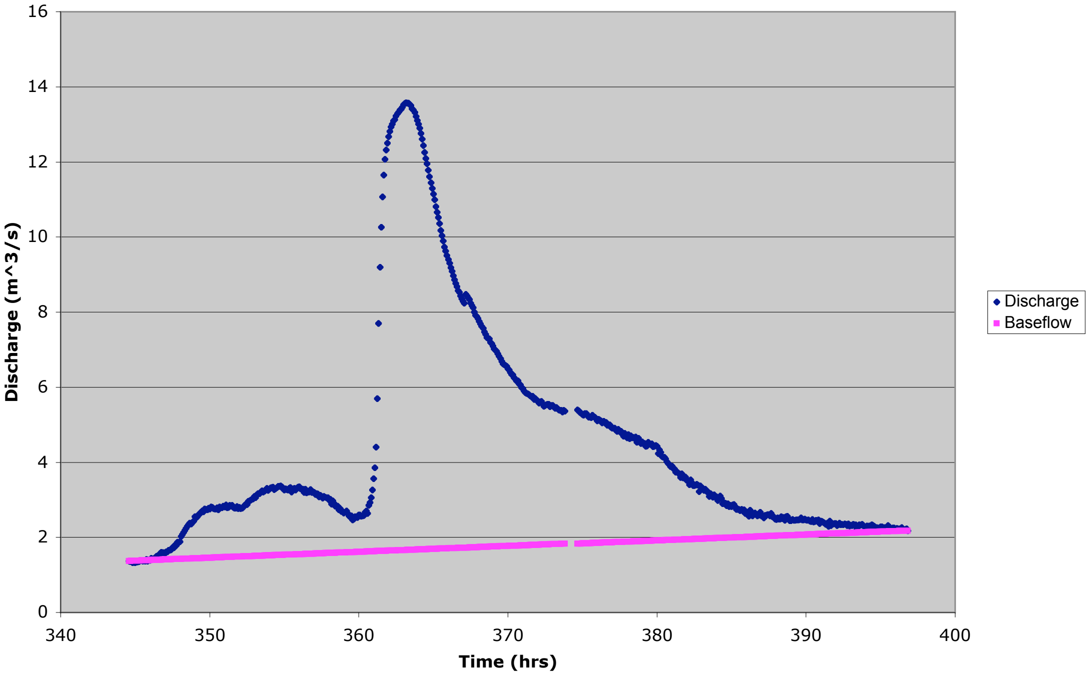


January 28, 2001 Hydrograph Separation - Sampler 1

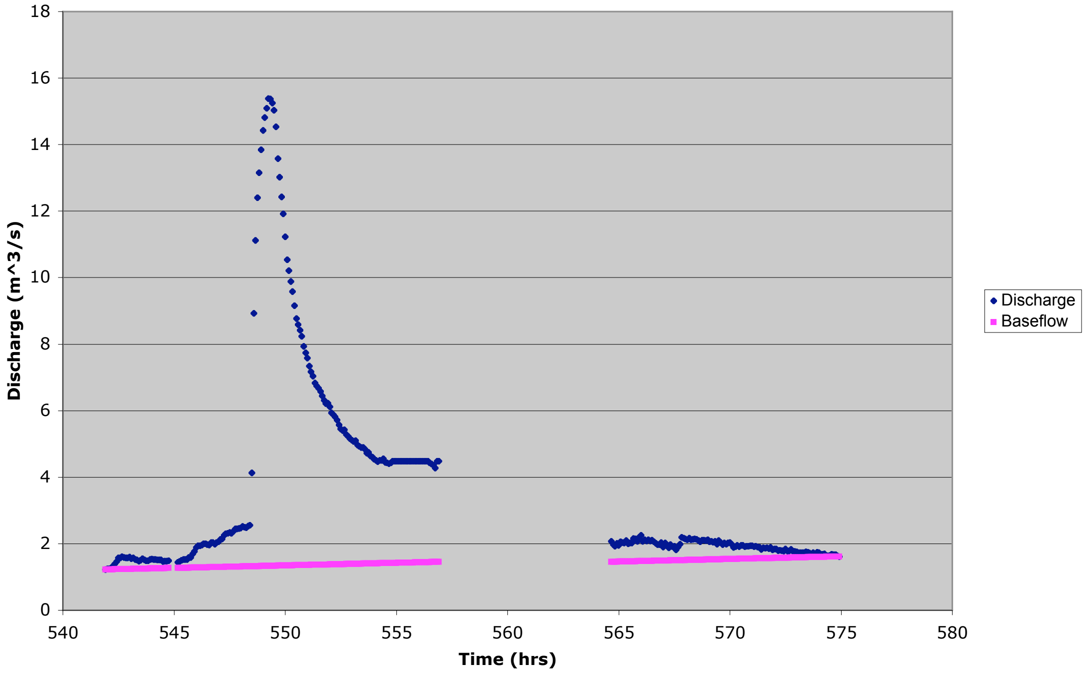


February 13, 2001 Hydrograph Separation - Sampler 1

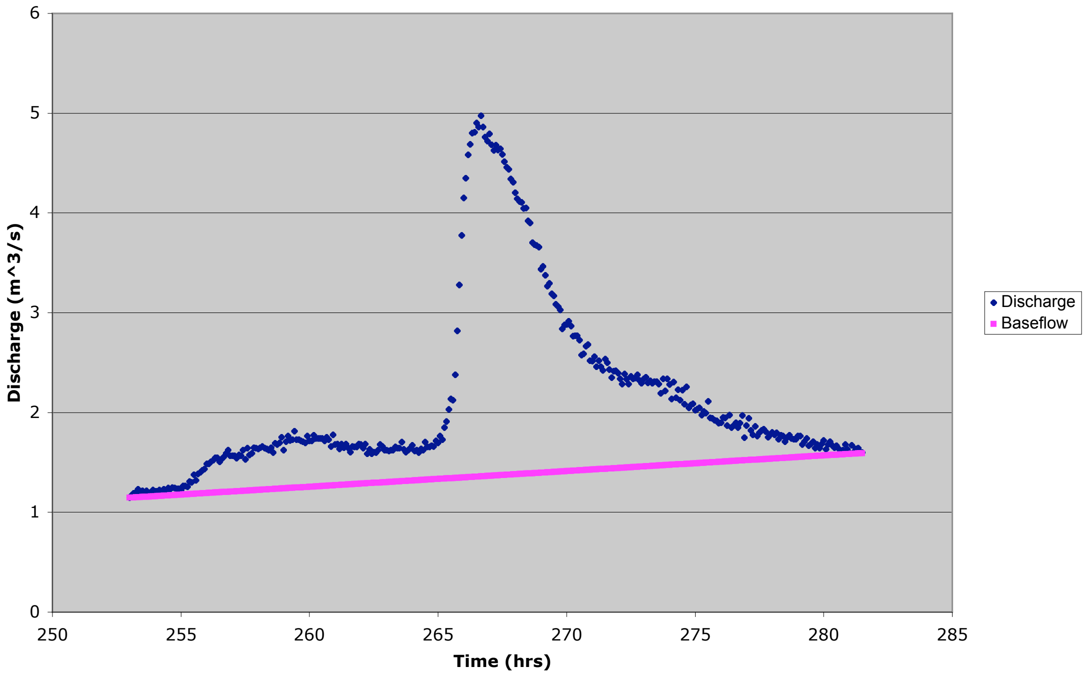




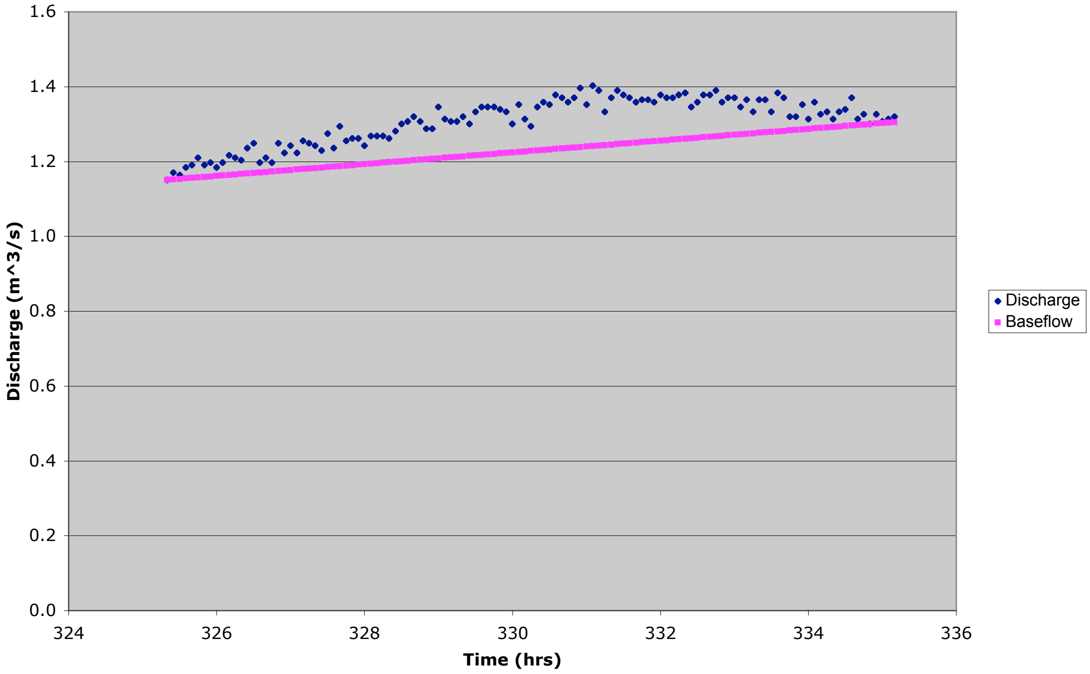
February 15, 2001 Hydrograph Separation - Sampler 1



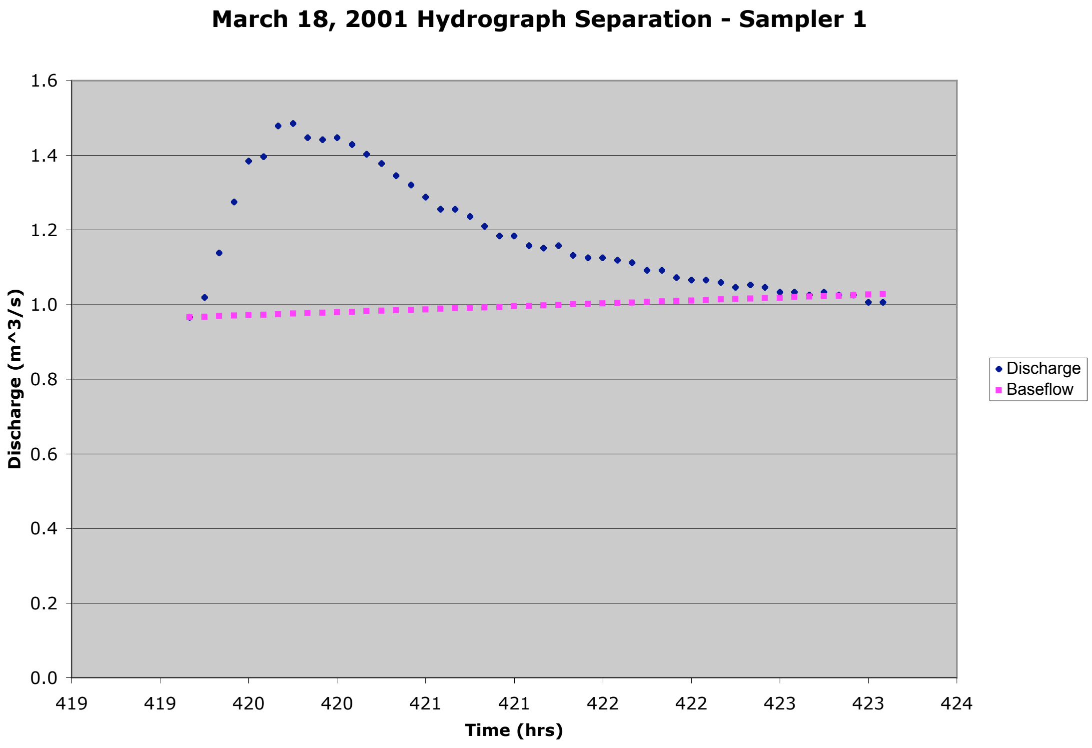
February 23, 2001 Hydrograph Separation - Sampler 1

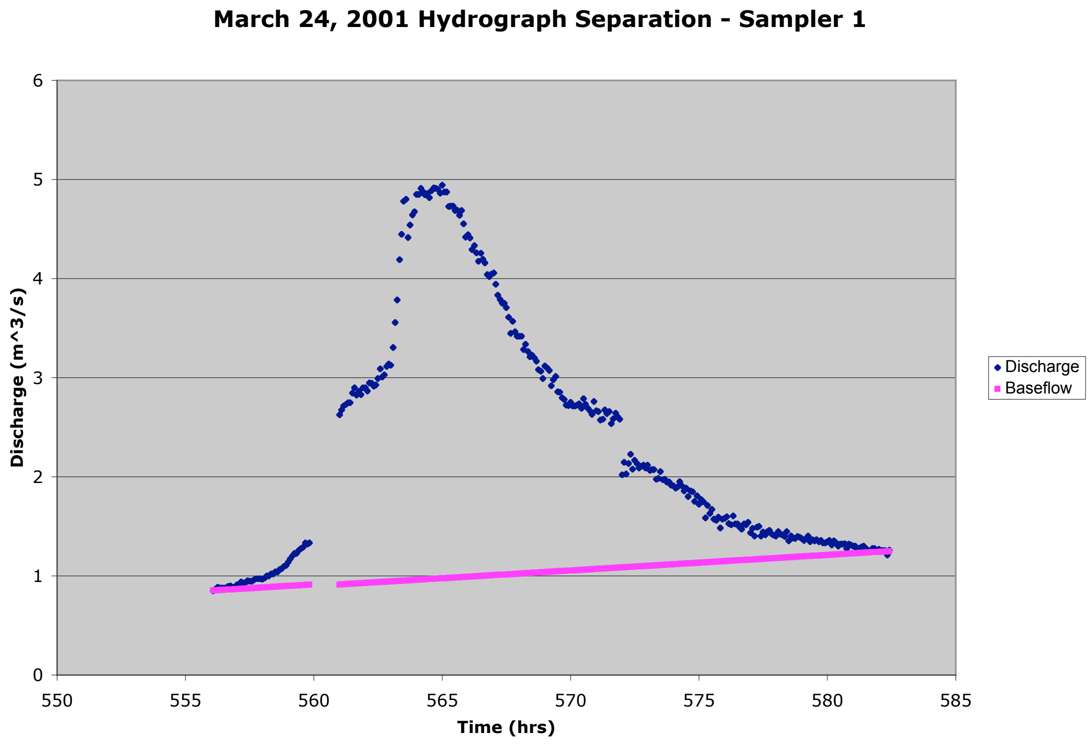


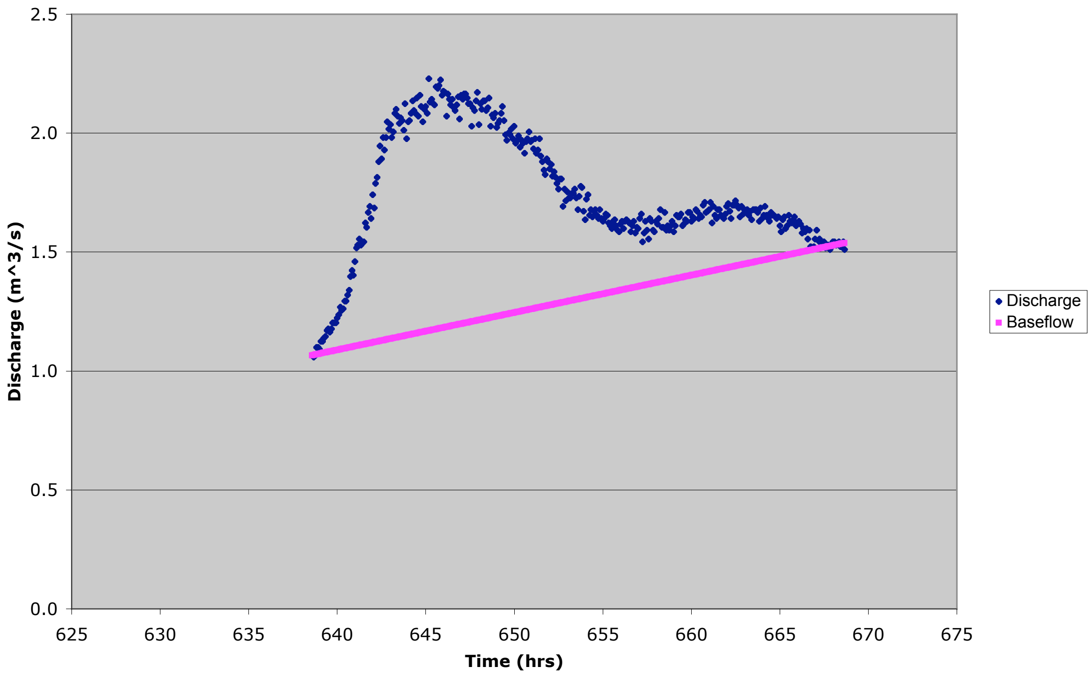
March 11, 2001 Hydrograph Separation - Sampler 1



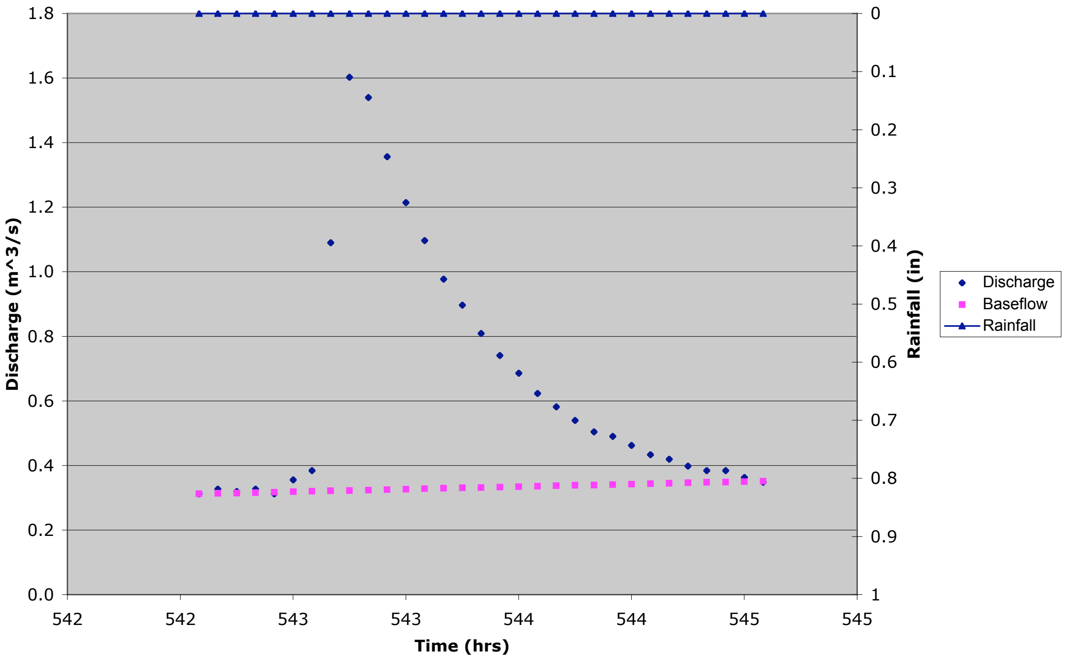
March 14, 2001 Hydrograph Separation - Sampler 1


March 18, 2001 Hydrograph Separation - Sampler 1
Discharge (m^3/s)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
419
419
420
420
421
421
422
422
423
423
424
Time (hrs)
◆ Discharge
■ Baseflow


March 24, 2001 Hydrograph Separation - Sampler 1
Discharge (m^3/s)
6
5
4
3
2
1
0
550
555
560
565
570
575
580
585
Time (hrs)
◆ Discharge
■ Baseflow

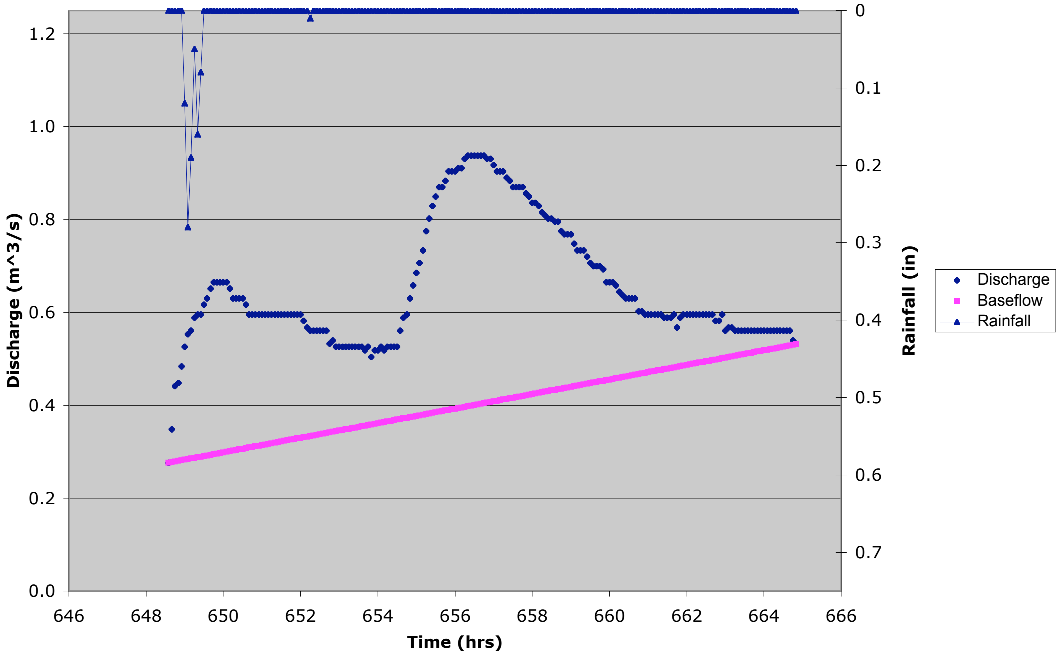


March 27, 2001 Hydrograph Separation - Sampler 1

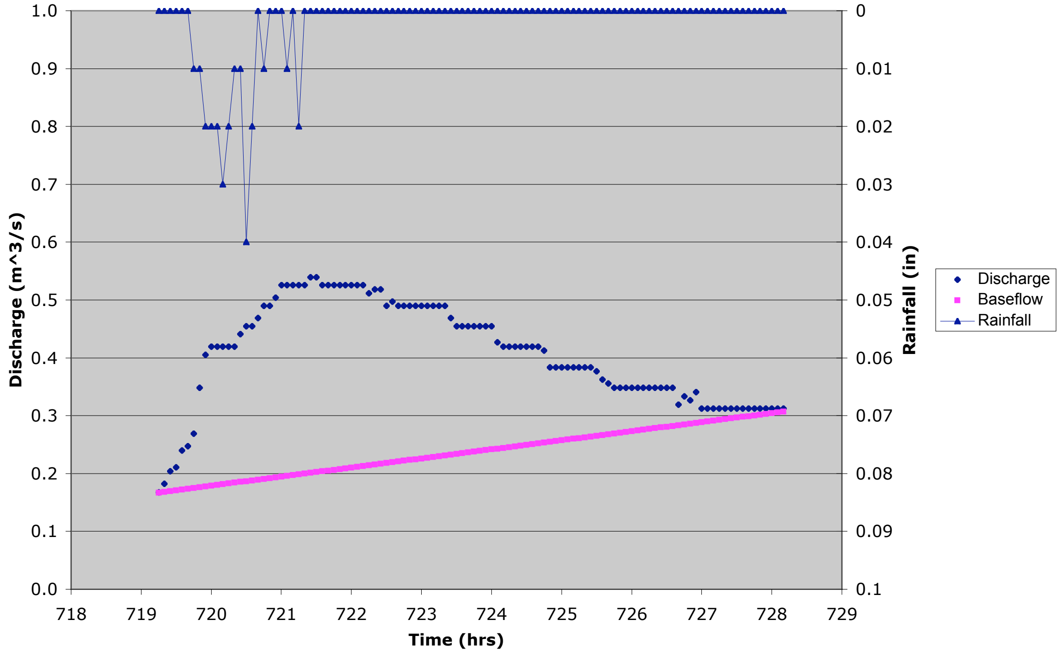


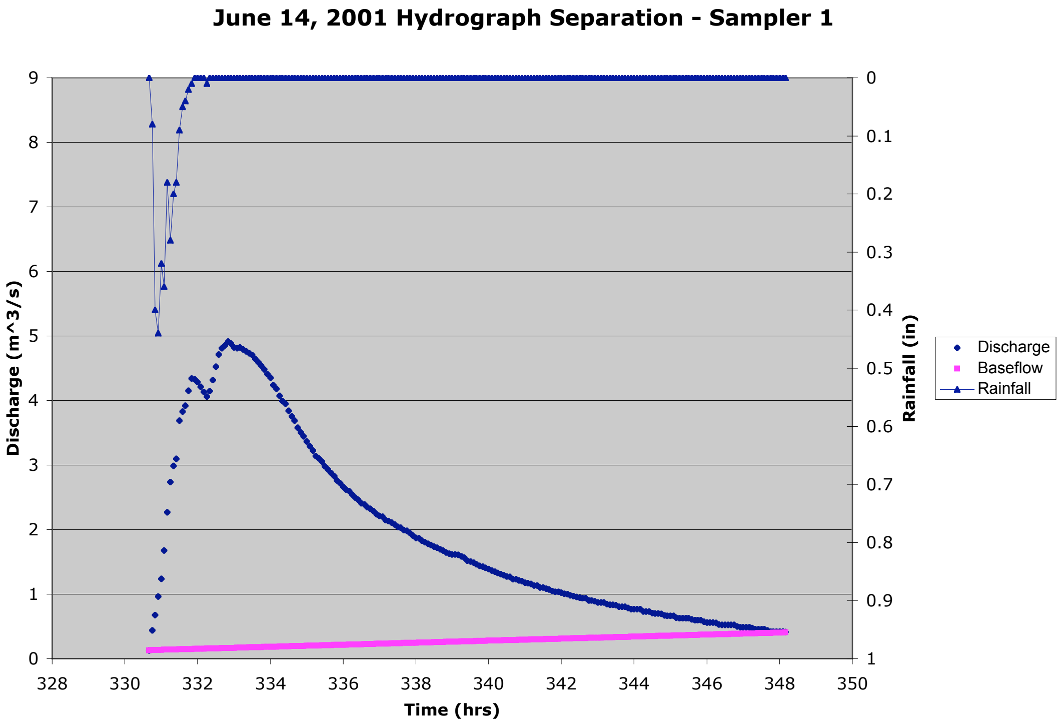
May 23, 2001 Hydrograph Separation - Sampler 1

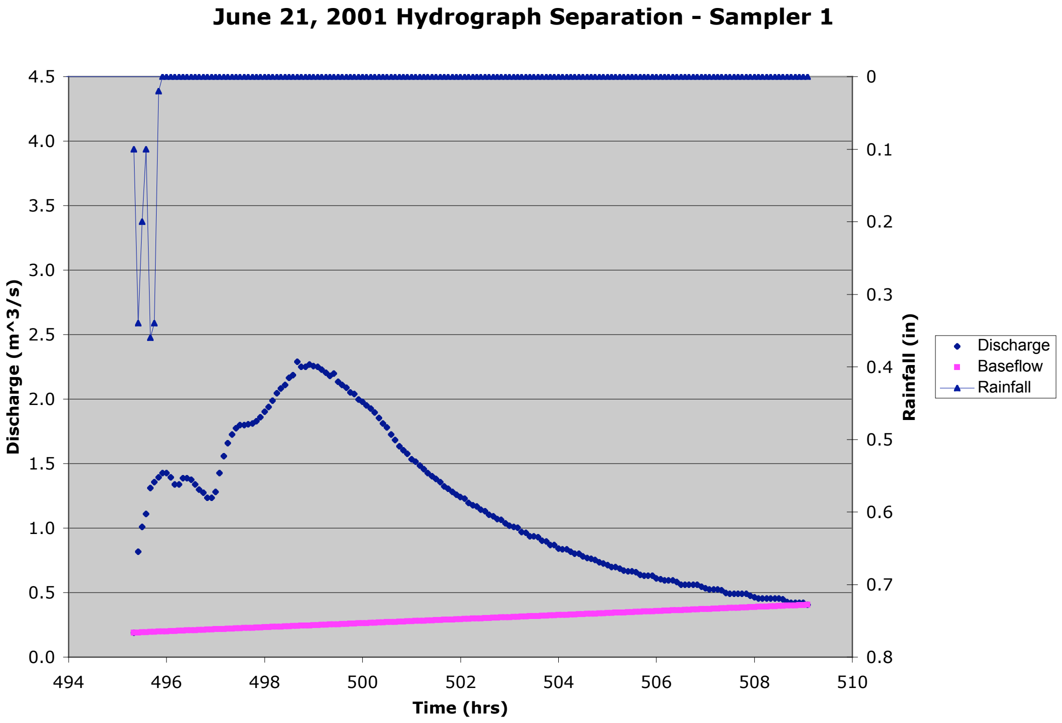
May 28, 2001 Hydrograph Separation - Sampler 1

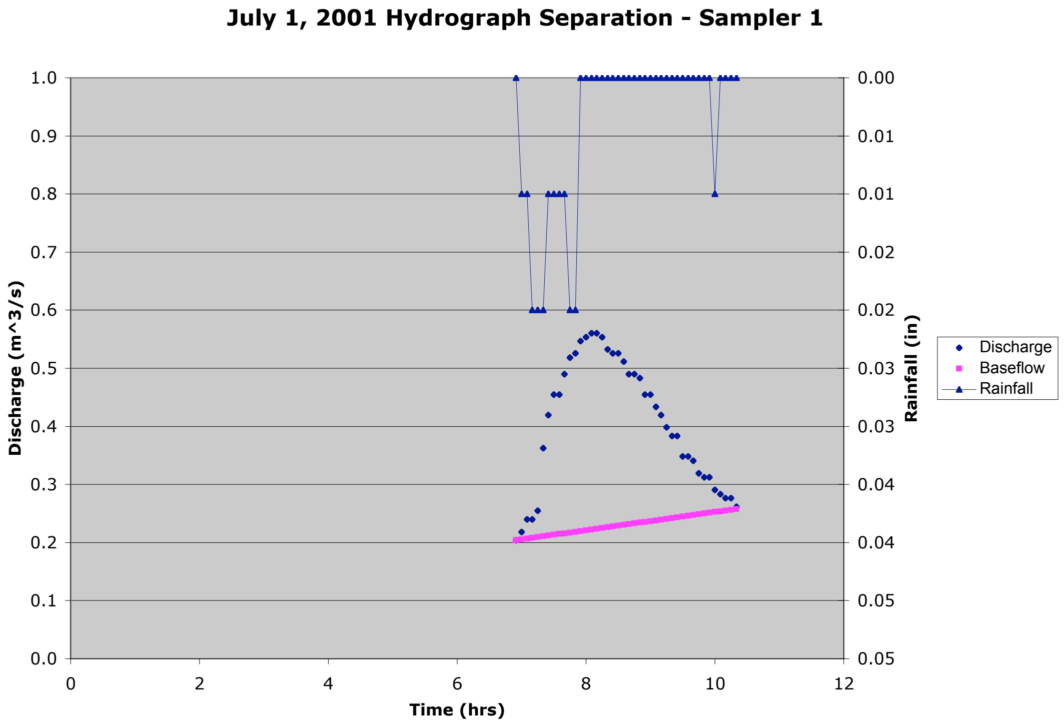


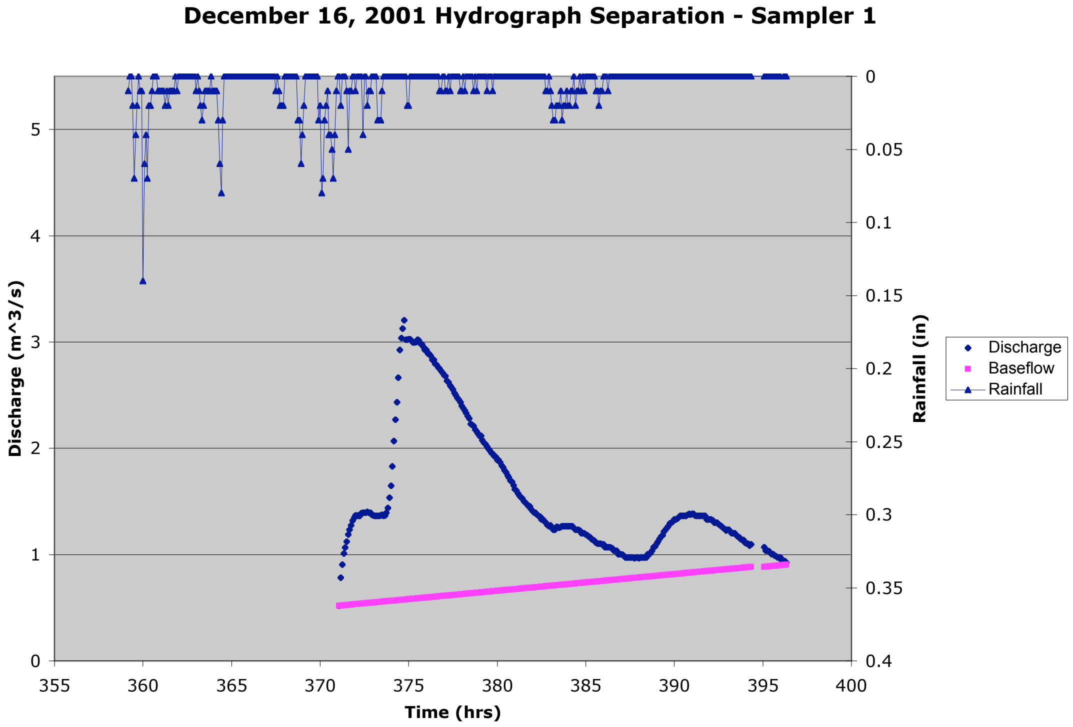
May 30, 2001 Hydrograph Separation - Sampler 1

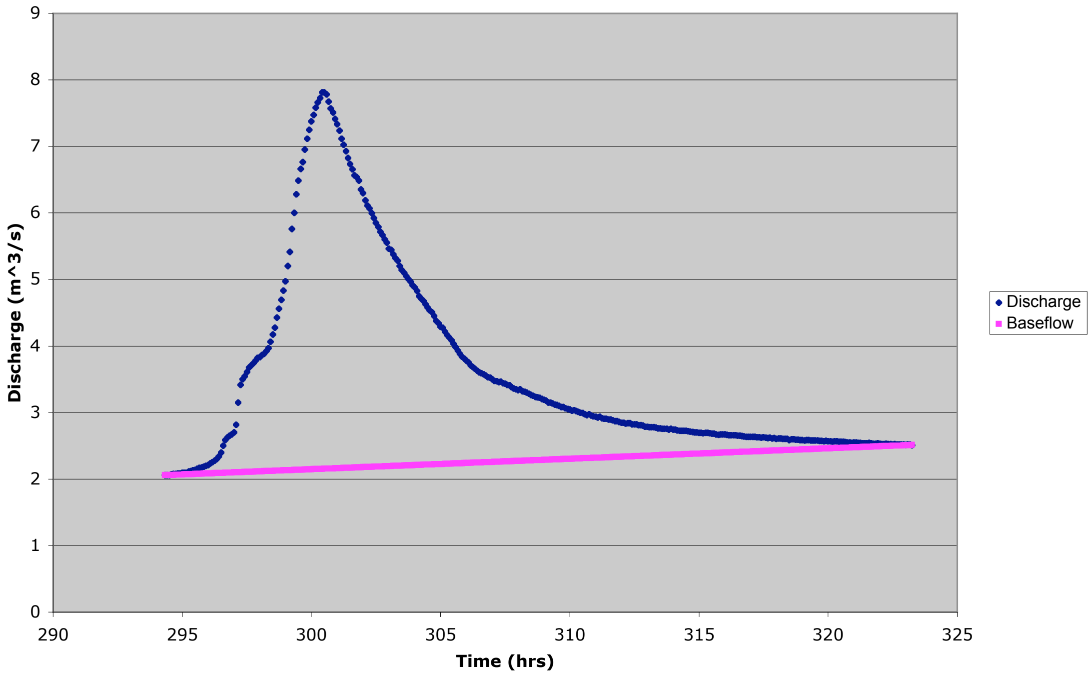


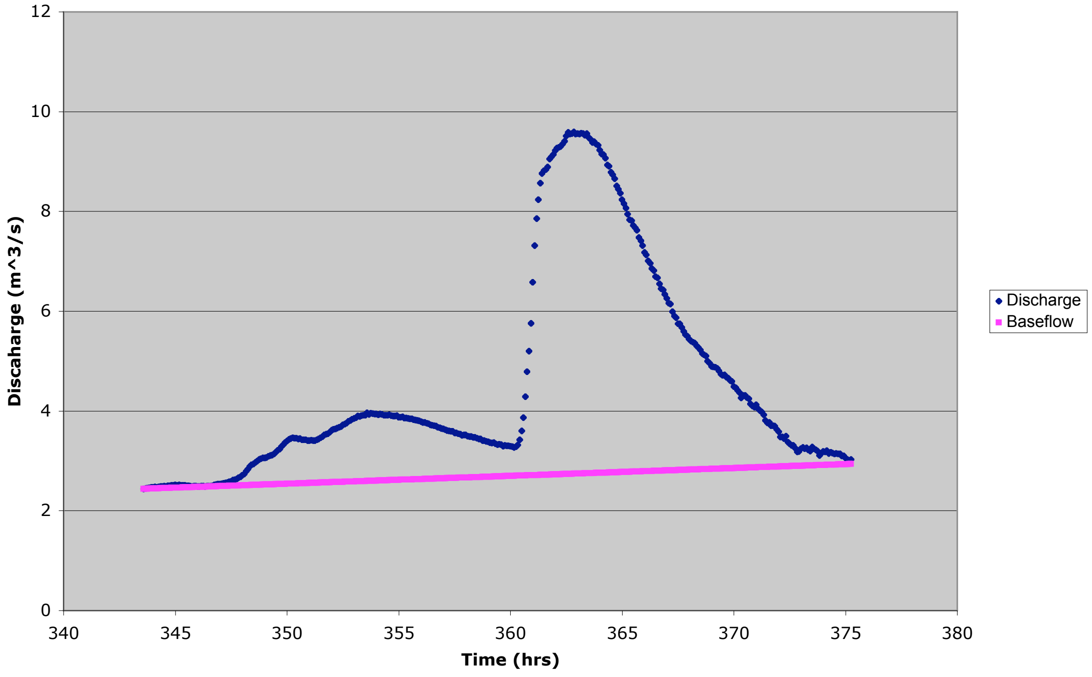

June 14, 2001 Hydrograph Separation - Sampler 1

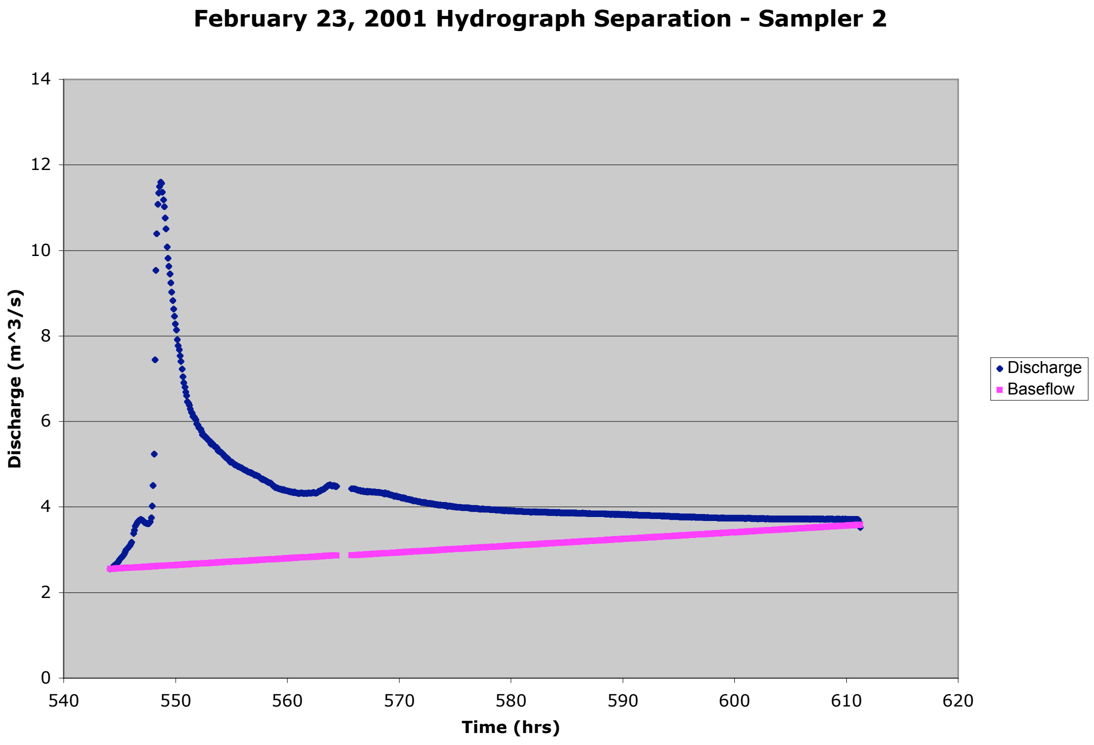

June 21, 2001 Hydrograph Separation - Sampler 1

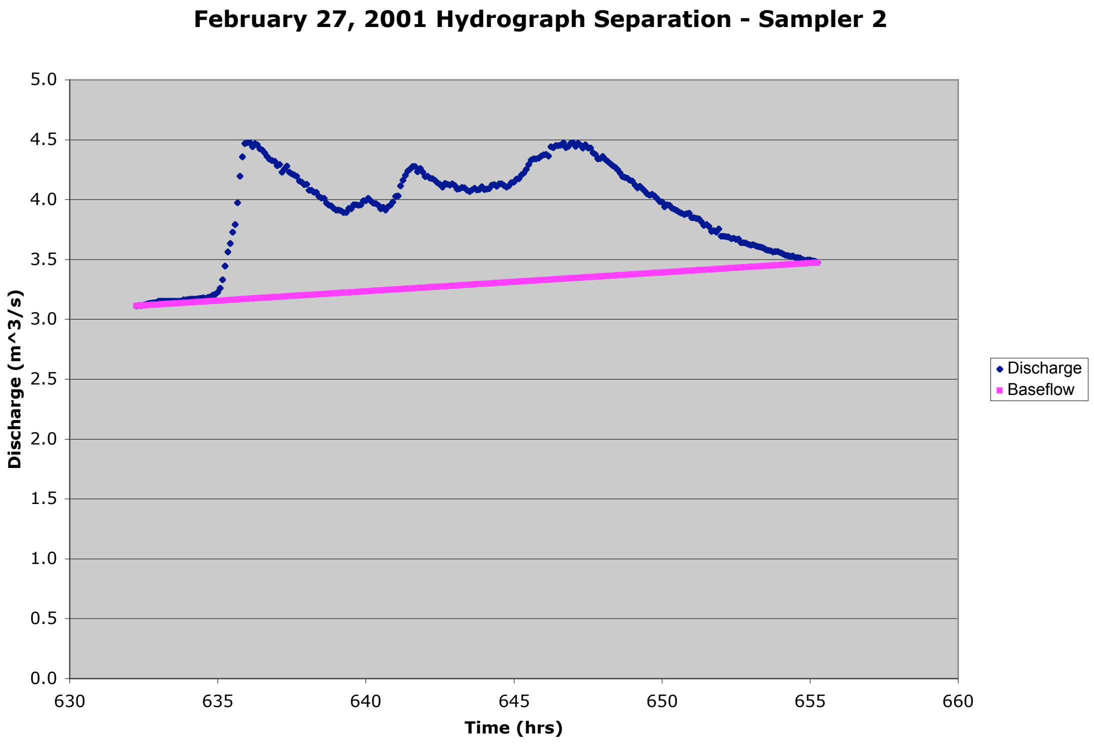

July 1, 2001 Hydrograph Separation - Sampler 1
Discharge (m^3/s)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Rainfall (in)
0.00
0.01
0.01
0.02
0.02
0.03
0.03
0.04
0.04
0.05
0.05
0
2
4
6
8
10
12
Time (hrs)
Discharge
Baseflow
Rainfall


December 16, 2001 Hydrograph Separation - Sampler 1
Discharge (m^3/s)
5
4
3
2
1
0
Rainfall (in)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
355
360
365
370
375
380
385
390
395
400
Time (hrs)
Discharge
Baseflow
Rainfall

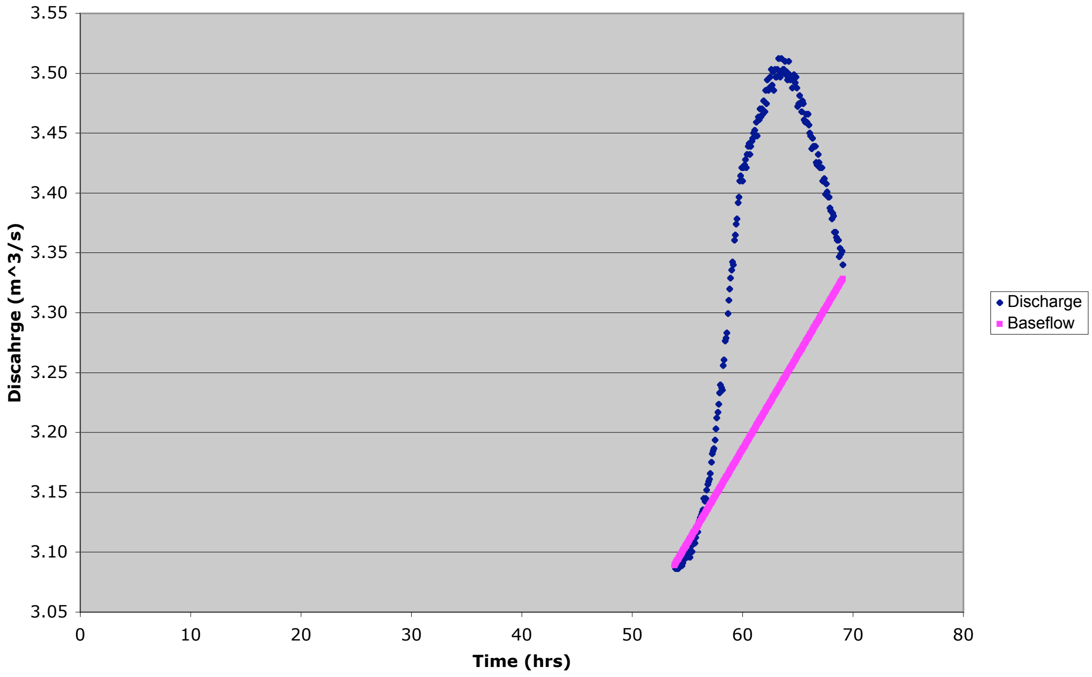

February 13, 2001 Hydrograph Separation - Sampler 2


February 15, 2001 Hydrograph Separation - Sampler 2

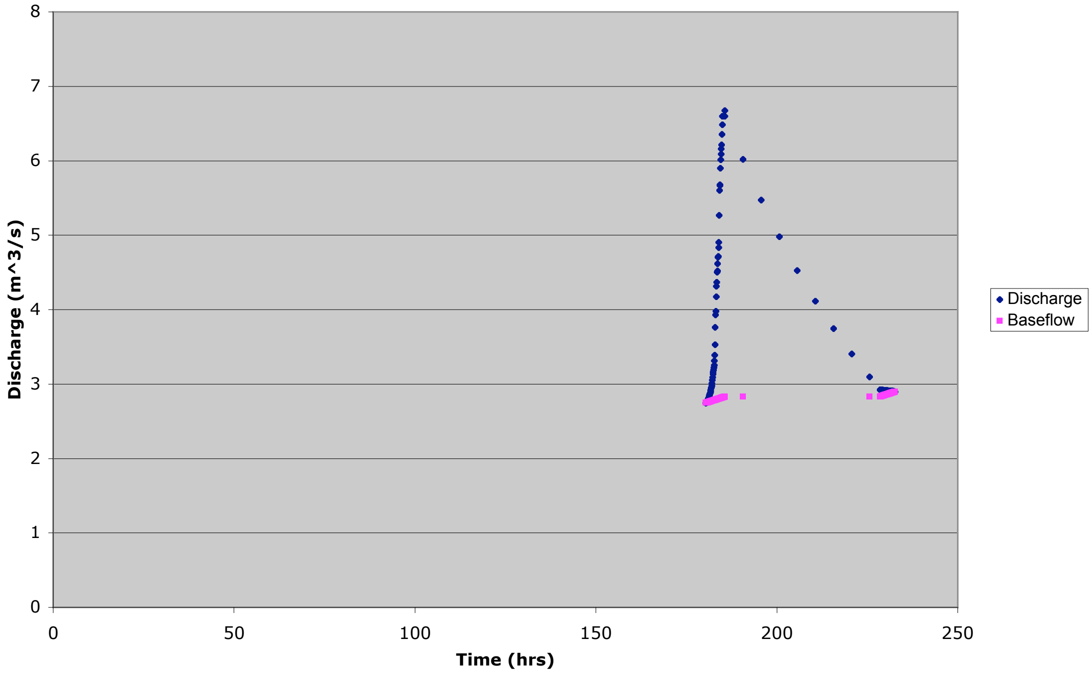

February 23, 2001 Hydrograph Separation - Sampler 2


February 27, 2001 Hydrograph Separation - Sampler 2

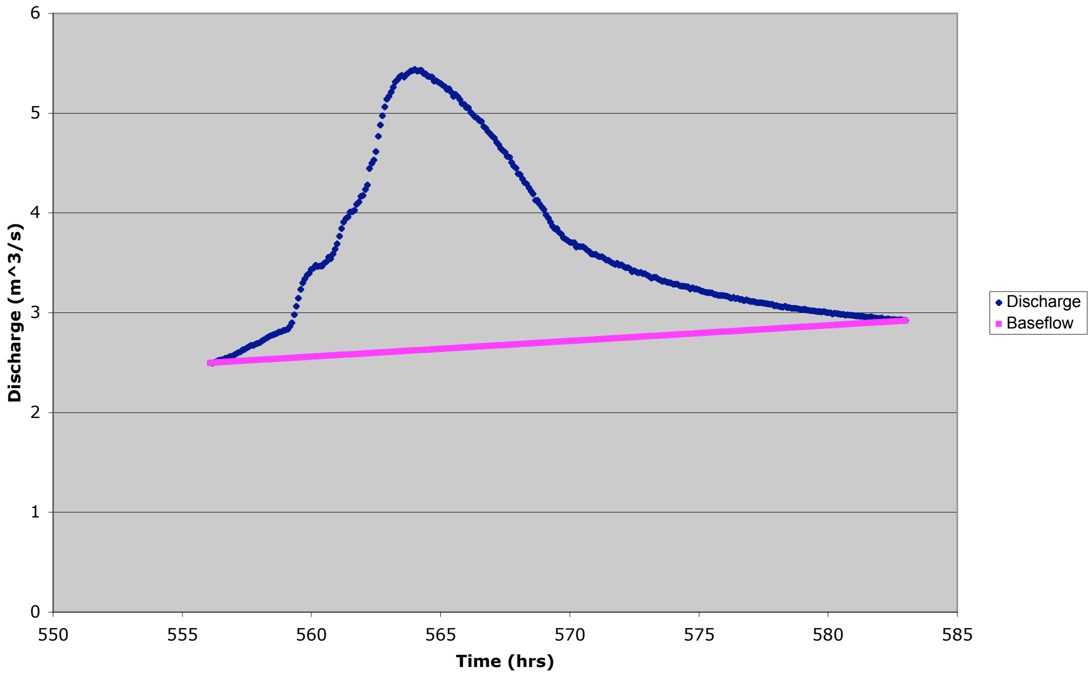
March 3, 2001 Hydrograph Separation - Sampler 2



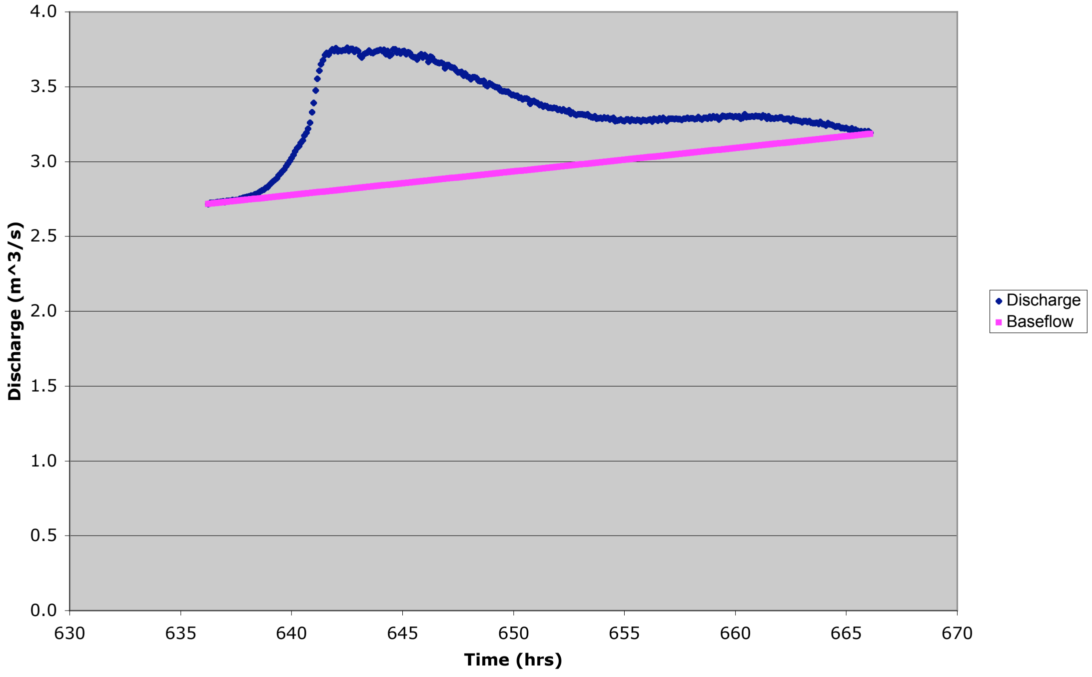
March 8, 2001 Hydrograph Separation - Sampler 2



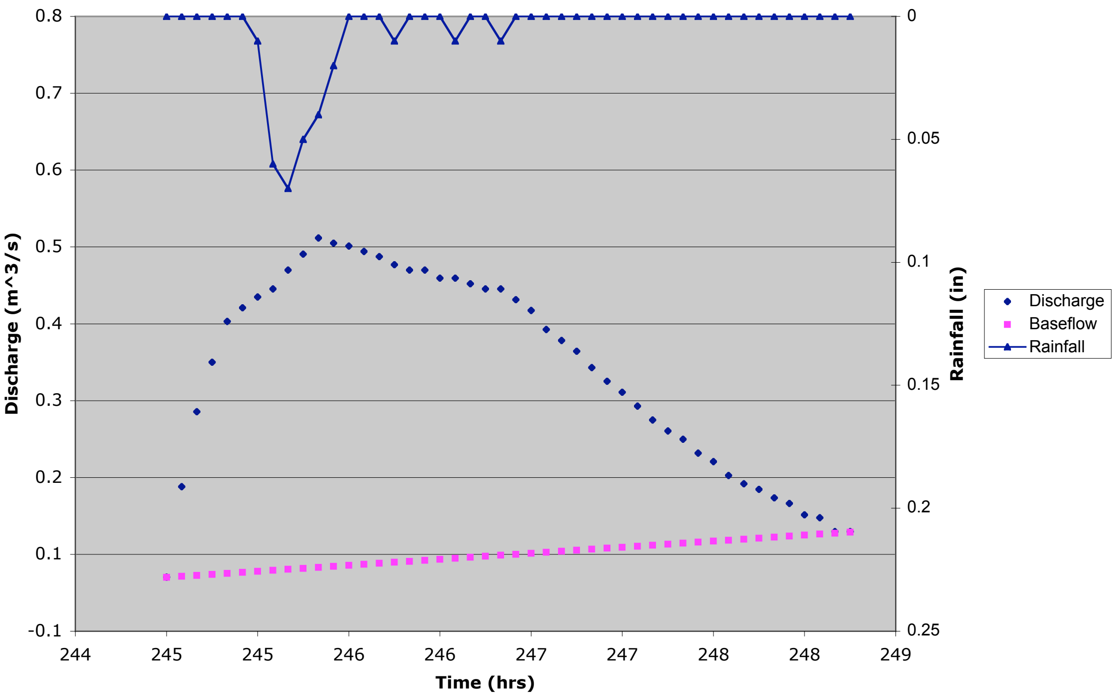
March 24, 2001 Hydrograph Separation - Sampler 2



March 27, 2001 Hydrograph Separation - Sampler 2



October 11, 2001 Hydrograph Separation - Sampler 2

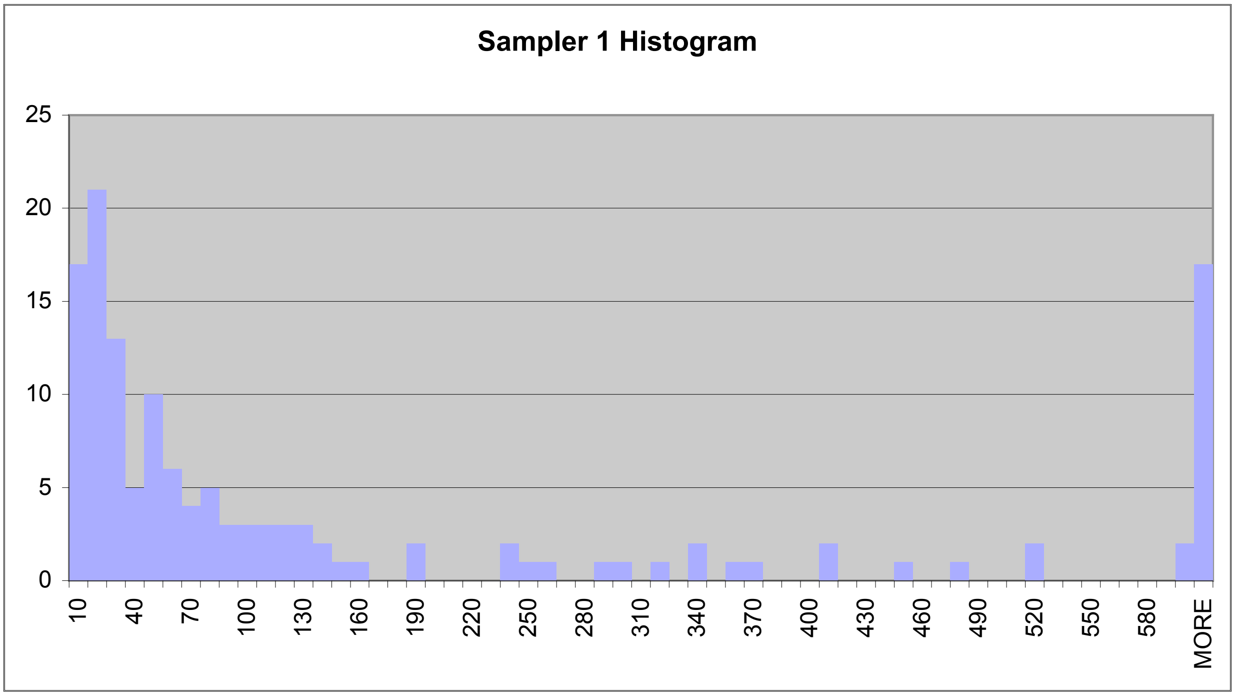


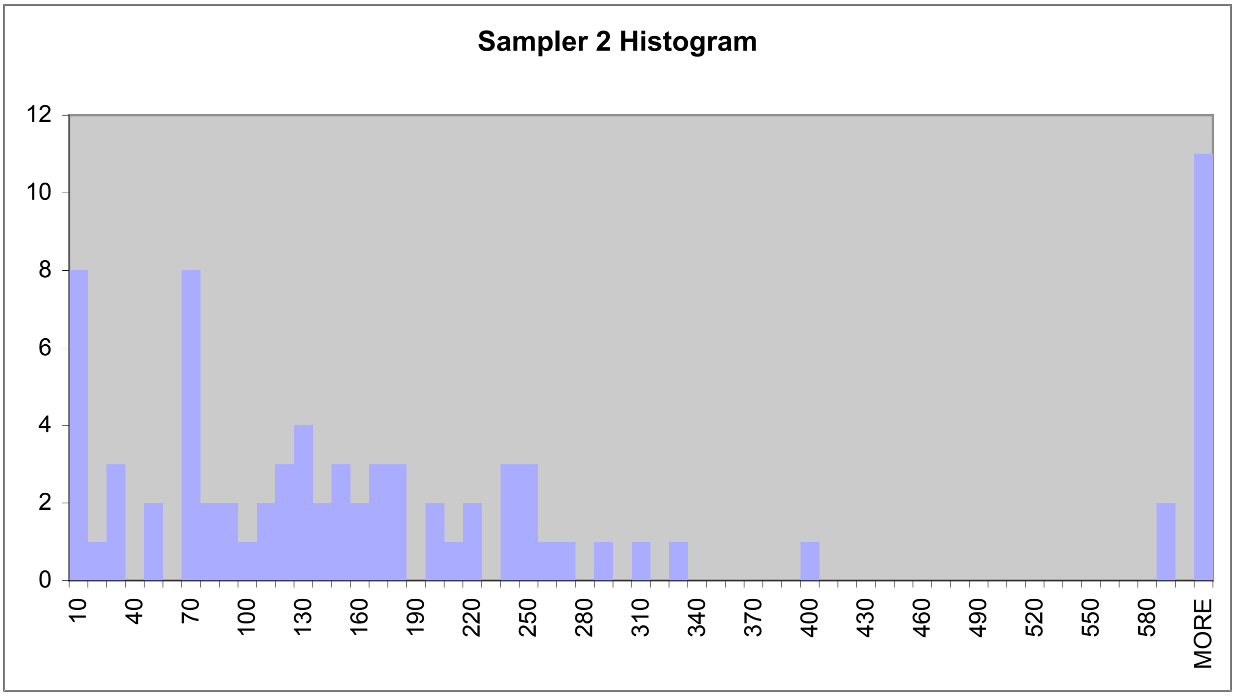
APPENDIX F: MANN-WHITNEY U STATISTICAL TEST

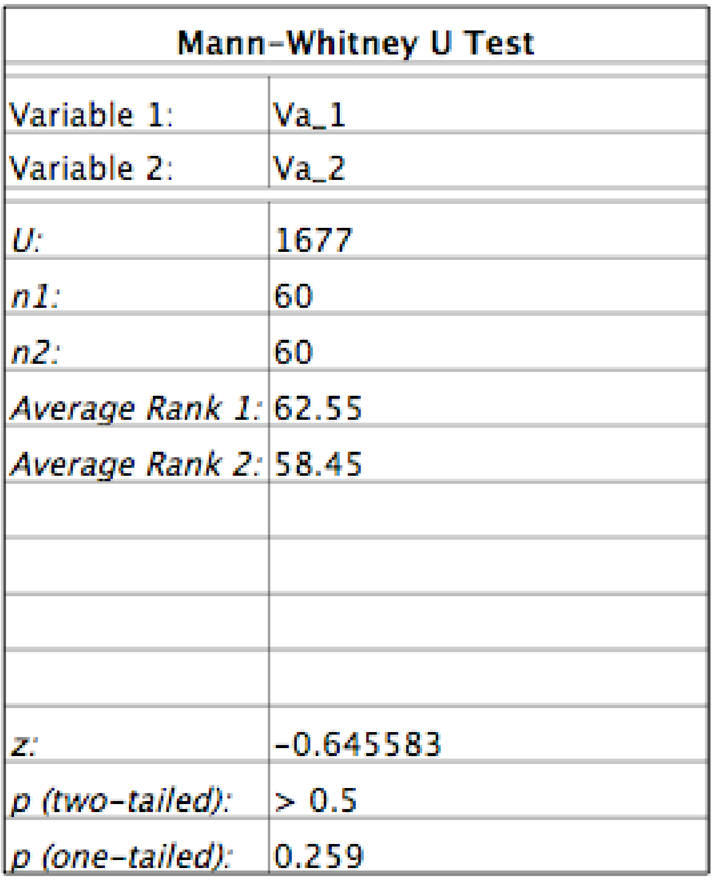
TSS DATA USED FOR DETERMINING NORMALITY						
Sampler 1				**Sampler 2**		
TSS Values	**TSS (cont.)**	**Bin Limits**	**Frequency**	**TSS Values**	**Bin Limits**	**Frequency**
2.4	30	10	17	0	10	8
3.9	30	20	21	0	20	1
5	30	30	13	0	30	3
5	30	40	5	0	40	0
5	30	50	10	0	50	2
5	30	60	6	0	60	0
5	35	70	4	5	70	8
5	35	80	5	10	80	2
10	35	90	3	16.95	90	2
10	35	100	3	22.9	100	1
10	36.1	110	3	25	110	2
10	42.85	120	3	27.5	120	3
10	45	130	3	45	130	4
10	45	140	2	46.75	140	2
10	45	150	1	65	150	3
10	45	160	1	65	160	2
10	45	170	0	65	170	3
15	45	180	0	65	180	3
15	48.75	190	2	65	190	0
15	50	200	0	65	200	2
15	50	210	0	65	210	1
15	55	220	0	70	220	2
15	55	230	0	75	230	0
15	55	240	2	80	240	3
15	55	250	1	85	250	3
15	60	260	1	85	260	1
15	60	270	0	100	270	1
15	65	280	0	105	280	0
15	65	290	1	110	290	1
19.4	65	300	1	115	300	0
20	70	310	0	116.1	310	1
20	70.4	320	1	118.8	320	0
20	75	330	0	125	330	1
20	75	340	2	126.9	340	0
20	75	350	0	130	350	0
20	75	360	1	130	360	0
20	85	370	1	134.3	370	0
20	85	380	0	135	380	0
24.35	90	390	0	145	390	0

25	100	400	0	147.8	400	1
25	100	410	2	150	410	0
25	100	420	0	160	420	0
25	105	430	0	160	430	0
25	110	440	0	165	440	0
30	110	450	1	170	450	0
115		460	0	170	460	0
115		470	0	175	470	0
120		480	1	180	480	0
130		490	0	180	490	0
130		500	0	200	500	0
130		510	0	200	510	0
135		520	2	207.55	520	0
140		530	0	213.44	530	0
145		540	0	215	540	0
155		550	0	231.5	550	0
185		560	0	235	560	0
190		570	0	240	570	0
235		580	0	243.65	580	0
240		590	0	246.42	590	2
250		600	2	250	600	0
255		MORE	14	256.25	MORE	11
290				265		
300				290		
315				307.6		
340				324.9		
340				399.8		
360				588.1		
370				590		
405				789.5		
410				800		
450				900		
480				1090		
515				1090		
520				1144.7		
600				1390		
600				1510		
675				1570		
735				1580		
840				1610		
980						
990						
1110						
1245						
1350						
1390						

1450						
1600						
1875						
2180						
4080						
4100.6						







Mann-Whitney U Test

Variable 1:	Va_1
Variable 2:	Va_2
U:	1677
n1:	60
n2:	60
Average Rank 1:	62.55
Average Rank 2:	58.45
z:	-0.645583
p (two-tailed):	> 0.5
p (one-tailed):	0.259

APPENDIX G: SITE PHOTOS

Spillway North of Sampling Site #1 – Low Flow

Spillway North of Sampling Site #1 – High Flow

Spillway North of Sampling Site #1 – Low Flow

Spillway North of Sampling Site #1 – High Flow

Riffle Area at Sampling Site #1
Low Flow

Riffle Area at Sampling Site #1
High Flow

No Flow, Isolated Pools at Sampling Site #1 – Eutrophication

Upstream from Sampling Site #2
Low Flow

Upstream from Sampling Site #2
High Flow

Downstream from Sampling Site #2 – Low Flow

Downstream from Sampling Site #2 – High Flow

No Flow, Isolated Pools Upstream from Sampling Site #2 - Eutrophication

No Flow, Isolated Pools Downstream from Sampling Site #2 - Eutrophication

Between Sampling Sites #1 and #2 – Low Flow

Between Sampling Sites #1 and #2 – High Flow

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ABSTRACT

A BASELINE STUDY OF SEDIMENT AND NITROGEN FLUX IN A PRE-URBANIZED WATERSHED, PARKER COUNTY, TEXAS

by Teresa Jo Moss, M.S., 2007
Department of Environmental Science
Texas Christian University

Thesis Advisor: Michael C. Slattery, Professor of Geology & Director of TCU's Institute of Environmental Studies

This study investigated the dynamics of sediment and nitrogen flux in response to storm runoff in a pre-urbanized watershed in Parker County, Texas. Mary's Creek was found to be a flashy creek with unusually low runoff coefficients, suggesting a larger-than-average storage capacity of the watershed. The predominant runoff-producing mechanism was found to be a combination of Hortonian overland flow and saturation overland flow. TSS concentrations increased in response to increased discharge. However, the sediment load being transported out of this basin was found to be well below tolerable limits. NH_3-N levels tended to decrease as discharge increased; whereas, NO_3-N levels increased as discharge increased. Both NH_3-N and NO_3-N concentration levels rarely exceeded TCEQ's screening level guidelines and were determined to be of no concern. The data collected in this study can be utilized to understand the long-term effects of urbanization on the water quality of the watershed.