ANALYSIS OF ENERGY GRADIENTS AND SEDIMENT LOADS OCCURRING IN THE IRISH CREEK WATERSHED LOCATED IN NORTHEAST KANSAS

by

JUSTINE DANIELLE SULLIVAN

B.A., Kansas State University, 2010

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Biological and Agricultural Engineering
College of Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2013

Approved by:

Major Professor
Dr. Philip Barnes

Abstract

Sediment is a large pollutant concern for the United States and is a major impairment source in water bodies (MARC 2013). Rivers and streams assessed in Kansas resulted in 87.8% being considered impaired, as well as 97.8% of the assessed lakes, reservoirs, and ponds (EPA 2012d). Tuttle Creek Reservoir is filling with sediment faster than any other federal reservoir in the region. Due to the importance of Tuttle Creek Reservoir, limiting the water impairments has been made a priority. The tributaries feeding the reservoir are all considered impaired, and TMDLs should be developed to limit the amount of sediment allowed in the water body. This study focuses on the stream energy and sediment loads occurring in a watershed in northeast Kansas over a six year period. When bankfull conditions occur, significant amounts of work are performed on the stream and excessive erosive forces may occur. The estimated bankfull discharge was 6.5 m^3/s, and this event occurred every year except in 2012. At the same location the bankfull discharge was estimated, automated and grab water samples were collected and stream power was calculated. The samples were analyzed for total suspended sediment, total nitrogen, and total phosphorus, and the total annual loads were estimated. The total sediment load occurring in the watershed was 10,298,283 kilograms. The nutrient loads occurring were 78,213 kg of TN and 22,625 kg TP. Elevations were measured at equal intervals in a sub-watershed. Energy gradients were calculated, and it was observed that many of the gradients could create favorable conditions for sediment erosion to occur. The stream power estimate was 26.85 kg/m/s. At this stage larger sediment particles and load could be transported. A gully formed by overland flow entering the stream was also measured to estimate amounts of sediment being contributed from gully side conveyances within the watershed. The estimated sediment loss from the gully was 1,693,899 kg. Results of this study could help improve water quality and help quantify the amount of sediment being carried from the watershed and streambanks, so BMPs and other design features may be implemented.

Table of Contents

List of Figures

List of Tables

Acknowledgements

I would like to give great thanks to my faculty advisor, Dr. Phil Barnes, for the counseling, supervision, encouragement, and advice provided to me throughout this process. Also, for teaching me what hard work and determination provides. I am forever indebted for the opportunities you have given me since I began working with you. Thank you so much.

I would also like to thank my committee members, Dr. Stacy Hutchinson and Dr. Tim Keane. You have provided crucial assistance and advisement to help provide me with an education. Your patience, knowledge, and support helped me get through this process. I would also like to thank all the research assistants that help me gather and analyze the research. Especially Erin Ogle and Bre Stout, for going on the countless trips to obtain water samples and help with the GIS questions I had.

Finally, I would like to thank my two older sisters, Katy and Bailey. Thank you so much for the editing, knowledge, and encouragement you have provided to me. You will never know how much I truly appreciate the things you do for me. You have been the best role models and cheerleaders. Thank you.

Dedication

I would like to dedicate this to my family. You have provided the strength and support to help me accomplish anything I set my mind to.

Chapter 1 - Research Objectives and Introduction

Research Purpose and Objectives

The purpose of this research is to explore how energy in a small watershed affects sediment erosion and transportation. The objectives for the project are to:

1. Evaluate the flow patterns and characteristics to determine when and how often bankfull conditions of the stream occur
2. Estimate the amount of sediment that is carried by a stream energy gradient
3. Look at the impacts that features in the watershed, like ponds, have on the stream energy
4. Look at the consequences that can occur if runoff entering a stream is not managed and monitored

By answering the objectives, the amount of sedimentation that occurs in water bodies could be limited by BMPs and other designs used to prevent detachment and transport of soil.

Introduction

Soil is a foundation of life and is linked to about everything on Earth. The soil provides the basis for food and biomass production, regulates water flow and quality, stores carbon and maintains balance for atmospheric gases, provides a multitude of raw materials, as well as providing habitats and sustains biodiversity (SSSA 2013). Unfortunately, sediment is also one of the largest and most common pollutants found in water bodies and many concerns have been created due to sediment pollution in the United States alone. Sediment associated with soil erosion causes around 16 billion dollars in environmental damages annually (MARC 2013), and the rate of sedimentation occurring in many lakes, ponds, and reservoirs is increasing rapidly.

While sediment erosion is a natural occurring process, only 30 percent of the total sediment load being transported in the water system can be attributed to these natural processes. The other 70 percent is due to accelerated erosion caused by changes in land use (MARC 2013).

Croplands and streambanks have been identified as two major sources of sediment from accelerated erosion, which cause significant damage to fields and can contribute large amounts of sediment to downstream reservoirs (Streeter et al. 2008). Government agencies have been working to limit the occurrence of erosion by creating programs and incentives for farmers, ranchers, and others to include conservation and best management practices (BMPs) which help reduce the amount of soil and runoff from surrounding lands (EPA 2013d). Since the implementation of these programs and practices, agricultural landscapes have experienced a general decrease in accelerated soil erosion. In some areas, the practices have reduced delivery of sediment from agricultural fields to streams by 65 percent (Hargrove et al. 2010).While the conservation practices and BMPs have taken strides in reduction of soil erosion, there is still a problem with sedimentation pollution occurring in water bodies. There could still be sediment coming with overland flows that was not caught by BMPs or other conservation practices, but the majority of sediment loads in watersheds that implemented BMPs and conversation practices is coming from the streambank and channel erosion (Zaimes et al. 2005; Simon and Rinaldi 2006).

As stated earlier, sediment can cause a multitude of environmental and economic concerns for water bodies. Figure 1.1 shows the general effects that soil erosion can cause to water bodies and surrounding property.

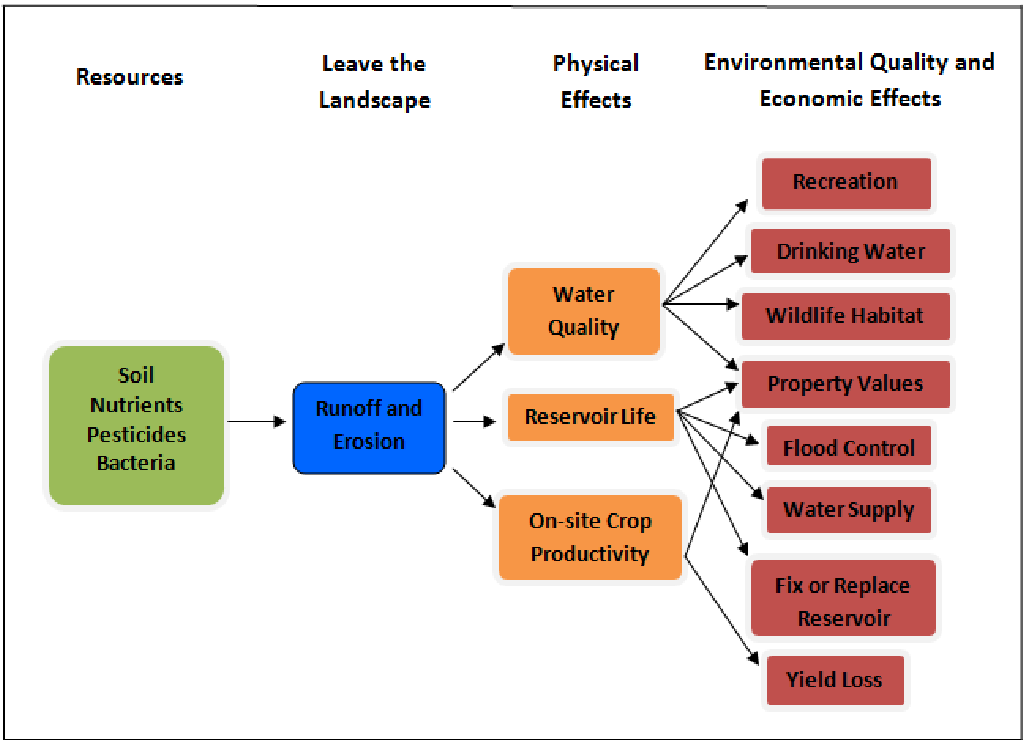

Figure 1.1 General effects of soil erosion (Reproduced from Streeter et al. 2008. Sedimentation in our reservoirs: Causes and solutions. Manhattan, KS: Kansas State University.)

Sediment can degrade the water quality and habitats of many organisms. The excess sediment can pollute the water to a point where the viability of aquatic life is affected (EPA 2013d):

- prevents natural vegetation growth
- destroys the environment of small stream organisms
- creates a decline in fish populations
- reduces disease resistance
- reduces growth rates of fish

Sediment can also increase flooding potential, reduce the amount of reservoir storage, and alter the flow and depth of water paths. Nutrients, pesticides, and herbicides that are attached to soil particles can also cause further impairments and risks to water quality. A flux of nutrients can lead to a disruption of the water balances, which can lead to algae blooms and eutrophication of water bodies (EPA 2012b). Since many reservoirs are public water supplies in addition to being public recreation sources, the deterioration of water quality associated with chemicals can cause public health and environmental concerns. Contaminated water bodies that are used as a drinking water sources require additional treatment to reduce the amount of sediment, chemicals, and nutrients. The additional treatments can cause an increase in the cost of treating the water source in order to meet drinking water standards. The increased cost could contribute to the economic burden already affecting many communities (EPA 2013d; Hargrove et al. 2010).

Soil erosion can also cause degradation of croplands. Increased erosion can cause the loss of the productive top soil that is abundant with nutrients, which can decrease productivity from those lands. There may also be a loss of land along the stream or riverbanks due to the water system trying to stabilize itself by cutting or widening of the streambed, which usually results in increased amounts of stream and bank erosion. The soil loss from streambank erosion and channel widening decreases the amount of land farmers can plant and could result in decreases in the yields they produce (Streeter et al. 2008).

Sediment can cause a significant amount of destruction to water bodies. Knowing where the sediment is coming from, how much sediment erosion is occurring, and if limiting the amount sediment erosion is possible is very important. Since most community's quality of life is dependent on reservoirs and other bodies of water, protecting the water bodies from excessive sedimentation, accelerated eutrophication, and poor water quality is vital for healthy communities.

Chapter 2 - Literature Review

Tuttle Creek Reservoir

Tuttle Creek Lake reservoir is located in the Big Blue River Basin system. The Big Blue River Basin watershed covers approximately 24,936 square kilometers of southeast Nebraska and northeast Kansas, with 75 percent of the basin being located in Nebraska (Franti et al. 2000). Figure 2.1, below, depicts the Big Blue River Basin.

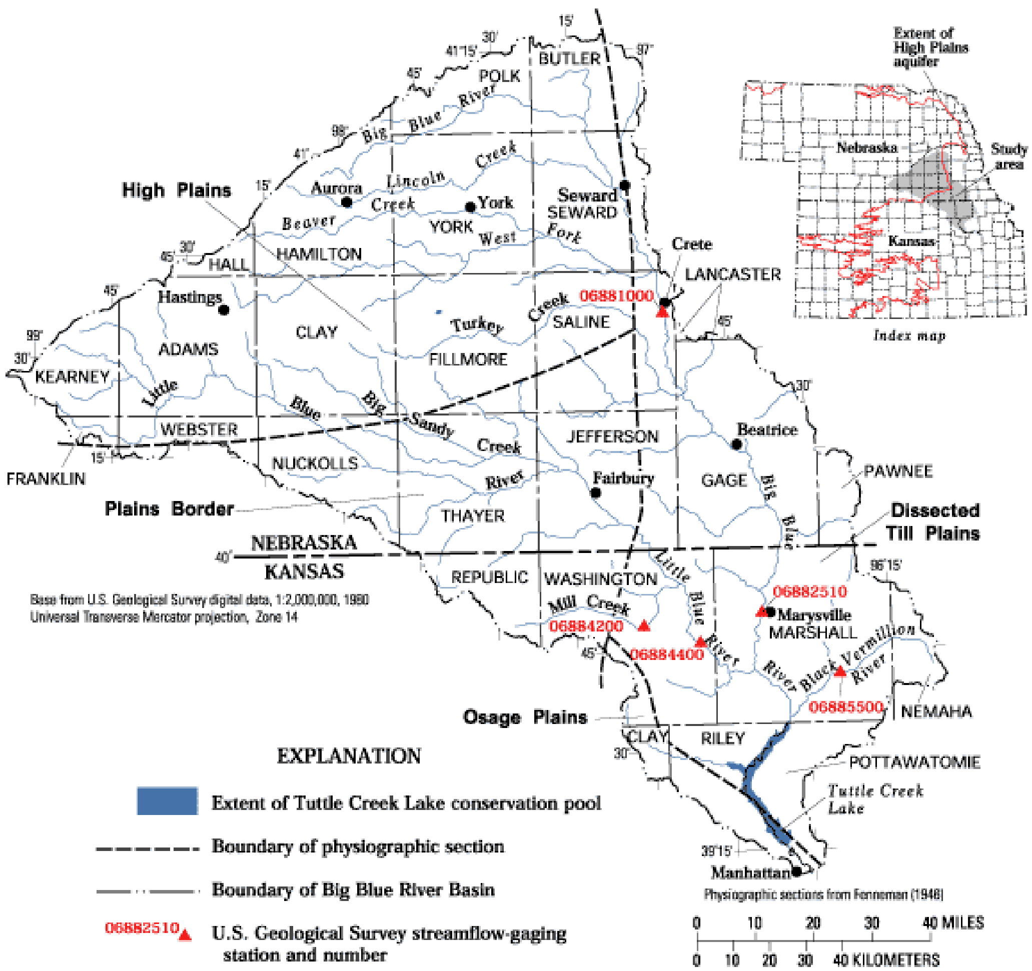

Figure 2.1 Location of Big Blue River Basin, physiography, streamflow-gaging station, and Tuttle Creek Lake, Northeast Kansas (Reproduced from Juracek and Mau. 2002. Sediment deposition and occurrence of selected nutrients and other chemical constituents in bottom sediment, Tuttle Creek Lake, northeast Kansas, 1962-99. U.S. Geological Survey- Water Resources Investigations Report 02-4048. Lawrence, KS: U.S. Geological Survey.)

The primary streams that feed into the basin are the Big Blue River, Little Blue River, and the Black Vermillion River (Franti et al. 2000). The streams converge together and flow into the reservoir near Manhattan, KS. The dam construction started in 1952, by the U.S. Army Corps of Engineers, after the Flood of 1951 caused damage to parts of northeast Kansas, including Manhattan, Topeka, and Kansas City. Although the main purpose of the dam is flood control, the reservoir is also used for recreation, water supply, fish and wildlife habitat, water-quality control, and navigation supplementation (Juracek and Mau 2002). At the time of completion of the dam construction in 1962, the lake originally had a surface area of around 6,406 hectares and a water-storage capacity of about 524,229,789 $meters^3$ (KWO 2012). The construction of the dam helped prevent flooding multiple times, including the Great Flood of 1993, and millions of dollars were saved in potential damages (USACE 2013). Since completion of the reservoir, the amount of designated storage has greatly decreased due to the amount of sediment coming into the reservoir from upstream.

The projected life of large reservoirs was predicted to be 150 to 200 years. In some cases the sedimentation rates greatly exceeded the original estimates, and the actual projected life is cut by 50 to 100 years (Hargrove et al. 2010). A decrease in the project life is occurring to Tuttle Creek Reservoir. Sediment accumulation has created a loss of over 42 percent of the total (multi-purpose and sediment) storage capacity. During the last reservoir survey in 2009, the Kansas Water Office estimated that 77 percent of the design capacity had already been reached by the sediment pool alone. The sediment pool is also expected to be completely full by the year 2023 if sediment conditions continue the way they are now (Zeigler and Juracek 2006). If sedimentation continues and the storage capacity reaches its limits, expensive remediation steps, including the possibility of dredging, will have to be done to the lake.

Tuttle Creek Reservoir is being used by the state of Kansas for water storage. The reservoir ensures that adequate supplies of water for downstream industries and municipalities (e.g., Topeka, Lawrence, and Kansas City area) may be met. Being used by the State ensures protection for Tuttle Creek Reservoir, and now the reservoir has been made a priority for water quality protection by national, state, and local stakeholders due to the economic value that it brings to the local economies surrounding Tuttle Creek, as well as trying to avoid the expensive dredging procedures (Nejadhashemi et al. 2011). One way the Government and EPA are trying to do protect Tuttle Creek Reservoir is through the Clean Water Act, by creating sediment TMDLs for Tuttle Creek Lake and the tributaries that lead into the lake.

Clean Water Act and Nonpoint Source Pollution

The Federal Water Pollution Control Act, or as it is more commonly known as the Clean Water Act (CWA), is the primary way the Government has been trying to protect water sources. The CWA's objective is to "restore and maintain the chemical, physical, and biological integrity of the Nation's water by preventing point and nonpoint pollution sources, providing assistance to publicly owned treatment works for the improvement of wastewater treatment, and maintaining the integrity of wetlands" (EPA 2013a). The pollution from nonpoint and point sources is one of the largest problems that the CWA faces. The Clean Water Act of 1987 defines the term *point source* as "any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft from which pollutants are or may be discharged (Clean Water Act of 1987 Section 502(14))" (EPA 2012a). For example, a point source could be discharge coming from a factory or wastewater treatment facility. The CWA's definition of *nonpoint source* is "any source of water pollution that does not meet the legal definition of point source" (EPA 2012f). The nonpoint source pollution may come from many different sources (Figure 2.2): precipitation, land runoff, infiltration, drainage, seepage, hydrologic modifications, and atmospheric deposition (EPA 1993).

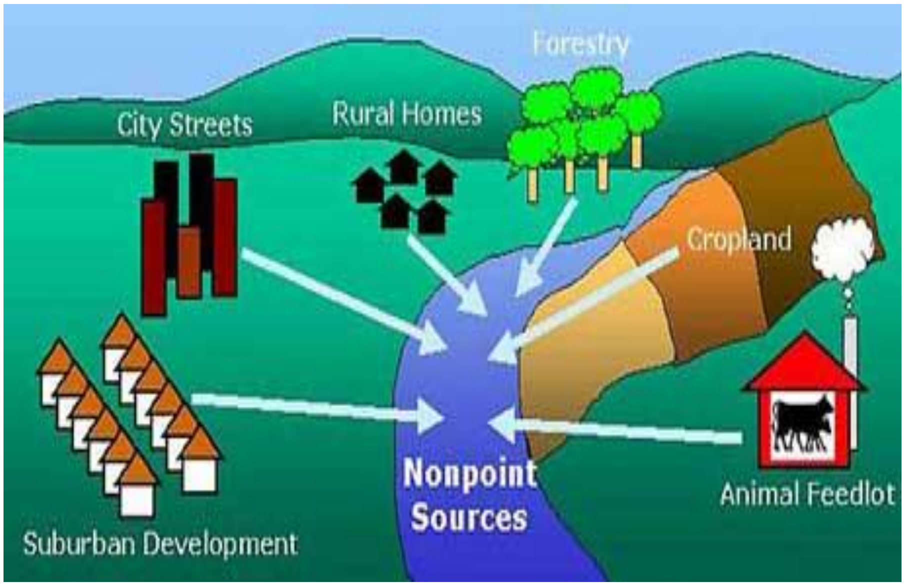

Figure 2.2 Sources of nonpoint source pollution (Reproduced from NOAA. 2008. Nonpoint source pollution. Silver Spring, MD: U.S. Department of Commerce National Oceanic and Atmospheric Administration.)

Pollutants are picked up and carried as the water moves over or through the ground. The water will then deposit the pollutants into slower moving or stagnant water bodies. While there has been significant work in limiting and monitoring the pollution from point sources (i.e. National Pollutant Discharge Elimination System and wastewater treatment facilities), focus then switched to finding and limiting nonpoint sources. In 1987, the Clean Water Act was amended to "address the need for greater federal leadership to help focus state and local nonpoint source efforts (Section 319)" (EPA 2013b). The amendment includes helping states, territories, and tribes to receive grant money to aid in decreasing nonpoint source pollution (EPA 2013c). The U. S. has also created numerous programs to help monitor and eliminate nonpoint source pollution: Nation Estuary Program, Pesticides Program (Federal Insecticide, Fungicide, and Rodenticide Act), Coastal Nonpoint Pollution Control Program, Safe Drinking Water Act, Source Water Assessment Programs, Rural Clean Water Program, and 2002 Farm Bill Conservation Provisions (EPA 1991).

One of the best programs created to source and monitor the water quality of the Nation's water bodies is actually part of the CWA. The Clean Water Act Section 305 (b) requires each State to report the condition streams, lakes, and estuaries are in, and also to identify the pollutants causing the impairments every two years (EPA 1997). In the latest data for the Reporting Cycle for the National Water Quality Inventory (2002 – 2012; Table 2.1) a majority of the assessed waters across the Nation were considered impaired. Approximately 53% of the kilometers of rivers, 67% of the hectares of lakes, and 66% of square kilometers of estuaries assessed being considered as threatened or impaired (EPA 2013f). The information is found in Table 2.1.

Table 2.1 Summary of the quality of assessed rivers, lakes, and estuaries for the Nation (Reproduced from EPA. 2013f. Watershed assessment, tracking, and environmental results; National summary of state information. Washington, DC: Office of Water; Water Quality Assessment and TMDL Information.)

Waterbody Type	Total Size	Amount Assessed (% of Total)	Condition of Assessed Waters		
			Good (% of Assessed)	Threatened (% of Assessed)	Impaired (% of Assessed)
Rivers and Streams (kilometers)	5,686,142	1,573,964 (27.7%)	733,262 (46.6%)	8,365 (<1%)	832,337 (52.9%)
Lakes, Reservoirs, and Ponds (hectares)	16,861,652	7,236,086 (42.9%)	2,369,103 (32.7%)	8,038 (<1%)	4,858,945 (67.1%)
Estuaries (sq. kilometers)	227,378	84,586 (37.2%)	28,676 (33.9%)		28,676 (66.1%)

Note: Percentages may not add up to 100% due to rounding.

The amount of impaired waters for the State of Kansas alone is extremely troubling (Table 2.2). Close to 88% of the rivers and streams and 98% of the lakes, reservoirs, and ponds assessed were considered to have impaired conditions (EPA 2012d). As seen in Table 2.4 and Table 2.5, a multitude of sources of impairments exist in Kansas water bodies that are reducing water quality. The high percentages and numerous amounts of impaired sources of the water conditions are potentially hazardous for humans, due to the high number of water bodies being used for domestic water supplies and recreational uses. The State of Kansas and the Nation need to take precautions to ensure that there is adequate quality for water.

Table 2.2 2012 State of Kansas monitoring summary results (Reproduced from EPA. 2012d. Watershed assessment, tracking, and environmental results; Kansas assessment data for 2012. Washington, DC: Office of Water; Water Quality Assessment and TMDL Information.)

Waterbody Type	Total Size	Amount Assessed (% of Total)	Condition of Assessed Waters	
			Good (% of Assessed)	Impaired (% of Assessed)
Rivers and Streams (kilometers)	216,196	47,209.5 (21.8%)	5,759.5 (12.2%)	41,449.9 (87.8%)
Lakes, Reservoirs, and Ponds (hectares)	105,322	103,583 (98.3%)	2,238 (2.2%)	101,345 (97.8%)

While there have been steps to limit nonpoint source pollution, the Nation's largest source of water quality problems remain to be from nonpoint source pollution, and significant strides still need to be done to control the pollution loads coming from these nonpoint sources (EPA 1996). One of the leading sources of nonpoint source pollution is agriculture. Since most watersheds in the Midwest are predominately rural with a majority of the land use being used for agriculture and grazing lands, the areas can be highly influenced by the potential management practices being implemented. Areas with poor management practices can have major impacts on rivers and streams by nonpoint source pollution and has some influence on the impairment in assessed lakes, ponds, and reservoirs in surrounding areas (Table 2.3) (EPA 2013f).

Table 2.3 Leading sources of impairment in assessed rivers, lakes, and estuaries (Reproduced from EPA. 2013f. Watershed assessment, tracking, and environmental results; National summary of state information. Washington, DC: Office of Water; Water Quality Assessment and TMDL Information)

Rivers and Streams	Lakes, Ponds, and Reservoirs	Estuaries
Agriculture	Atmospheric deposition	Atmospheric deposition
Atmospheric Deposition	Unknown/unspecified*	Unknown/unspecified*
Unknown/unspecified*	Agriculture	Municipal discharges/Sewage

**Source unknown or undocumented due to insufficient information*

Mismanaged practices could include poorly located or managed animal feeding operations. Excessive soil erosion from overland flow may be the result of overgrazing, over tilling, or tilling at the wrong time. Improper usage of pesticides, fertilizers, or irrigation and excessive or poorly timed uses of pesticides, fertilizers, or irrigation may also cause pollutants to be found in water bodies (EPA 2005). Channel incision and streambank erosion could also be affected by the agriculture processes. When there is an increase in the amount of runoff and decrease in infiltration on a field, the streambank and channel itself may contribute a considerable amount of sediment to help control the energy created by the increase in the amount of flowing waters.

Sedimentation Regulations

Sediment is a nonpoint source pollutant carried and deposited in water systems. The sediment has been a major contributor to pollution to both rivers and streams (Table 2.4), as well as to lakes, reservoirs, and ponds (Table 2.5) in Kansas. Sediment is responsible for the solids (suspended/bedload) that are carried in the water, as well as the sedimentation/siltation that is occurring to the fluvial system (Kerr 1995). Sediment pollution ranked as the third and 16th most commonly found impairments in rivers and streams in Kansas (Table 2.4), as well as the second highest reason for impairment in Kansas's lakes, ponds, and reservoirs (Table 2.5). As noted, sediment can also be linked to the nutrients and pesticides that are attached to soil particles. So many of the other causes of impairments found in the water bodies may also be related to the amount of sediments found in the water.

Table 2.4 2012 Cause of impairments in Kansas rivers and streams (Reproduced from EPA. 2012d. Watershed assessment, tracking, and environmental results; Kansas assessment data for 2012. Washington, DC: Office of Water; Water Quality Assessment and TMDL Information.)

Cause of Impairment	Cause of Impairment Group	Miles Threatened or Impaired
Phosphorus, Total	Nutrients	11,085.1
Sulfates	Salinity/Total Dissolved Solids/Chlorides/Sulfates	8,809.2
Solids (Suspended/Bedload)	Sediment	7,892.9
Fecal Coliform	Pathogens	7,284.2
Selenium	Metals (other than Mercury)	7,261.0
Dissolved Oxygen	Organic Enrichment/Oxygen Depletion	6,312.4
Aquatic Macroinvertebrate Bioassessments	Cause Unknown - Impaired Biota	5,469.1
Lead	Metals (other than Mercury)	4,762.2
Chloride	Salinity/Total Dissolved Solids/Chlorides/Sulfates	4,305.1
Escherichia Coli (E. Coli)	Pathogens	3,647.1
Copper	Metals (other than Mercury)	3,135.5
Atrazine	Pesticides	2,913.4
Arsenic	Metals (other than Mercury)	2,058.6
Nutrient/Eutrophication Biological Indicators	Nutrients	1,557.9
Fluoride	Toxic Inorganics	1,495.4
Sedimentation/Siltation	Sediment	797.2
Temperature, Water	Temperature	523.3
Nitrogen, Nitrate	Nutrients	390.1
pH, High	pH/Acidity/Caustic Conditions	292.5
PCB(s) in Fish Tissue	Polychlorinated Biphenyls (PCBs)	172.4
Alachlor	Pesticides	154.5
Zinc	Metals (other than Mercury)	147.4
Boron	Toxic Inorganics	145.3
Diazinon	Pesticides	91.4
Mercury in Fish Tissue	Mercury	81.9
Cadmium	Metals (other than Mercury)	76.5
Ammonia, Total	Ammonia	10.9
Gross Alpha	Radiation	4.7

Table 2.5 2012 Cause of impairment in Kansas lakes, reservoirs, and ponds (Reproduced from EPA. 2012d. Watershed assessment, tracking, and environmental results; Kansas assessment data for 2012. Washington, DC: Office of Water; Water Quality Assessment and TMDL Information.)

Cause of Impairment	Cause of Impairment Group	Acres Threatened or Impaired
Nutrient/Eutrophication Biological Indicators	Nutrients	223,492.0
Sedimentation/Siltation	Sediment	139,002.0
Dissolved Oxygen	Organic Enrichment/Oxygen Depletion	78,461.0
pH, High	pH/Acidity/Caustic Conditions	42,049.0
Sulfates	Salinity/Total Dissolved Solids/Chlorides/Sulfates	35,303.0
Chloride	Salinity/Total Dissolved Solids/Chlorides/Sulfates	35,065.0
Atrazine	Pesticides	16,258.0
Alachlor	Pesticides	15,459.0
Lead	Metals (other than Mercury)	14,937.0
Copper	Metals (other than Mercury)	11,050.0
Arsenic	Metals (other than Mercury)	7,836.0
Fecal Coliform	Pathogens	1,480.0
Aquatic Plants (Macrophytes)	Noxious Aquatic Plants	1,240.0
Selenium	Metals (other than Mercury)	394.0
Fluoride	Toxic Inorganics	84.0
Perchlorate	Toxic Inorganics	33.0
Boron	Toxic Inorganics	11.0

Water Quality Standards

One of the ways that the Government helps monitor and protect water quality is with the Water Quality Standard (WQS) program (CWA Section 303(c)). The WQS was developed by the CWA, and the law requires that states, territories, and tribes set water quality standards for waters within their jurisdictions. The water quality standards must define the use for the water bodies, identify specific water quality criteria, as well as contain antidegradation policies. Designating the use of a water body usually entails examining the "suitability based on the physical, chemical, and biological characteristics, as well as the geographical setting and scenic qualities, and the social-economic and cultural characteristics of the surrounding areas" (EPA

2013g). Considering the use and value of the water body for public water supplies, wildlife habitats, and recreational, agricultural, industrial, and navigational purposes also are used in developing standards. Water quality criteria may be both numeric and narrative. A numeric criterion is important to have when a certain amount may be toxic or a certain level of pollutant has potential health impacts or bioaccumulation potential. Narrative criteria may be used when there is no numeric standard or when toxicity cannot be traced to a certain pollutant. The states, territories, and tribes usually select one of the following as their standards: 1) adopt the criteria that the EPA publishes under Section 304 (a) of the CWA, 2) modify the Section 304(a) guidance to reflect site-specific conditions, or 3) base standards off of the site-specific conditions, biological monitoring, or other scientifically defensible methods. Protecting the improvements made to water quality and waters that already have high qualities is very important. This is done by an antidegradation policy within the CWA. The antidegradation policy ensures that water quality is maintained at a sufficient level to protect the existing uses of the water body. The outstanding national resource waters are generally the waters that have the highest water quality in the United States or the waters that are considered to have an "exceptional ecological significance" (EPA 2013g). Protected waters can be any water body that is considered "important, unique, or sensitive ecologically" (EPA 2013g).

Water quality standards are reviewed and revised every three years after public hearings are held by the State or Tribes. Once the public's requirements are met, the State certifies and ensures that the standards are met in accordance with State law. The standards are then submitted to the EPA Regional Administrator for review. Here the EPA reviews to determine if there were adequate analyses used to establish the standards, evaluates if the uses and criteria fit the entire water body, and ensures that downstream water quality is protected. The EPA will then decide if the standards meet requirements, or if standards are not met they get rejected. If the standards are rejected, the State would be required to make changes until they are approved by the EPA (EPA 2013g).

The standards for sediment are set considering the suspended and bedded sediments, which includes clean sediment, suspended sediment, total suspended solids, bedload, and turbidity. Suspended and bedded sediments (SABS) are “particulate organic and inorganic matter that suspend in or are carried by the water, and/or accumulate in a loose, unconsolidated form on the bottom of natural water bodies” (EPA 2006). SABS are commonly broken down by the particle size, and the sizes of the particles vary greatly. Particles smaller than 0.85 mm are considered to be fine sediment and particles larger than 9.5 mm are considered to be coarse. The State and EPA are striving for new/improved water quality criteria for SABS or for better methodologies for deriving SABS’ criteria on a regional or site specific basis because of the numerous problems that sediment creates for water quality. Due to these problems, the EPA water quality criteria program has listed SABS as one of the highest priorities to set new standards. SABS’ standards are currently developed to protect aquatic life, but including other forms of criteria may be necessary to improve the overall quality of water (i.e. sediment standards for drinking waters). The EPA’s 304(a) water quality criteria recommendation was developed in 1976 and is based on light reduction. It states “Solids (Suspended, Settleable) and Turbidity- Freshwater fish and other aquatic life: Settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10 percent from the seasonally established norm for aquatic life” (EPA 1986). The EPA also has an aesthetic standard which might affect the sediment quantity entering water bodies. The aesthetic standard states “Aesthetic Qualities- All waters shall be free from substances attributable to wastewater or other discharges that: settle to form objectionable deposits; float as debris, scum, oil, or other matter to form nuisances; produce objectionable color, odor, taste, or turbidity; injure or are toxic or produce adverse physiological response in humans, animals, or plants, produce undesirable or nuisance aquatic life" (EPA 1986). The clarity and turbidity of water is an important quality mostly due to the major safety factor that it can create for water bodies, especially water bodies used for recreational purposes. The favorable visual factors, such as color and clarity, can allow for detection of subsurface hazards and submerged objects, while also decreasing chances of drowning incidents (EPA 2006). Since sediment is causing a significant amount of damage to water bodies, better criteria and standards for the allowable amount of SABS needs to be developed.

Individual states have set slightly different sediment criteria based on what is found pertinent to each state. The wide variety of criteria used has created the range of standards around the U.S. Some states have used numeric criteria, narrative criteria, or a combination of both. Eight states have no criteria set for sediment at all, but five out of the eight have an alternative method or guide for establishing criteria. In some states, the different stream channel substrates types have individual criteria for each substrate. The states can even use the amount of soil loss as a criterion. The soil loss criterion could be based on an average soil loss over a long period of time or a daily maximum concentration. Numerical criteria is often based on previous turbidity data, but other methods, like suspended solids, transparency, amount of deposition, and clarity, have also been used. The narrative criterion usually pertains to turbidity or appearance, but it may also include biological effects, like how actions will affect humans or wildlife (i.e. "No actions which will impair or alter the communities") (EPA 2006).

The EPA has looked at all the different criteria that the states have set and is considering a few different approaches to improve the overall national standards for SABS' criteria. The potential approaches include looking at toxicological dose-responses; stream bed stability and sedimentation; conditional probabilities based on survey data; basing a criterion on an analytical approach that is derived from conditional probabilities and on the empirical and theoretical relationships of watershed characteristics and morphology and stream dynamics; fluvial geomorphology characteristics; basing criteria for designated uses other than aquatic life; using the successful State or International methods for determining criteria; or using a combination or portions of any of these approaches (EPA 2006). Regardless of which approach they use, an improved overall national SABS criterion developed to improve water quality would be superior to the criteria currently employed.

Total Maximum Daily Loads

After sediment standards are set, water qualities are monitored to determine if the standards set are being met. If the standards are not being met or the water body is considered impaired, priority rankings and total maximum daily loads (TMDLs) should be developed for these waters bodies. TMDLs are "calculations of the maximum amount of a pollutant that a water body can receive and still safely meet water quality standards" (EPA 2013e). The allowable loadings provide a basis to establish water quality-based controls, and thus standards may be met by the pollution reduction in both point and non-point sources. The TMDLs are usually developed on a watershed extent, so as to take into effect all the different sources of pollution. The TMDL process is described in Figure 2.3; it includes the following steps (EPA 1991):

1) Identification of water quality- limited waters that still need TMDLs developed

2) Priority ranking and targeting

3) TMDL development

4) Implementation of control actions

5) Assessment of water quality-based control actions

The first two steps of the TMDL process have been discussed previously. It determines if water bodies are meeting standard regulations, or if there are problematic areas. If water bodies are considered impaired or show signs of decreasing water quality, they will be reported by the agencies monitoring the water bodies to the EPA and put on the CWA Section 303(d) lists. The priority that one of the impaired water bodies receives is based on risk to human health and aquatic life and habitat, public interest, the importance of a particular water body, as well as some other factors.

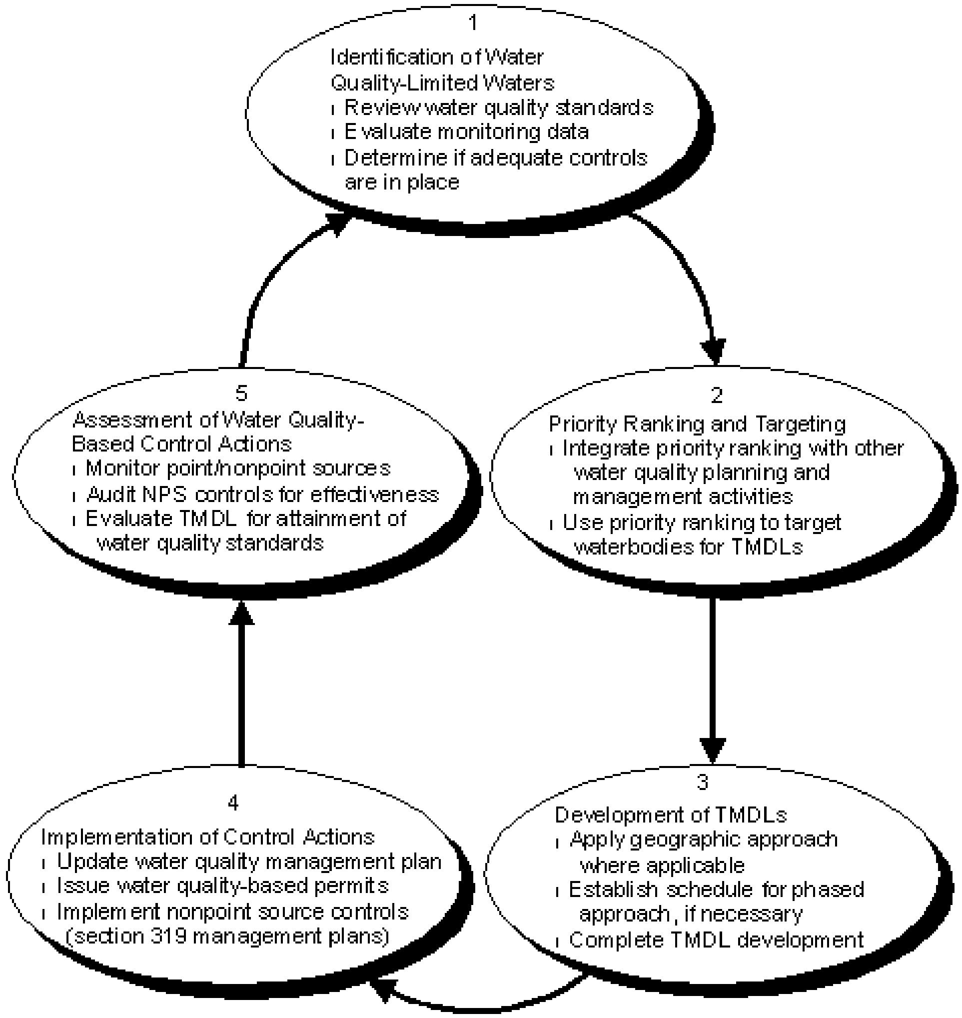

Figure 2.3 Developmental, implementation, and assessment processes for TMDLs
(Reproduced from EPA. 1991. Guidance for water quality-based decisions: The TMDL process (EPA 440/4-91-001). Washington, DC: Environmental Protection Agency; Office of Water.)

The third step is development of TMDLs. For decades, emphasis has been focused on chemical contaminate load reduction in water bodies, like for nutrients and metals. While these chemical contaminate load reductions will remain a major portion of water quality, non-chemical factors, like hydrology, channel morphology, and habitat, are now being addressed. The EPA and States are developing methods, and ultimately TMDLs, to address the issues that non-chemical factors are creating so water quality standards can be met. Today, TMDLs are developed using one or a combination of three technical approaches: 1) chemical specific approach, 2) whole effluent toxicity approach, and 3) biocriteria approach. The chemical specific approach is usually used to create TMDLs that address the loading that is directly affecting human health. For the protection of aquatic life, all three approaches are used. Regardless of the approach used to develop TMDLs, monitoring and re-assessment should be used to oversee that water quality standards may be attained. The fourth step of the process is the implementation of the TMDLs. Here, the EPA or States are responsible for implementing controls to meet the load allocations set in the TMDL. During this step, the states or tribes update the water quality plans, determine some different pollution allocation schemes of both point and nonpoint sources, and finally put these schemes and designs into practice. Some of the allocation schemes include the National Pollutant Discharge Elimination System permitting process or using Section 319 State management programs (BMPs) to limit pollution. Step four requires interdisciplinary work between the State, local agencies, landowners, operators, and mangers to correctly implement and manage the outlines and structures. The last step of the TMDL process is to assess the control actions established for load reductions. This is done by continual monitoring of the water bodies and reinforcements to ensure the TMDL goals are being met (EPA 1991).

The TMDLs developed usually consists of three parts: point source allocations, nonpoint source allocations, and an extra allocation for uncertainty. The basic equation for TMDLs is shown in Figure 2.4. Each part is allowed a certain amount of pollution from their respective sources. The margin of safety allocation is included so that unforeseen factors may be included in the TMDL. The allocations will help limit the amount of overall pollution coming into water bodies.

A TMDL is the sum of the individual wasteload allocations for point sources and load allocations for nonpoint sources and natural background (40 CFR 130.2) with a margin of safety (CWA Section 303(d)(1)(c)). The TMDL can be generically described by the following equation:

$$TMDL = LC = \sum WLA + \sum LA + MOS$$

where:

- LC = loading capacity,[a] or the greatest loading a waterbody can receive without violating water quality standards;
- WLA = wasteload allocation, or the portion of the TMDL allocated to existing or future point sources;
- LA = load allocation, or the portion of the TMDL allocated to existing or future nonpoint sources and natural background; and
- MOS = margin of safety, or an accounting of uncertainty about the relationship between pollutant loads and receiving water quality. The margin of safety can be provided implicitly through analytical assumptions or explicitly by reserving a portion of loading capacity.

[a]TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures.

Figure 2.4 Basic equation for developing TMDLs (Reproduced from EPA. 1999. Protocol for developing sediment TMDLs; first edition (EPA841- B-99-004). Washington DC: Office of Water.)

Sediment TMDLs

When developing TMDLs that focus on sediment pollutant reduction, sediment is the only pollutant considered. No other contaminates that may be associated with sediment are addressed. Thus, the amounts of nutrient or chemical reductions are not included in the sediment TMDL, but a given water body may have other individual TMDLs that address the concerns of other pollutants. Sediment TMDLs development varies greatly. The variation for development comes for the amount of data available for the region being considered impaired. The data can include knowing the number of sources the sediment can be coming from, the size of the watershed, the amount of data and resources that are available to help calculate the allowable sediment, as well as the available cost and funding. The more detailed the information, the smaller the result in margin of safety (MOS in Figure 2.4), however detailed approaches require more data, increase completion times, and increase costs (EPA 1999).

It is often difficult to determine how much sediment loads needs to be reduced; this is because erosion is a natural process, and some sediment is needed to maintain stream systems (Rosgen 1996). There has to be an evaluation of how much excess sediment discharge there is compared to the sediment erosion rates and patterns occurring during natural processes, which is often difficult to determine. Predicting excessive erosion and transport is also hard to derive for average sediment yield conditions due to the radically diverse areas the sediment is delivered from. Not only do sediment conditions vary regionally, but they can change drastically from watershed to watershed and from season to season. This leads to a substantial level of uncertainty in amounts of sediment delivery, storage, and transport estimations. Sediment TMDLs are usually expressed in terms of maximum mass load per unit time, but in some cases, predicting the maximum mass load can be difficult to do. When it is difficult to express TMDLs in mass load per unit time, TMDLs for sediment can also be expressed in numeric targets of substrate or channel conditions, aquatic biological indicators, or by hillslope indicators. The TMDL can also be expressed in terms of different time units or functions of watershed processes, like setting a sediment load that is associated with a certain amount of precipitation or runoff. Regardless of how a TMDL is developed and set, the important step is to know where the sediment is coming from (EPA 1999).

Source assessment methods can occur in different ways. One method is by looking at the vulnerability or future erosion that may occur. Predicting the vulnerability or amount of future erosion includes looking at a watershed and focusing on watershed and resource management issues. Knowing what is going on in the watershed provides a general framework for quantification and synthesis of watershed process assessment evaluations, but seeing what is going on in the watershed will not provide load estimates. The analysis of vulnerability or soil erosion method gives a general description of what is going on in the watershed. The second method is using erosion models to provide load estimates. The models estimate erosion as a function of several factors, some including soil characteristics, topography, vegetation characteristics, and precipitation. The models can also range from fairly simple processes (RUSLE, WEPP, USGS Regression) to models that require great detail and require a greater amount of inputs (SWMM, HSPF, SWAT). The third method is done by using direct measurement methods. This method uses past measurements of erosion rates and amounts, like sediment budgets and sediment rating curves. All these methods are helpful in determining the amount of allocation for sediment in water bodies (EPA 1999).

A TMDL was developed for Tuttle Creek Lake in 2000 due to the consistently high levels of turbidity and siltation occurring in the lake. The intent of the TMDL was to reduce the rate of loss of storage from 1999-2008. The desired endpoint of this TMDL was to have 333,040,101 to 339,207,510 cubic meters of storage after 2008. The TMDL developed for Tuttle Creek Lake had no wasteload allocations, because this pollutant (sediment) is associated with agricultural non-point source pollution. The load allocation from non-point sources included reducing the historic storage loss rates by 45%. The projected loads during this time frame would be reduced by 48%, which results in around 29,603,565-30,837,046 cubic meters of sediment accumulation to occur (or 3 million tons per year of TSS). The margin of safety was set at 6,167,409 cubic meters of storage. To meet these desired TMDLs, certain implementation activities were put into practice. The practices used to meet TMDL levels included implementing and maintaining conservation farming, including conservation tillage, contour strips, and no till farming. Other load reduction practice included installing grass buffer strips along streams, reduction of activities within riparian areas, and minimizing road and bridge construction impacts on streams (KDHE 2000).

After the study ended in 2008, the same load allocation estimates were being used to maintain the storage in the conservation pool to remain within 90% of the 1996 storage (333,040,101 to 339,207,510 cubic meters) (WRAPS 2010), but the assessment of water bodies in 2012 classify all feeding tributaries and Tuttle Creek Lake as still being impaired. Thus, updated TMDLs for these tributaries and for the lake still need to be developed (EPA 2012e). Continued work and monitoring is still an obvious need for improved water quality for Tuttle Creek Reservoir.

Soil Erosion

To help improve water quality, there is an importance in knowing the sediment sources and how sediment is transported. Soil erosion is the “breakdown, detachment, transport, and redistribution of soil particles by forces of water, wind, or gravity, and this is a naturally occurring process”; however, accelerated soil erosion is occurring due to human uses and changes in land use activities (USDA 2013). After detachment of soil particles, the sediment is transported by moving water and wind. When there is not enough sufficient energy, the transportation of particles cease and deposition occurs (Morgan 2005). The transportation medium is usually how erosion is classified (i.e. wind, water, gravity, etc.), and water is one of the leading causes of erosion. Water erosion is created by the movement of sediment particles by any form of water, usually rainfall or surface runoff. The movement of sediment by water may be by surface, mass, or channel erosion (Rosgen 2009).

Surface erosion can be further categorized into splash, sheet, rill, and gully erosion (Rosgen 2009). The forms of overland erosion are displayed in Figure 2.5. Splash erosion occurs when precipitation strikes bare soil surface causing soil particles to be transferred (Morgan 2005). The large soil aggregates can be displaced or dispersed, but the smaller particles can be splashed over several feet away (Ellison 1948), and splash erosion is particularly a problem on landscapes with steep slopes that have very little vegetation coverage (Dunne and Leopold 1978). Sheet erosion is the uniform removal of soil particles in thin layers by the force of overland flow (NSERL 2013). Sheet erosion often encompasses splash erosion, because the two forms of erosion are very difficult to separate in the field, but together, the two processes are responsible for the erosion and transportation of soil from the hillslope (Dunne and Leopold 1978).

Rill erosion is the removal of soil particles by concentrated overland flow running through streamlets or head-cuts. Rill erosion can create enough sediment movement that the rills become large enough they are classified as gullies (NSERL 2013). Gully erosion is broken up into two main categories based upon the size of the developing "channel". Classical gullies have been defined when the "channels are cut to a depth greater than 1 foot" (UNEP 1998) or when "channel development has progressed to the point where the gully is too wide and too deep to be crossed by farm equipment" (NSERL 2013). Ephemeral gullies are channels that can be crossed with farm equipment depending on depth and width, and the channels are more of transitory structures. Ephemeral gullies tend to reform in the same locations where the upslope region of overland flow concentrates (NSERL 2013). Surface erosion may add a significant amount of sediment to water bodies, but it does so over long periods of time. Splash and sheet erosion may go unnoticed for years before noticeable amounts of soil loss are evident. The significance of rill erosion is often times overlooked due to tillage operation destroying any evidence of the small channel formations (Dunne and Leopold 1978). It is only when gully formations and head-cuts start to appear that apparent erosion and significant soil loss is taking place.

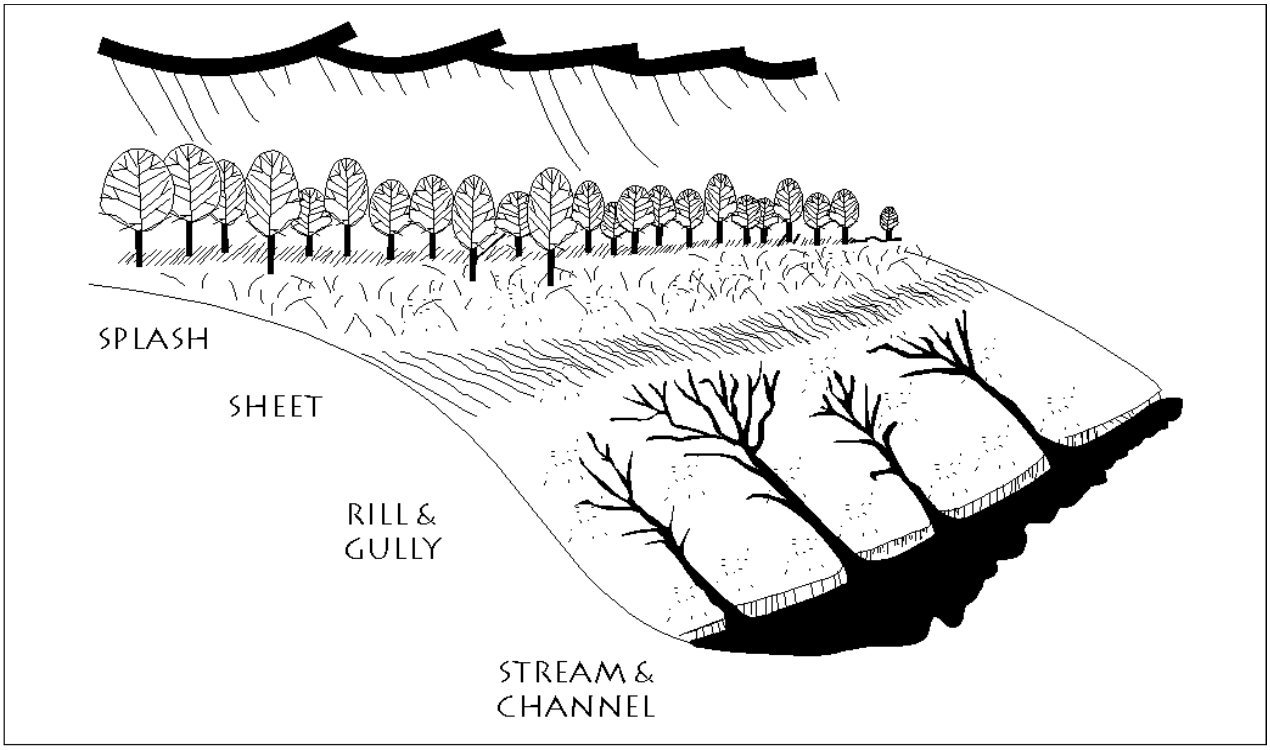

Figure 2.5 Types of soil erosion (Reproduced from UNEP. 1998. Best management practices for agricultural non-point sources of pollution. CEP Technical Report No. 41. Nairobi, Kenya: United Nations Environment Programme; Caribbean Environment Programme.)

Mass erosion occurs in shallow, fast movements of debris avalanches and mudflows, due to high intensity or long duration of precipitation. They may also occur in slow slumps that move intermittently over varying time periods, due to infrequent events or disturbance factors. Due to the sporadic nature of climatic events that create the conditions for mass erosion to occur, being able to predict if and when these slumps or avalanches will happen, is very difficult.

Observing the vegetation changes of landscapes and road construction are often indicators that mass erosion events could take place, but it might take years for the mass erosion events to occur. When these events do occur, they may contribute a massive amount of sediment in a very short period of time to the fluvial system, and eventually to downstream waters (Rosgen 2009).

While the total amount of sediment yield is usually associated with sheet, rill, and gully erosion, a number of studies have shown that channel erosion is contributing a major portion of the sediment yield (Rosgen 2009). Stream and channel erosion is the sediment that is coming from the banks and bed of the channel and this includes mass erosion that occurs due to bank failure. Some studies have found that bank erosion can contribute from 50-90% of any given stream sediment and phosphorus loads (Zaimes et al. 2005), while other studies stated that stream banks can contribute up to 80% of a stream's total suspended load (Simon and Rinaldi 2006).

Streambank and bed erosion is a type of erosion that may occur due to certain stream characteristics and hydraulic forces (Rosgen2009). When little riparian vegetation is present near streambanks and there is an increase in runoff and discharge occurring in the stream, conditions become right for streambank failure to occur. Depending on the stability of the stream or river, conditions might also be met where the channel characteristics start to change. Changes in the channel might include modifications to the channel's width, depth, sinuosity, and profile, until the stream reaches an equilibrium state. Channel modification may also add a tremendous amount of sediment to the system (Rosgen 1996). The changing of stream characteristics is directly linked to the amount of energy and power created by the stream.

Stream Energy

Stream energy is the capacity or power to do work in a channel. The stream must be able to transport both the size and type of sediment loads associated with the local deposition and scour, while a stable dimension, pattern, and profile are maintained and the stream system neither aggrades nor degrades (Rosgen 1996). Most of the energy in streams is created by gravity. The gravitational force of the weight of the water pulls the water downhill. The counteracting force is drag, or flow resistance. This will create a friction force acting in the opposite direction of movement, slowing down the movement. In general, the water maintains a constant velocity; this is because the flow of the stream and the flow resistance are equal but opposite to each other. Because of this constant velocity, or no acceleration in water, the "fall of elevation for any given distance represents potential energy changed into kinetic energy and then into heat or used in work" (Dunne and Leopold 1978). This means that the stream gradient creates the downstream flow and is an essential hydraulic factor. A majority of the kinetic energy produced is used up in friction, or the drag, of the motion of flow and turned into heat, while the remainder of energy is used to transport sediment or alter the channel dimensions (Dunne and Leopold 1978). Being able to plan for the amount of energy that occurs in streams may help planners, engineers, and environmentalists understand what the stream system actually needs to do to reach and maintain stability, while continuing to transport a given discharge and sediment load.

Stream Gradient

The stream gradient is the slope of a stream and is measured by the difference in elevation between two points. The gradient looks at how far the water drops in elevation over how far the water actually travels and represents the change from potential energy to kinetic energy (Dunne and Leopold 1978). This factor greatly influences the velocity, and ultimately, the discharge. The steeper a stream gradient is results in a greater velocity occurring in the stream, only if all other factors (sediment size, sediment amount, or stream discharge) are held constant (Hill 2009). The streams with high gradients (steeper gradients) have a more erosive force. Streams with steeper gradients can create more erosion in the channel, and the stream gradient is directly related to the sediment carried in the stream (size and load). The opposite is true about stream flow, and the stream gradient is inversely related to stream flow. The channel slope will decrease in a downstream direction in response to an increase in discharge and a corresponding increase in sediment size or load. So generally, as any of these factors (sediment and discharge) change, the stream gradient adjusts the steepness to compensate for the change in energy that is created in the stream by the change in sediment load and/or size or discharge amounts. Steep gradients tend to be straight, and they dissipate energy along closely spaced step and pool features. The stream gradient and bankfull width determines the spacing between these features. They are inversely related to the slope and proportional to the bankfull width. When the gradients decrease, the features change into riffle and pool features. These features are spaced farther apart, and they are functions of the channel width (Rosgen 1996). Thus a high gradient stream will have a higher velocity and have a higher load capacity than a low gradient stream of the same size. Due to the stream gradient being the main driving force for the movement of water, it is a major factor to account for when calculating velocity. The gradient, or slope, is usually represented with the symbol S and expressed in feet per mile or meters per kilometer (Dunne and Leopold 1978).

Flow Resistance

In stream flow, energy is continually being dissipated because of the work the fluid has to do against the resisting forces (Henderson 1966). In stream channels, the forces that retard water movement are the sediment size and amounts. By increasing either the sediment size or sediment load in a stream, a decrease in discharge or a change in slope will occur. The sediment load of a stream is distributed in the channel. This occurs in beds, bars, pools, riffles, and point bars. Each of these forms may have one or several different types of loads within it (Dunne and Leopold 1978). Table 2.6 lists the sediment and sizes of these particles that occur in streams.

Table 2.6 Sediment sizes (Reproduced from Williams, S.J. 1981. Sand resources and geological character of Long Island Sound. Technical Paper No. 81-3. Fort Belvoir, VA: U.S Army, CORPS of Engineers; Coastal Engineering Research Center.)

Unified Soils Classification	ASTM Mesh	mm Size	Phi Value	Wentworth Classification
COBBLE				BOULDER
		256.0	-8.0	
				COBBLE
		76.0	-6.25	
COARSE GRAVEL				
		64.0	-6.0	
				PEBBLE
		19.0	-4.25	
FINE GRAVEL				
	4	4.76	-2.25	
SAND: coarse				
	5	4.0	-2.0	
				GRAVEL
	10	2.0	-1.0	
SAND: medium				SAND: very coarse
	18	1.0	0.0	
				SAND: coarse
	25	0.5	1.0	
				SAND: medium
	40	0.42	1.25	
SAND: fine				
	60	0.25	2.0	
				SAND: fine
	120	0.125	3.0	
				SAND: very fine
	200	0.074	3.75	
SILT				
	230	0.062	4.0	
				SILT
		0.0039	8.0	
CLAY				CLAY
		0.0024	12.0	
				COLLOID

The bed materials range from microscopic to larger than 250 mm. The larger the particle size, the higher the resistance will be, and thus how high the velocity will have to reach for movement to ensue. Friction is also increased when the load amount carried in the actual stream is increased, and the increase in friction will decrease velocity (Rosgen 1996). When calculating the velocity of the water, roughness coefficients are included. The roughness coefficients, which come from the amount and type of material, are represented as n in Manning's Equation, as f in the Darcy-Weisbach equation, and C in the Chezy's formula (Nitsche et al. 2011).

Stream Velocity and Discharges

Stream velocity plays a very important role in sediment transport, as well as erosive capabilities. The velocity of a stream depends on the slope of the channel, the material that is creating the flow resistance, and the cross-sectional area that the water is flowing through. Usually one of the most important components of velocity of any fluid would be the flow type. However, water in nature rarely has smooth simple streamlines; thus it is usually classified as having laminar flows. The movement that occurs in the water is very complex. This results in the water flow being classified as turbulent. Turbulent flow means there are secondary eddies and swirls in addition to the main downstream current. Water tends to roll in rivers. The rolling movement is caused by the resistance in the bottom of the channel. The vertical flows, associated with this rolling action, can keep some sediment suspended for long periods of time (Hamblin and Christiansen 2003). The weight of sediment carried in a stream is also directly related to the velocity. The weight carried is known as the stream's capacity. The stream's capacity is approximately a three to four power increase of the flow velocity. For example, if a stream velocity is doubled, the capacity of the stream is then 8 to 16 times as much as the amount it was previously (Hamblin and Christiansen 2003). The stream competence, or the size of particles that can be moved by water, is also dependent on stream velocity. The competence of a stream varies approximately to the sixth power of velocity, thus doubling the velocity results in a 64 times increase in competence (Columbia 2013).

The velocity of the water will determine when sediment is transported, eroded, or deposited. Some sediment, like clays, may be suspended until the velocity is extremely low or stagnant, while other larger sediment, like gravel and pebbles, needs only a small drop in velocity to be deposited. Erosive zones for sediment particles vary depending on the particle size and the amount of power and energy in the stream. Smaller sediments, like silts and sands, can start to erode and be transported at lower velocities. Clays and larger particles require more power and energy for erosion to occur (Cronodon 2011). As velocities increase, the stream power also increases. The increase of power results in an increase in sediment erosion and transport. The velocities that occur when bankfull conditions are met are velocities in which a significant amount of sediment could be eroded and transported. Both extremely small and large particles can start to erode at the bankfull stage. The typical velocity occurring at bankfull for medium to large size streams is 1.22-1.52 m/s (4.5-5 ft/s) (Rosgen 1996; Dunne and Leopold 1978).

The velocity in a stream also varies depending on location in the stream. Figure 2.6 shows isovels in a diagram of natural channel streams (Hamblin and Christiansen 2003). Isovels are lines that connect points of equal flow velocity (IIT 2012).

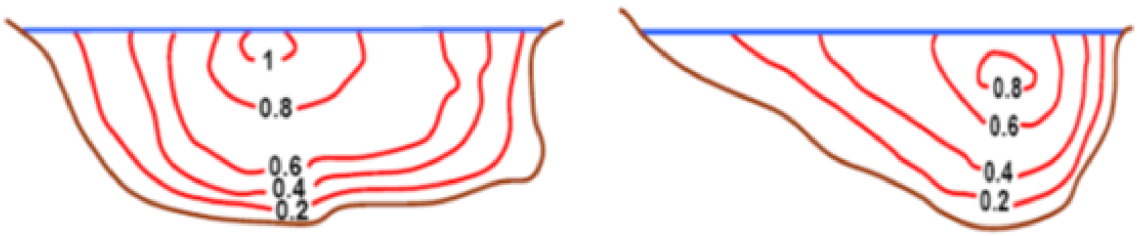

Figure 2.6 Isovels in natural channel streams (Reproduced from Cronodon. 2011. River processes.)

The highest velocity is located in the middle of a symmetrical channel just below the surface. The stream velocities are the slowest near the banks and bed of the channel due to flow resistance or friction created from their materials. When the channel is asymmetric, the highest velocity is located to one side of the stream channel, like shown in the diagram on the right in Figure 2.6. The water velocity will increase around a bend because it has to travel further. For the stream to stay connected, it has to increase on the outside of the bend, while the water on the inside has to decrease (Hamblin and Christiansen 2003). To get the best estimate of the stream velocity, the average velocity of the stream is usually used in determining discharge flows and the energy that is occurring.

The average velocity of water in a stream is determined by the depth, slope, and the resistance. Velocity is commonly calculated in two different ways: Chezy Formula (Equation 2-1) or Manning's Equation (Equation 2-2). These equations are very similar, but they use different resistance variables. The equations are taken from Dunne and Leopold (1978).

Chezy Formula:

$$u = C\sqrt{(RS)} \qquad (2\text{-}1)$$

Here u = water velocity (m s^{-1})

C = resistance factor (large for smooth boundaries and small for rough boundaries) ($m^{(1/2)}$ s^{-1})

R = hydraulic radius (ratio of cross-sectional area of flowing water to wetted parameter, A / wp) (m)

S = energy gradient (slope of the water surface) (unit less: m/m)

Manning's Equation:

$$u = \frac{1.00\ R^{2/3}\ S^{1/2}}{n} \qquad (2\text{-}2)$$

Here u = water velocity (m s^{-1})

R = hydraulic radius (m)

S = energy gradient (unit less: m/m)

n = Manning resistance coefficient (large n coefficients for rough boundaries, or increase friction)

* 1.00 is the conversion factor to obtain SI units ($\text{Length}^{(1/3)}$/Time) in place of the 1.49 that is used in the equation from Dunne and Leopold (1978)

Using either the Chezy formula or Manning's equation can determine the mean velocity of the stream. Manning's equation is more commonly used by American engineers, but both are comparable to the actual velocity in a stream (Dunne and Leopold 1978). The velocities calculated by the Chezy formula or Manning's equation can then be used to determine the amount of discharge at a certain time.

Discharge is the amount of water that flows down a stream at a certain point in a certain moment of time, and it is expressed as a measure of volume per unit of time (USGS 2013b). It is calculated by taking the cross-sectional area of the channel multiplied by the velocity of the flowing water. Figure 2.7 shows how the typical channel dimensions are measured, and it also gives a visual of the cross-sectional area. The *w* stands for the width of the channel at water level and the *d* represents the depth to the channel from the water level (Dunne and Leopold 1978). Since natural channels are not uniformly shaped, the depth of the water is not easily defined. To simplify things, the average depth of water across the channel is used to calculate the cross-sectional area (EPA 2012c). The equation to calculate the discharge is shown in Equation 2-3 below (Dunne and Leopold 1978).

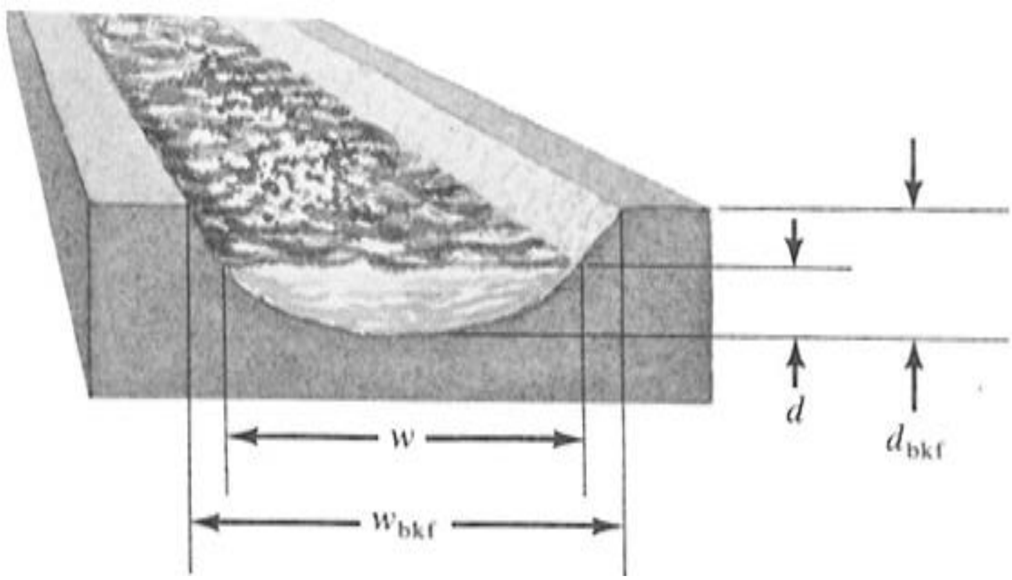

Figure 2.7 Cross-sectional area of a natural channel (Reproduced from Dunne, T., and L. Leopold. 1978. Water in environmental planning. San Francisco, CA: W.H. Freeman and Company)

Discharge:

$$\boldsymbol{Q = Au = wdu} \qquad (2\text{-}3)$$

Here Q = Discharge or flow ($m^3 s^{-1}$)

A = Cross-sectional Area (m^2)

u = velocity of stream (ms^{-1})

w = width of water (m)

d = depth of water (m)

When the cross-sectional area of the channel is held constant, the relationship between discharge and velocity is directly related. The relationship shows that as the velocity increases the discharge would increase by the same factor. However, this rarely happens in nature, and both the depth and width of the channel would also increase with the increase in discharge (Dunne and Leopold 1978).

Because stream flows fluctuate greatly and seldom have flows that fill the whole channel, it is important to be able to measure certain features consistently so that rates and discharges can be compared. To prevent this inconsistency, measurements are commonly taken at bankfull conditions, and many of the stream characteristics (dimensions, patterns, and bed features) are described as a function of the channel width measured at bankfull. Bankfull is the flow stage of a river where the water surface elevation corresponds to "the discharge at which channel maintenance and formation is the most effective" (Rosgen 1996). At bankfull discharge, the channel is at capacity (Dunne and Leopold 1978), or has the momentary maximum flow a channel carries without flooding (Rosgen 1996). Bankfull conditions occur, on average, every 1.5 years, which gives designers, planners, and engineers a better idea of how to plan and prepare for higher discharge and velocity rates. The discharge at bankfull is described in Equation 2-4 (Dunne and Leopold 1978).

$$\mathbf{Q}_{bkf} = \mathbf{A}_{bkf} \times u_{bkf} = w_{bkf} \times u_{bkf} \times d_{bkf} \qquad (2\text{-}4)$$

Where Q_{bkf} = bankfull discharge (cubic meters/sec)

A_{bkf} = Area at bankfull (square meters)

u_{bkf} = velocity at bankfull (meters/sec)

w_{bkf} = bankfull width (meters)

d_{bkf} = bankfull depth (meters)

Figure 2.7 also shows the bankfull dimension for a natural stream channel. They are depicted as W_{bkf} for the width of the channel at the bankfull level and d_{bkf} for the depth at bankfull level.

Stream Power

Stream power is the sole mechanism for the transport of sediment and comes from the movement of a mass of water over a change in elevation. Power is the work over time, or weight multiplied by distance divided by time. The weight used to calculate work is the excess weight, or the dry weight less the buoyant weight of the water displaced (Dunne and Leopold 1978). It can also be calculated by using the energy of a stream. Since water is not accelerating in the stream and assuming the river cross section stays constant, which is a good assumption for an average reach of a stream over a modest distance, the potential energy is all lost due to the friction or work against the bed. Thus, the potential energy drop is equal to the work done on the bed and banks, which is the stream power (Bagnold 1966). The equation for stream power is listed below in Equation 2-5 (Dunne and Leopold 1978).

$$\boldsymbol{Power = \frac{Weight \times Distance}{Time} = \frac{Work}{Time}} \qquad (2\text{-}5)$$

This indicates that power will be determined by the velocity and weight, but these variables can be difficult to measure in streams and rivers. A modified power equation was developed with terms that are more easily measured in streams. The modified power equation states "the available power over a unit area of stream bed is proportional to the product of the discharge rate times the gradient, or slope, of the water surface" (Dunne and Leopold 1978). As the channel slope or discharge is increased, the stream power is also increased (Gordon et al. 2004). The modified equation for stream power is listed below in Equation 2-6 (Bagnold 1966). The local stream power can also be estimated by the near bank stress (Sass 2008).

$$\textbf{Stream Power} = \frac{Discharge \times Slope \times Density \times Gravity}{Water\ Surface\ Width} \quad (2\text{-}6)$$

If a stream is large and traveling at a high rate, it can generate more power compared to streams that are small and slow (Hamblin and Christiansen 2003). When there is enough power occurring in the channel, degradation (starting with the smaller sediment particles) of the channel bed will ensue and sediment will be transported by the water. The higher the stream power is, the more sediment load or size is needed to satisfy the transport capacity. When the power subsides, sediment will start to deposit and aggradation occurs (Dunne and Leopold 1978). Both these processes are essential for channel modification and energy dissipation.

Energy Dissipation

Natural rivers are self-constructed and self-maintained, and they are constantly seeking stability (Leopold et. al. 1964). They must be able to transport both a size and type of sediment load associated with local deposition and scour without either aggrading or degrading (Rosgen 1996). To reach a state of equilibrium, a stream has many important mechanisms to dissipate excess energy. Some of these mechanisms result in changing the stream's channel dimensions, patterns, and profile.

Channel Incision

Channel incision is the process of channel adjustments by which the stream bed cuts down over an extended period of time until it ultimately reaches a lower bed elevation. The bed cuts down by the process of bed degradation, which has been defined as "the universal and defining characteristic of incised stream channels" (Darby and Simon 1999). The channel incision process is considered to be a consequence of rapid morphologic change due to disequilibrium that is occurring in the stream. Bed degradation usually occurs in streams that have an excess amount of shear stress or stream power and channel capacity, which expedites further channel incision, bank erosion, and sediment transport and delivery processes (Darby and Simon 1999). The severity of bed degradation depends on the type of bed material and its ability to resist erosion (Hanson and Simon 2001) and is said to be instigated if any of the following changes occur (Meade 2009):

a) changes that cause a decrease in sediment loads
b) an increase in annual or peak discharges
c) an increase in channel gradient and slope
d) a concentration of flows

The exact causes of channel incision vary widely and can be numerous, and both human and natural factors influence the susceptibility to incision (Darby and Simon 1999). The most common human influences of channel incision are land use changes and channelization. The clearing of native vegetation (such as grasses, shrubs, and trees) within a given landscape results in a decrease in that region's ability to intercept precipitation and prevent it from infiltrating into the soil. Thus, removing vegetation results in increased runoff and increased erosion and sediment loadings (Simon and Rinaldi 2006). Increased amounts of runoff and sediment that are contributed to streams increases the risk of flooding. Although floods are important for natural functions of a fluvial system, in order to alleviate problems associated with flooding, the channels are re-aligned physically in order to shorten or straighten that channel by dredging and excavations (Brookes 1985). However well intended channelization may have been, it has caused numerous negative effects to the fluvial system and is regarded as "one of the most harmful anthropomorphic disturbances to fluvial systems" (Davis 2007) and "one of the most widespread human-caused triggers of channel incision" (Simon and Rinaldi 2006).

Channelization can cause lowered streambeds, increased channel capacities, increased channel gradients, and increased velocities. These can all cause rapid morphologic changes to the fluvial system including unstable banks, upstream degradation, and downstream aggradation (Simon and Rinaldi 2006). The soil composition is a major factor in determining how vulnerable the channel will be to incision. The types of sediment particles that make up the channel influence the ability to resist erosion. The loess and glacial till-covered area of the Midwest is considered to be a "worst-case scenario" for channel stability (Simon and Rinaldi 2000). The combination of highly erodible soils and extensive human disturbance can create prime conditions for channel incision to occur.

Incised channels are often characterized by increased bank heights and ability to contain flows of greater recurrence intervals than non-incised channels (Simon and Rinaldi 2006). The channel's cross section increases due to the incision, thus there is a transmission of a larger volume of water and a greater capacity downstream. This results in the recurrence interval of bankfull discharge to decrease to less than the "stable stream's" 1.5 year recurrence. The original floodplain then becomes a terrace, and the stream loses the ability to dissipate energy along the floodplain. The lack of a floodplain results in the flows to contain higher shear stresses and power, and as a result they are capable of transporting larger amounts of sediment (Darby and Simon 1999). The combination of land use changes, soils vulnerability to erosion, increase streamflow all lead to channel instability and may lead to other modifications to the stream, including channel enlargement.

Channel Enlargement

Stream width is a function of streamflow, sediment loads, and the bed and bank materials of the channel (Rosgen 1996). Bankfull width is the most consistent parameter for estimating both water yields and flood peak expectancies (Dunne and Leopold 1978). A channel can maintain a relatively stable width even though the stream is migrating laterally at a constant rate. This is done by lateral erosion occurring on one bank which is then compensated by sediment deposition along the opposite bank. However, when lateral erosion occurs on both banks, the channel widens (Rosgen 2009).

Channel enlargement can be caused by various reasons. These may include a combination of processes of incision, bank erosion, direct modification by construction activities, and large floods of incised channels (Rosgen 2009). As stated earlier, when channel incision occurs, it generates higher and steeper streambanks (Simon and Rinaldi 2006). This results in increased risk of bank erosion. The bank erosion is commonly caused by hydraulic erosion, or the lateral erosion occurring on the bank toe caused by the stream discharge. Energy is dissipated along the stream bank and bed, and it causes increased instability of these higher streambanks (Langendoen and Simon 2008). The stability of the bank toe will eventually decrease, and a critical height and bank angle is reached to a point where the bank fails, and gravity causes a mass of the bank to fall into the stream (Darby and Simon 1999).

Changes to riparian vegetation that alter resistance to streambank erosion and changes in the watershed that may affect the streamflow regime may also increase the risk of channel enlargement (Rosgen 1996). Trans-basin diversions, storm runoff from urbanized areas, high flows from reservoir releases, and scour below culverts and bridges also often contribute to channel enlargement. Often channels are mechanically enlarged to increase flood flow capacity for bridge construction or for flood control. When the channel is enlarged, it is often over-widen. The over-widening of the channel results in excess deposition, which actually decreases the channel capacity. Channel enlargement also results in increased bank erosion and requires extensive maintenance (Rosgen 2009).

So as the channel makes width adjustments, it triggers even more instability and increases the amount of sediment added to the fluvial system. It can also cause increased amounts of deposition due to decreased shear stress and stream power, loss of habitat, increased water temperatures, loss of land, and shifts in stream classifications (Rosgen 2009). No matter the consequences of natural channel widening and bank erosion, these are important processes for promoting the recovery of incised streams. Widening of the channel reduces available shear stress for cutting of the channel bed to occur, develops a new flood plain, and reduces the depth of flows (Simon 1992). The channel width adjustment is just a step to eliminate excess energy and power through channel succession for the development of a stable stream.

Sinuosity

Stream patterns may be described as straight, meandering, or braided; however, streams are rarely straight for great distances and tend to follow a sinuous course (Leopold et al. 1964). The sinuosity of a stream is defined as "an index of channel pattern determined from the ratio of stream length to valley length or the ratio of valley slope to channel slope" (Rosgen 2009). The sinuosity varies in rivers from a "value of unity to a value of 4 or more" (Yeasmin and Islam 2011). Any river with a value of 1.2 or larger is considered meandering, and anything below 1.2 is considered straight (Leopold et al. 1964). Multiple channels divide and rejoin to make up the braided channel pattern. The meandering and braided patterns are modes of stream energy dissipation, and they are related to the channel gradient, valley width, streamflow regimes, and sediment load (Shelby et al. 1990), and the meandering geometry is often expressed as a function of bankfull width (Rosgen 1996).

Channel patterns that are naturally developed dissipate kinetic energy of moving water and the transportation of sediment. Straightened channels are often associated with a state of disequilibrium and instability compared to those that were more meandering. Natural streams are continually changing to maintain a dynamic and continuing balance between sediment loads and the energy available from streamflow to perform work. To help keep the state of equilibrium, the channel pattern exhibits adjustments in sinuosity so slope may be maintained in the stream system to neither degrade nor aggrade (Rosgen 1996). Thus, streams that are considered to have a more meandering pattern, or have a sinuosity 1.5 or greater, are considered to have more stability and are less likely to have excessive erosion loads from the streambanks and the channel.

Changes in channel patterns can dissipate the given energy in many different ways. Depending on the energy in the stream, meandering of the stream involves both the lateral and downstream migration of channel bends. Streams that are considered meandering have more bends. These bends are great energy dissipation features due to the secondary, or helical, flow that is created due to the forces in the meander bend (Shelby et al. 1990). Figure 2.8 shows an example of the helical flows in a meander bend.

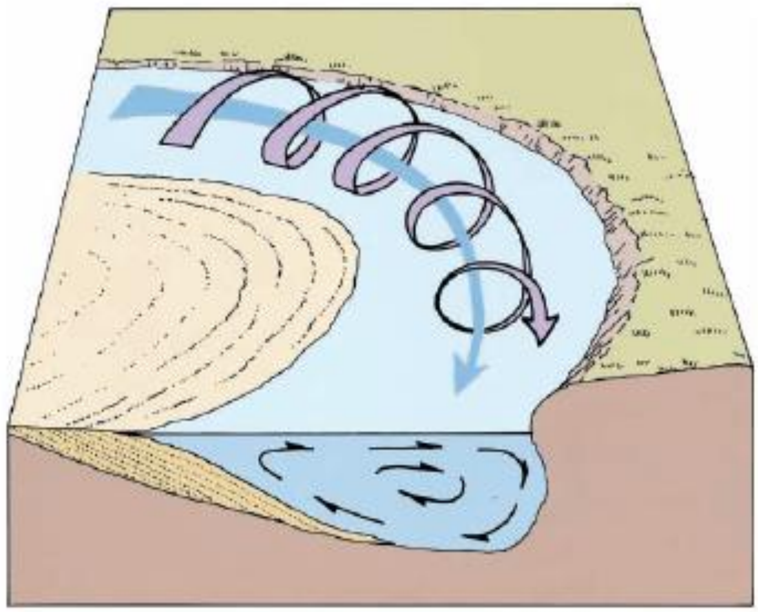

Figure 2.8 Helical flow in streams (Reproduced from Hamblin, W.K. and E.H. Christiansen. 2003. *Earth's dynamic systems*. 10th Edition. Upper Saddle River, NJ: Prentice Hall.)

As the water flows around the meander bend, the flow of the water takes a corkscrew shape. The helical shape is formed by the difference in velocities on each of the banks and the frictional drag on the channel banks and bed (Hamblin and Christiansen 2003). The helical flow patterns contribute to the scouring of cutbanks on the outside of the bend and the deposition of sediment on point bars that form on the inside of the bend. The developed point bars function as a floodplain and can be very effective at dissipating stream energy. Especially when the point bar starts to develop vegetative coverage, which slows and induces sedimentation during flood flows. In times of increased flows and/or increased sediment loads, a stream could decrease its sinuosity and become straighter, which would reduce the amount of energy expended in the meandering process (Shelby et al. 1990).

Ponds

There are many small ponds found in the Midwest due to the number of ranches and cattle operations in the area, as well as for recreational, aesthetic, and scenic qualities. These ponds are commonly manmade water bodies created when small earth dams are built on tributaries (USGS 2013a). Water is mostly stored upstream of the earth dam, but some water is allowed to flow downstream of the dam. Water usually flows by a primary spillway, or pipe, that runs through the dam. During intense storm events, when the discharge rates from the streams increase and the water level of the pond rises, the excess water may be released through the pond primary spillway to flow downstream. During flooding events, emergency spillways are built around the dam and are used to transport water to avoid dam failure (Poff and Hart 2002). These small ponds act as very efficient structures for dissipating energy coming from the upstream tributaries.

A dam's purpose is to hold back the movement of water for collection and storage, so as the water reaches the dam, it slows down and the kinetic energy in the water diminishes. It is during the slowing of water that sediment being carried begins to settle and can be deposited. It is also common for most dams to have a catchment area on the downstream side of the dam to help eliminate erosive forces coming from pipe discharge (Nissen-Peterson 2006). This area acts as a forebay and has two primary functions: 1) dissipate energy of the water flow from the dam and 2) allow settling of sediment and other influent debris. The runoff coming from the primary spillway culvert has enough energy to scour the bottom and sides of the forebay, so they are typically lined with large rocks to prevent any other soil erosion from occurring (Johnson 2006). The dam efficiently helps eliminate energy on both the upstream and downstream of the dam structure.

Chapter 3 - Methods and Materials

Site Selection

Two areas were used to address the research objectives, the lower portion of the Irish Creek watershed and a sub-watershed of the Irish Creek watershed that is referred to as the research area watershed. The areas that were used in this study were chosen for several reasons. Firstly, the location of the watershed is about 70 kilometers from Kansas State University. Being close to the university makes traveling convenient, and grab samples for large precipitation events could be captured. Secondly, the area has been a part of an ongoing study, and it has had several years of sediment and nutrient concentrations monitored. Lastly, the watershed experiences various land use practices. Having a variety of land uses subjects the land to different amount of sediment erosive forces, and may influence the amount of runoff and loading levels.

Study Area: Irish Creek Watershed

The focus of this research is on a small portion of the Irish Creek stream. Irish Creek is a tributary that flows into the larger Black Vermillion River located in northeast Kansas. The Black Vermillion River then flows into the Big Blue River which ultimately leads into Tuttle Creek Reservoir. The Black Vermillion River and Irish Creek stream make up the major streams of the Black Vermillion Watershed. The Black Vermillion watershed drains approximately 1062 square kilometers in Marshall, Nemaha, and Pottawattamie counties (Sass 2011). Research has shown that the Black Vermillion watershed has a landscape that has a relatively high potential for runoff and a higher risk for erosion (Juracek 1999). The area is primarily rural with a few small urban towns spotted throughout the watershed. The largest towns are Frankfort, which has a population of 726, and Centralia, which has a population of 512 (U.S. Census Bureau 2010).

The Black Vermillion watershed can be broken up into three sub-watersheds: Irish Creek, the Main Stem of the Black Vermillion, and the North Fork of the Black Vermillion. This study only focuses on the lower portion of the Irish Creek watershed and a very small portion of the Irish Creek sub-watershed. The Irish Creek sub-watershed is located in Marshall County and a minor portion of Pottawattamie County, and it has a drainage area of approximately 121.5 square kilometers and 27.4 kilometers of stream length.

The portion of the research that focuses on stream energy is limited to a sub-section of the sub-watershed (Irish Creek watershed) located in Marshall County, which has an approximate drainage area of 10.20 square kilometers. The 10.20 square kilometer drainage area is for the entire uncontrolled watershed, which means that the flood control features, like ponds, were included in the calculation for total drainage area.   The Black Vermillion watershed (red), Irish Creek watershed (green), and the research area (black) for the study are all located in Figures 3.1 and Figure 3.2. The maps also include the towns, the stream systems, and roadways located in the watersheds. The watersheds were mapped and drainage areas were all calculated using ArcGIS 10.1. The research area used in this study was also delineated by using a 2009 National Elevation Dataset digital elevation map and ArcGIS 10.1 (ESRI 2012).

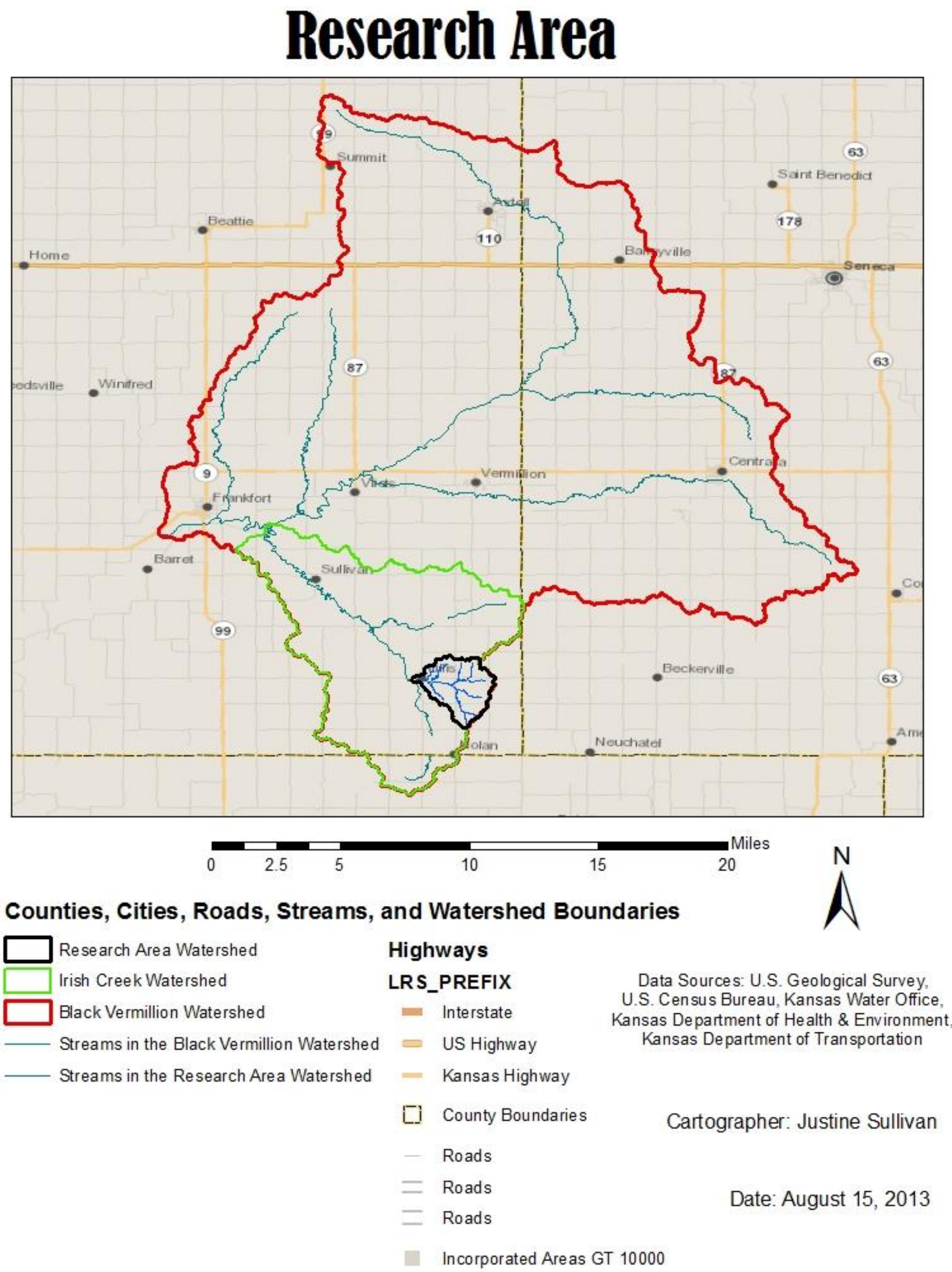

Figure 3.1 Map of the Black Vermillion watershed, Irish Creek watershed, and the Research Area watershed

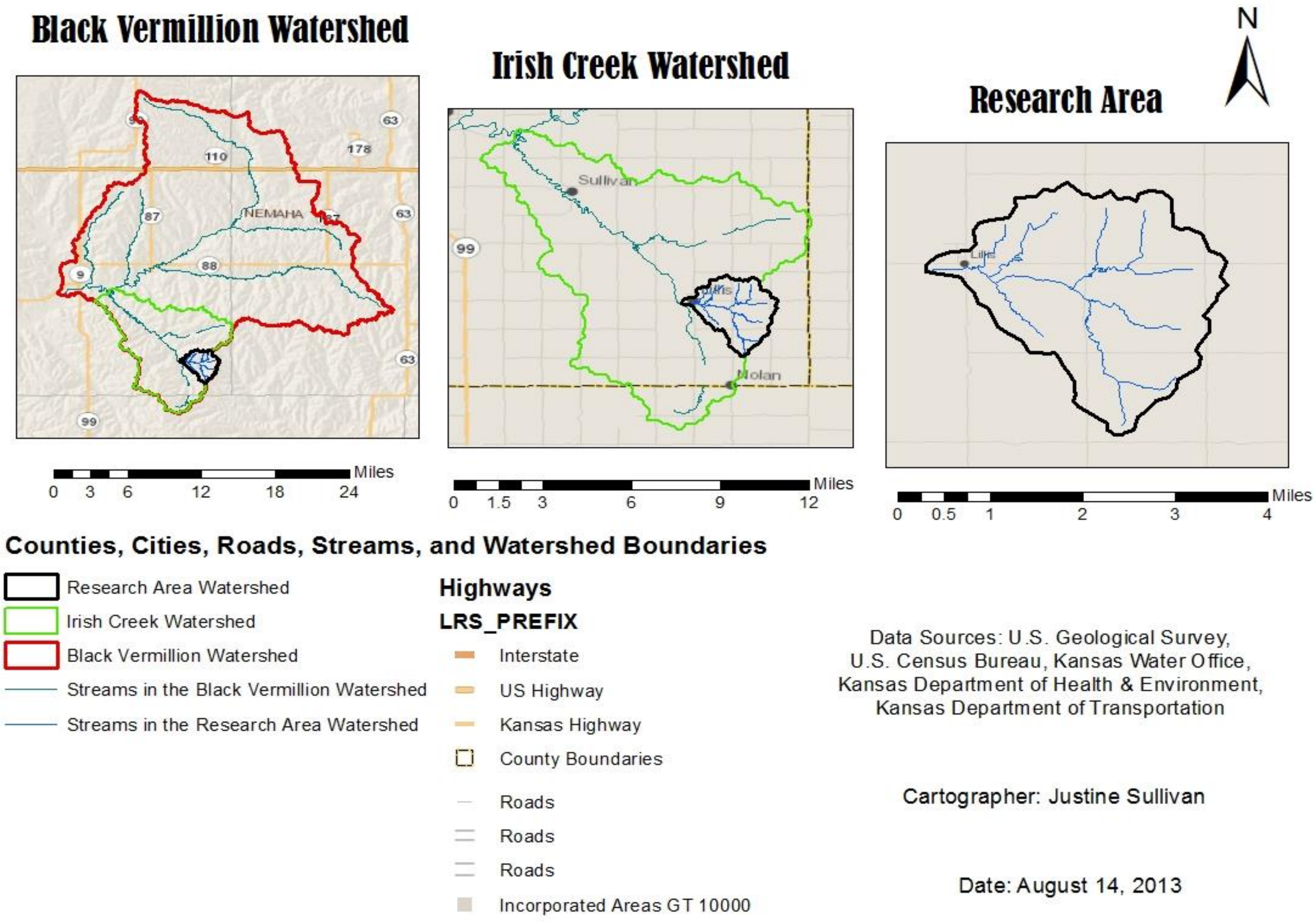

Figure 3.2 Map of the Black Vermillion watershed, Irish Creek watershed, and the Research Area watershed

Geology and Soils

The geology that occurs in the research area is due to the Kansan (Pleistocene) glacier that dates back between 1.2 and 0.6 million years ago (Merriam 2003). The ice sheet that covered parts of Kansas was in some places 153 meters thick (KGS 2005). The Kansan epoch of the huge glacier modified the terrain and left behind glacial till, outwash, reworked till, and windblown and lake sediments in its path (Merriam 2003). The materials that occur in the research area (Figure 3.3) are made up of mainly glacial alluvium and a small portion of the Council Grove group.

The Council Grove group is defined as a combination of beds between Foraker limestone and the base of the Wreford formation. The beds types include the Americus limestone, Elmdale shale, Neva limestone, Eskridge shale, Cottonwood limestone, and Garrison shale (KGS 2000). The limestone and shale groups are then covered by thick glacial alluvium, which is the sediment and rocks transported by glaciers. The alluvium is directly deposited on the land or indirectly in streams and lakes. The sediment consists of a mixture of clays, silts, sand, gravel, and boulders, ranging in size and shapes (KGS 2005).

The soils found on the upland areas of the watershed have been classified as Pawnee clay loams, Shelby clay loams, Steinauer-Shelby clay loams, and Wymore silty clay loams, which all are consistently dark topsoils with clay based subsoils. The soils found along the stream and floodplains have been identified as Muir silt loam, Kennebec silt loam, Wabash silt clay loam, and Olmitz loam. The alluvial soils are subjected to frequent or occasional flooding (USDA 1980). Information about the amount and percentage of each soil type, as well as the drainage class, the location, and other characteristics are found in Table 3.1.

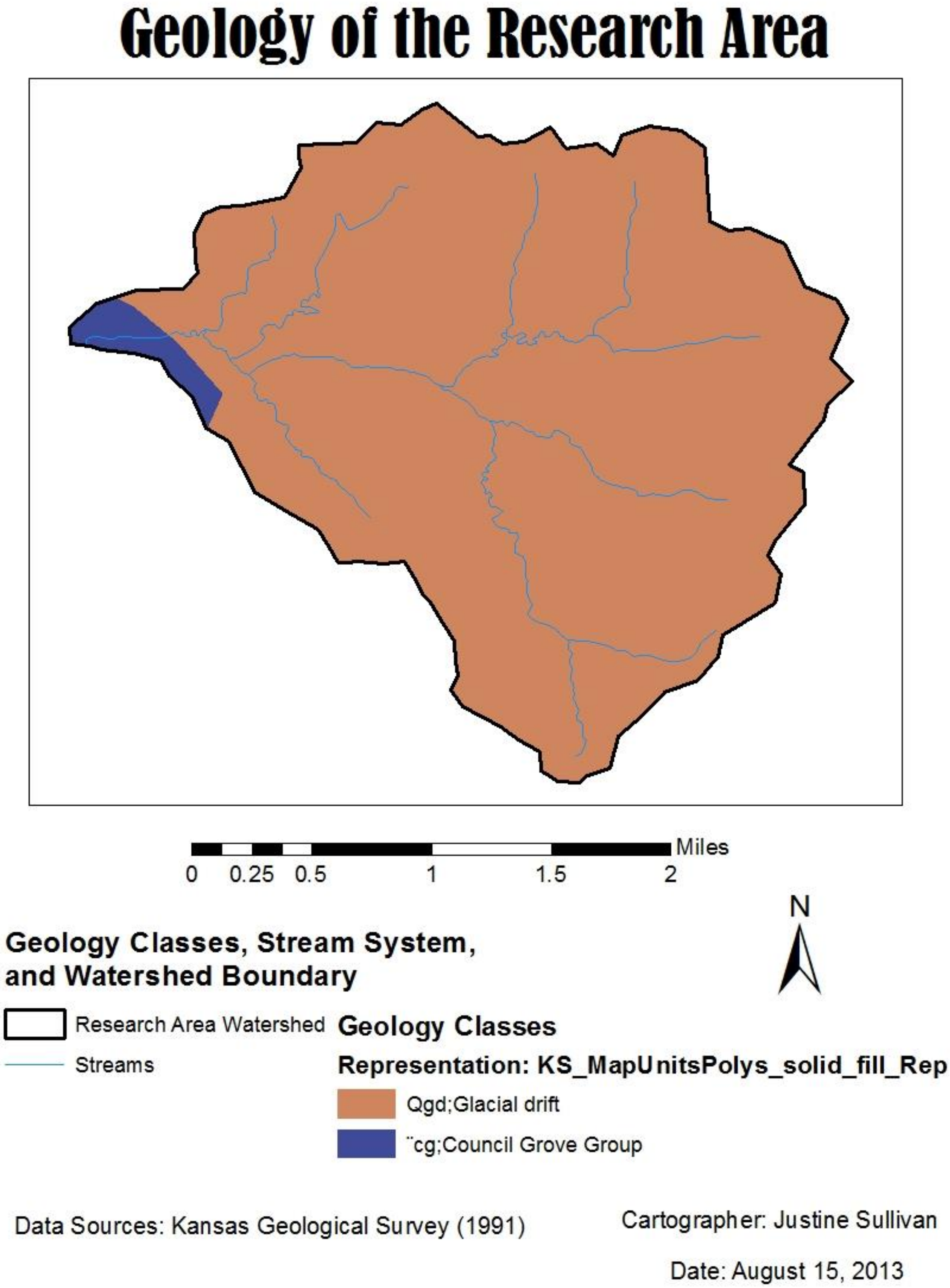

Figure 3.3 Geology map of the research area watershed

Table 3.1 Soil information for the research area (Reproduced from USDA. 1980. Soil survey of Marshall County, Kansas.; NRCS. 2013. Custom soil resource report for Marshall County, Kansas. Salina, KS: U.S. Department of Agriculture Natural Resources Conservation Service.)

Soil Series	Research Area (km^2)	Percent of Research Area	Drainage Class	Location/Characteristics
Muir silt loam	0.07	0.7 %	Well drained	Found on low terraces, permeability is slow, and surface runoff is low
Kennebec silt loam	1.09	10.7 %	Moderately well drained	Found on floodplains, permeability is moderate, and surface runoff is low
Wabash silty clay loam	0.02	0.2 %	Poorly drained	Found on floodplains, permeability and runoff are very slow
Olmitz loam, 1 to 5 percent slopes	0.01	0.1 %	Well drained	Found on foot slopes and alluvial fans, permeability is moderate, and surface runoff is medium
Pawnee clay loam, 1 to 3 percent slopes	3.04	29.8 %	Moderately well drained	Found on Uplands on ridgetops and side slopes, permeability is slow, and surface runoff is medium
Pawnee clay loam, 4 to 8 percent slopes, eroded	2.44	24.0 %	Moderately well drained	Found on Uplands on side slopes, permeability is slow, and surface runoff is medium
Shelby clay loam, 7 to 12 percent Slopes	1.69	16.7 %	Moderately well drained	Found on Uplands on side slopes and narrow ridgetops, permeability is slow, and surface runoff is rapid
Steinauer-Shelby clay loams, 10 to 14 percent slopes	0.03	0.2 %	Well drained	Found on Uplands on side slopes, permeability is moderately slow, and surface runoff is rapid
Wymore silty clay loam, 1 to 3 percent slopes	1.64	16.0 %	Moderately well drained	Found on Uplands on broad ridgetops, permeability is slow, and surface runoff is medium
Arents, earthen dam	0.03	0.3 %		
Water	0.14	1.3 %		
Totals for Research Area	10.20	100.0 %		

Topography

The research area is a mixture of tilled plains and a rock-controlled type of topography that is similar to that of the Flint Hills region. Between major drainage lines, the area is gently rolling and the local relief seldom exceeds 30 meters (KGS 2004). However, the relief around large streams can be more pronounced and the slopes can range anywhere from two to ten percent (Meade 2009). The a map of the elevations found in the research area watershed is found in Figure 3.4

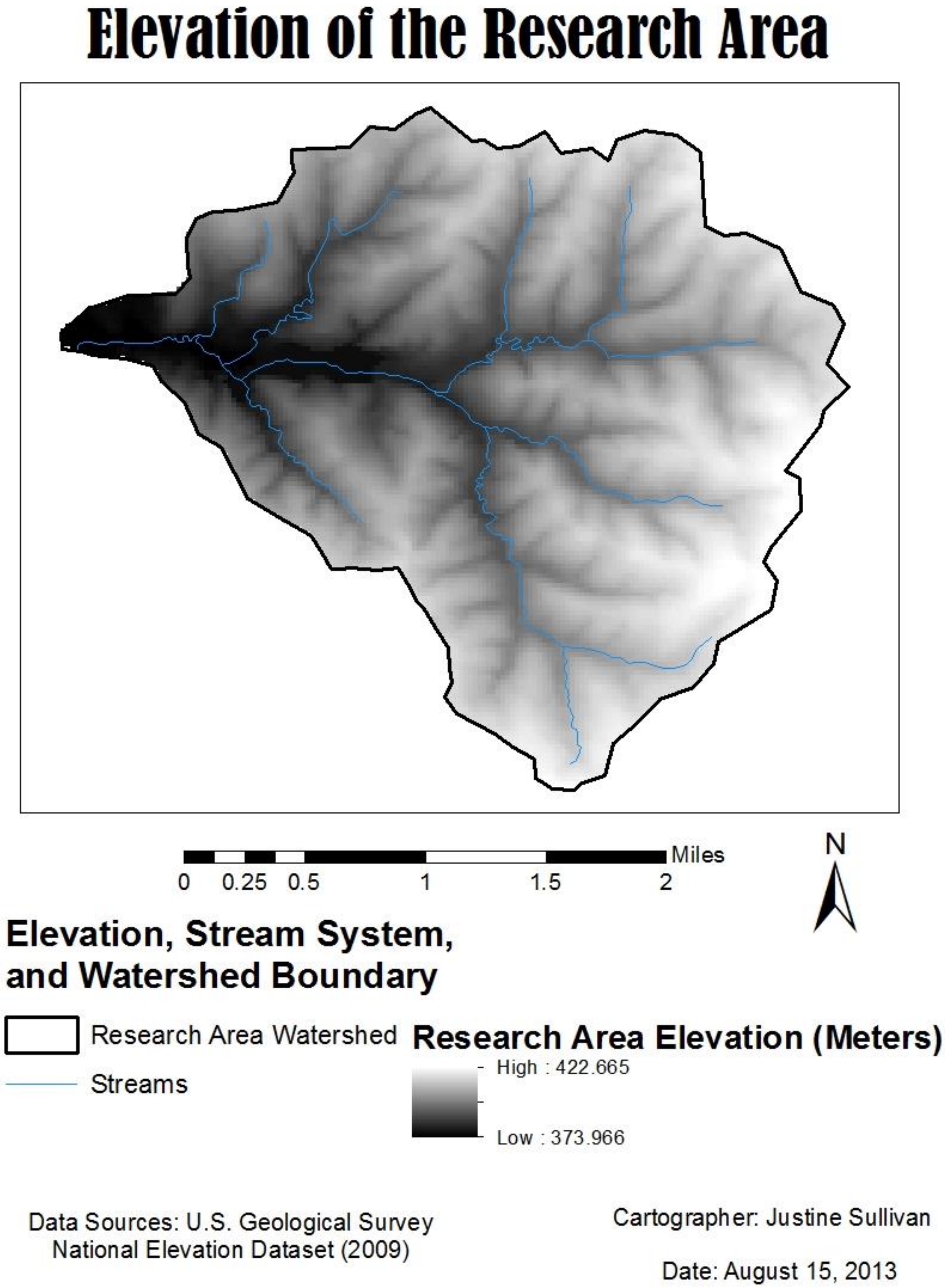

Figure 3.4 Elevation of the research area watershed

Elevations in the research area range from approximately 373 to 423 meters above sea level (Figure 3.4) throughout the watershed. The lowest elevations occur near the convergent point of the tributaries and the Irish Creek stream. The highest elevations are located in a hilly upland area near the southeast edge of the watershed (USGS 2009).

Land Uses

The majority of the land use for the research area is a mixture of agricultural fields and grasslands, due to this region's economy being mainly dependent on agriculture and ranching practices. In 2005, croplands covered approximately 44 percent of the research area. The second most common land use for the research area is grasslands, which cover approximately 33 percent of the watershed. Conservation Reservation Program (CRP) land, woodland, and water make up the remaining area of the watershed, covering approximately ten percent, 11 percent, and two percent of the total watershed area, respectively (Figure 3.5) (KARS and KBS 2005).

The land's topography plays an important role in what the land is used for. This is especially apparent in the research area. The hilly terrain that is present in the upland areas along with thinner soils and bedrock exposure limit the crop growth, so a major portion of the land is used for grazing and rangeland (Meade 2009). The land that is suitable for agriculture is usually planted with corn, grain sorghum, wheat, soybeans, and alfalfa (USDA 1980), with a majority of the agriculture planted being row crops, like corn and soybeans. A further breakup of the total cropland found in 2005 shows that 41 percent of the cropland was planted in non-irrigated corn, 37 percent was planted in non-irrigated soybeans, one percent planted in irrigated soybeans, and 21 percent planted in non-irrigated sorghum (Figure 3.6) (KARS and KBS 2005).

In the research area, grasslands are evenly distributed with cool and warm season grasses (Figure 3.6). Some of the area has the native tallgrass prairies vegetation that was present before

European cultivation began in the region (Meade 2009). The native vegetation includes big bluesteam (*Andropogon gerardli*), little bluestem (*Schizachyrium scoparium*), switchgrass (*Panicum virgatum*), and indiangrass (*Sorghastrum nutans*). While most of the area is tallgrass prairie, some of the heavy clays soils on the uplands support a natural mixed prairie plant community that is common to central Kansas (USDA 1980).

Woodland areas are present in the watershed, especially in areas around the stream (Figures 3.5 and 3.6). Although the woodlands only make up a small percent of the watershed, they play an important role in riparian buffering and channel stability. Hardwood species make up most of the species in the wooded areas. This includes black walnut (*Juglans nigra*), soft maple (*Acer saccharinum*), bur oak (*Quercus macrocarpa*), hackberry (*Celtis*), green ash (*Fraxinus pennsylvanica*), elm (*Ulmus*), cottonwood (*Populus aigeiros*), and sycamore (*Platanus occidentalis*). There are also plant species that grow in this research area that are considered large shrubs or small trees, such as osage orange (*Maclura pomifera*) and honeylocust (*Gleditsia triacanthos*) (Meade 2009).

Due to the combination of the geology, soil types, and field practices, soil erosion is a major problem on areas in Marshall County. It is especially worrisome where the slope is more than one percent, which is very common in the upland areas of the research area (USDA 1980). To help limit the amount of erosion that occurs, terraces and diversions are used to reduce the length of slopes. The terraces are extremely useful on deep, well drained soils with uniform, regular slopes, which fit most soils in the watershed. Terraces are commonly found throughout the research area watershed (Figure 3.7). Contour tillage, no till, and minimum till are also commonly used in this area to help increase infiltration and reduce runoff and erosion (USDA 1980).

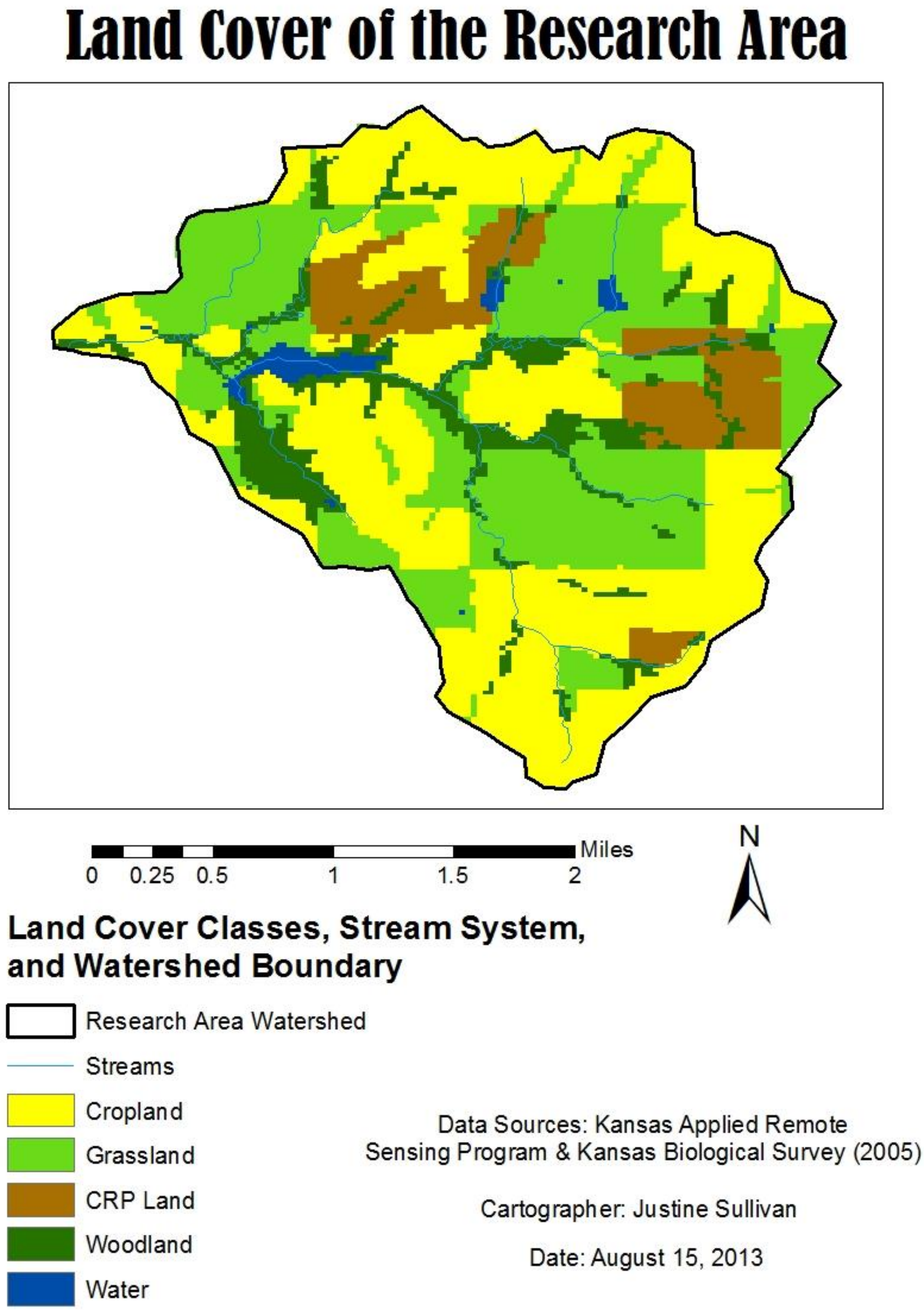

Figure 3.5 Land cover classifications of the research area

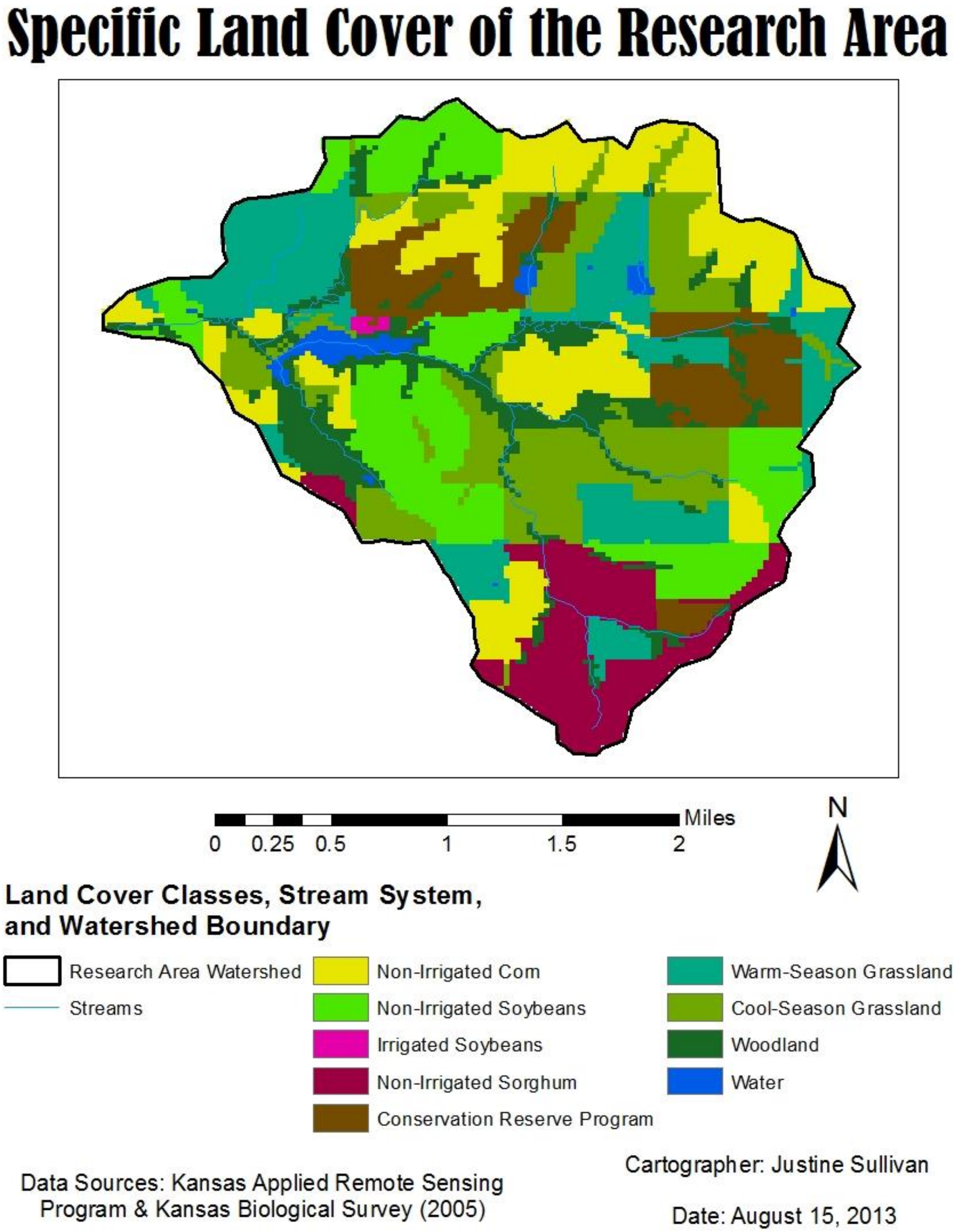

Figure 3.6 Specific land use classification for the research area

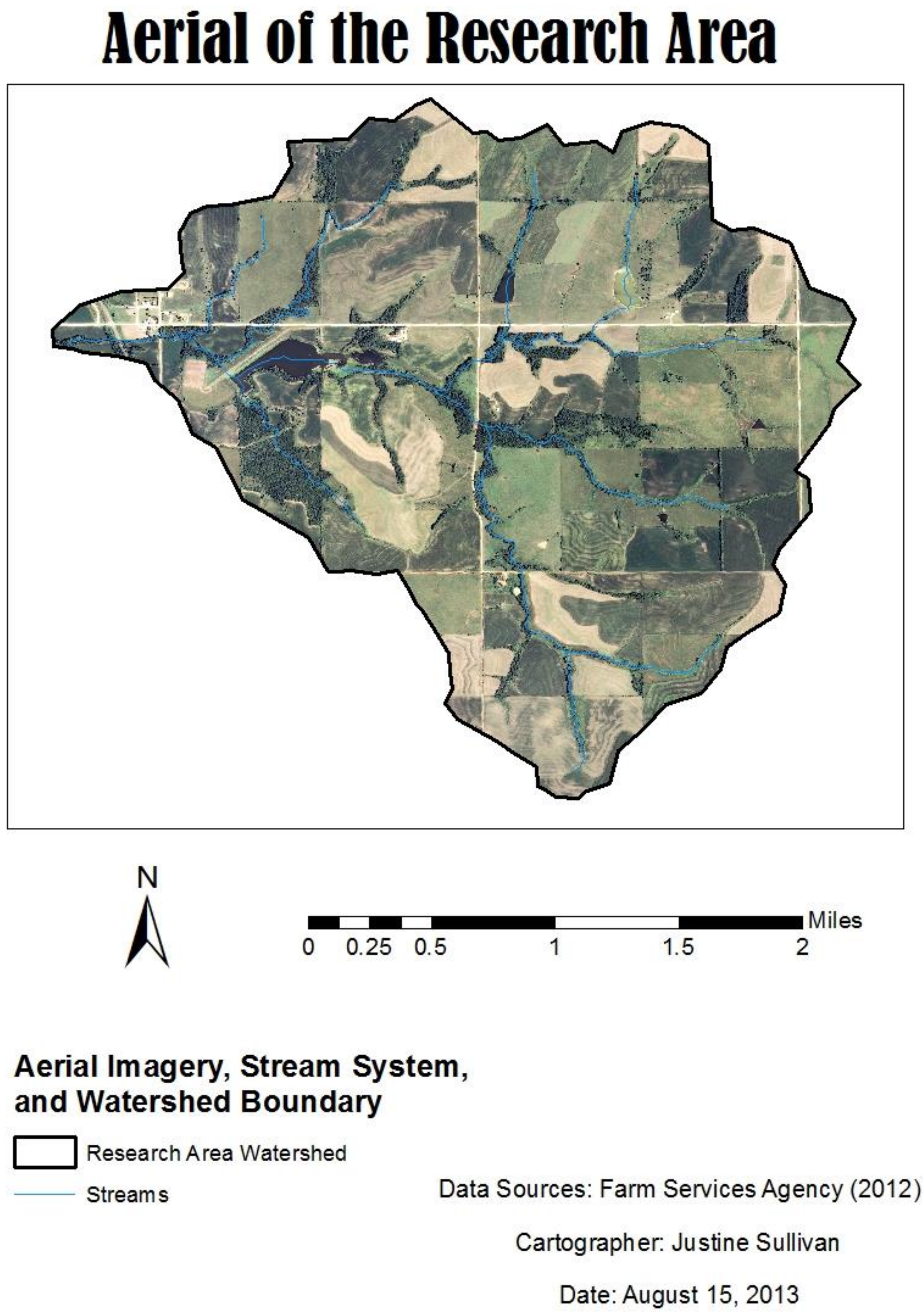

Figure 3.7 Aerial imagery of the research area

Climate

The research area is located on the Great Plains region of the United States, and has a typical continental climate expected in the interior of a large land mass. It has a typical Kansas temperature variation, both annually and daily, that can produce large changes in temperature. Winters are cold due to frequent cold fronts coming from Polar regions, and typically the conditions last from December to the end of February. The average temperature from December to February is -2.22ºC (28.0ºF), with the average daily minimum temperature occurring at -8.50ºC (16.7ºF). Warm temperatures occur in about six months of the year, with the transition seasons being moderately short. The six month period of warm temperatures, from April to September, provides the area with enough time for an appropriate growing season for crops. The average temperature occurring during the warm period is 24.56ºC (76.2ºF), and the average daily maximum temperature being 31.4ºC (88.5ºF) (USDA 1980).

Moisture-laden air from the Gulf of Mexico provides the area with the precipitation. Most of the precipitation is heaviest in late spring and early summer. The average annual precipitation for Lillis, KS (1967- 2010) is 86.28 cm (33.97 inches) (NCDC 2013), and around 75 percent of this usually falls between April and September (USDA 1980). This provides most of the crops a sustainable amount of water, accordingly there is little irrigation used in the area (USDA 1980). In 2005, only one percent of the total cropland was irrigated (Figure 3.6).

Some of the storms that occur between April and September may be very intense events, and the storm can deliver a large amount of precipitation to the watershed in a short amount of time. These events may create situations where there may be a high quantity of runoff, and thus a high potential risk for erosion. It is common to find large amount of sediment contributed to the fluvial system during these intense storm events.

Watershed Monitoring

To measure the channel's characteristics, elevations along the profile and multiple cross-sections were surveyed prior to this research. At this time nine study reaches, three per each sub-watershed, were chosen in the Black Vermillion watershed, and elevations were measured throughout these channels as well as cross-sections at specific sites on some of the reaches (Sass 2008; Sass 2011). One of these sites was selected to become part of an ongoing study to measure the amount of sediment and nutrients coming from the surrounding areas. The site is located in the middle of the Irish Creek watershed. To aid in this research a Teledyne ISCO automatic water sampler was installed at the site. The ISCO takes a depth reading every five minutes. The calibration on the ISCO, which is based on the cross-sectional area of the intersection, then uses the depth readings to estimate the flow rates. The flow rates are then totaled and averaged for a 24 hour period. A certain depth was also set on the ISCO, and when water levels meet or exceed this level, a sample was collected through a sampling tube located in the centroid of the stream. The ISCO allows for samples to be taken during the peak discharge events, or when grab samples could not be collected (Teledyne 2013).

ISCO samples are not taken during the winter months to protect the ISCO from being damaged. To get a more accurate idea of amount of total loads occurring in the lower portion of the Irish Creek watershed, estimates of the sediment and nutrient loads were calculated for the missed events. Percentages of the loadings for total suspended solids (TSS), total nitrogen (TN), and total phosphorus (TP) were taken to estimate the loads occurring during larger storm events, in which samples were not collected or if the event was missed. The percentages were calculated by taking the estimated load amount for TSS, TN, and TP, and dividing them by the maximum load event. The percentages were then plotted against the flow rates, excluding the events that were being estimated, and a linear trendline was best fitted to the data. The trendline provided an equation that could be used to estimate the percentage of the load event based on the flow rate. The load amount was then converted back by taking the estimated percentage multiplied by the maximum load event.

The bankfull discharges were estimated by using data and methods from Simon et. al. (2004). The methods included using the "Western Corn Belt Plains", which is similar to the Level III ecoregion of the Black Vermillion River. The data provided the estimated discharge amount (m^3/s) associated with the drainage area of the watershed (km^2). The drainage area for the area that drains to the location of the ISCO cross-section (lower portion of the Irish Creek watershed) is approximately 34 km^2. The bankfull discharge determined using Simon et al. (2004) was also compared to the bankfull discharge determined by Sass (2011). The bankfull discharge estimated by Sass was obtained by the analyses of gage data and checked with field observations of bankfull features. Sass's research was done on the same reach as the research for this study. The discharge was also compared to a flood frequency analysis performed at the USGS gage station (USGS 06885500) located near Frankfort, KS. The gage is located near the location where the Irish Creek Stream and the Black Vermillion River merge. The flood frequency analysis was done by taking annual peak discharges and ranking them from largest to smallest. The ranks are the numerical value ranging from one to the total amount of data points. The recurrence interval is then calculated by taking the total number of flow events plus one and then divided by the rank of individual flow. To develop the flood frequency analysis the recurrence interval is plotted against the corresponding flow amount (Rao and Hamed 2000). The corresponding flow (discharge) amount associated with the 1.5 year recurrence interval is the estimated bankfull discharge amount. The bankfull discharge that occurs near Frankfort was then multiplied by the factor 0.056, which is approximately the fraction of the drainage area that flows to the ISCO cross-section divided by the amount of drainage area of the Black Vermillion watershed that drains into the point near where the Black Vermillion River and Irish Creek stream converge.

Grab samples were collected at the cross-section where the ISCO is located. Water samples were collected around once a month during winter flows when flow is minimal and collected at least once a week, or directly following a storm event during warmer months (April to September). This was done manually by a water sampling device (Figure 3.8).

Figure 3.8 Water sampling device (Reproduced from Steele, K.L. 2008. Atrazine best management practices: Impact on water quality. MS thesis. Manhattan, KS: Kansas State University, Department of Biological and Agricultural Engineering.)

The device is lowered into the centroid of the stream, and water is pulled into the bottle within the sampler. This provides a sample that represents the entire water column. The water samples were collected in clear bottles. All bottles were washed with soapy water, rinsed with methanol, and baked at 100º C for approximately 24 hours. The samples were placed on ice until brought back to the lab, where they were stored at 4ºC to preserve any nutrient or chemical in the sample. Samples were then tested for sediment, total nitrogen, and total phosphorus.

Water Quality Analysis

The analysis for sediment was performed by the Water Quality Laboratory in the Biological and Agricultural Department at Kansas State University. The analysis for total phosphorus (Total P) and total nitrogen (Total N) was performed by the Soil Testing Laboratory in the Department of Agronomy at Kansas State University.

The amount of sediment in a sample was determined by measuring the total suspended solids (TSS). This analysis was performed by taking 25 mL of the sample and running it through a 47mm glass fiber filter setup (Steele 2008). The setup is shown in Figure 3.9. ProWeigh preweighed filters for gravimetric analysis were used for the measurement of TSS. The saturated filters were then dried for 12 hours at 70ºC. After this time, a final weight of both the filter and canister together, as well as the weight of the canister alone were measured. The initial weight of the filter was provided by the manufacturer. These weights were then used to calculate the TSS in the sample.

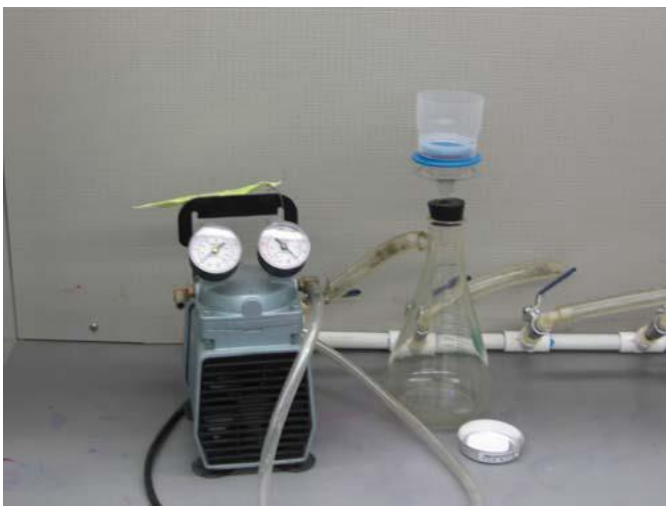

Figure 3.9 Vacuum filtration system used to analyze TSS (Reproduced from Steele, K.L. 2008. Atrazine best management practices: Impact on water quality. MS thesis. Manhattan, KS: Kansas State University, Department of Biological and Agricultural Engineering.)

A water sample was taken to the Soil Testing Laboratory, and Total N and Total P were analyzed for the sample. The nutrient levels were determined by using a Potassium Persulfate digestion. Technicon Analyzer II was used to analyze the sample for phosphorus. An Alpken RFA analyzed the sample for nitrate nitrogen (KSU 2005; Hosomi and Sudo 1986).

Stream Energy Analysis

Elevations and GPS locations were measured in equal intervals along the thalweg of the main stream and side tributaries throughout this watershed by using a Leica Rugby 100 laser level and leveling rods with sensors attached to the top of the rod. Measurements were taken to the hundredth of a foot. The accuracy for measurements by the laser level is ± 1.5 mm at 30 meters (Leica 2013). Points were measured from the starting point, where the cross-section for the ISCO sampler is located, to the edge of sediment basin (area where the primary spillway releases water from the big pond). A cross-section was also measured on the stream where the ISCO sampler was set up. The cross-section was measured by using a the same laser level and leveling rods that were used to measure the elevations for the profile of the reach, as well as cam-line measuring tape. The cross-sectional analysis allowed for elevations to be measured from bank to bank to obtain a detailed image of the stream cross-section. The cross-section survey was performed in 2007. Due to the cross-section occurring at a riffle and at a bridge location, the cross-section is at a stable location and should not have significant profile or dimensional changes (Rosgen 1996). Thus, the cross-section was not re-surveyed during this research.

Other elevations and GPS locations were taken for the upstream tributaries by using a national elevation dataset (NED) digital elevation map (USDA 2009) in ArcGIS 10.1(ESRI 2012) and Google Earth (Google 2013). Elevations taken using the NED and Google Earth are not as precise of elevation measurements. The resolutions for both the NED and Google Earth images are around 10-15 meters. However, only a general idea of the energy gradients being created in the upland regions were being analyzed, so precise measurements were not as important, as elevations taken to determine bankfull discharge and the power created. All GPS positions and elevations were then put into Surfer, which is a contour and 3D surface mapping program (Golden Software 2013). This program creates maps in which the elevation change occurring in the stream and tributaries could be expressed, as well as showing the high elevations compared to the depression areas (low points) that occur in the streams. Surfer can also be used to create contour maps to determine the flow directions (Golden Software 2013).

Ponds act as extremely efficient energy dissipation features, and they are scattered throughout the research watershed. The ponds locations can be seen in the land cover figures in Chapter 3 (Figures 3.5 and 3.6). There are four small ponds located in the watershed, which accounts for much of the energy dissipation occurring in the research area watershed. Elevations and GPS positions were taken along the pond's water edges as well as for points in the tributaries that flow into the ponds. The elevations and GPS positions were measured using a national elevation dataset digital elevation map (USDA 2009) in ArcGIS 10.1 (ESRI 2012) and Google Earth (Google 2013).

Multiple gully side conveyances were also noticed during the elevation profile survey of the main stream. These conveyances can contribute a large amount of sediment to the river system. To estimate the amount of sediment that is contributed to the system from these side conveyances the bank heights, widths, and GPS positions were measured. The widths were measured from bank to bank and the depth was measured at the thalweg of the channel.

Measurements were taken at three points along the gully. All measurements were taken by using measuring tape and leveling rods.

To calculate the amount of sediment coming from one of these gully side conveyances a linear interpolation was done between measured points, so every meter interval had an associated width and height. The cross-sectional area was calculated for each of the intervals. The average area between two points was then multiplied by a meter to determine the volume of the section. Each section was then multiplied by a bulk density. The bulk density for this area was calculated by taking the weighted average bulk densities for the different types of soils located in the research area watershed. The calculated bulk density for the research area watershed was 1587.95 kg/m^3. Each volume section was then summed together to get a total soil loss from the gully side conveyance.

Chapter 4 - Results and Discussion

Bankfull Discharge and Sediment Loading

Objectives

As stated in Chapter 1, bankfull discharge creates the conditions in which the optimum amount of work is performed on the stream channel and may cause excessive erosion to occur. Thus, it is important to know how often and when these conditions occur. To determine the bankfull conditions and the amount of sediment transported, the pattern, profile, and other characteristics (i.e. locations of abandoned floodplains, changes in bank slope, and changes in vegetation) of the stream have to be measured. The primary objectives of this research were to measure bankfull discharge for the Irish Creek watershed and examine how often bankfull conditions occurred. The secondary objective was to measure the sediment loading that occurred in the watershed.

Bankfull Discharge Results

The bankfull discharge associated with the drainage area of the lower portion of Irish Creek watershed (drainage area of approximately 34 km^2) from the Simon et al. data is approximately 6.5 m^3/s (229.55 ft^3/s). The estimated bankfull discharge was then compared to the bankfull discharge from Sass's (2011) data, which is approximately 6.51 m^3/s (230.00 ft^3/s). The flood frequency analysis showed that the discharge that occurs at the 1.5 recurrence interval, or the bankfull discharge, is approximately 7.95 m^3/s (280.75 ft^3/s). The flood frequency analysis for Irish Creek near Frankfort, KS is located below in Figure 4.1.

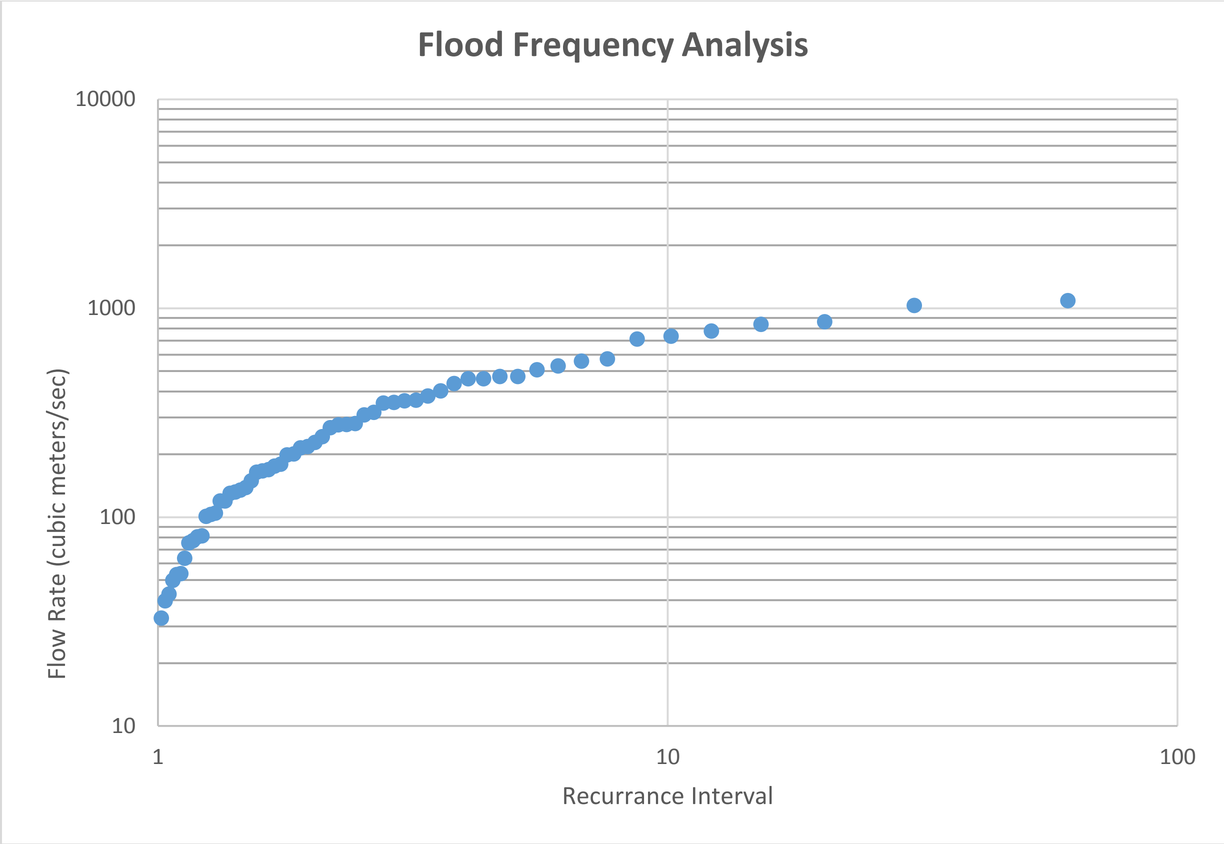

Figure 4.1 Flood frequency analysis for Irish Creek near Frankfort, KS

The 1.5 year recurrence interval that is associated with bankfull discharge for the entire Black Vermillion watershed is 142.0 m^3/s (5015 ft^3/s). The estimated bankfull discharge that occurs at the ISCO cross-section was calculated by multiplying the bankfull discharge for the entire Black Vermillion watershed by the fraction of the Irish Creek watershed that is draining at the ISCO cross-section, which is approximately 0.056. Using the flood frequency analysis for the entire Irish Creek watershed method provides a rough estimate of bankfull discharge. The estimated bankfull discharge occurring at the ISCO cross-section is approximately 7.95 m^3/s (280.75 ft^3/s). Certain features in the watershed, like ponds, will have an impact on the estimated discharge. Because of these features, the rough estimate from the flood frequency analysis is estimated to be too high. The Simon et al. (2004) was also very similar to the discharge found by Sass (2011). So the Simon et al. (2004) method for determining bankfull discharge was determined to give the best estimation of the amount of bankfull discharge. The bankfull cross-section at the area where the ISCO was implemented is shown in Figure 4.2.

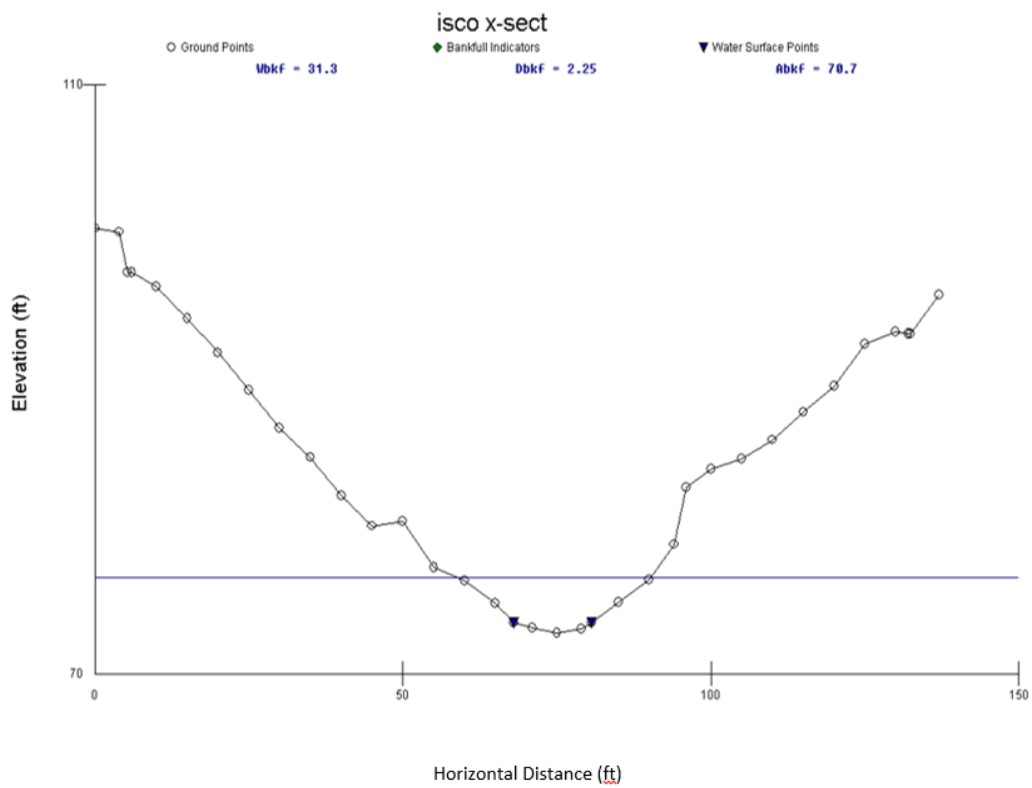

Figure 4.2 ISCO cross-section

The bankfull width is 9.5 meters (31.3 ft), the mean bankfull depth is 0.69 meters (2.25 ft), and the cross-sectional area is 6.57 m^2 (70.7 ft^2). To determine if the bankfull discharge is reasonable, the estimated discharge was divided by the cross-sectional area to obtain the velocities ($V = Q/A = (6.5\ m^3/s)/(6.57m^2)$). The velocity calculated is 0.99 m/s (3.25 ft/s). The bankfull velocity for medium to large streams is typically between 1.22 m/s to 1.52 m/s (4-5 ft/s) (Rosgen 1996). Due to the pond features in the watershed, the velocities could be estimated to be lower than 1.22m/s, which indicates that the set bankfull discharge for the study was fairly accurate.

It is at the 6.5 m^3/s discharge where the stream is doing optimum work for "maintenance and formation" (Rosgen 1996) and a considerable amount sediment loading and/or size would be transported somewhere downstream. The calculated stream power quantity associated with the bankfull discharge at the ISCO cross-section is approximately 26.85 kg/m/sec. This was calculated by taking the bankfull discharge ($6.5m^3/s$) multiplied by the slope of the reach (0.0040 m/m) multiplied by the specific weight of water (9810 N/m^3), then divided by the bankfull width (9.5m) (Equation 1-6: $\omega(\text{power})_{bkf} = (6.5\ m^3/s \times 0.0040\ m/m \times 9810\ N/m^3)/9.5\ m$). The amount of power and energy created by the bankfull discharge and velocity could cause a significant amount of sediment erosion and transport to occur.

Bankfull conditions were met multiple times during the study period. A particularly wet year occurred in 2007, which had the most precipitation accumulation the area had seen in the previous ten years (KSU 2013). The flow was graphed against the day of the year; this is shown in Figure 4.3. The flow data graphs for the rest of the study period are found in Appendix A.

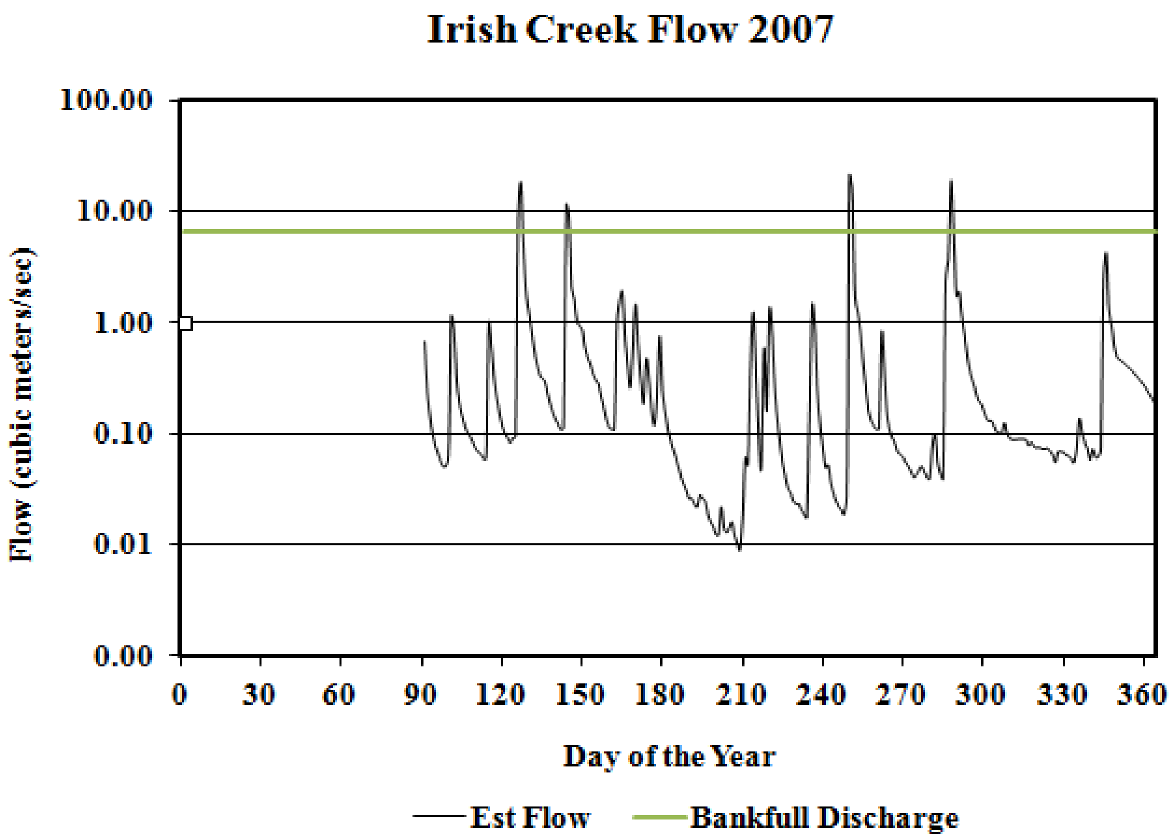

Figure 4.3 2007 Irish Creek flow data

The bankfull conditions were met during four events from the starting date (April 1, 2007) of the study period to the end of the year (December 31, 2007), with the discharge equaling or exceeding the bankfull conditions a total of seven days during these events. The highest discharge rate reached 20.65 m^3/s on September 7. Table 4.1 includes the number of events that reached bankfull conditions, how many days met or exceeded the estimated bankfull discharge amount, and the highest discharge rate met during the year.

Table 4.1 Irish Creek bankfull events

Irish Creek	Bankfull Discharge (m^3/s)	Events	Days Bankfull Conditions Were Met	Highest Flow (m^3/s)
2007	6.5	4	7	20.65
2008	6.5	2	2	6.614
2009	6.5	2	2	10.55
2010	6.5	2	3	10.18
2011	6.5	1	1	7.57
2012	6.5	0	0	4.68

Sediment Analysis Results

The sediment concentrations and loadings were calculated for samples for the entire study period, 2007-2012. The concentrations measured the amount of sediment per unit of volume for every sample that was taken over the entire research period. The sediment loading for each sample was calculated by taking the flow rate (m^3/s) multiplied by the concentration for the sample (g/m^3) and then converted to total sediment loading for that day (kg/day) by a unit conversion factor of 86.4. Estimated loads were calculated for events in which a sample was not collected or if it missed the event. The graphs used to estimate the percentage of the missing loads so more accurate total loads could be calculated are located in Appendix A.

To obtain the total loading for the year, the concentration of TSS for individual water samples collected in that year had to be measured. The daily concentrations for 2007 are shown in Figure 4.4. The graph shows that when a high flow rate is present the amount of TSS concentration for the samples also increases. The rest of the study period's sediment concentration figures are found in Appendix A.

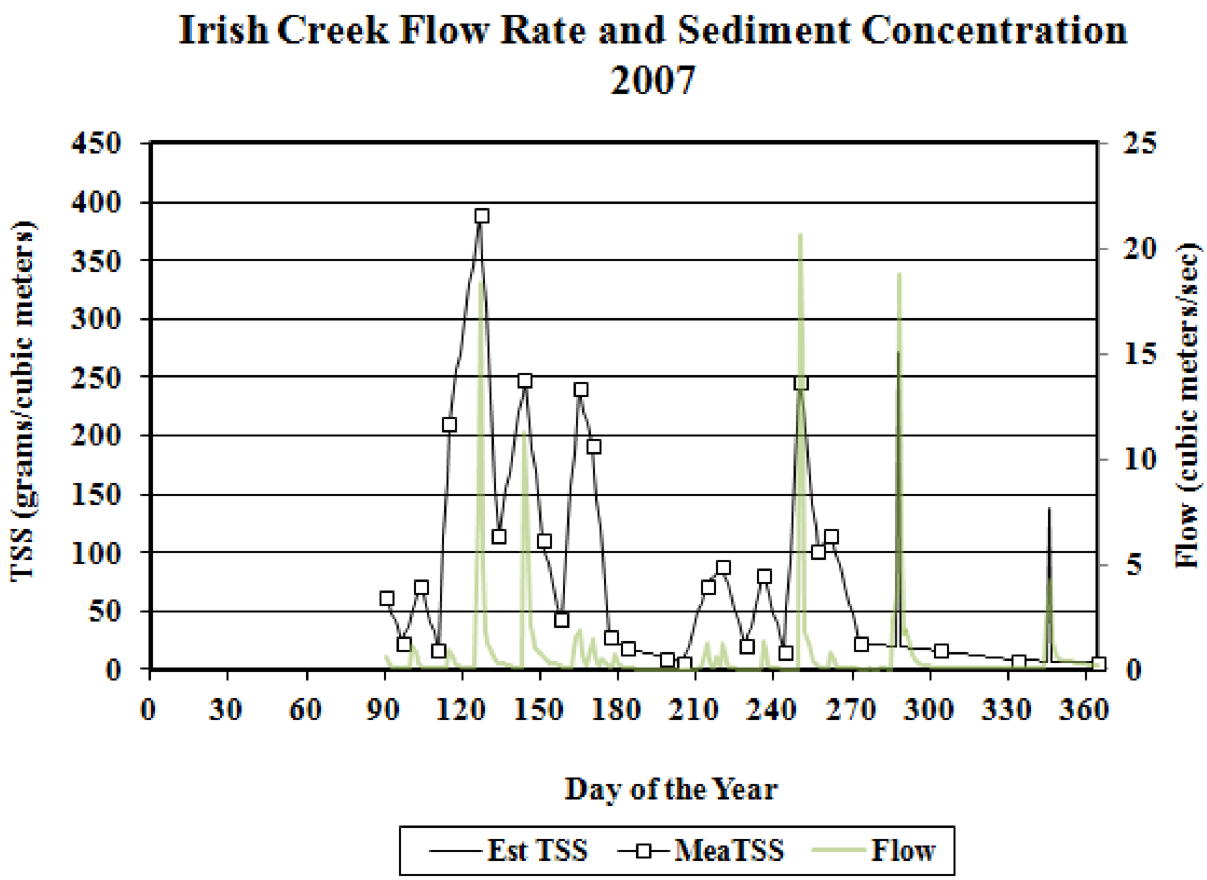

Figure 4.4 Flow rates and sedimentation concentrations for 2007

The sediment loading graph for 2007 is shown in Figure 4.5. The total sediment loading for 2007 was calculated to be 3,396,722 kilograms, with the greatest loading event occurring on May 7th at a flow rate 18.34 m^3/s. This one event added 616,453 kilograms (18.15% of total 2007 load) of sediment to the river system. The event occurred during the time period where the region gets the greatest amount of precipitation, and areas usually have lower vegetative coverage.

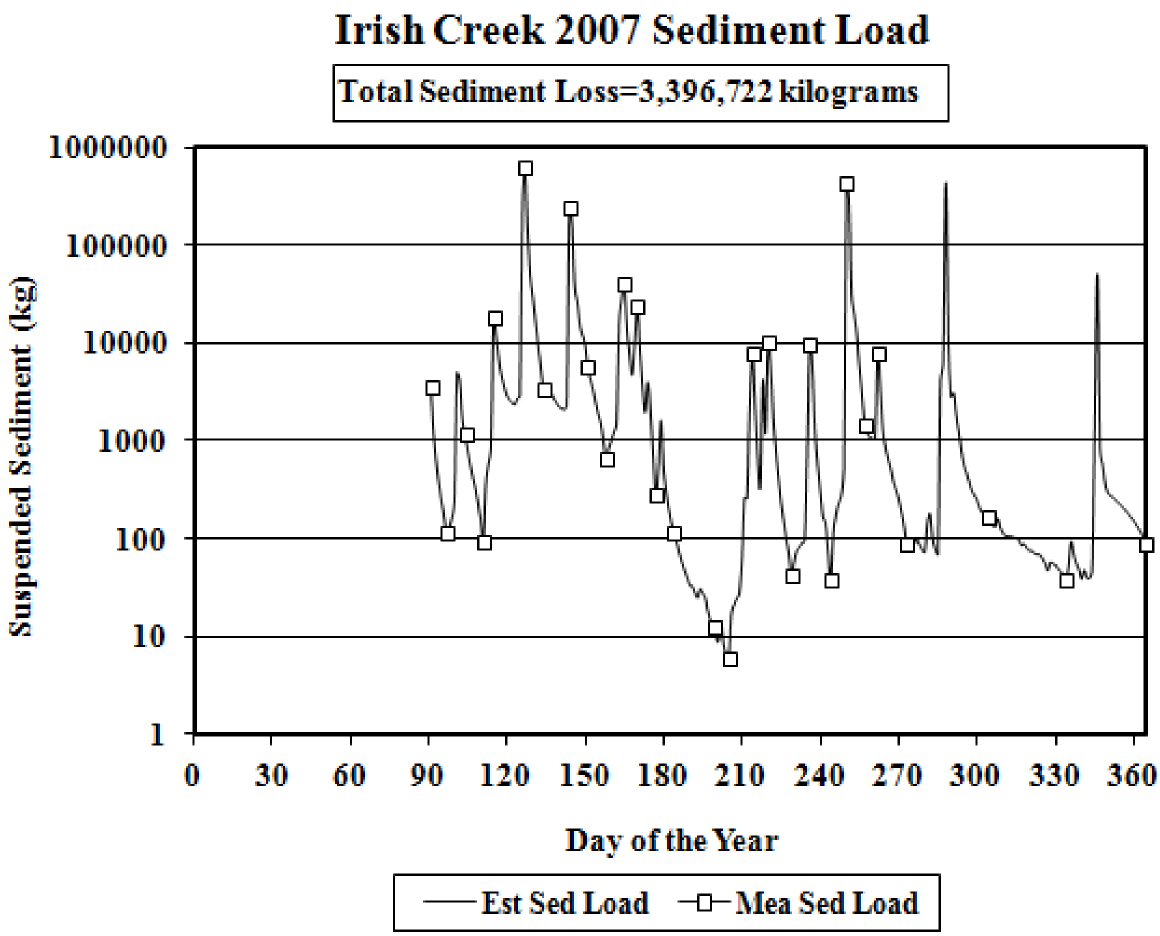

Figure 4.5 Sediment loading for 2007

The rest of the study period's sediment loading figures are found in Appendix A. Table 3.3 lists the sediment loadings for the entire study period. It also lists the event date and amount when the greatest sediment load occurred. Most of the large sediment loading events occurred in the spring, and they are usually accompanied by a large flow event. This shows that increasing flows usually results in an increase in the transport of the amount of sediment size and/or load.

Table 4.2 Total sediment loads and greatest loading events (2007-2012)

Year	Total Sediment Load (kg)	Greatest Sediment Load (kg)	Date of Greatest Sediment Load	Flow Rate at Greatest Sediment Load Event (m^3/s)
2007	3,396,722	616, 453 (18.15%)	May 7, 2007	18.34
2008	507,030	53, 273 (10.50%)	June 6, 2008	6.51
2009	1,379,212	197, 315 (14.31%)	April 27, 2009	10.55
2010	3,863,684	15,180 (27.87%)	June 21, 2010	10.18
2011	1,016,295	422, 830 (41.60%)	June 2, 2011	7.57
2012	135,340	25,478 (18.82%)	April 15, 2012	3.13

A total of 10,298,283 kilograms of sediment has been added to the river system in the last six years. This is a significant amount of sediment has been added to Tuttle Creek Reservoir by the Irish Creek Watershed alone. However, this is only a very small portion of the total watershed that could lead into Tuttle Creek, and it is expected that there is a considerable amount of sediment being eroded, transported, and deposited in the other areas of the Big Blue Basin watershed.

Much of the Irish Creek watershed has structures and BMPs that limit the amount of sediment erosion and transport. Because of these structures and practices, a significant portion of the sediment is coming from the streambank and channel. To determine how much sediment is coming from overland flows, the amount of croplands, grasslands, CRP land, and woodlands for the area that drains to the ISCO cross-section (lower portion of Irish Creek) were found and multiplied by erosion rates. There is 10.12 km^2 (2,500 acres) of croplands, 17.35 km^2 (4,287 acres) of grasslands, 2.19 km^2 (541 acres) of CRP, and 3.96 km^2 (978 acres) of woodlands. The erosion rates for pastures, which are in good condition and have BMPs, is approximately 0.5

tons/acre/year. The erosion rate for croplands, which have BMPs and increased coverage, is approximately 1.5 tons/acre/year. The amount of the total soil loss coming from the area was calculated by taking the approximate erosion rates by the areas (i.e. Cropland erosion = 2,500 acres × 1.5 tons/acre/yr = 3,750 tons/yr of sediment is coming from croplands). The pasture erosion rate was used for the grasslands, CRP, and woodland areas. The calculations resulted in an rough estimate of 3,402,342 kg/yr (3,750 tons/yr) coming from the croplands, 1,944,360 kg/yr (2,143 tons/yr) is coming from grasslands, 245,285 kg/yr (270 tons/yr) is coming from the CRP areas, and 887,299 kg/year (489 tons/yr) is coming from the woodlands. Total erosion from the uplands for the area is 6,035,636 kg/yr. Approximately 75% of the entire area is controlled by ponds, so most of the sediment would be trapped in these features. Due to the ponds, the estimated sediment coming from overland flow is 1,508,909 kg/yr (0.15 × 6,035,636 kg/yr). For the entire study period, a total of 8,676,227 kg (1,508,909 kg/yr × 5.75 years) of sediment was coming from the overland flow, which is 84% of the total sediment load for the study period. So roughly 16% of the sediment is coming from streambank and channel erosion.

Nutrient Analysis Results

As stated earlier, nutrients are often linked with sediment erosion. This is due to nutrients attaching to clay and humus particle's surfaces (Brady and Weil 2009; Hillel 2003). While most of the research for this study focuses on sediment loading and erosion, the amount of nutrients in the water is also very important. It is especially important because a disruption in the nutrient balances can cause eutrophication of lakes and in some cause are the source of certain toxic cyanobacteria.

The nutrient concentrations and loading for both Total Nitrogen (TN) and Total Phosphorus (TP) were also calculated for samples taken during the study period, 2007-2012.

The concentrations measured the amount of nutrient per unit of volume for every sample tested. The nutrient loading for each sample was calculated by taking the flow rate (m^3/s) multiplied by the concentration for the sample (g/m^3) and then converted to total nutrient loading for that day (kg/day) by a unit conversion factor of 86.4. The estimated amounts of nutrients that occurred during events that were either missed or samples were not collected were also measured. The graphs used to calculate the percentage of the missing event, which were then used to obtain an accurate estimate of the total annual loads, are located in Appendix A. To obtain the total loading for the year, a sum of the total daily TN and TP loading was calculated. The daily concentrations for 2007 are shown in Figures 4.6 and 4.7. The rest of the study period's nutrient concentration figures are found in Appendix A.

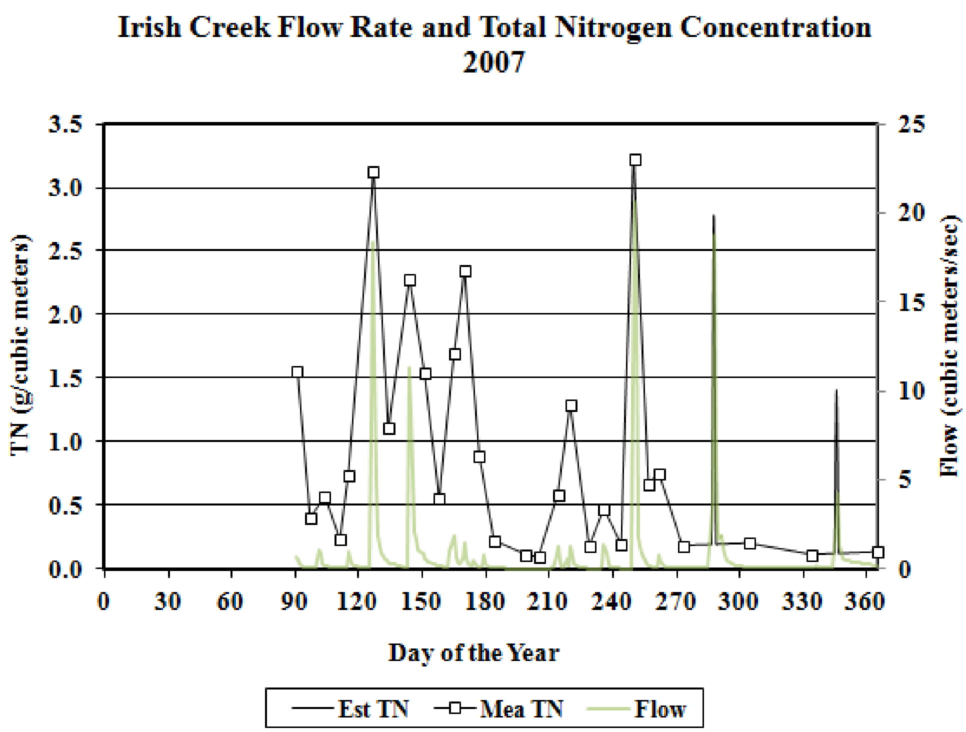

Figure 4.6 Flow rates and Total Nitrogen concentrations for 2007

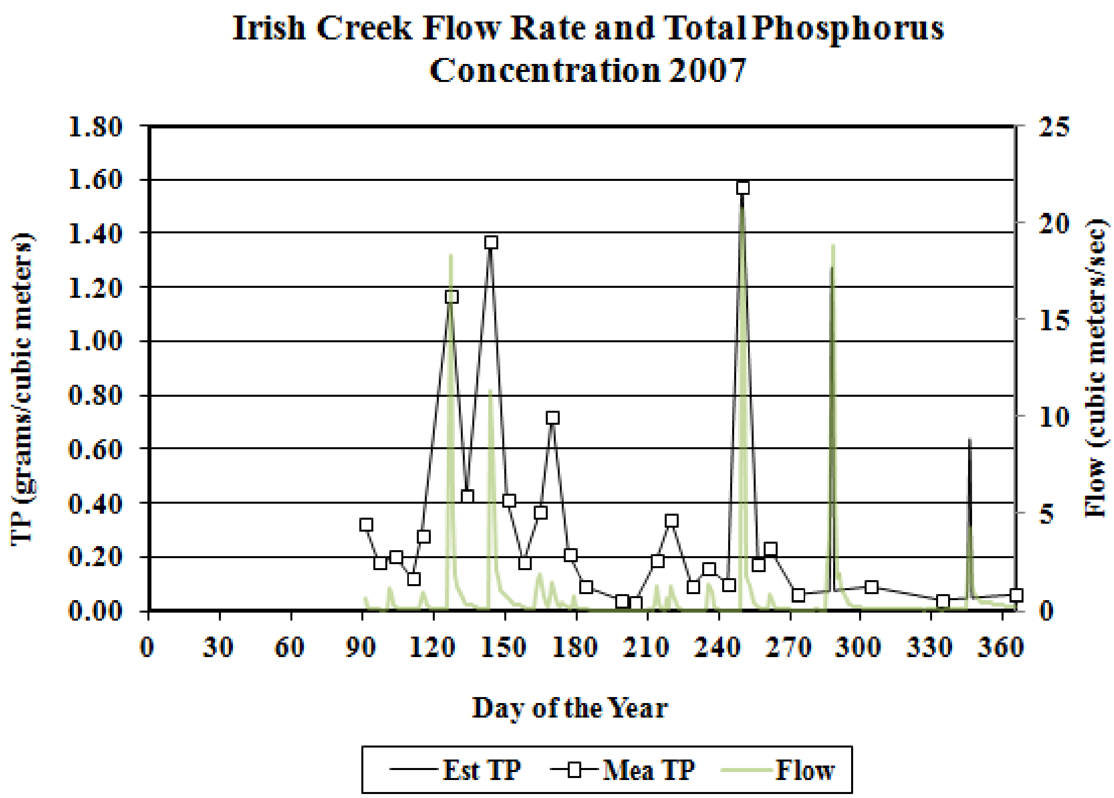

Figure 4.7 Flow rates and Total Phosphorus concentrations for 2007

The nutrient loading graphs for 2007 are shown in Figures 4.8 and 4.9. The TN loading for 2007 was calculated to be 33,608 kilograms, and the total TP loading for 2007 was 14,809 kilograms. The greatest loading events occurred on the same day, September 7th, at a flow rate of 20.65 m^3/s. This event added 5,746 kilograms of nitrogen (17.10% of the total 2007 TN load) and 2,801 kilograms of phosphorus (18.91% of the total 2007 TP load) to the river system.

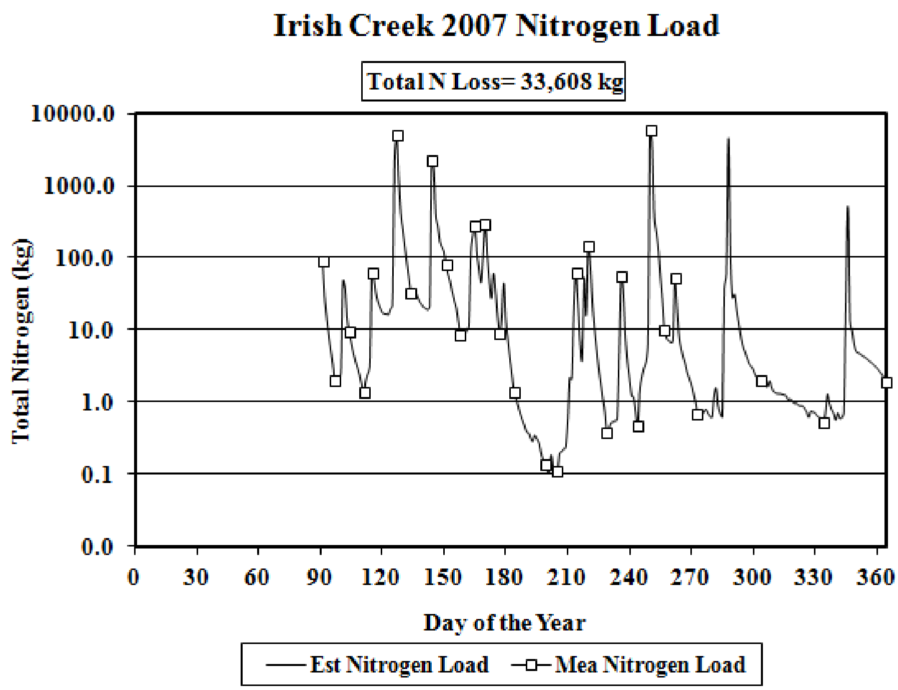

Figure 4.8 Total Nitrogen loading for 2007

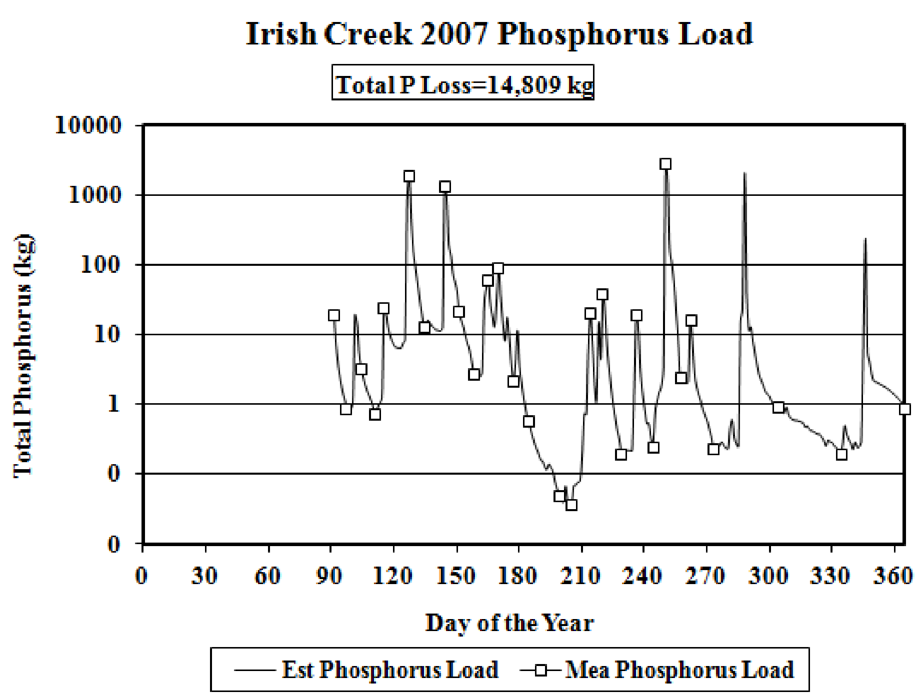

Figure 4.9 Total Phosphorus loading for 2007

The rest of the study period's nutrient loading figures are found in Appendix A. Table 4.3 lists the total TN loadings for the entire study period and Table 4.4 lists the total TP loadings for the entire study period. Tables 4.3 and 4.4. also list the event date and amount when the greatest nutrient loss occurred.

Table 4.3 Total Nitrogen load and greatest loading events (2007-2012)

Year	Total Nitrogen Load (kg)	Greatest Nitrogen Load (kg)	Date of Greatest Nitrogen Load	Flow Rate at Greatest Nitrogen Load Event (m^3/s)
2007	33,608	5,746 (17.10%)	September 7, 2007	20.65
2008	10,188	1,374 (13.49%)	June 6, 2008	6.51
2009	12,927	1,516 (11.73%)	April 27, 2009	10.55
2010	14,326	32 (15.85%)	June 21, 2010	10.18
2011	6,084	1990 (32.71%)	June 2, 2011	7.57
2012	1,080	161 (14.91%)	June 21, 2010	4.68

Table 4.4 Total Phosphorus loads and greatest loading events (2007-2012)

Year	Total Phosphorus Load (kg)	Greatest Phosphorus Load (kg)	Date of Greatest Phosphorus Load	Flow Rate at Greatest Phosphorus Load Event (m^3/s)
2007	14,809	2,801 (18.91%)	September 7, 2007	20.65
2008	2,078	209 (10.06%)	September 13, 2009	5.23
2009	1,989	202 (10.16%)	April 27, 2009	10.55
2010	1,940	4 (15.88%)	June 21, 2010	10.18
2011	1,264	398 (31.49%)	June 2, 2011	7.57
2012	545	78 (14.31%)	April 15, 2012	3.13

A total of 78,213 kilograms of total nitrogen and 22,625 kilograms of total phosphorus were transported by the river system in the last six years. Overall, it was also confirmed that nutrients are directly linked to sediment. The relationship is shown by looking at the dates when the greatest loading events occurred. For the most part, the greatest sediment load occurred on the same date/event as when the greatest nutrient load occurred. The events can also contribute a significant amount of nutrients to the system at once. For example in 2011, when the greatest nutrient loading and sediment load occurred, approximately 32.71% of the total TN load, 31.49% of the total TP load, and 41.60% of the total sediment load for the entire year occurred in that single event. The amount of nutrient and sediment loads that occur in a single event shows that much of the erosion and transport is episodic, and a great amount of nutrients and sediment could be contributed and transported to the system in a single event.

Bankfull Discharge and Sediment Loading Summary

The research proves that a considerable amount of sediment can be moved during events that are at bankfull or higher. The bankfull discharge was estimated to occur at 6.5 m^3/s, and the stream power created at this stage is approximately 26.85 kg/m/sec. Bankfull conditions were also met at least once a year, except in 2012, which was considered to be experiencing drought conditions. The total amount of sediment that was added to the system for the entire study period was 10,298,283 kilograms. The total amount of nutrient loading that occurred during the study period was 78,213 kilograms of total nitrogen and 22,625 kilograms of total phosphorus. That amount of sediment and nutrients could cause considerable problems downstream.

Energy in the Irish Creek Tributaries

Objectives

Stream energy is a major component in determining the amount of erosion and transport of sediment that is occurring in a stream. The energy exists in potential, kinetic, and thermal forms in streams. The potential energy is stored energy and is determined by gravity. This means that upstream reaches have higher potential energy than downstream. As water starts to move downstream the potential energy is converted to kinetic energy. Work is done in the stream by the formed kinetic energy. The stream first has to overcome the viscous shear, turbulent, and friction forces before changes in the streams start to occur, like channel or streambank erosion. The remaining work in the stream is responsible for sediment transportation. The energy not converted to the kinetic form is converted to thermal energy (Sass 2011). This energy is lost to the atmosphere by the heat produced to overcome the friction factor (Knighton 1998). The kinetic energy can be dissipated in many different ways, such as adjusting the cross-sectional form, bed configuration, channel pattern, and bed slope (Molnár and Ramírez 1998). This study focuses on events when the kinetic energy is high enough (bankfull conditions) that it overcomes the internal and friction forces and sediment is being carried by the stream.

Ponds built by earth dams are also common in the study watershed. Most ponds in the watershed act as water sources for cattle operations, but they also act as energy dissipation features. The ponds function is similar to the functions of floodplains or a pool. As water enters the pond, it begins to spread out over the area and starts to slow, losing the kinetic energy. The slowing velocities also allow for deposition of sediment that is being transported. A study has shown pools can dissipate approximately two thirds of the total energy (Wilcox et al. 2011). Ponds act a little differently than pools, because in most cases water is being held back and stored. The storage allows for the kinetic energy to be converted back into potential energy until the water level becomes high enough that water can be released through the outlet or around the emergency spillway. In most cases the kinetic energy, or erosive forces produced by the stream power in the pond is zero.

The watershed is subjected to many different land uses, which results in the land to respond to precipitation events differently. Some areas could be highly vegetated with grasses, and the interception and infiltration on the land is high. Other areas might be overgrazed or over tilled, and this results in more runoff and erosion to occur. Gully formation starts to occur when runoff and overland flow accumulates and narrow channels start to form due to soil removal. The path usually leads to a watercourse at a lower energy level. Soil removal usually starts when a nick point forms. The nick point formation usually starts at a location where there is a significant change in grade along the flow path (i.e. when overland flow enters a stream). The nick point then forms into a head-cut, and it will continue to migrate and erode forming a gully. As intense storm events occur, the gully will expand in both length and width (Catchments and Creeks 2010). Figure 4.10 demonstrates head-cuts and formation of gullies. The water erodes the soil to try to obtain a similar energy as the stream. "The drainage networks naturally evolve into structures that are most efficient in draining the watershed" (Molnár and Ramírez 1998).

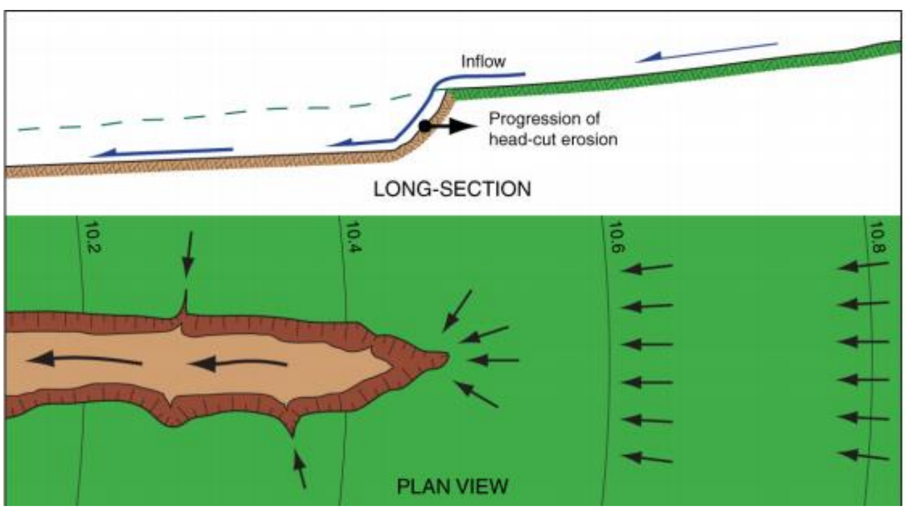

Figure 4.10 Initial stages of gully erosion showing the migration of the head-cut
(Reproduced from Catchments and Creeks. 2010. Gully Erosion Fact Sheet. Ferny Hills, Australia: Catchments & Creeks Pty Ltd.)

The objectives for this study are to examine the energy gradient occurring in the research area watershed, and to look at a few features in which energy is dissipated in the stream. The study also examines the effects that excess runoff has on the water system. These objectives will help examine the effects energy has on the stream and surrounding areas.

Stream Energy Results

Significant elevation changes occur throughout the entire research area watershed. The elevation and GPS points that were measured were put into Surfer 10 (Golden Software 2013). This program is a full-function 3D visualization, contouring, and surface modeling package. Figure 4.11 displays the contour map of the research area created by the Surfer 10 program. The map shows the different latitudes and longitudes with the corresponding elevations, as well as connecting lines will the same elevation. The highest elevation occurs in the southeast portion of the watershed at 420.32 meters. The lowest elevation point occurs near the ISCO cross section at 370.35 meters. The contour map also shows the general movement of water is in the northwest direction.

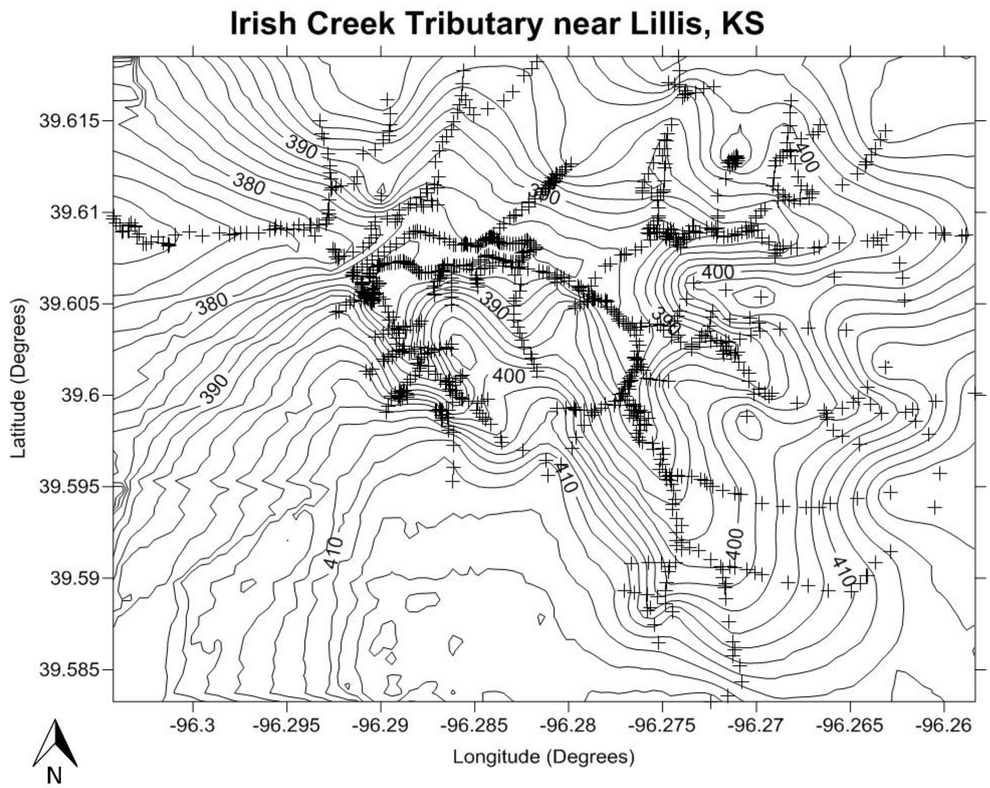

Figure 4.11 Contour map of the research area

The wireframe and 3-D surface imagery created by the Surfer 10 program shows a better representation of the elevation change occurring in the watershed. The wireframe figure is shown in Figure 4.12. Two 3-D surface images are found in Figures 4.13 and 4.14. The wireframe figure shows how most of the small tributaries in the watershed drain into the big pond, where there is a depression area in the middle of the higher upland elevations . The 3-D images give a good understanding the energy gradients. The white areas are correlated with high elevations, and the green color represents lower elevations. Looking at these two figures (4.13 and 4.14) it is evident that there are steeper gradients occurring in the upland portions of the research area watershed to the big pond area. The elevation change from the big pond to the ISCO sampler cross section creates a gentler slope. So based purely on gradient steepness, the upland areas would create more energy and power compared to the slope from the big pond to the ISCO.

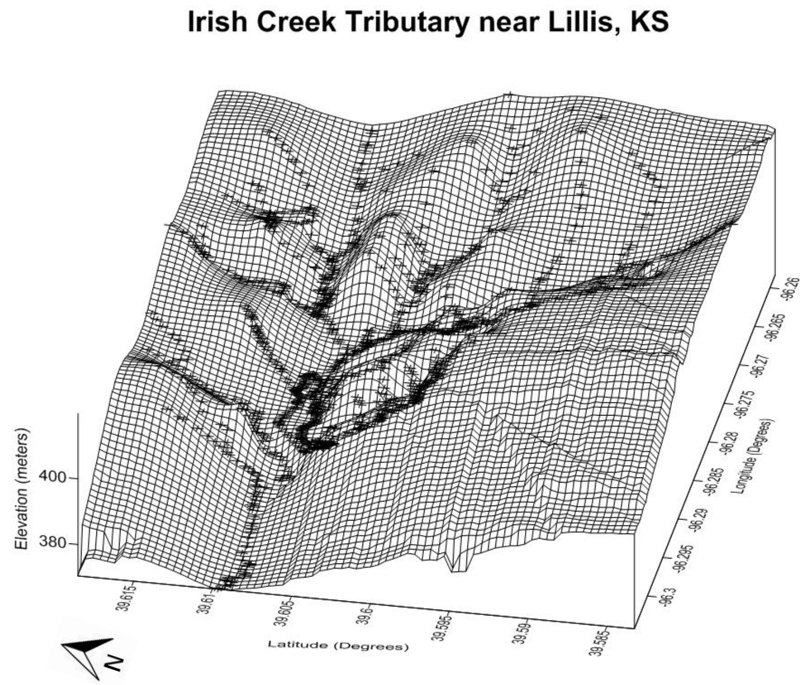

Figure 4.12 Wireframe mapping of the research area

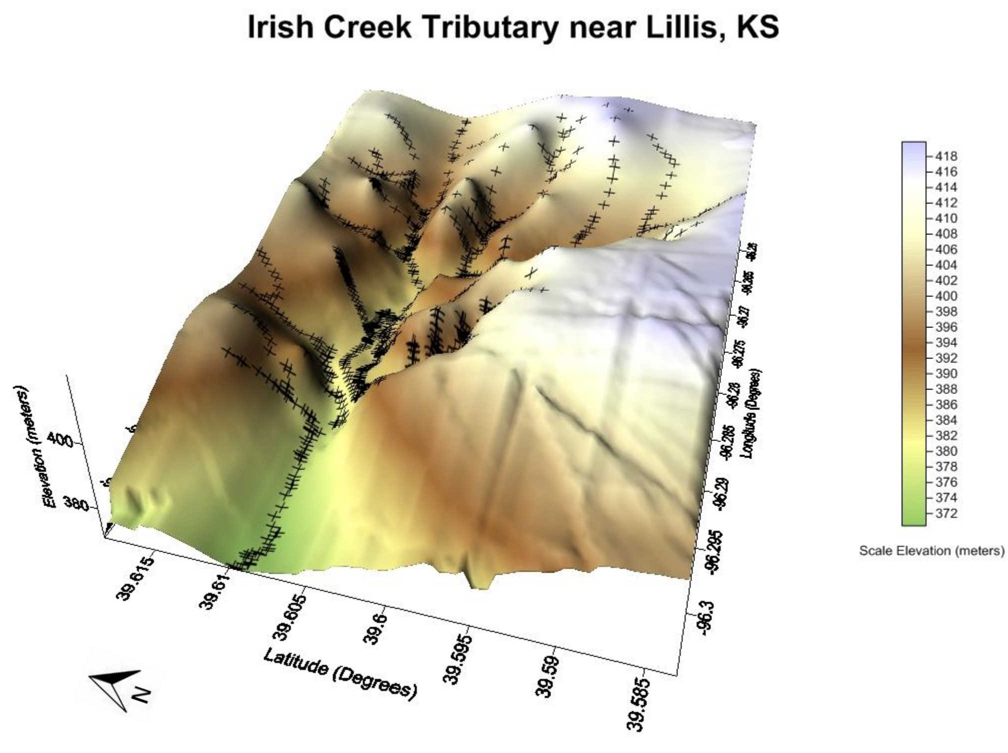

Figure 4.13 3-D imagery of the elevation change occurring in the research area watershed View 1

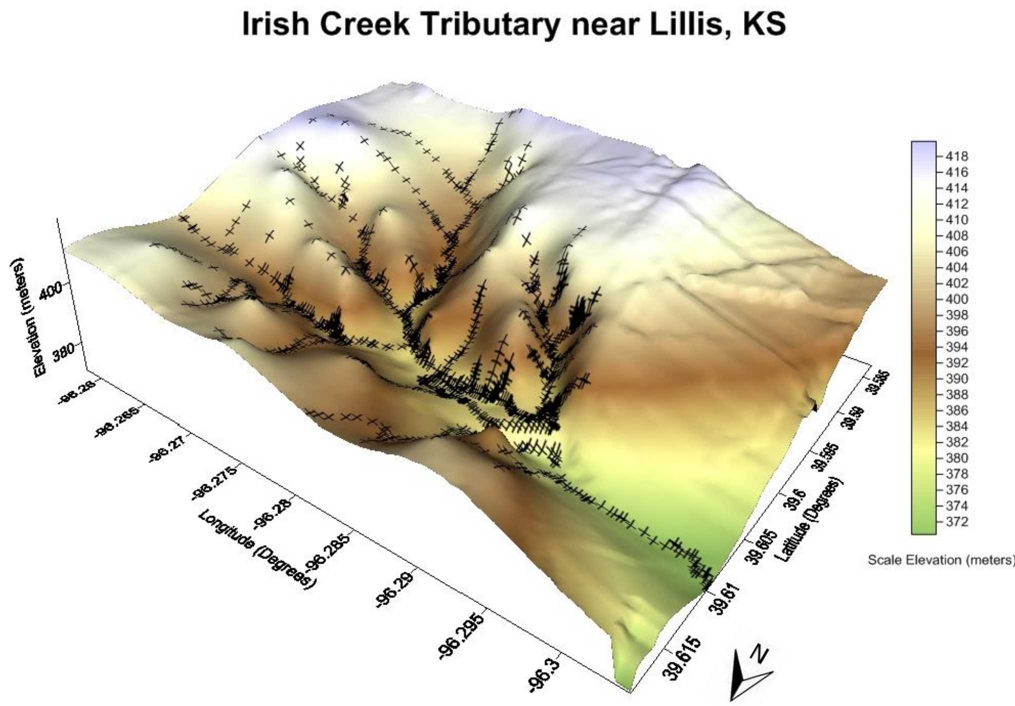

Figure 4.14 3-D imagery of the elevation change occurring in the research area watershed View 2

Each tributary has a unique energy gradient. To determine the slopes, the change in elevation between two points was divided by the distance between the points. The slope for a few of the tributaries were calculated and listed in Table 4.5. The first slope represents the energy gradient from the small sediment basin next to big pond to the ISCO sampler's location. This energy gradient shows the slope from the data collected during the field measurements using the laser level and rods. A profile figure is found in Appendix A. The second and third slopes are energy gradients that do not encounter any ponds. The next three slopes show the energy gradients from the three pond's outlets, found in the north section of the watershed, to the big pond. The seventh slope measures the change in elevation divided by the distance from highest elevation in the watershed to the big pond. The final slopes measure the energy gradients from points above the three ponds to the inlet to the ponds.

Table 4.5 Energy gradients for different reaches in the research area watershed

Reaches	Starting Point Location	Ending Point Location	Change in Elevation	Distance Between Points	Slope (m/m)
Sediment Basin to ISCO	N39°36.446' W96°17.535'	N39°36.589' W96°18.252'	6.91 meters	1,728.76 meters	0.004
Tributary Pt. to ISCO	N39°37.095' W96°16.902'	N39°36.589' W96°18.252'	26.73 meters	3, 862.09 meters	0.007
Tributary Pt. to ISCO	N39°36.969' W96°17.378'	N39°36.589' W96°18.252'	33.00 meters	2, 369.01 meters	0.014
East Pond Outlet to Big Pond	N39°36.639' W96°16.124'	N39°36.454' W96°17.065'	20.77 meters	1, 989.14 meters	0.010
Middle Pond Outlet to Big Pond	N39°36.754' W96°16.279'	N39°36.454' W96°17.065'	24.03 meters	1, 991.06 meters	0.012
West Pond Outlet to Big Pond	N39°36.642' W96°16.516'	N39°36.454' W96°17.065'	13.91 meters	1, 257.37 meters	0.011
Tributary Pt. to Big Pond	N39°35.679' W96°15.771'	N39°36.454' W96°17.073'	39.62 meters	3,071.12 meters	0.012
Tributary Pt. to East Pond Inlet	N39°37.229' W96°16.218'	N39°36.844' W96°16.483'	8.31 meters	848.17 meters	0.010
Tributary Pt. to Middle Pond Inlet	N39°36.812' W96°16.266'	N39°36.781' W96°16.264'	6.51 meters	57.99 meters	0.112
Tributary Pt. to West Pond Inlet	N39°36.965' W96°16.090'	N39°36.802' W96°16.099'	6.39 meters	319.04 meters	0.020
Tributary Pt. to West Pond Inlet	N39°36.869' W96°15.789'	N39°36.657' W96°16.027'	12.93 meters	554. 40 meters	0.023

Stream energy is often expressed as stream power or shear stress. The stream power is calculated by taking the specific weight of water multiplied by the discharge and the slope. Shear stress is “fluid forces per unit area, tractive forces, acting on the streambed” (Rosgen 2009). The shear stress is calculated by taking the specific weight multiplied by the hydraulic radius and slope ($\tau = \gamma R S$) (Rosgen 2009). The shear stress can then be converted to the stream power by multiplying the shear stress by the mean velocity ($\omega = \tau u$) (Rosgen 2009). For comparable figures, measurements are taken at points that are easily duplicated. This usually occurs at the bankfull stage, or the 1.5 year recurrence interval. At the reaches that slopes were measured (Table 4.1), neither the bankfull discharge nor the cross-sections were measured. So neither the stream energy nor power could be adequately measured. However, assuming that the bankfull discharges were similar, it can be seen that streams with steeper gradients will have a greater stream power and energy. Many of these gradients have slopes greater than one percent. Slopes that are one percent or greater could create conditions in which erosion could occur, especially considering the soil types occurring in the research area watershed. Sediment erosion is still occurring in much of the watershed, and can be noted by the bank erosion and head-cuts occurring on many of the tributaries. The stream power at the bankfull discharge could be calculated at the cross-section where the ISCO sampler is located. This value turned out to be 26.85 kg/m/s. At this stage larger sediment particles and a significant load could be eroded and transported.

When calculating either the stream power or shear stress, increasing either the discharge or the slope will result in an increase in stream power and shear stress. Increasing the slope will also increase velocity. The increase in velocity will create more stream power, which ultimately leads to increased erosion rates. After stream power is changed, the energy dissipation must also change if the channel is to maintain the dimensions and neither aggrade nor degrade (Rosgen 2009). The energy is commonly dissipated by increasing the sediment quantity or sediment size being transported, increasing the channel roughness, or increasing the meander pattern.

Stream Feature Results

Ponds are also very efficient energy dissipation features. There were four ponds selected in the research area watershed (Figures 3.5, 3.6, and 3.7). The gradients of tributaries leading to the inlet of the ponds were calculated (Table 4.5). These gradients had some of the steepest slopes calculated in the watershed. Steep gradients would mean that there could be a significant amount of stream power created, and ultimately, the potential for a great amount of sediment erosion. As a result of the stream gradients being steepest above the pond, the ponds have started to experience some level of sedimentation. The sedimentation occurring in three of the ponds is shown in Figure 4.15. The change in the color, from dark blues to browns or light green, of the water shows the sediment deposition.. Once the water reaches the pond, the velocity is slowed and the energy changes from kinetic to potential energy. The sediment will start to deposit during this transition.

Figure 4.15 Image of three ponds in the research area watershed (Reproduced from Farm Services Agency (FSA). 2012. FSA national agriculture imagery program (NAIP) 2012. Salina, KS: Farm Services Agency.)

Sedimentation in the middle and right pond found in Figure 4.15 is clearly visible, and some sediment has started to deposit at the upper end of the pond on the left. The ponds in the area obviously are very efficient energy dissipation features, but they are starting to see the effects of excessive upstream erosion that is occurring. Based on a rough estimate of the amount of the research area watershed that drains into the ponds, approximately 70% of the research area watershed is controlled by the ponds. Therefore, a majority of the sediment being eroded and transported is caught by the pond features in the research area watershed.

Gully Side Conveyance Results

Multiple gully side conveyances were noticed during the survey portion of this research. Ten of the features were located from the Lillis Bridge to the edge of the sedimentation basin next to the big pond's outlet. One of these gully conveyances was chosen to measure the amount of sediment lost from one of these features. Figure 4.16 shows a picture of the gully side conveyance that was measured in this study.

Figure 4.16 Image of gully side conveyance outlet

Figure 4.17 Aerial image of the location of the gully side conveyance

Figure 4.17 Aerial image of the location of the gully side conveyance (Reproduced from Google. 2013. Google Earth 7.1.1. Mountain View, CA: Google, Inc.)

Figure 4.17 shows the location of the gully side conveyance within the Irish Creek watershed. The gully has two branches coming off it, and the branches extend out of the riparian area into the surrounding fields. The heights and widths of the side conveyance were measured at three locations, starting from where the stream and gully meet to the head-cut formation. The energy gradient for this conveyance was calculated to be 0.09401 m/m. The slope is an extremely steep gradient, and could cause high velocities and stream power. Thus, the energy gradient has a great potential for high sediment erosion and transport. Figure 4.18 shows the 3-D surface images that were created by Surfer (Golden Software 2013) using the elevations and GPS locations measured for the gully side conveyance.

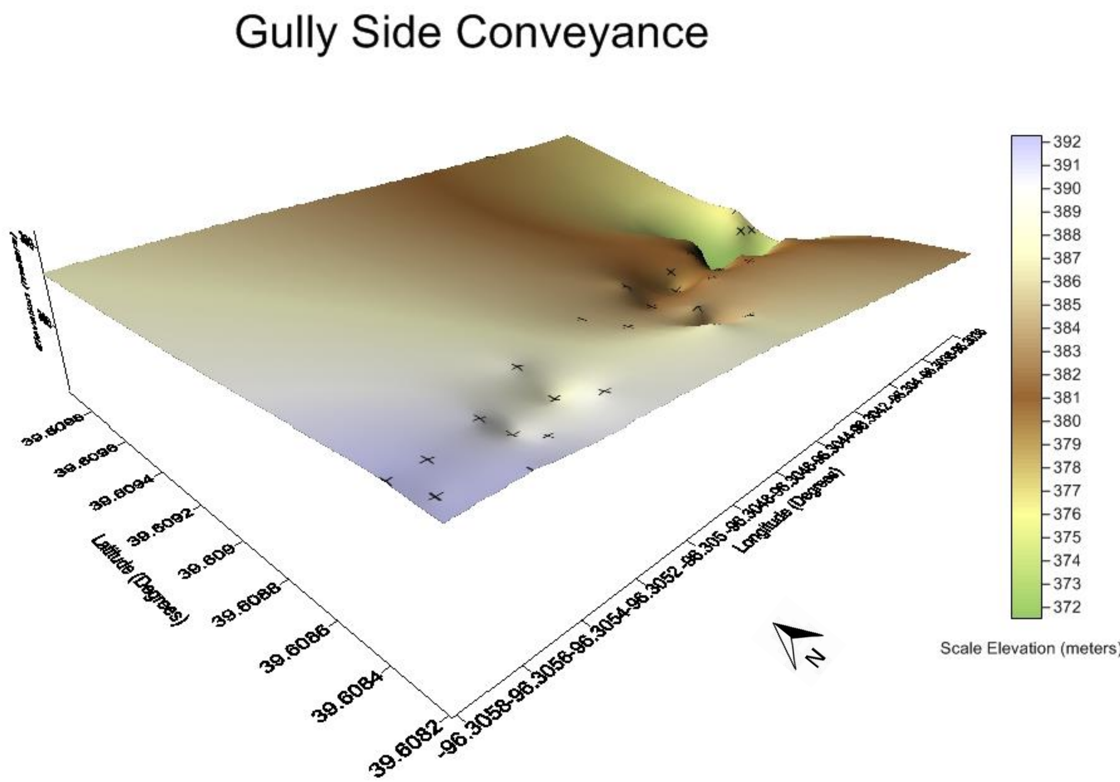

Figure 4.18 3-D surface image of gully side conveyance
View 1

The image shows how steep the energy gradient is from the head-cut to where the stream and gully meet. The top elevation is around 392 meters, and the bottom elevation is around 372 meters. The gully branches extending from the head-cut do not have as pronounced gradients, but the branches will continue to deepen and extend if there is no attempt to prevent the erosive forces that displace and transport sediment. The amount of sediment eroded from the measured gully side conveyance was calculated, and a total of 1, 693, 889 kg (1867 tons) of soil was lost from the side conveyance.

Summary

This research shows that the energy gradients found in the research area watershed could create favorable condition for sediment erosion to occur. The gradients measured range from 0.4

to 11.2%, with an average of 2.14% slopes occurring. When slopes greater than one percent are combined with certain geology, soil types, and field practices, excessive soil erosion can be a major problem in the watershed (USDA 1980), which does occur in the study watershed. However, the ponds located in the research area watershed also appear to be very efficient energy dissipating features. But as a result of the excess sediment the upland tributaries are carrying, the ponds look as if they are experiencing a degree of sedimentation. Finally, the study shows that multiple gully side conveyance features are forming in the sub-watershed. The conveyance formation is due to the overland flow trying to reach the stream, which is at a lower energy level. The feature continues to cut and expand trying to obtain the same energy level as the stream. Analysis of one of these features reveals a total of 1,693,889 kg of soil was added to the stream and transported downstream. The calculated energy gradient of this feature was 9.4%, which could create very high velocities and stream power. Sediment erosion could be extreme when gradients are this steep.

Chapter 5 - Conclusions

Sediment pollution is a common problem for many water bodies throughout the world, and a high percentage of this sediment is coming from accelerated erosion (MARC 2013). This accelerated erosion has caused early sedimentation issues in many reservoirs in Kansas. Upon examination of many Kansas rivers and streams, it was discovered that approximately 88% were considered impaired with a pollutant, and TMDLs needed to be developed for all these water bodies (EPA 2012d). The sediment TMDLs would help limit the allowable loads that are occurring in the streams and rivers, and this would help eliminate the sediment entering other water bodies.

The purpose of this research was to examine a small watershed in northeast Kansas and see how energy and power created in the stream determines the amount of sediment transported in the water system, especially the influence of the stream gradient. Research was performed on the selected study area for a six year period, from April 2007 to 2012.

The first objective was to address when and how often bankfull conditions were met. Bankfull conditions were picked as the optimum level, because this is the level in which "maintenance and formation is most effective" (Dunne and Leopold 1978). At the bankfull stage, conditions for a significant amount of work to be done on the stream occur. The estimated bankfull discharge is 6.5 m^3/s. It was found that each year experienced at least one bankfull event, except for 2012. The stream power was also calculated to be 26.85 kg/m/s. The power would allow for large amounts of sediment loads and/or an increase in sediment size to be transported downstream compared to times when there was lower flows. The increased load transportation was illustrated by the sediment load analysis.

The second objective was to estimate the amount of sediment being transported during the high bankfull flow events. The total sediment load occurring during the study period in the lower portion of the Irish Creek watershed was 10,298,283 kilograms and anywhere from 11 to 42% of the total yearly sediment loads were carried in one event. Nutrient data was also collected during the study period. The nutrient analysis also showed a great quantity of nitrogen and phosphorus were transported downstream. The total amount of nutrient loading that occurred during the study period was 78,213 kilograms of total nitrogen and 22,625 kilograms of total phosphorus. The data also indicated that nutrients and sediment are directly linked. The link was shown by observing how nutrient loads were usually highest during the same events when sediment loads were high. A large amount of both TN and TP loads were transported in a single event. The large amounts of both sediment and nutrients being transported in a single event shows how important the larger storm events are to the water system. Being able to limit the amount discharge that occurs during the large events could drastically decrease the sediment and nutrients loads that are transported downstream.

The third research objective addressed how ponds in the watershed affect the stream energy created by the gradients, which were created by the elevation changes.   Elevations and energy gradients in the smaller sub-watershed of Irish Creek were measured to examine the possible stream energy. The contour map showed a general movement of water in the northwest direction. The data also showed that much of the research area watershed's tributaries drain into the big pond located in the northwestern portion of the watershed. Three other small ponds were also located, and all these ponds eventually drain into the larger pond. The steepest energy gradients occurred from points in the upland areas of the research area watershed to the inlets of the ponds. The ponds act as energy dissipation features, and they convert most the kinetic energy that was created by the upstream energy gradient to potential energy. As a result of the energy transformation, sedimentation has started to occur in the ponds. The greatest stream gradient that does not intercept a pond is around 1.4%. Gradients that are one percent or greater are capable of creating enough stream energy and power that erosive forces occur. This is obvious by the bank erosion, head-cuts, and gully formations that are occurring throughout the watershed.

The final objective looked at features created as overland flows enter a stream at a lower elevation. The survey showed that multiple gully side conveyances have formed as overland flow enters the stream. Analysis of one of these conveyances showed that an estimated 1,693,889 kg of soil was lost from this feature. The energy gradient associated with this loss is close to 10%. This is an extremely steep gradient, and could cause high velocities and stream power, thus a great potential for high sediment erosion and transport. It is expected that formations like these will continue to appear if no effort is made to control overland flow and excessive erosion.

Recommendations

Since much of the watershed area is used for cropland fields and grazing lands, controlling the runoff and sediment erosion that comes from these areas is an essential way to decrease the total sediment load occurring in the water system. Best management practices (BMPs) are defined as practices that can be implemented to prevent or control the discharge of pollutants in the most efficient, practical, and cost-effective way (TCEQ and TSSWCB 2005). The strategies to control sediment erosion involve reducing soil detachment, reducing sediment transport, and trapping sediment. The first method for reducing soil detachment revolves around keeping a sufficient amount of cover on the soil. This involves leaving crop residues or a living vegetative coverage to intercept and dissipate energy coming from falling precipitation. Some of other following practices can also be used to reduce soil detachment (EPA 2003; Streeter et. al. 2008):

- Chiseling and subsoiling
- Conservation cover
- Conservation crop rotation
- Residue management
- Cover crops
- Reduced or Minimal tillage
- Critical area planting
- Diversion
- Mulching
- Surface roughening
- Tree planting
- No tillage

Sediment transport can be reduced in several ways. This can include field coverage, increased vegetation, and reductions in slope length and steepness. The increased crop residues and vegetative coverage slows the runoff, increases infiltration, and traps sediment. Decreasing the slope will decrease the velocity and the energy, thus reducing the sediment capable of being carried in the water. Some of the practices used to reduce sediment transport include (EPA 2003; Streeter et al. 2008):

- Contour farming
- Grassed waterways
- Contour stripcropping
- Field stripcropping
- Reduced or minimum tillage
- Water and sediment control structures
- Terraces
- Contour buffer strips
- Vegetative and riparian buffer/filters
- No Tillage
- Grade stabilization structures

Practices that trap sediment before it reaches the water systems are also extremely helpful in reducing sediment loadings. The deposition process is usually achieved when water velocities are reduced and there is increased infiltration. Some of the practices useful for trapping sediment include (EPA 2003):

- Sediment basins
- Field boarders
- Ponds
- Vegetative and riparian buffer/filters
- Water and sediment control structures

BMPs can greatly influence water quality, but despite these features sediment yields in streams and lakes remain constant for several decades (Trimble 1999). The continuing sediment yields may come from continual erosion from channels and streambanks (Simon and Rinaldi 2006). Practices designed to repair or protect streambanks from erosion include (EPA 2003):

- Grade stabilization structures
- Live fascines and brushlayering
- Trench packing
- Riprap
- Revetments
- Streambank protection
- Live Staking
- Tree and shrub planting
- Brushrolls, brushmattresses, or brush boxes

Different management practices and stabilization designs could help to limit the accelerated erosion of the gully side conveyances. The practices many include any of the bioengineered or structural designs mentioned in the practices used for the protection of streambanks (EPA 2003). One particular design is to use rock chutes to convey water to a lower elevation (Robinson et al. 1998). This structure allows for safe flow of surface water to a stream (Lamarre 2009), while protecting the soil surface, maintaining a stable slope, and dissipating a portion of the flow energy (Robinson et al. 1998). It “helps stabilize banks by preventing retrogressive erosion of the bottom of waterways and the formation of erosional gullies in fields” (Lamarre 2009). The spillway is used at low ends of fields, outlets of furrows, interceptions of channels or grassed waterways, or any other place where water flows into a stream. This design feature provides a flexible, low-cost, and effective structure to help eliminate excessive erosion in overland flow to a stream. It is readily adaptable, has few drawbacks for agricultural practices, and can be aesthetically pleasing (Lamarre 2009; Robinson et al. 1998). Construction of these features can also be done by unskilled labor with a relatively small amount of equipment (Robinson et al. 1998). However, this feature does not allow for water retention and sedimentation, like what would occur in an inlet well with a sedimentation basin (Lamarre 2009). If correctly designed and implemented, the rock chute would be a very efficient way to dissipate the energy created from the elevation change from overland flow to stream flow. Dissipating the energy could greatly reduce the sediment erosion and transport that is occurring in the gully side conveyances.

To help improve water quality, sediment loads moving downstream have to be decreased. Soil erosion control methods and TMDLs still need to be developed in order for this to happen. If nothing is done to prevent the movement of sediment, water bodies will continue to degrade and it will put human health at further risk. Further monitoring and research should be done to ensure there are no excessive amounts of sediment loads and other pollutants in water bodies.

References

Bagnold, R.A. 1966. An approach to the sediment transport problem from general physics. Washington, DC: United States Department of the Interior.

Brady, N.C. and R.R. Weil. 2009. *Elements of nature and properties of soil*. Upper Saddle River, NJ: Prentice Hall

Brookes, A. 1985. River channelization: Traditional engineering methods, physical consequences, and alternative practices. *Progress in Physical Geography* 9 (1): 44-73.

Catchments and Creeks. 2010. Gully erosion fact sheet. Ferny Hills, Australia: Catchments & Creeks Pty Ltd. Available at: http://www.catchmentsandcreeks.com.au/docs/Gully1-1.pdf. Accessed 27 October 2013.

Columbia University. 2013. Stream processes. New York, NY: Columbia University. Available at: http://www.columbia.edu/~vjd1/streams_basics.htm. Accessed 14 June 2013.

Cronodon. 2011. River processes. Available at: http://cronodon.com/files/River_ Processes _1.pdf. Accessed 6 November 2011.

Darby, S.E. and A. Simon. 1999. *Incised river channels – Processes, forms, engineering, and management*. Hoboken, NJ: John Wiley & Sons.

Davis, L. 2007. Spatial patterns of geomorphic processes in channelized tributary streams. *Physical Geography* 28 (4): 301-310.

Dunne, T. and L. Leopold. 1978. *Water in environmental planning*. San Francisco, CA: W.H. Freeman and Company.

Ellison, W.D. 1948. Erosion of soil by raindrops. *Scientific American* 180: 40-45.

Environmental Protection Agency (EPA). 1986. Quality criteria for water 1986 (EPA 440/5-86-001). Washington, DC: Environmental Protection Agency; Office of Water; Regulations and Standards. Available at: http://water.epa.gov/scitech/swguidance/standards/criteria/ aqlife/upload/ 2009_01_13_ criteria_goldbook.pdf. Accessed 3 June 2013.

EPA. 1991. Guidance for water quality-based decisions: The TMDL process (EPA 440/4-91-001). Washington, DC: Environmental Protection Agency; Office of Water. Available at: http://water.epa.gov/scitech/datait/models/upload/1999_11_05_models_SASD0 109.pdf. Accessed 4 June 2013.

EPA. 1993. Guidance specifying management measures for sources of nonpoint pollution in coastal waters (EPA840-B-92-002). Washington, DC: Environmental Protection Agency; Office of Water. Available at: http://water.epa.gov/polwaste/nps/czara/index.cfm. Accessed 30 May 2013.

EPA. 1996. Nonpoint source pollution: the Nation's largest water quality problem (EPA841-F-96-004A). Washington, DC: Environmental Protection Agency; Office of Water; Outreach and Communication. Available at: http://water.epa.gov/polwaste/nps/outreach/point1.cfm. Accessed 29 May 2013.

EPA. 1997. Guidelines for preparation of the comprehensive State water quality assessments (305 (b) reports) and electronic updates (EPA841-B-97-002). Washington, DC: Environmental Protection Agency; Office of Water; Monitoring and Assessment. Available at: http://water.epa.gov/type/ watersheds/monitoring/guidelines.cfm. Accessed 30 May 2013.

EPA. 1999. Protocol for developing sediment TMDLs; first edition (EPA841- B-99-004). Washington DC: Office of Water. Available at: http://www.epa.gov/owow/tmdl/sediment/pdf/sediment.pdf. Accessed 4 June 2013.

EPA. 2003. National management measures to control nonpoint source pollution from agriculture (EPA-841-B-03-004). Washington, DC: Environmental Protection Agency; Office of Water. Available at http://water.epa.gov/polwaste/nps/agriculture/agmm_index.cfm. Accessed 24 May 2013.

EPA. 2005. Protecting water quality from agricultural runoff (EPA 841-F-05-001). Washington, DC: Environmental Protection Agency; Office of Water; Outreach and Communication. Available at: http://www.epa.gov/owow/nps/Ag_Runoff_Fact_Sheet.pdf. Accessed May 23 2013.

EPA. 2006. Framework for developing suspended and bedded sediments (SABS) water quality criteria (EPA/822-R-06-001). Washington, DC: Environmental Protection Agency; Office of Water and Office of Research and Development. Available at: http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=164423. Accessed 3 June 2013.

EPA. 2012a. Clean Water Act, Section 502 general definitions. Washington, DC: Environmental Protection Agency; Office of Water. Available at: http://water.epa.gov/lawsregs/guidance/wetlands/sec502.cfm. Accessed 30 May 2013.

EPA. 2012b. Contaminated sediments in water. Washington, DC: Environmental Protection Agency; Office of Water. Available at: http://water.epa.gov/polwaste/sediments /cs/aboutcs.cfm. Accessed 20 May 2013.

EPA. 2012c. Stream flow. Washington, DC: Environmental Protection Agency; Office of Water; Monitoring and Assessment. Available at: http://water.epa.gov/type/rsl/ monitoring/vms51.cfm. Accessed 18 June 2013.

EPA. 2012d. Watershed assessment, tracking, and environmental results; Kansas assessment data for 2012. Washington, DC: Office of Water; Water Quality Assessment and TMDL Information. Available at: http://ofmpub.epa.gov/waters10/attains_state.report_control?p_state=KS&p_cycle=2012&p_report_type=A. Accessed 31 May 2013.

EPA. 2012e. Watershed assessment, tracking, and environmental results; Kansas, lower Big Blue watershed. Washington, DC: Office of Water; Water Quality Assessment and TMDL Information. Available at: http://iaspub.epa.gov/waters10/attains_watershed .control?p_state=KS&p_huc=10270205&p_cycle=2012&p_report_type=A. Accessed 4 June 2013.

EPA. 2012f. What is nonpoint source pollution?. Washington, DC: Environmental Protection Agency, Office of Water. Available at: http://water.epa.gov/polwaste/nps/whatis.cfm. Accessed 30 May 2013.

EPA. 2013a. Clean Water Act. Washington, DC: Environmental Protection Agency, Agriculture. Available at: http://www.epa.gov/agriculture/lcwa.html. Accessed 23 May 2013.

EPA. 2013b. Clean Water Act Section 319. Washington, DC: Office of Water. Available at http://water.epa.gov/polwaste/nps/cwact.cfm. Accessed 24 May 2013.

EPA. 2013c. Clean water act; total maximum daily loads. Washington, DC: Environmental Protection Agency; Office of Water. Available at: http://www.epa.gov/agriculture/lcwa. html#Total Maximum Daily Limits. Accessed 24 May 2013.

EPA. 2013d. Economic incentives. Washington, DC: Environmental Protection Agency; National Center for Environmental Economics. Available at http://yosemite.epa.gov/ ee/epa/eed.nsf/pages/EconomicIncentives.html. Accessed 17 May 2013.

EPA. 2013e. Impaired waters and total maximum daily loads. Washington, DC: Environmental Protection Agency; Office of Water. Available at: http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/index.cfm. Accessed 31 May 2013.

EPA. 2013f. Watershed assessment, tracking, and environmental results; National summary of state information. Washington, DC: Office of Water; Water Quality Assessment and TMDL Information. Available at: http://ofmpub.epa.gov/waters10/attains_nation_cy.control. Accessed 31 May 2013.

EPA. 2013g. Water quality standards. Lenexa, KS: Environmental Protection Agency Region 7; Water. Available at: http://www.epa.gov/region07/water/wqs.htm. Accessed 31 May 2013.

Environmental System Research Institute (ESRI). 2012. ArcGIS Desktop: Release 10.1. Redland, CA: Environmental Systems Research Institute.

Franti, T.G., D.L. Devlin, C.W. Rice, and F.W. Roeth. 2000. Improving water quality in the Big Blue River Basin, Nebraska and Kansas: An extension and research case study. In Proc. of the International Conservation Tillage Symposium. Ames, IA: Mid-American International Agricultural Consortium; Natural Resources Program Committee.

Farm Services Agency (FSA). 2012. FSA national agriculture imagery program (NAIP) 2012. Salina, KS: Farm Services Agency. Available at: http://www.kansasgis.org/catalog/index.cfm. Accessed 2 August 2013.

Golden Software. 2013. Surfer 9. Golden, CO: Golden Software.

Google. 2013. Google Earth 7.1.1. Mountain View, CA: Google, Inc.

Gordon, N. D., T.A. McMahon, B.L. Finlayson, C.J. Gippel, and R.J. Nathan. 2004. *Stream hydrology: An introduction for ecologists*. 2nd Edition. Hoboken, NJ: John Wiley & Sons.

Hamblin, W.K. and E.H. Christiansen. 2003. *Earth's dynamic systems*. 10th Edition. Upper Saddle River, NJ: Prentice Hall.

Hanson, G.J. and A. Simon. 2001. Erodibility of cohesive streambeds in the loess area of the midwestern USA. *Hydrological Processes* 15: 23-38.

Hargrove, W.L., D. Johnson, D. Snethen, and J. Middendorf. 2010. From dust bowl to mud bowl: Sedimentation, conservation measures, and the future of reservoirs. *Journal of Soil and Water Conservation* 65(1): 14A-17A, doi:10.2489/jswc.65.1.14A.

Henderson, F.M. 1966. *Open channel flow*. New York, NY: Macmillan Publishing Company.

Hill, M.H. 2009. Stream gradient. Jacksonville, AL: Jacksonville State University; JSU Distance Learning. Available at http://www.aegis.jsu.edu /mhill/phylabtwo/lab8 /gradcalf.html. Accessed 20 October 2011.

Hillel, D. 2003. *Introduction to environmental soil physics*. Waltham, MA: Academic Press.

Hosomi, M. and R. Sudo. 1986. Simultaneous determination of Total Nitrogen, and Total Phosphorus in freshwater samples using persulfate digestion. *International Journal of Environmental Studies* 27: 267-275.

Indian Institute of Technology (IIT). 2012. Flow dynamics in open channels and rivers. Kharagpur, India: Indian Institute of Technology; Civil Engineering. Available at: http://nptel.iitm.ac.in/courses/Webcoursecontents/IIT%20Kharagpur/Water%20Resource%20Engg/pdf/m2l08.pdf. Accessed 8 November 2011.

Johnson, J.L. 2006. Evaluation of stormwater wetland and wet pond forebay design. MS thesis. Raleigh, NC: North Carolina State University, Department of Biological and Agricultural Engineering.

Juracek, K.E. 1999. Estimation of potential runoff-contributing areas in the Kansas-Lower Republican River Basin, Kansas. U.S. Geological Survey- Water Resources Investigations Report 99-4089. Lawrence, KS: U.S. Geological Survey.

Juracek, K.E. and D.P. Mau. 2002. Sediment deposition and occurrence of selected nutrients and other chemical constituents in bottom sediment, Tuttle Creek Lake, northeast Kansas, 1962-99. U.S. Geological Survey- Water Resources Investigations Report 02-4048. Lawrence, KS: U.S. Geological Survey.

Kansas Department of Health & Environment (KDHE). 2000. Kansas-Lower Republican basin total maximum daily load: Tuttle Creek Lake. Topeka, KS: Kansas Department of Health & Environment. Available at: http://www.kdheks.gov/tmdl/klr/TuttleSILT.pdf. Accessed 4 June 2013.

KDHE. 2010. Surface water register- Lakes and streams. Topeka, KS: Kansas Department of Health & Environment. Available at: http://www.kansasgis.org/catalog/index.cfm. Accessed 30 July 2013.

Kansas State University (KSU). 2005. Manhattan, KS: Department of Agronomy; Soil Testing Laboratory. Available at: http://www.agronomy.ksu.edu/soiltesting/p.aspx?tabid=31. Accessed 9 September 2013.

KSU. 2013. Weather Data Library: Precipitation summary for Marshall County- Lillis. Manhattan, KS: K-State Research and Extension. Available at: http://www.ksre.ksu.edu /wdl/precip%20files/ms_p.asp. Accessed 17 July 2013.

Kansas Applied Remote Sensing Program and Kansas Biological Survey (KARS and KBS). 2005. Kansas land cover patterns, level IV-2005. Lawrence, KS: Kansas Applied Remote Sensing Program and Kansas Biological Survey. Available at: http://www.kansasgis.org/catalog/index.cfm. Accessed 4 August 2013.

Kerr, S.J. 1995. Silt, turbidity, and suspended sediments in the aquatic environment: an annotated bibliography and literature review. North Bay, ON: Ontario Ministry of Natural Resources, Southern Region Science and Technology Transfer Unit Technical Report TR-008.

Kansas Geological Survey (KGS). 1991. Geology detailed surficial. Lawrence, KS: Kansas Geological Survey. Available at: http://www.kansasgis.org/catalog/index.cfm. Accessed 3 August 2013.

KGS. 2000. Geology of Riley and Geary counties, stratigraphy Council Grove Group. Lawrence, KS: Kansas Geological Survey. Available at: http://www.kgs.ku.edu/General/Geology/Riley/strat03b.html. Accessed 1 August 2013.

KGS. 2004. Marshall County geohydrology. Lawrence, KS: Kansas Geological Survey. Available at: http://www.kgs.ku.edu/General/Geology/Marshall/04_geog.html. Accessed 17 July 2013.

KGS. 2005. Glaciated region. Lawrence, KS: Kansas Geological Survey. Available at: http://www.kgs.ku.edu/Extension/glacier/glacier.html. Accessed 16 July 2013.

KGS. 2013. Kansas base map (counties, cities, roads, and hillshades). Lawrence, KS: Kansas Geological Survey. Available at: http://services.kansasgis.org/arcgis/rest/services/ Basemap/basemap_utm14/MapServer. Accessed 3 August 2013.

Knighton, D. 1998. *Fluvial forms and processes*. London, England: Arnold Publishers.

Kansas Water Office (KWO). 2011. HUC boundary 10-digit level. Topeka, KS: Kansas Water Office. Available at: http://www.kansasgis.org/catalog/index.cfm. Accessed 31 July 2013.

KWO. 2012. Tuttle Creek Lake; reservation information sheet. Topeka, KS: Kansas Water Office. Available at http://www.kwo.org/reservoirs/ReservoirFactSheets/Rpt_Tuttle Creek_2011 .pdf. Accessed 17 May 2013.

Lamarre, G. 2009. Rock chute spillways. Quebec City, Quebec: Agriculture and Agri-Food Canada (AAFC) and Ministère de l'Agriculture, des Pê-cheries et de l'Alimentation du Québec (MAPAQ). Available at: http://www.agrireseau.qc.ca/references /6/Fiches_MAPAQ-AAC_Erosion/DeversoirEnroche_EN_web.pdf. Accessed 1 November 2013.

Langendoen, E.J. and A. Simon. 2008. Modeling the evolution of incised streams II: Streambank erosion. *Journal of Hydraulic Engineering-ASCE* 134 (7): 905-915.

Leica Geosystems. 2013. Lecia Rugby 100/100LR. Available at: http://www.leica-geosystems.com/en/Leica-Rugby-100100LR_4243.htm. Accessed 20 November 2013.

Leopold, L. B., M.G. Wolman, and J.P. Miller. 1964. *Fluvial processes in geomorphology*. San Francisco: W. H. Freeman and Company.

MARC. 2013. Keep sediment out of our waters. Kansas City, MO: Mid-America Regional Council. Available at: http://www.marc.org/environment/water/sediment.htm. Accessed 8 March 2013.

Meade, B.K. 2009. Spatial extent, timing, and causes of channel incision, Black Vermillion watershed, Northeastern Kansas. MS thesis. Manhattan, KS: Kansas State University, Department of Geography.

Merriam, D.F. 2003. Southern extent of Kansan Glaciation (Pleistocene) in Douglas County, Kansas. *Transaction of the Kansas Academy of Science* 106(1/2): 17-28.

Molnár, P. and J.A. Ramírez. 1998. Energy dissipation theories and optimal channel characteristics of river networks. *Water Resources Research* 34(7): 1809-1818.

Morgan, R.P.C. 2005. *Soil erosion & conservation*. 3rd Edition. Malden, MA: Blackwell Publishing.

Nejadhashemi, A., C. Smith, J. Williams, K. Douglas-Mankin, and B. Gordan. 2011. An analysis of sedimentation reduction strategies for Tuttle Creek Lake; 2008-2011 final progress report. Manhattan, KS: K-State Research and Extension; Kansas Center for Agricultural Resources and the Environment. Available at: http://www.kcare.ksu.edu/doc4162.ashx. Accessed 20 May 2013.

Nissen-Peterson, E. 2006. *Water from small dams: A handbook for technicians, farmers, and other on site investigations, designs, cost estimates, construction and maintenance of small earth dams*. Danida, Kenya: ASAL Consultants Ltd.

Nitsche, M., D. Rickenmann, J.M. Turowski, A. Badoux, and J.W. Kirchner. 2011. Evaluation of bedload transport predictions using flow resistance equations to account for marco-roughness in steep mountain streams. *Water Resources Research* 47: W08513, doi:10.1029/2011WR010645.

National Climatic Data Center (NCDC). 2013. Annual climatological summary for Lillis, KS. Asheville, NC: National Climatic Data Center; U.S. Department of Commerce; National Oceanic & Atmospheric Administration; National Environmental Satellite, Data, and Information Service. Available at: http://www.ncdc.noaa.gov/cdo-web/datasets. Accessed 17 November 2013.

National Oceanic and Atmospheric Administration (NOAA). 2008. Nonpoint source pollution. Silver Spring, MD: U.S. Department of Commerce National Oceanic and Atmospheric Administration. Available at: http://oceanservice.noaa.gov/education/kits/pollution /04nonpointsource.html. Accessed 31 May 2013.

Natural Resource Conservation Service (NRCS). 2013. Custom soil resource report for Marshall County, Kansas. Salina, KS: U.S. Department of Agriculture Natural Resources Conservation Service. Available at: http://websoilsurvey.sc.egov.usda .gov/App/HomePage.htm. Accessed 2 August 2013.

NSERL. 2013. Soil erosion and WEPP technology. West Lafayette, IN: Purdue University. Available at: http://milford.nserl.purdue.edu/weppdocs/overview/intro.html. Accessed 22 June 2013.

Poff N.L. and D.D. Hart. 2002. How dams vary and why it matters for the emerging science of dam removal. Bioscience 52: 659-668.

Rao, A.R. and K. Hamed. 2000. Flood frequency analysis. Boca Raton, FL: CRC Press LLC.

Robinson, K.M., C.E. Rice, and K.C. Kadavy. 1998. Design of rock chutes. *Transactions of the ASAE* 41(3): 621-626.

Rosgen, D. 1996. *Applied river morphology*. 2nd Edition. Pagosa Springs, CO: Wildland Hydrology.

Rosgen, D. 2009. *Watershed assessment of river stability and sediment supply (WARSSS)*. 2nd Edition. Fort Collins, CO: Wildland Hydrology.

Sass, C.K. 2008. Inventory and analysis of the Black Vermillion river system riparian corridors. MS thesis. Manhattan, KS: Kansas State University, Department of Landscape Architecture/Regional and Community Planning.

Sass. C.K. 2011. Evaluation and development of predictive streambank erosion curves for northeast Kansas using Rosgen's "BANCS" methodology. PhD dissertation. Manhattan, KS: Kansas State University, Department of Environmental Design & Planning College of Architecture, Planning & Design.

Shelby, B., B.P. Van Haveren, W.L. Jackson, D. Whittaker, D. Prischard, and D. Ellerbroek. 1990. *Resource values and instream flow recommendations; Gulkana National Wild River, Alaska*. Denver, CO: U.S. Department of the Interior Bureau of Land Management.

Simon, A. 1992. Energy, time, and channel evolution in catastrophically disturbed fluvial channels. *Geomorphology* 5: 345-372.

Simon, A., W. Dickerson, and A. Heins. 2004. Suspended-sediment transport rates at the 1.5-year recurrence interval for ecoregions of the United States: transport conditions at the bankfull and effective discharge?. *Geomorphology* 58: 243-262.

Simon, A. and M. Rinaldi. 2000. Channel instability in the loess area of the Midwestern United States. *Journal of the American Water Resources Association* 26 (1): 133-150.

Simon, A. and M. Rinaldi. 2006. Disturbance, stream incision, and channel evolution: The roles of excess transport capacity and boundary materials in controlling channel response. *Geomorphology* 79: 361-383.

SSSA. 2013. Why is soil important?. Washington, DC: Soil Science Society of America. Available at: http://www.envirothon.org/pdf/CG/Why_Soil_is_Important.pdf. Accessed 10 October 2013.

Steele, K.L. 2008. Atrazine best management practices: Impact on water quality. MS thesis. Manhattan, KS: Kansas State University, Department of Biological and Agricultural Engineering.

Streeter, T., W.L. Hargrove, F. DeNoyelles, M. Jakubauska, D.G. Huggins, R.C. Everhard, A. Dzialowski, J. Kriz, D.S. Baker, D. Devlin, P. Barnes, J. Williams, C. Smith, M.A. Townsend, N.O. Nelson, D. Goard, and D. Presley. 2008. Sedimentation in our reservoirs: Causes and solutions. Manhattan, KS: Kansas State University. Available at: http://www.kwo.org/reports_publications/reports/kwri_book.pdf. Accessed 6 March 2013.

Teledyne ISCO. 2013. 6712 Portable samplers installation and operation guide. Available at: http://www.isco.com/pcfiles/PartPDF/SL000005/UP001ALI.pdf. Accessed 11 September 2013.

Texas Commission on Environmental Quality and Texas State Soil and Water Conservation Board (TCEQ and TSSWCB). 2005. Texas nonpoint source management program (SFR-068/04). Austin, TX: Texas Commission on Environmental Quality and the Texas State Soil and Water Conservation Board. Available at: https://www.tsswcb.texas.gov /files/docs/admin/Sunset2009/21G-NPS%20MGMT%20Program.pdf. Accessed 1 November 2013.

Trimble, S. 1999. Decreased rates of alluvial sediment storage in the Coon Creek Basin, Wisconsin, 1975-93. *Science* 285(5431): 1244-1246.

UNEP. 1998. Best management practices for agricultural non-point sources of pollution. CEP Technical Report No. 41. Nairobi, Kenya: United Nations Environment Programme; Caribbean Environment Programme.

USACE. 2013. Project history for Tuttle Creek Lake. Kansas City, MO: U.S. Army Corps of Engineers; Kansas City District. Available at http://www.nwk.usace.army.mil/Locations /DistrictLakes/TuttleCreekLake/History.aspx. Accessed 17 May 2013.

U.S. Census Bureau. 2010. Census block group data. Suitland, MD: US Census Bureau. Available at: http://www.kansasgis.org/catalog/index.cfm. Accessed 1 August 2013.

U.S. Department of Agriculture (USDA), Soil Conservation Service, and Kansas Agricultural Experiment Station. 1980. Soil survey of Marshall County, Kansas. Available at: http://soildatamart.nrcs.usda.gov/manuscripts/KS117/0/marshall.pdf. Accessed 16 July 2013.

USDA. 2009. National elevation dataset (NED). Reston, VA: United States Geological Survey. Available at: http://www.kansasgis.org/catalog/index.cfm. Accessed 5 August 2013.

USDA. 2013. Erosion. Washington, DC: USDA Natural Resources Conservation Service. Available at: http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/landuse/ crops/erosion/. Accessed 21 June 2013.

U.S. Geological Survey (USGS). 2013a. Lakes and reservoirs. Reston, VA: United States Geological Survey; Water Science School. Available at: http://ga.water.usgs.gov /edu/earthlakes.html. Accessed 16 July 2013.

USGS. 2013b. Science topics: Stream discharge. Reston, VA: United States Geological Survey. Available at: http://www.usgs.gov/science/science.php?term=998. Accessed 27 June 2013.

Wilcox, A.C., E.E. Wohl, F. Comiti, and L. Mao. 2011. Hydraulics, morphology, and energy dissipation in an alpine step-pool channel. *Water Resources Research* 47(7).

Williams, S.J.. 1981. Sand resources and geological character of Long Island Sound. Technical Paper No. 81-3. Fort Belvoir, VA: U.S Army, CORPS of Engineers; Coastal Engineering Research Center.

WRAPS. 2010. Tuttle Creek Lake watershed restoration and protection strategy. Manhattan, KS: Kansas State University Research and Extension. Available at: http://www.kcare.ksu.edu/doc4169.ashx. Accessed 4 June 2013.

Yeasmin, A and M.N. Islam. 2011. Changing trends of channel patterns of the Ganges-Padma river. *International Journal of Geomatics and Geosciences* 2(2): 669-675.

Zaimes, G.N., R.C. Shultz, T.M. Isenhart, S.K. Mickelson, J.L. Kovar, J.R. Russell, and W. Powers. 2005. Stream bank erosion under different riparian land-use practices in northeast Iowa. AFTA 2005 Conference Proceedings.

Zeigler, A. and K. Juracek. 2006. Sediment in Kansas streams and reservoirs. Presentation to the Kansas Sediment Workshop; March 15, 2006.

Appendix A - Water Samples Analysis

2008

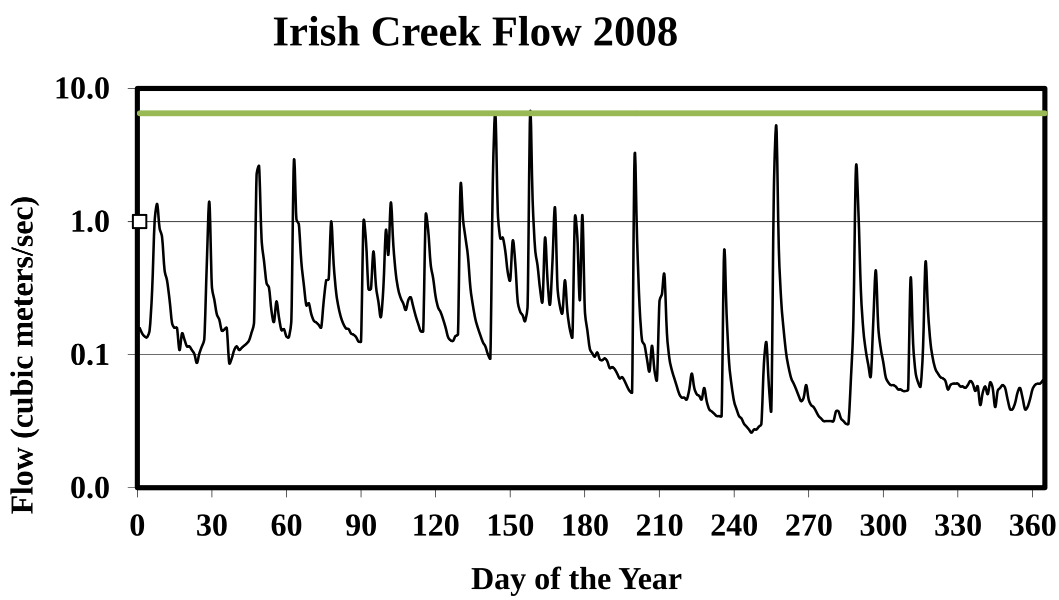

Figure A.1 2008 Irish Creek flow data

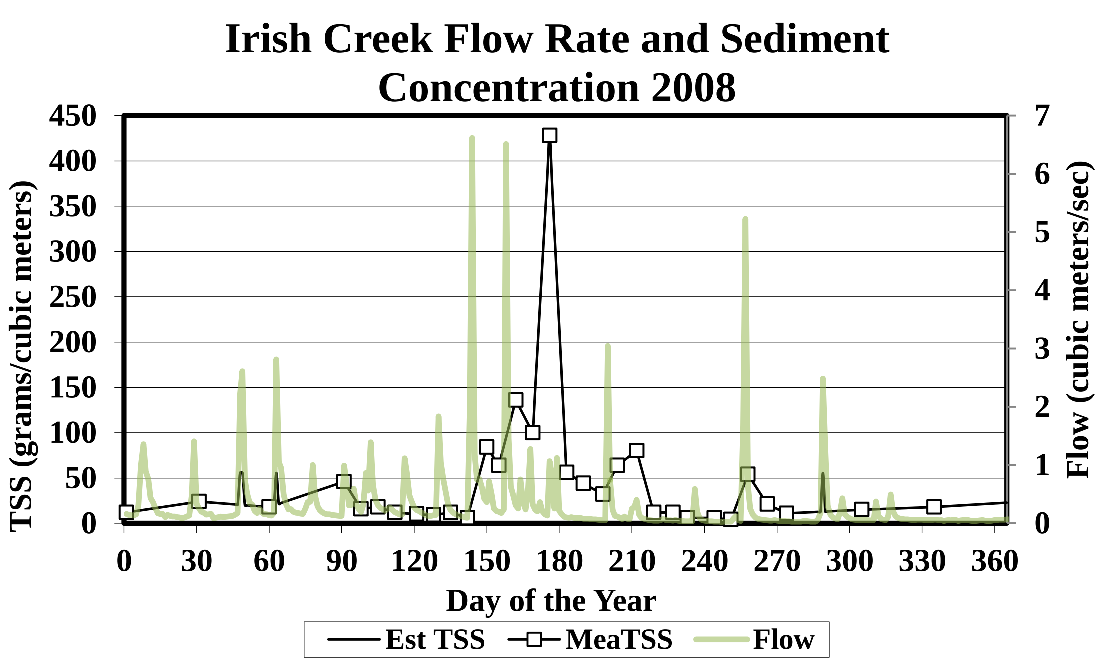

Figure A.2 Flow rates and sediment concentrations for 2008

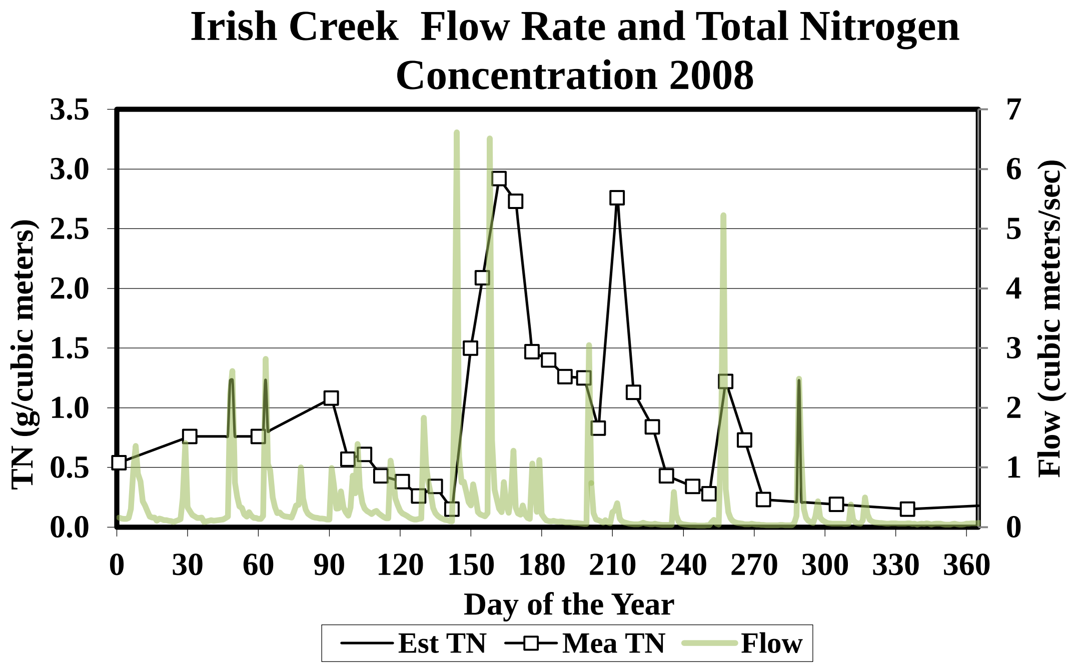

Figure A.3 Flow rates and Total Nitrogen concentrations for 2008

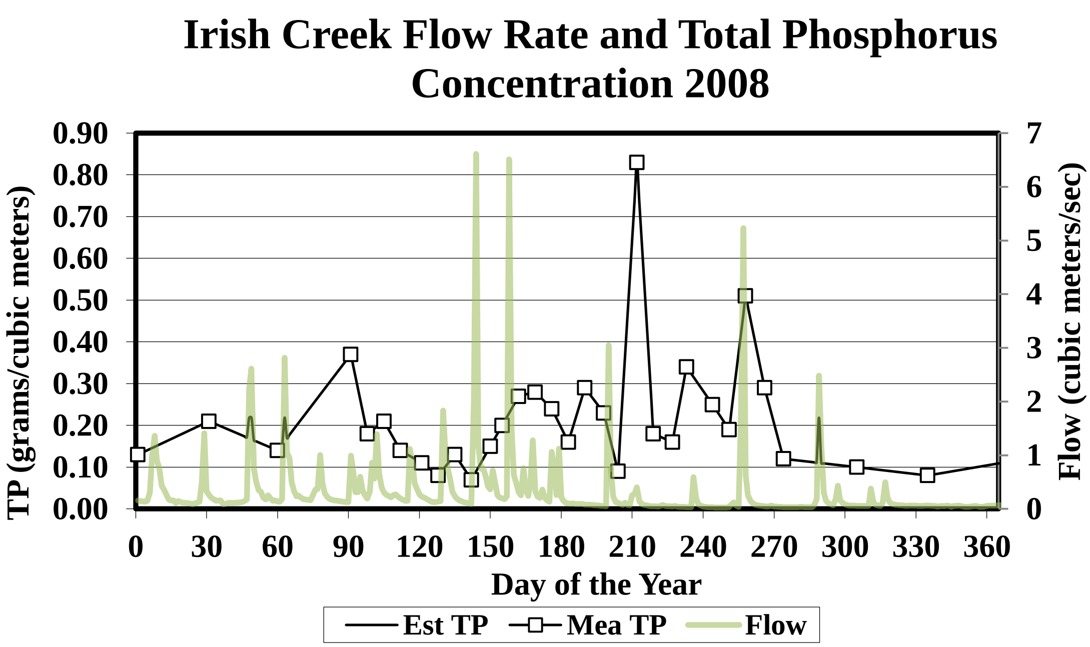

Figure A.4 Flow rates and Total Phosphorus concentrations for 2008

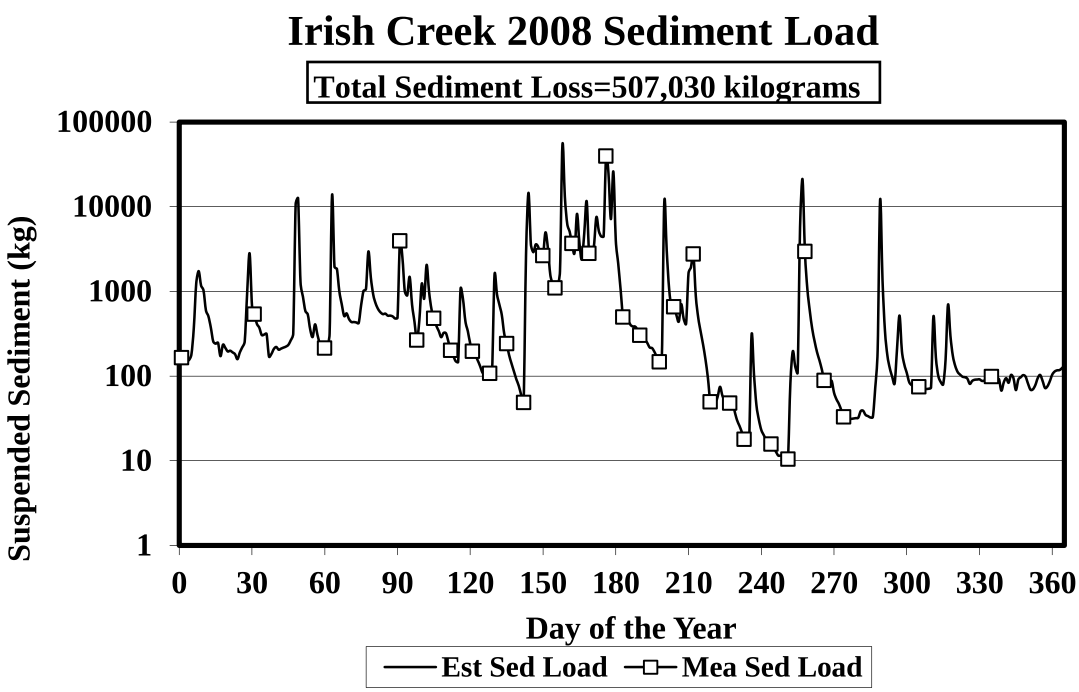

Figure A.5 Sediment loading for 2008

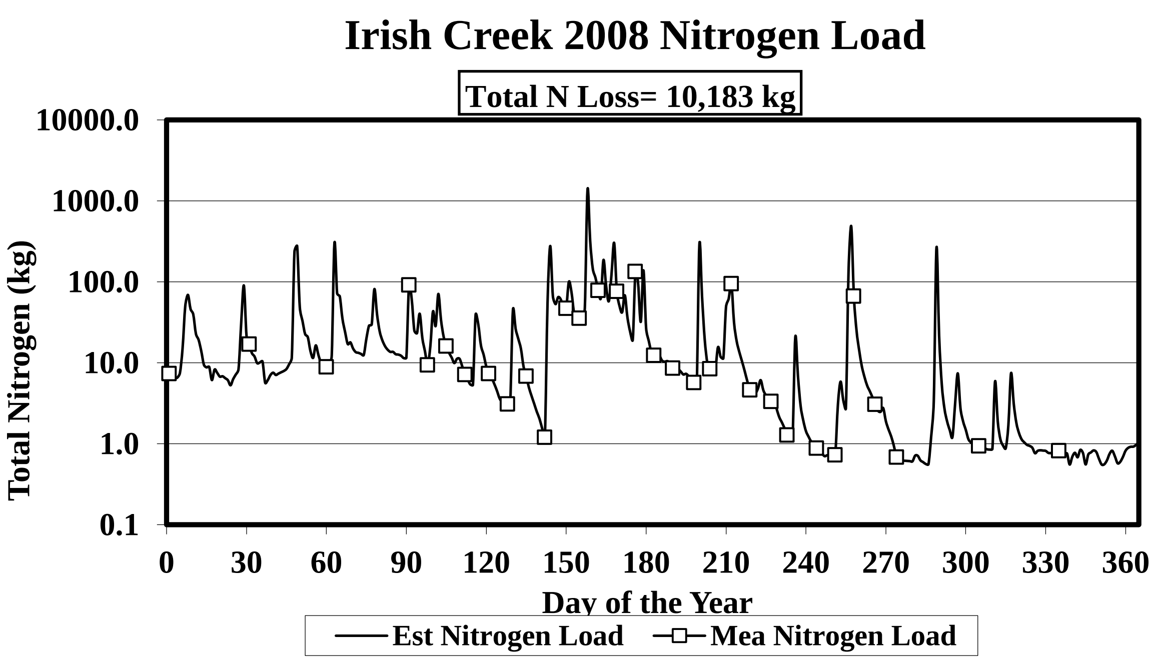

Figure A.6 Total Nitrogen loading for 2008

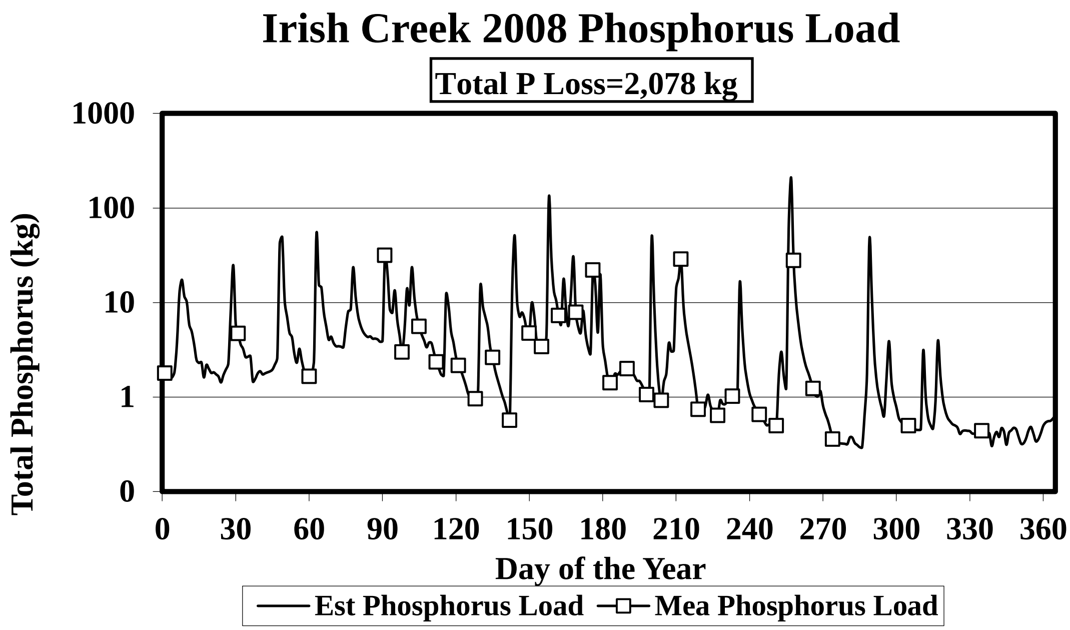

Figure A.7 Total Phosphorus loading for 2008

2009

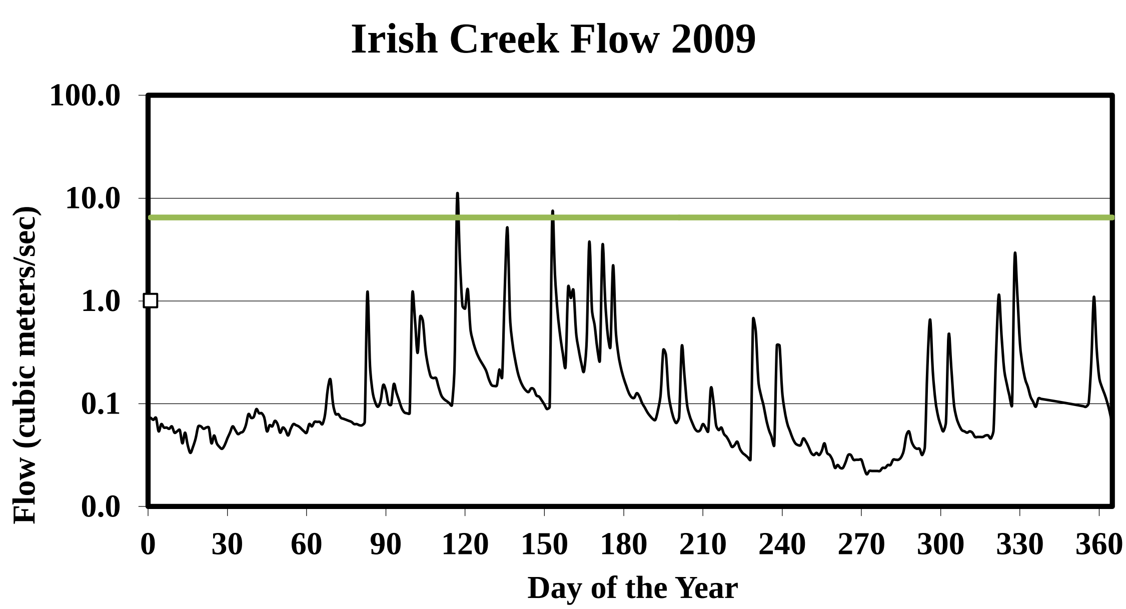

Figure A.8 2009 Irish Creek flow data

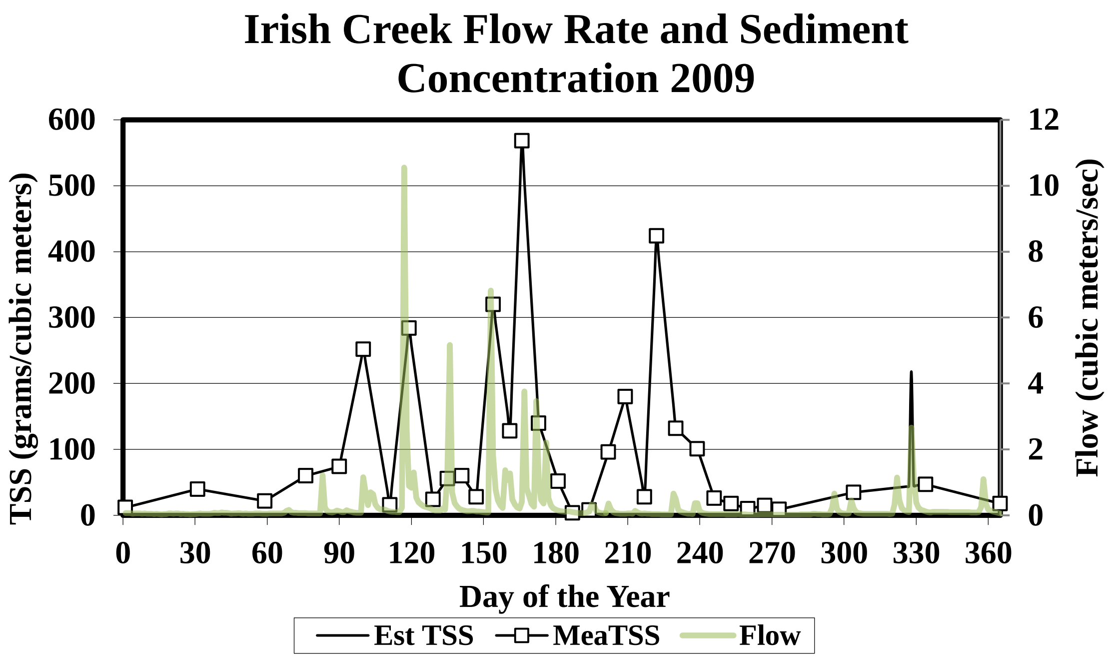

Figure A.9 Flow rates and sediment concentrations for 2009

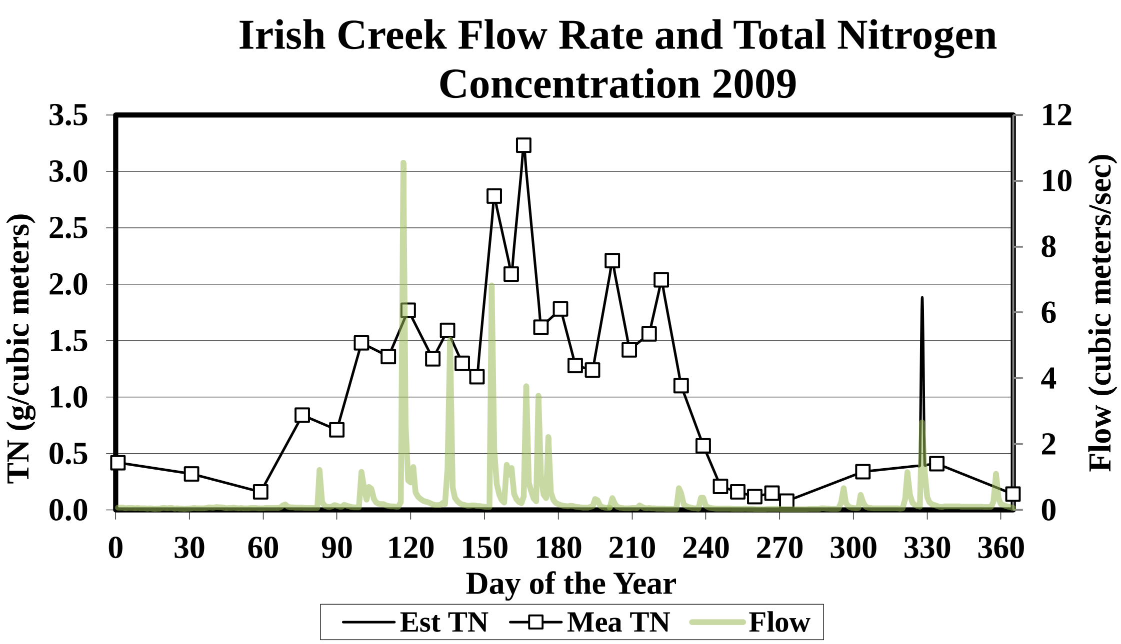

Figure A.10 Flow rates and Total Nitrogen concentrations for 2009

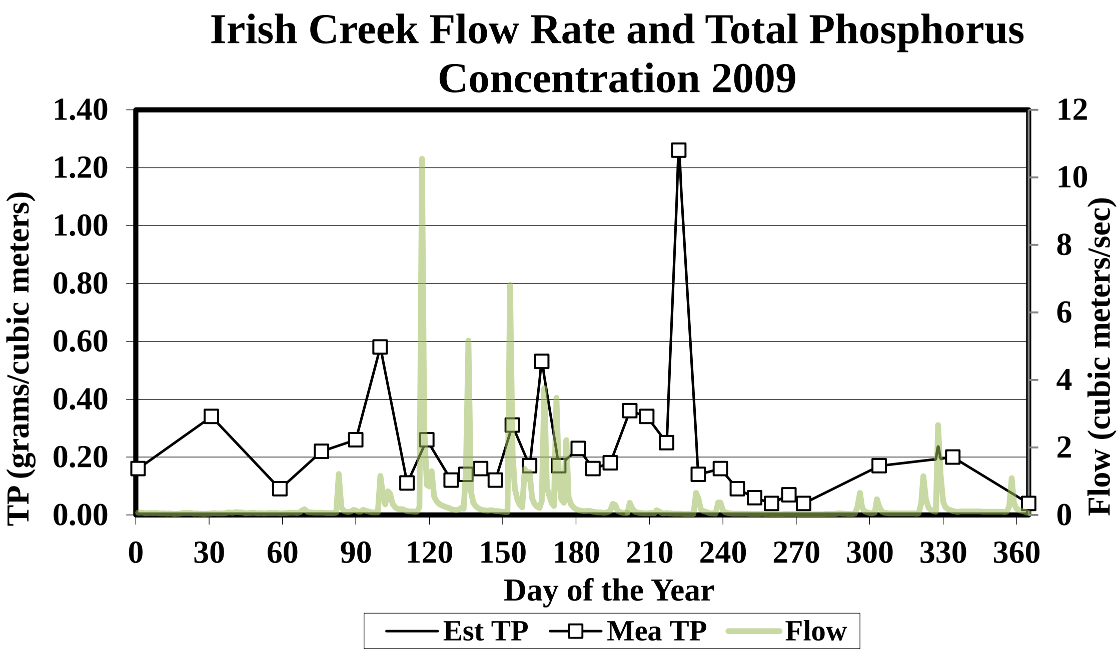

Figure A.11 Flow rates and Total Phosphorus concentrations for 2009

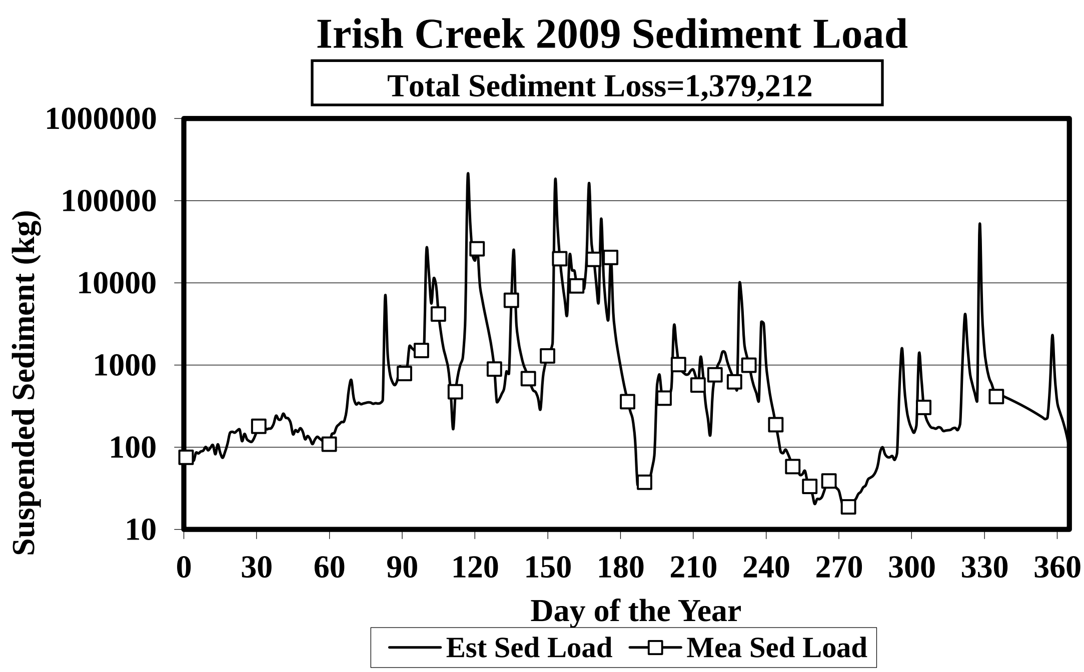

Figure A.12 Sediment loading for 2009

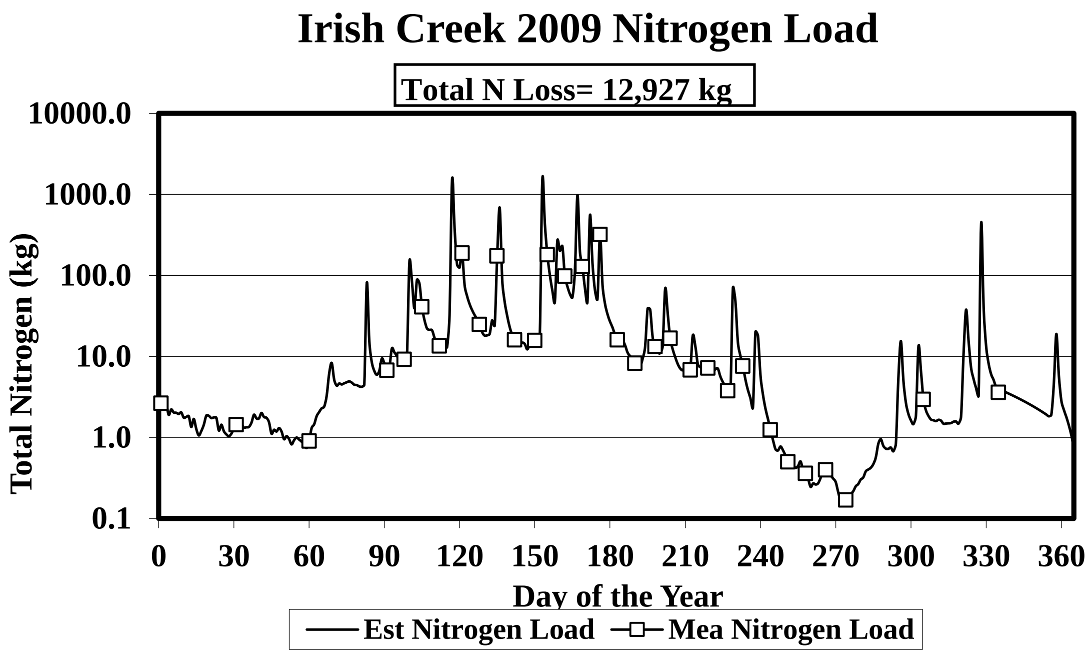

Figure A.13 Total Nitrogen loading for 2009

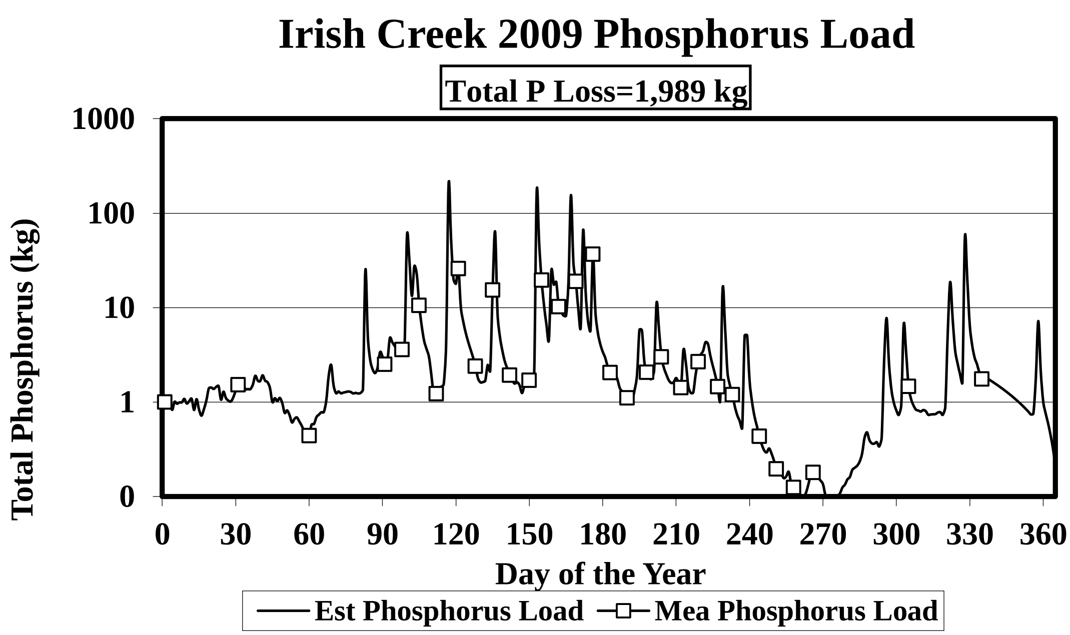

Figure A.14 Total Phosphorus loading for 2009

2010

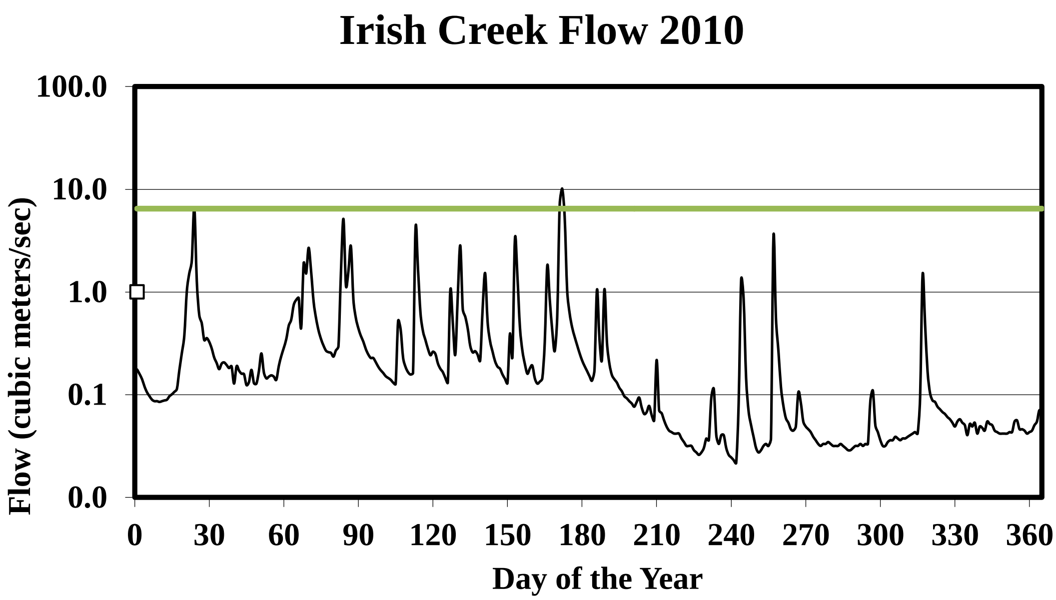

Figure A.15 2010 Irish Creek flow data

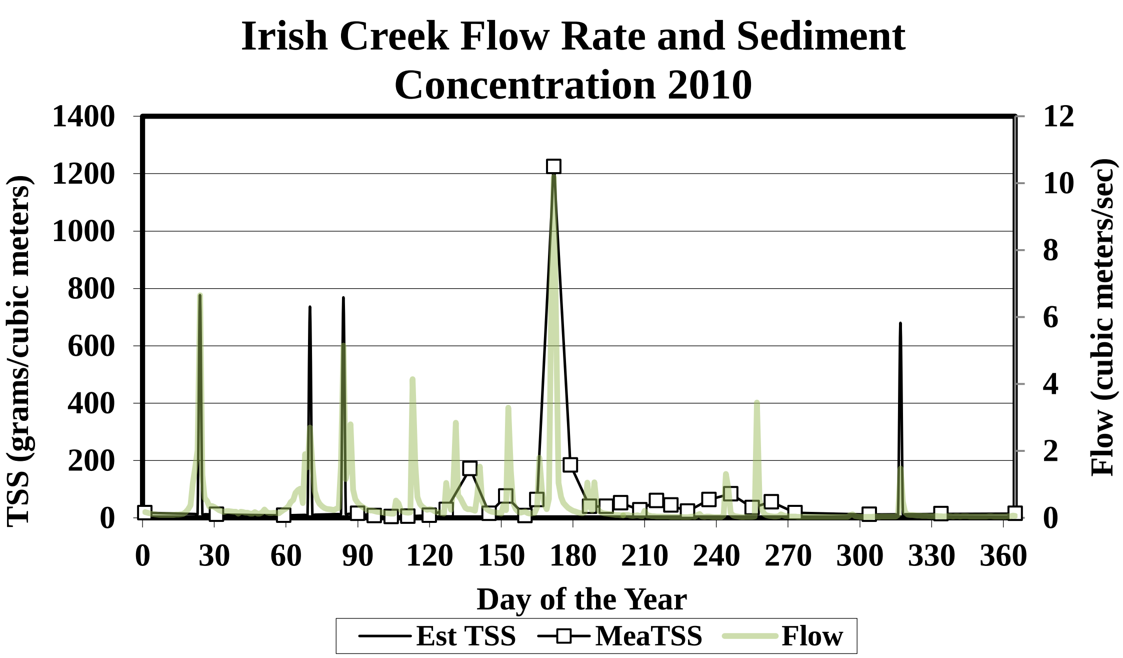

Figure A.16 Flow rates and sediment concentrations for 2010

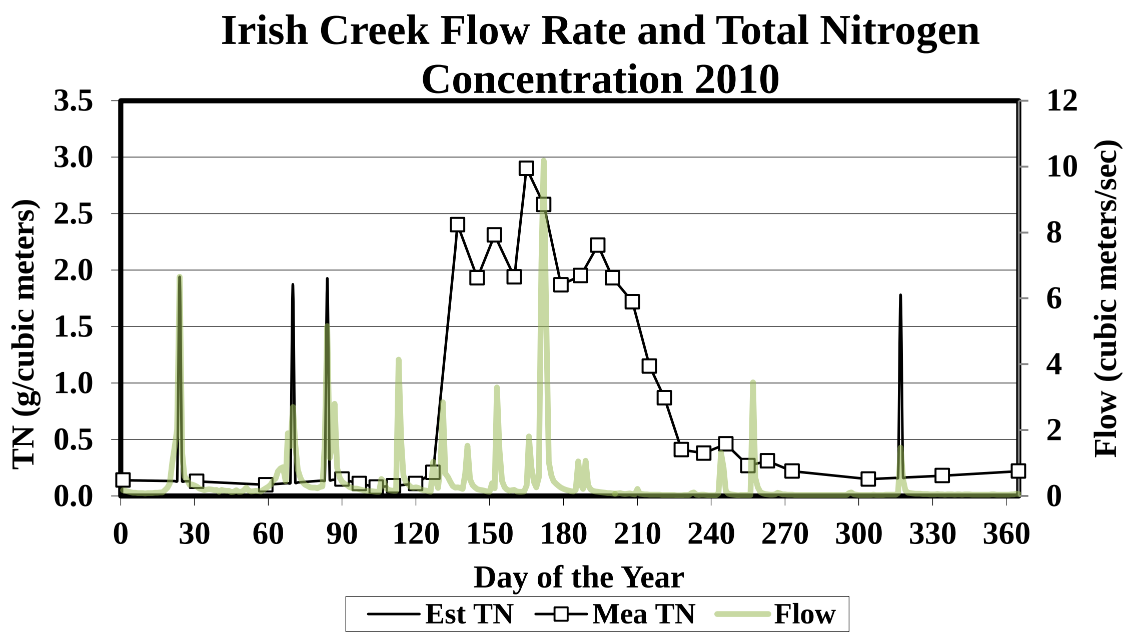

Figure A.17 Flow rates and Total Nitrogen concentrations for 2010

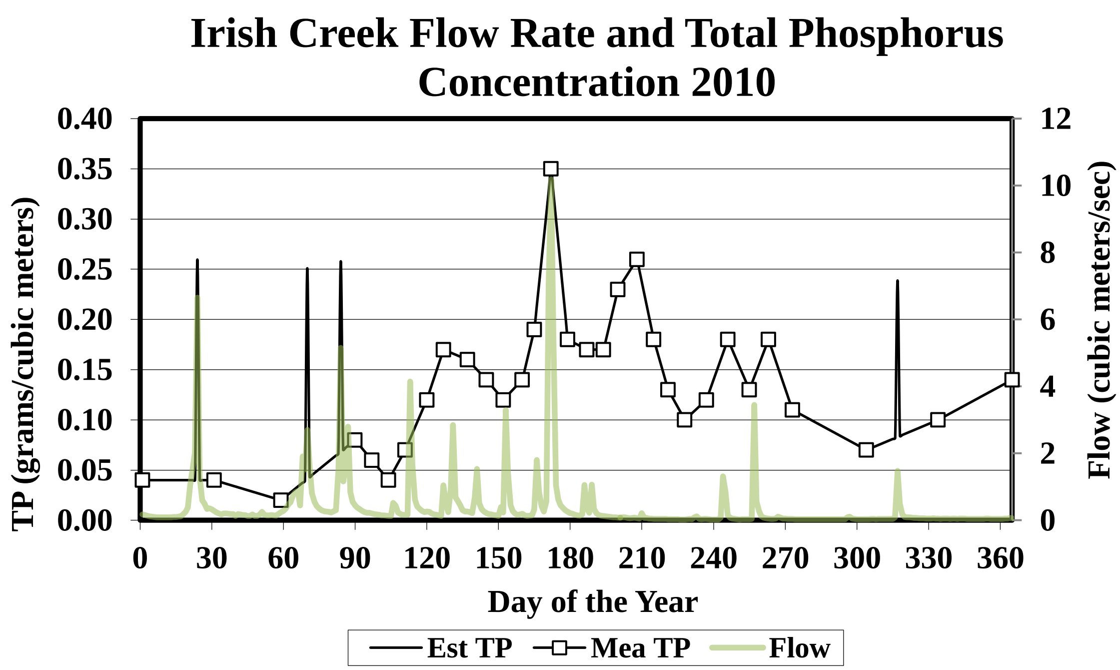

Figure A.18 Flow rates and Total Phosphorus concentrations for 2010

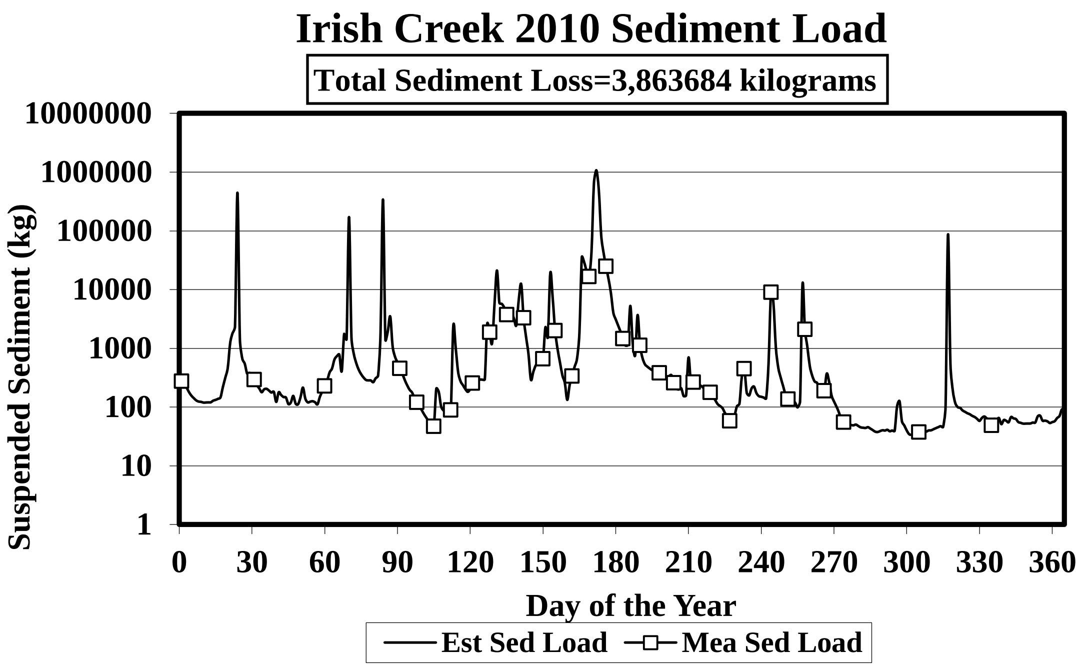

Figure A.19 Sediment loading for 2010

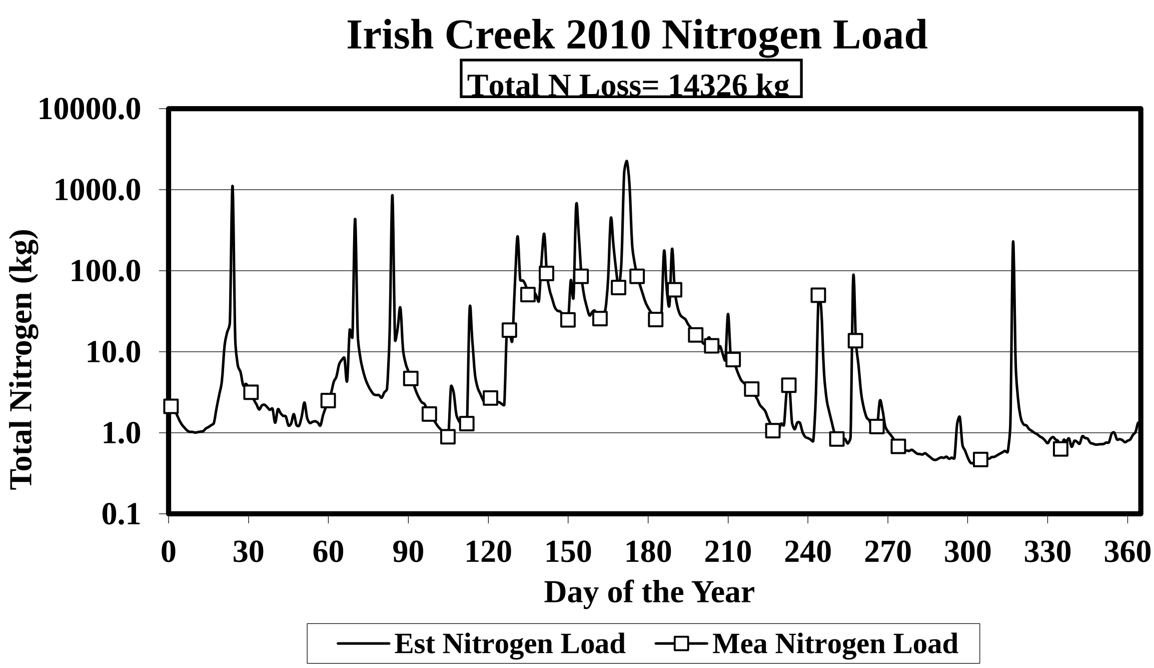

Figure A.20 Total Nitrogen loading for 2010

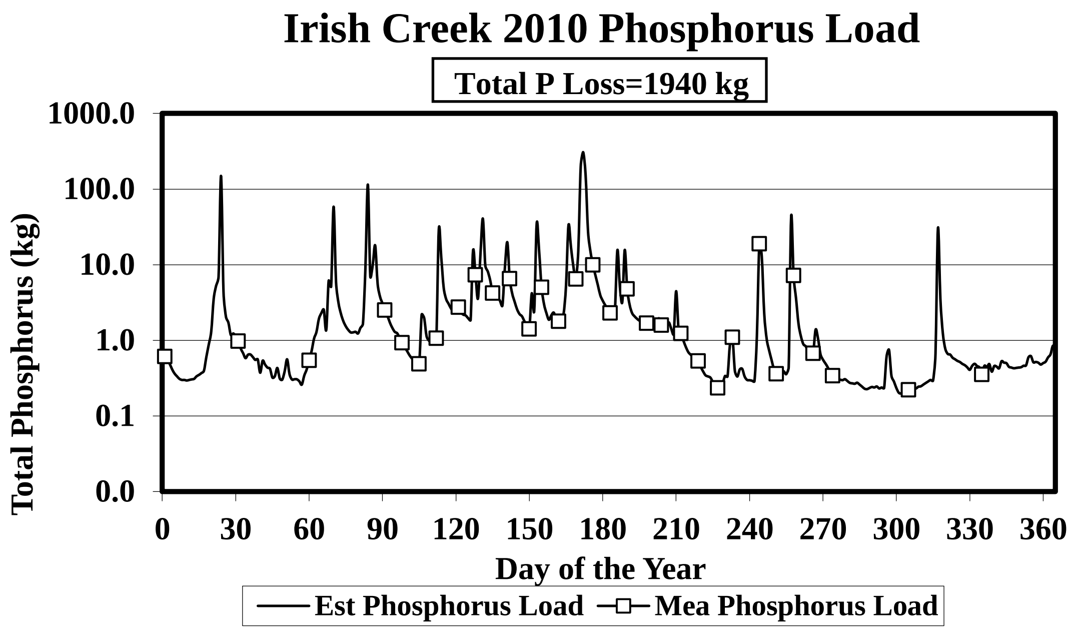

Figure A.21 Total Phosphorus loading for 2010

2011

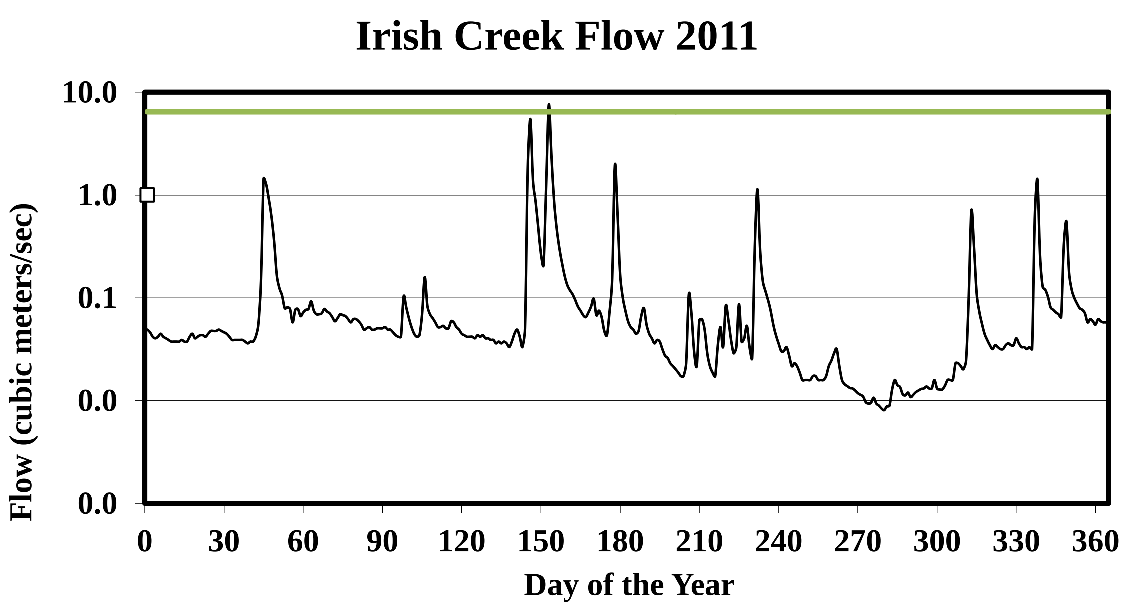

Figure A.22 Irish Creek flow data for 2011

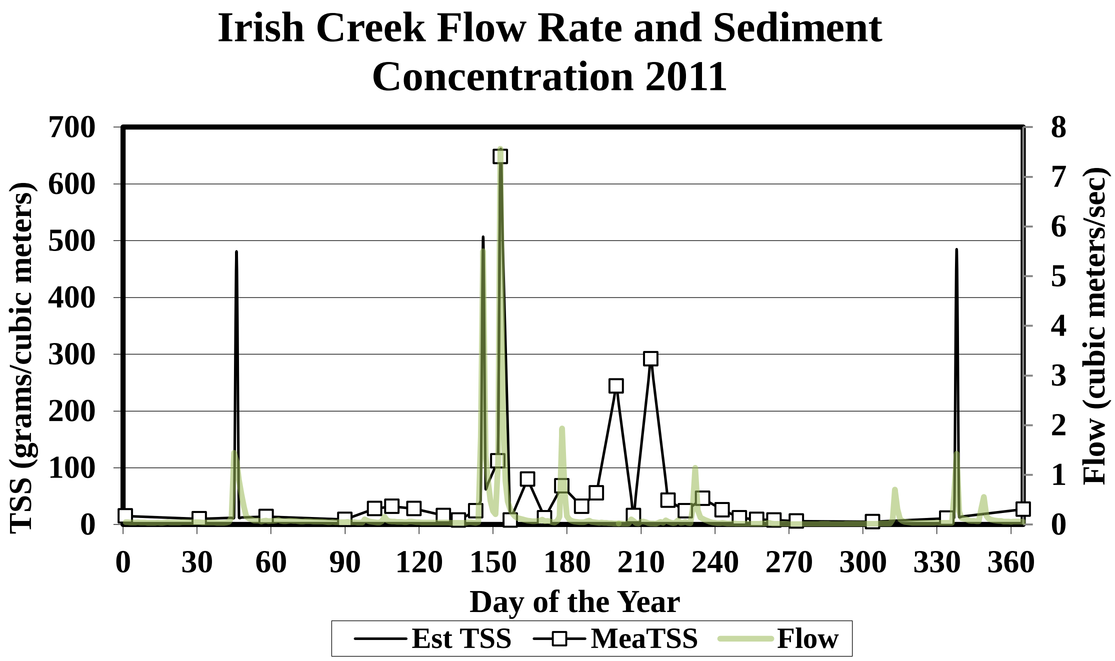

Figure A.23 Flow rates and sediment concentrations for 2011

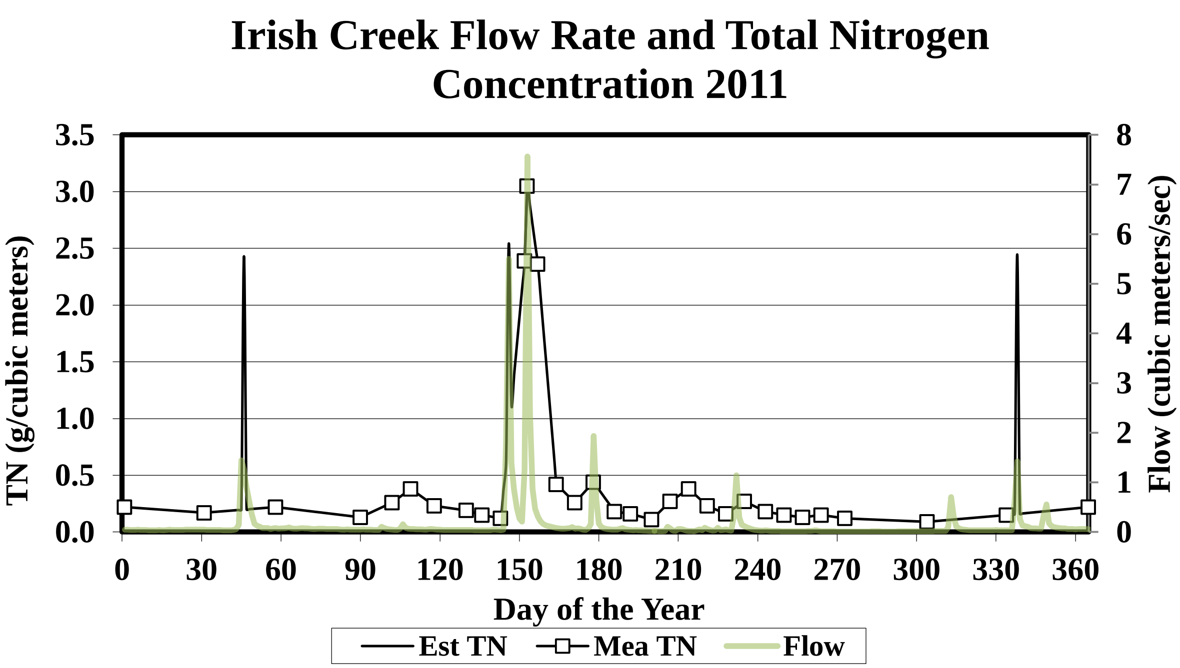

Figure A.24 Flow rates and Total Nitrogen concentrations for 2011

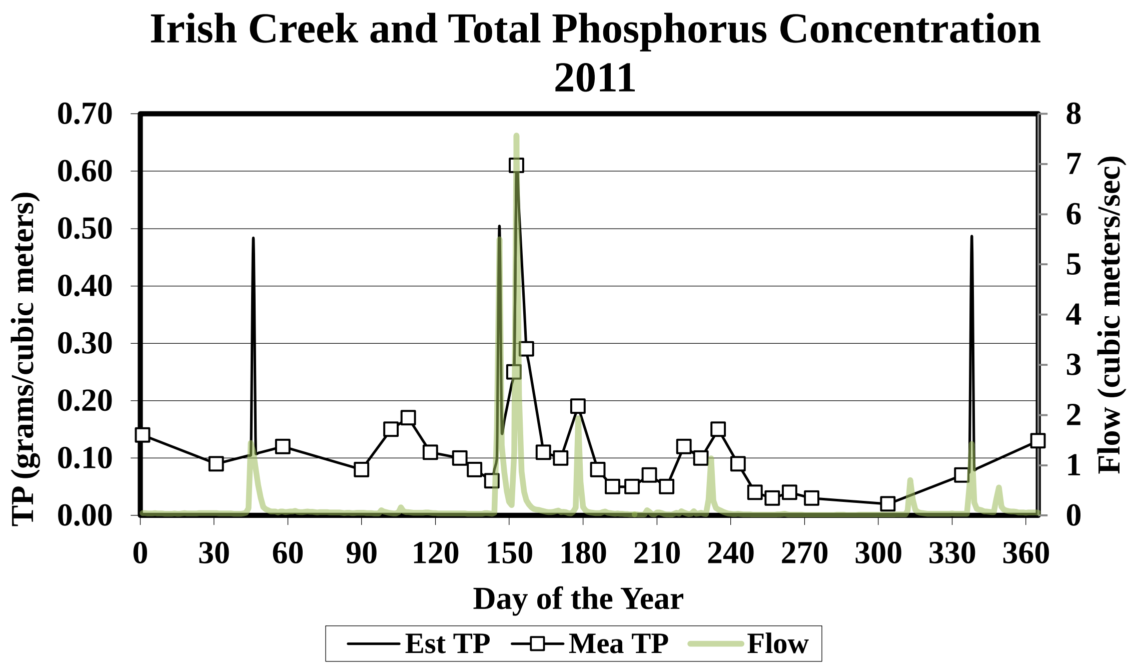

Figure A.25 Flow rates and Total Phosphorus concentrations for 2011

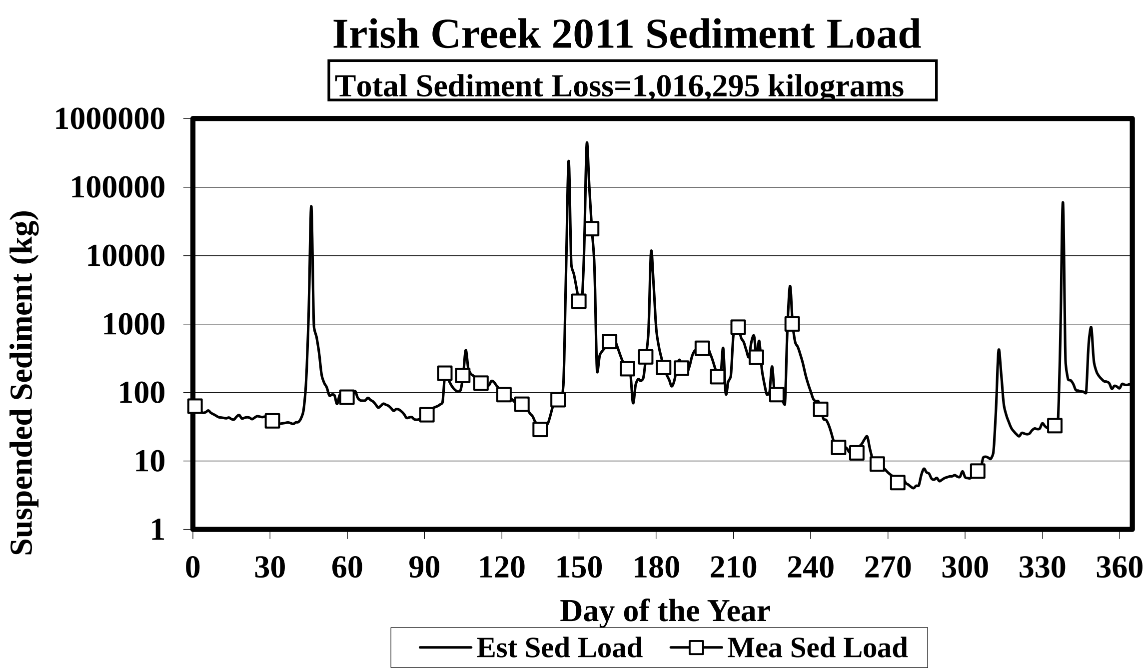

Figure A.26 Sediment loading for 2011

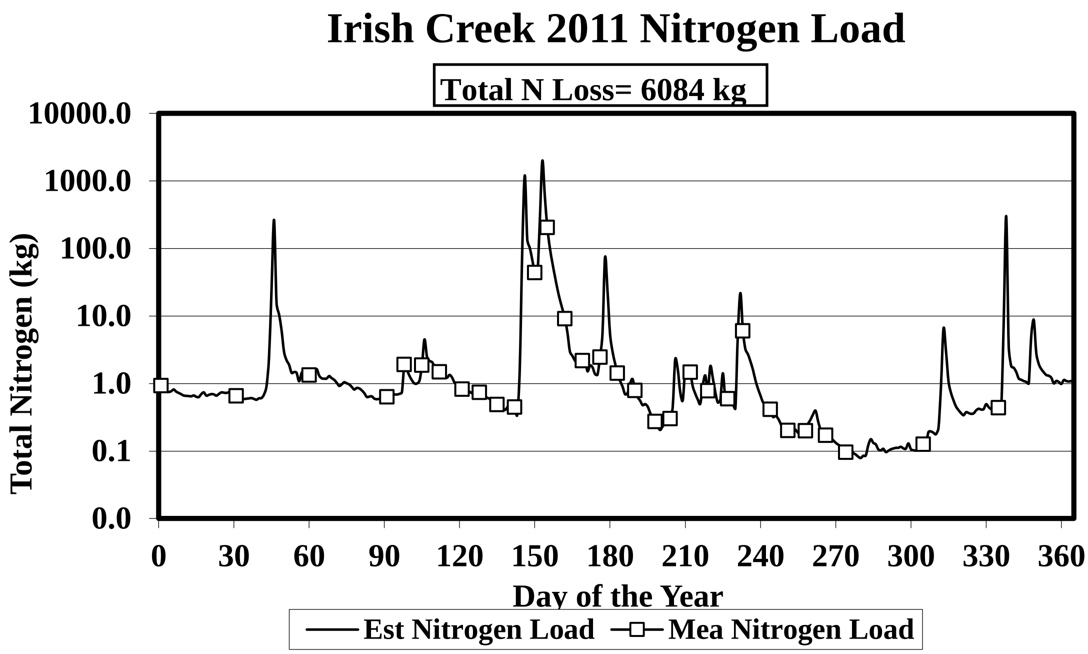

Figure A.27 Total Nitrogen loading for 2011

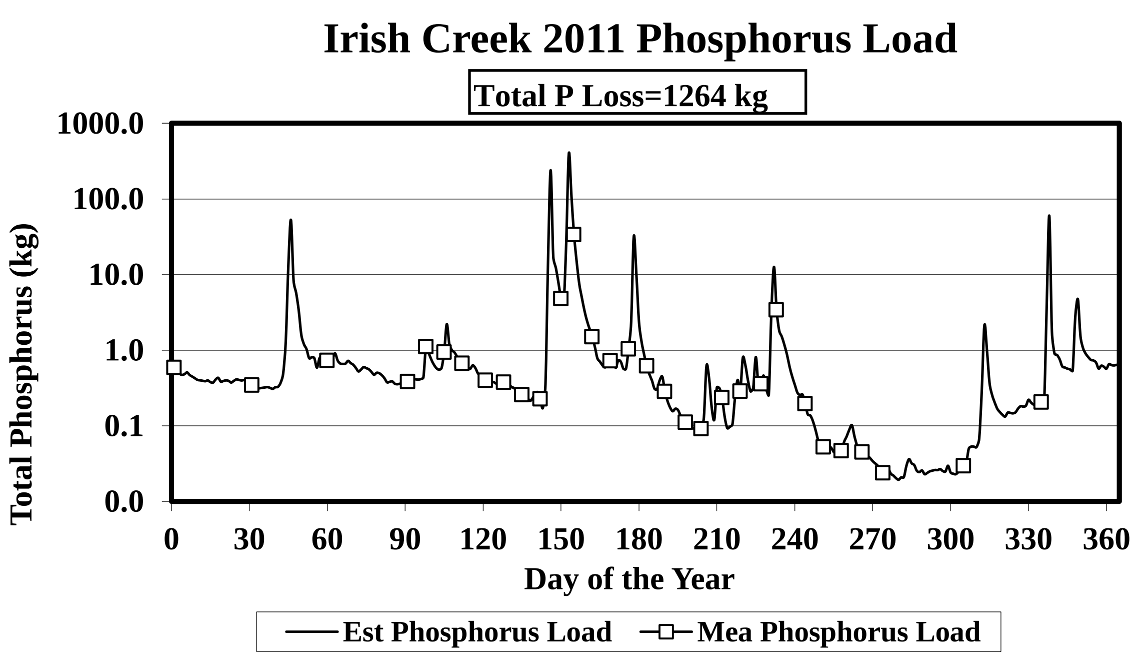

Figure A.28 Total Phosphorus loading for 2011

2012

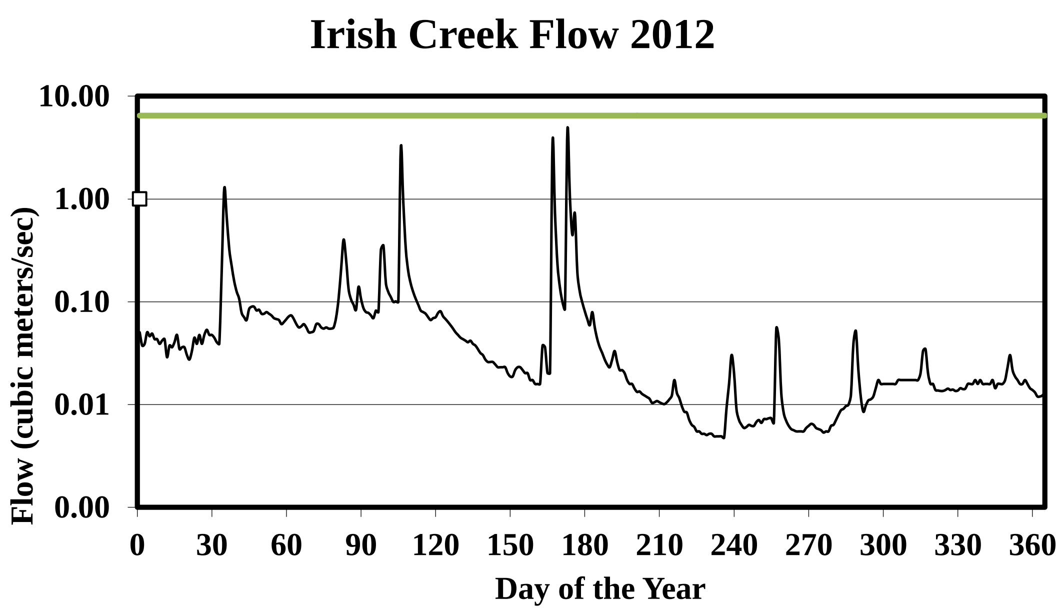

Figure A.29 2012 Irish Creek flow data

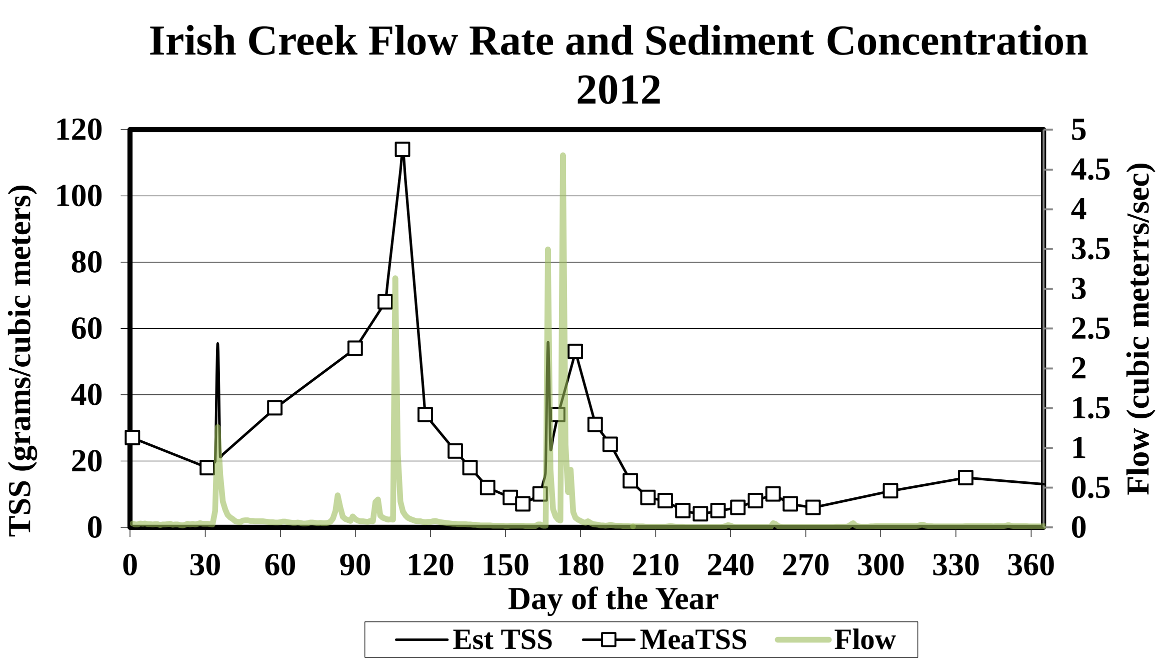

Figure A.30 Flow rates and sediment concentrations for 2012

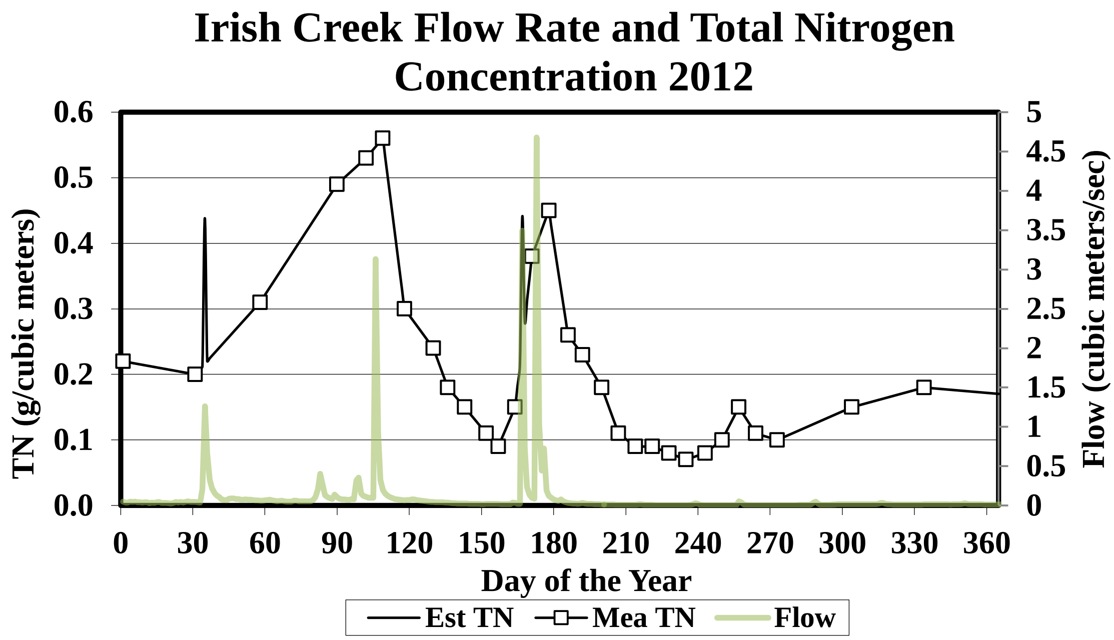

Figure A.31 Flow rates and Total Nitrogen concentrations for 2012

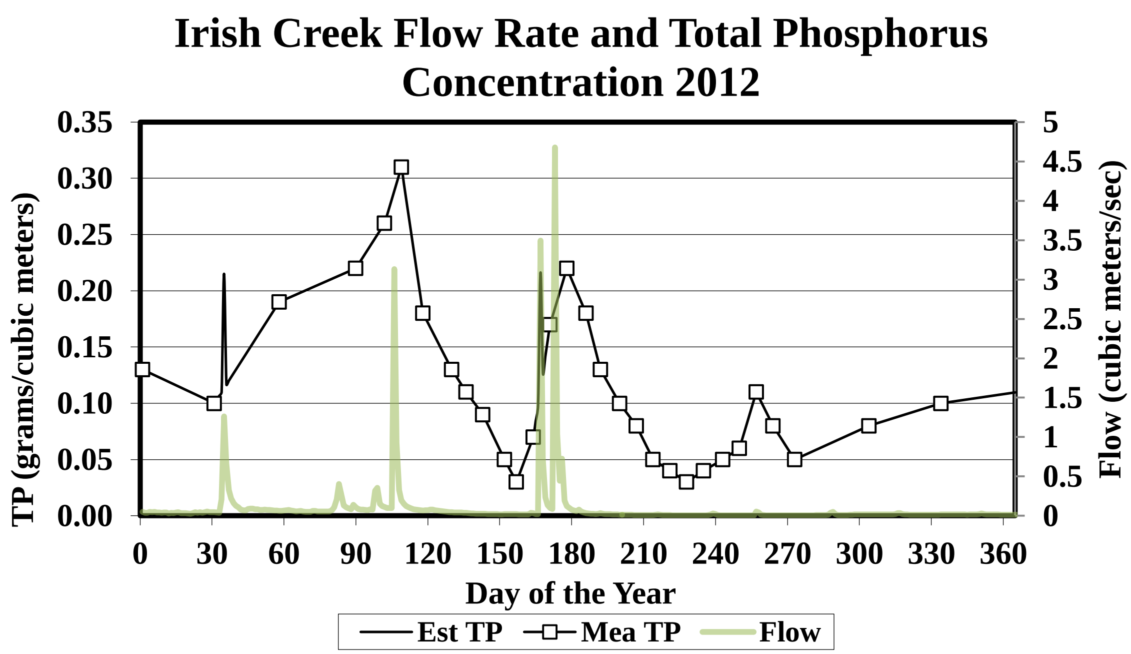

Figure A.32 Flow rates and Total Phosphorus concentrations for 2012

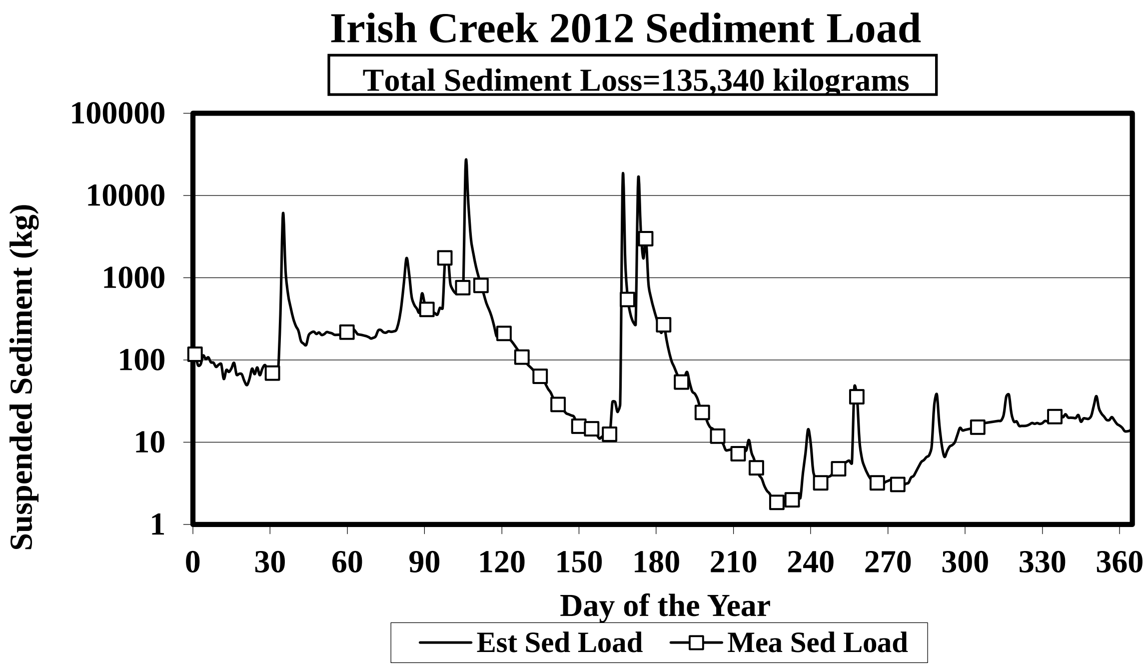

Figure A.33 Sediment loading for 2012

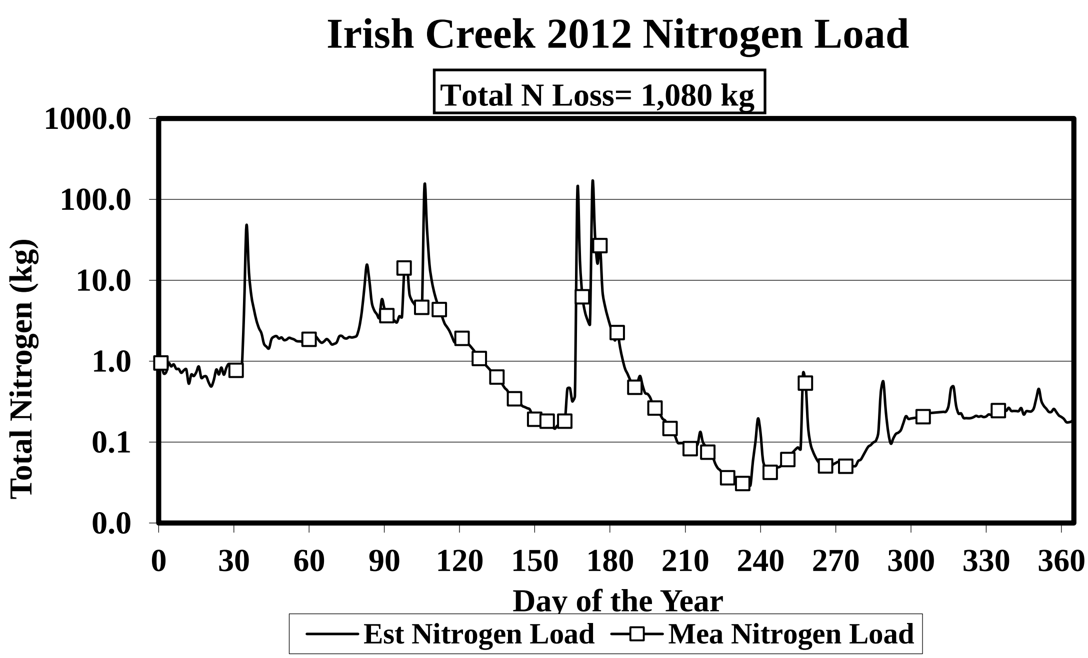

Figure A.34 Total Nitrogen loading for 2012

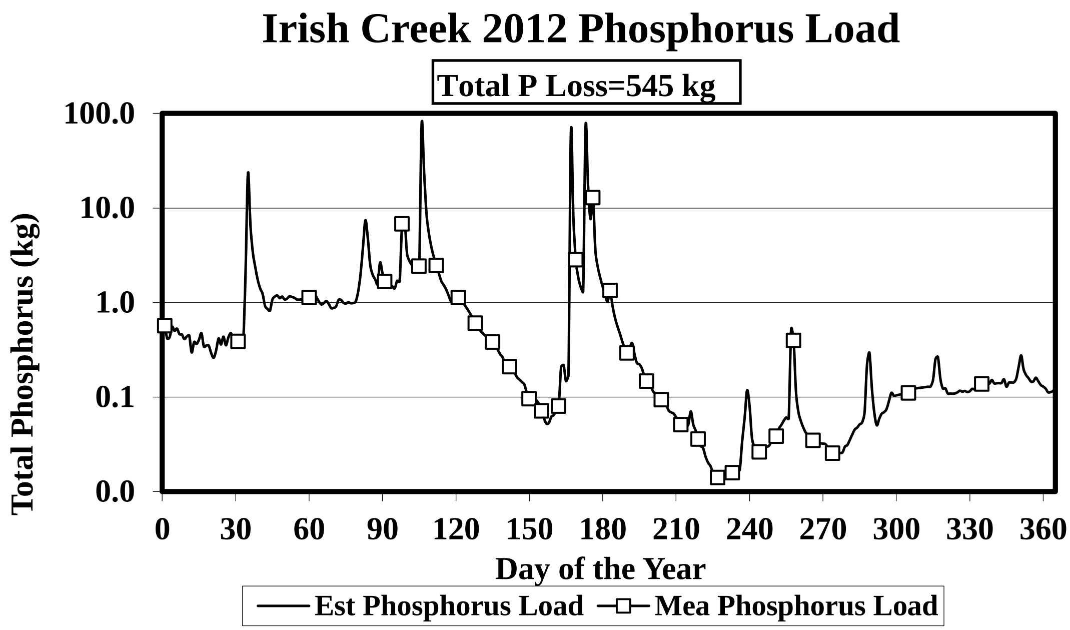

Figure A.35 Total Phosphorus loading for 2012

Correction graphs for missing events (2007-2012)

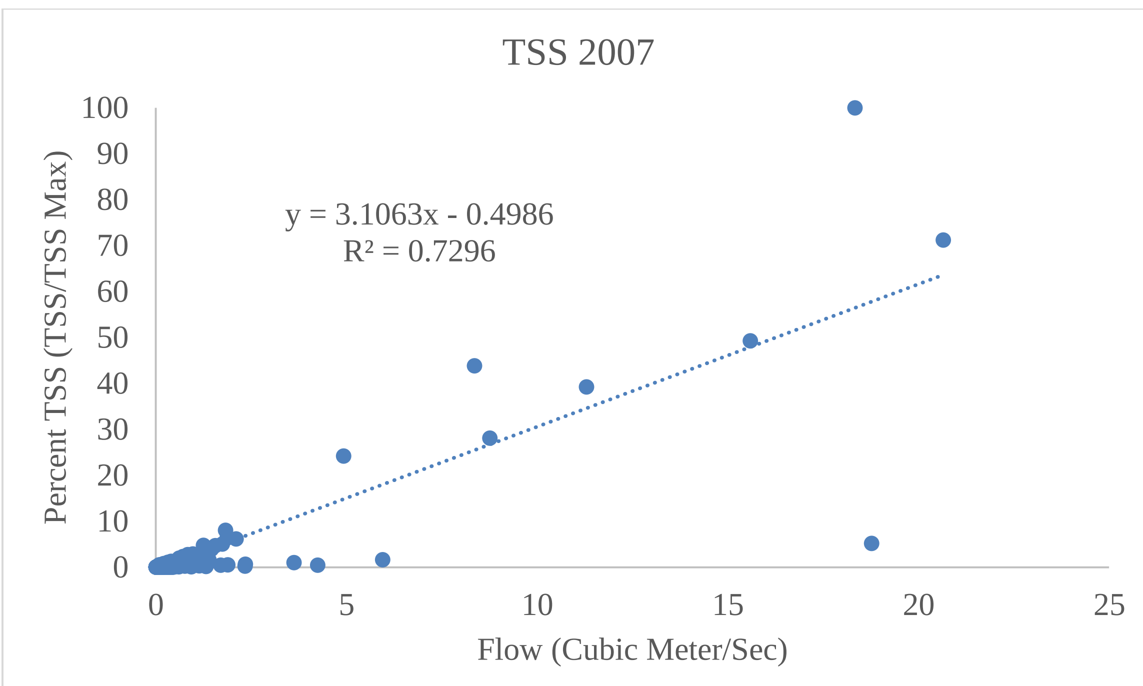

Figure A.36 Load estimation correction graph for TSS 2007

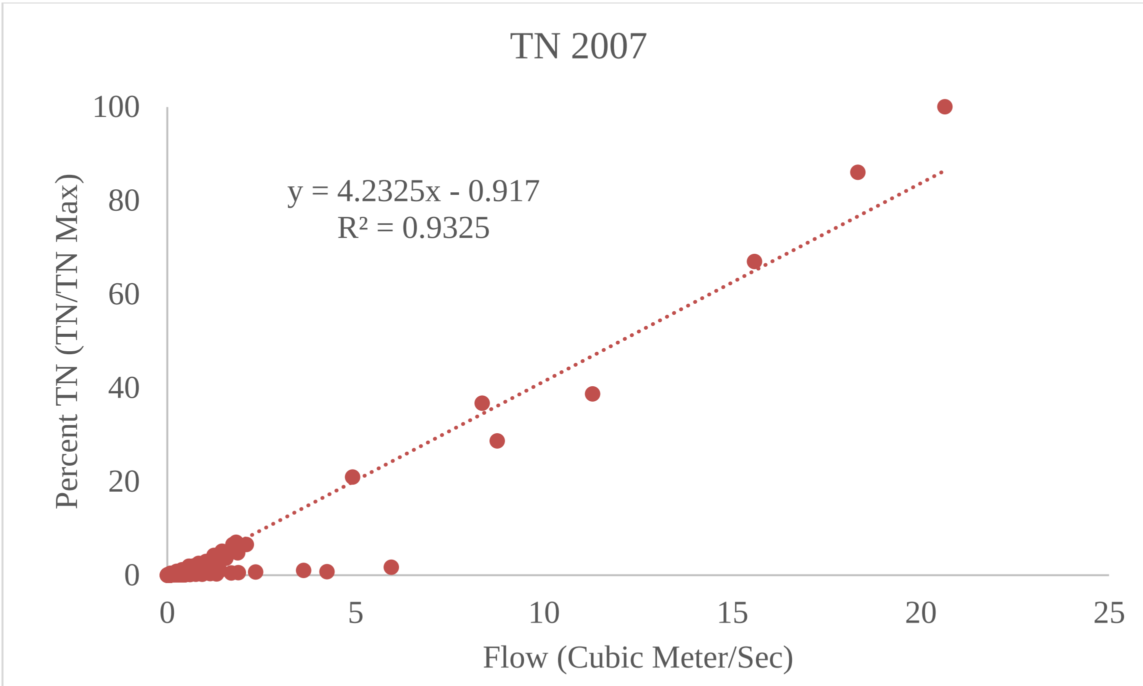

Figure A.37 Load estimation correction graph for TN 2007

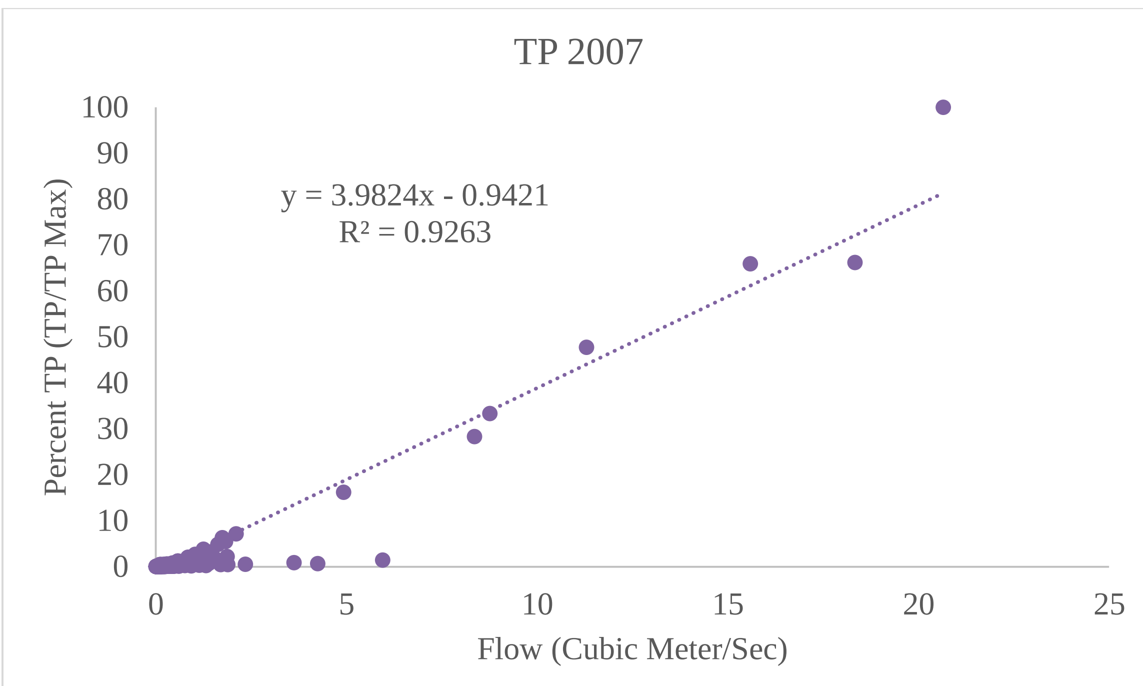

Figure A.38 Load estimation correction graph for TP 2007

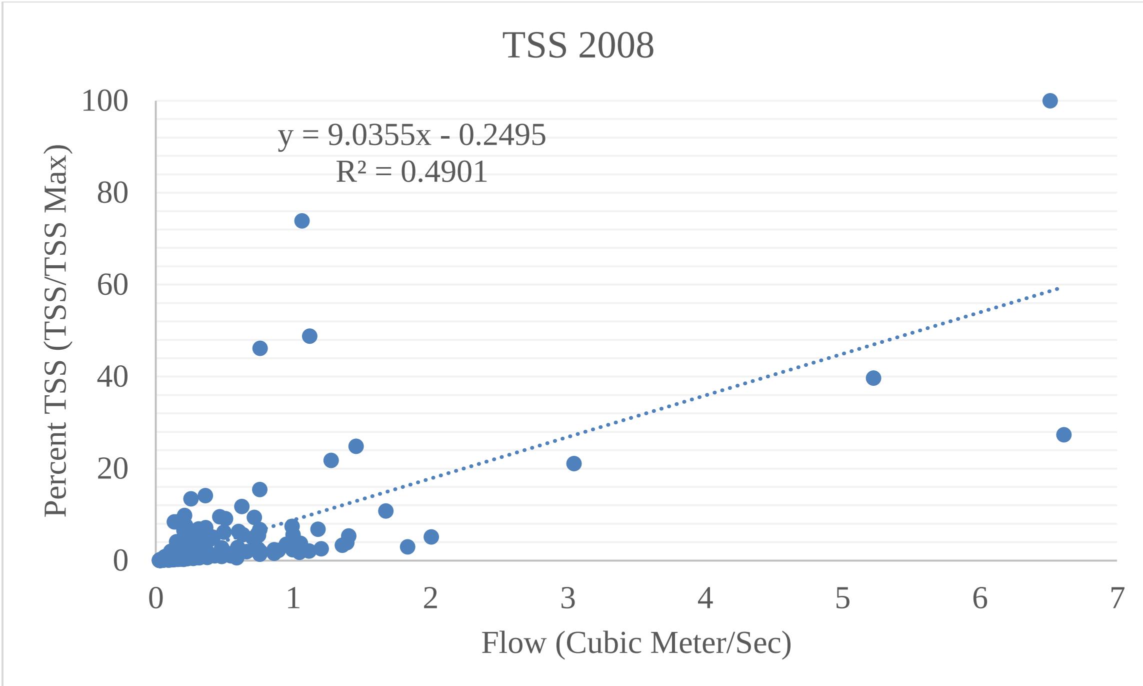

Figure A.39 Load estimation correction graph for TSS 2008

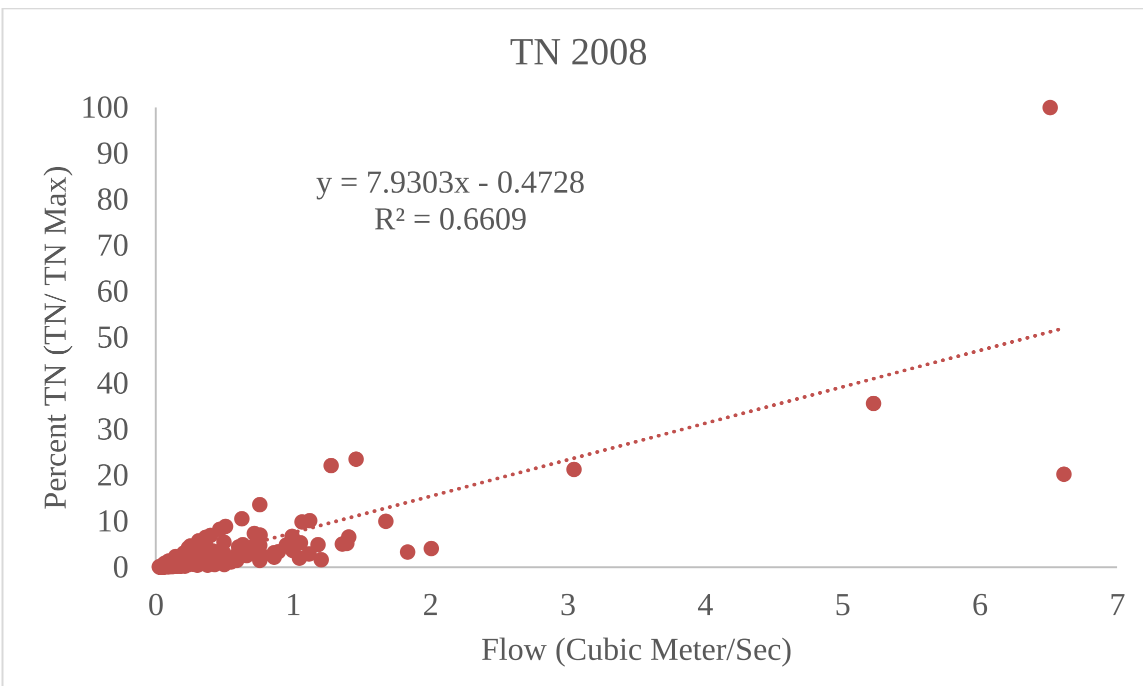

Figure A.40 Load estimation correction graph for TN 2008

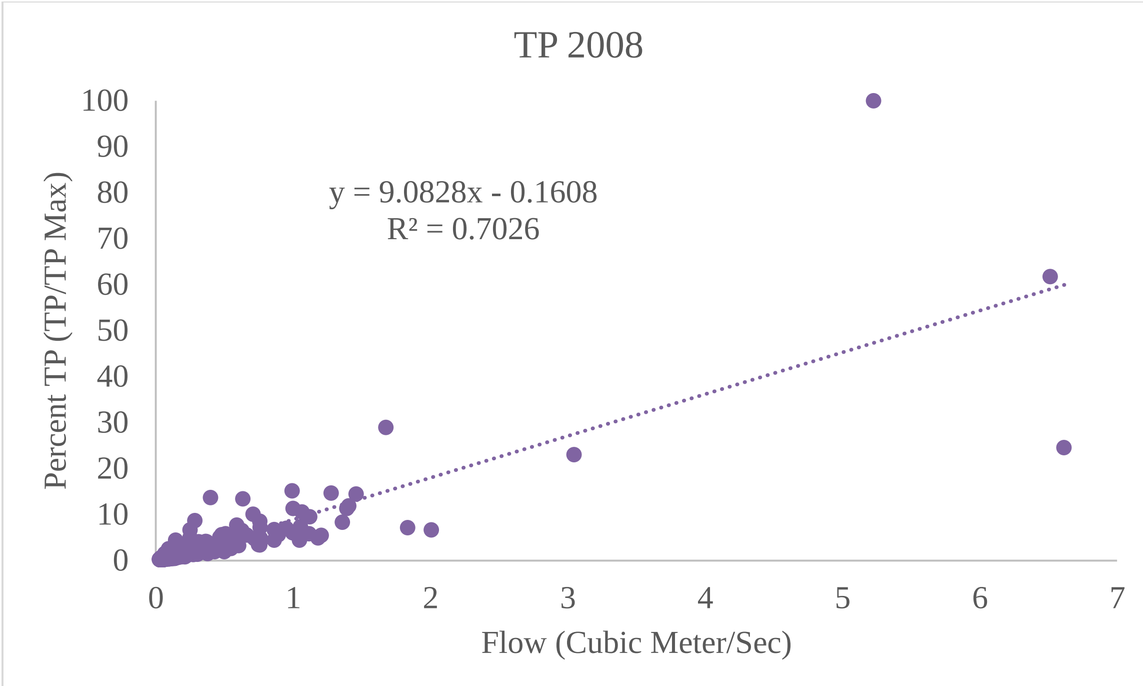

Figure A.41 Load estimation correction graph for TP 2008

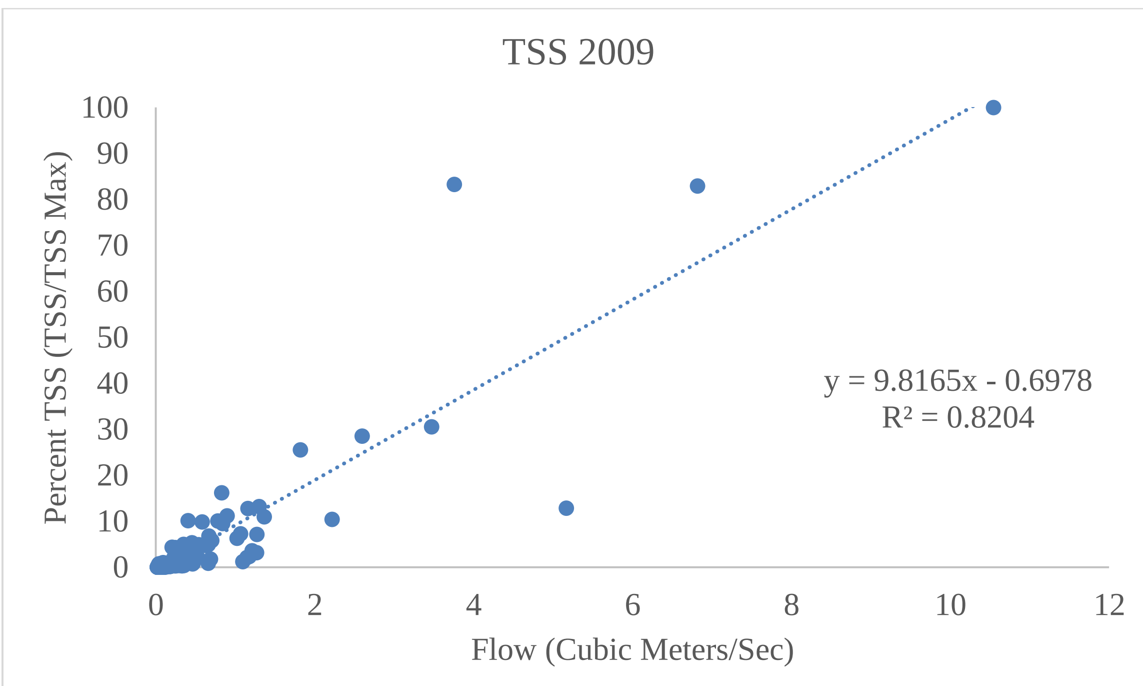

Figure A.42 Load estimation correction graph for TSS 2009

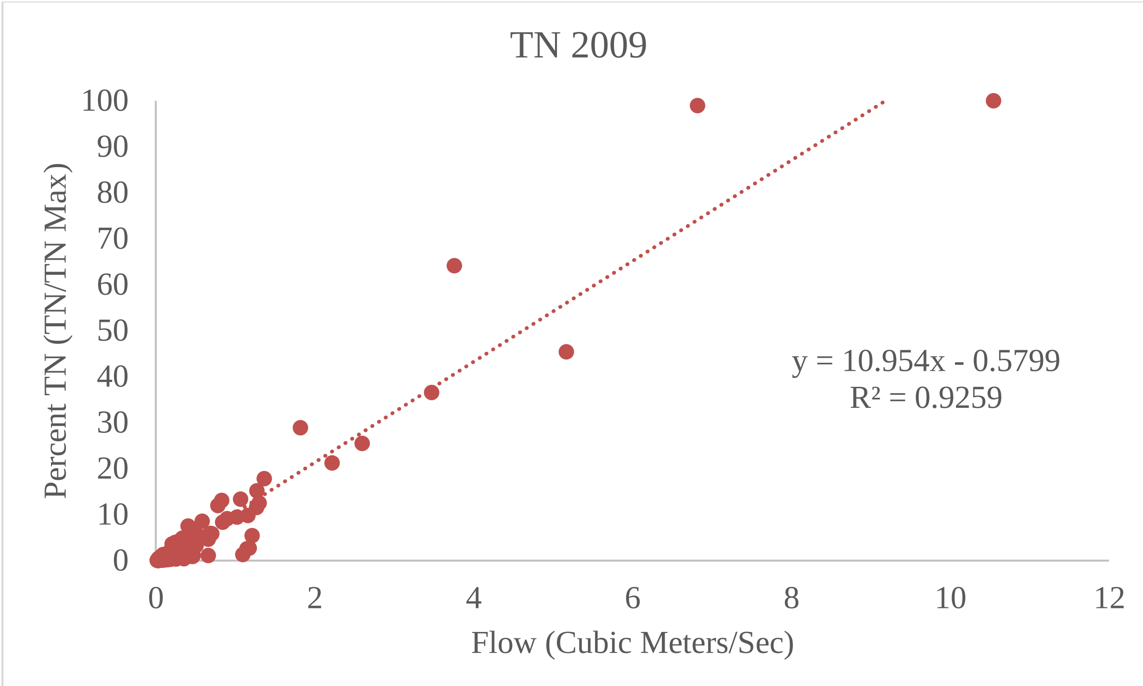

Figure A.43 Load estimation correction graph for TN 2009

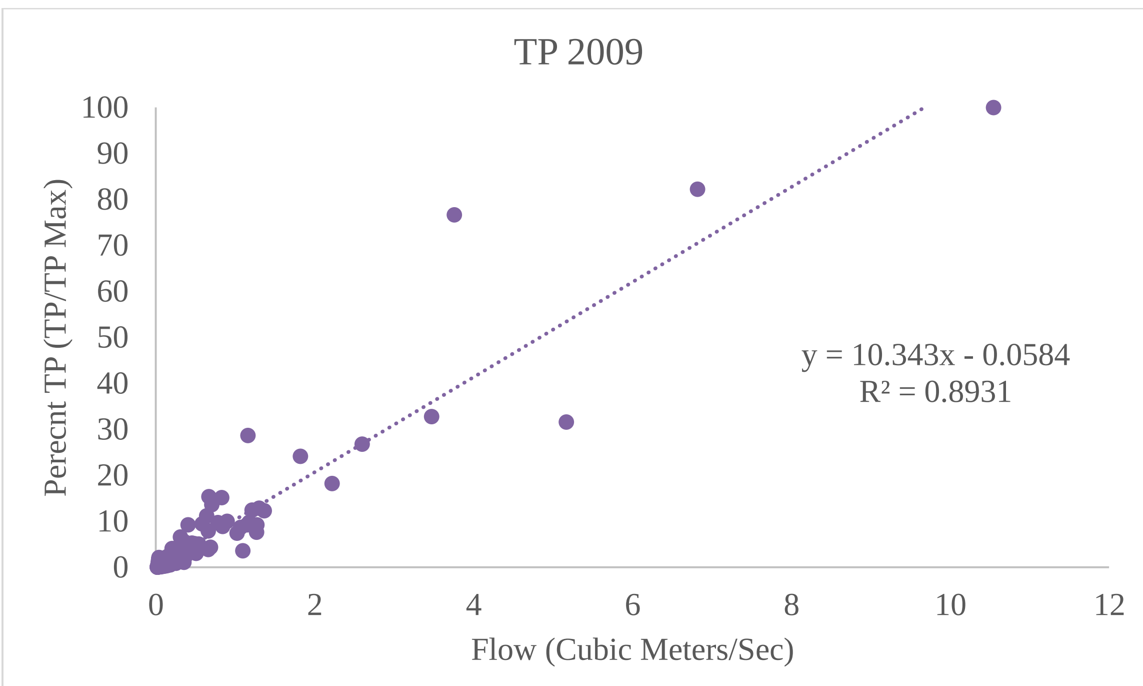

Figure A.44 Load estimation correction graph for TP 2009

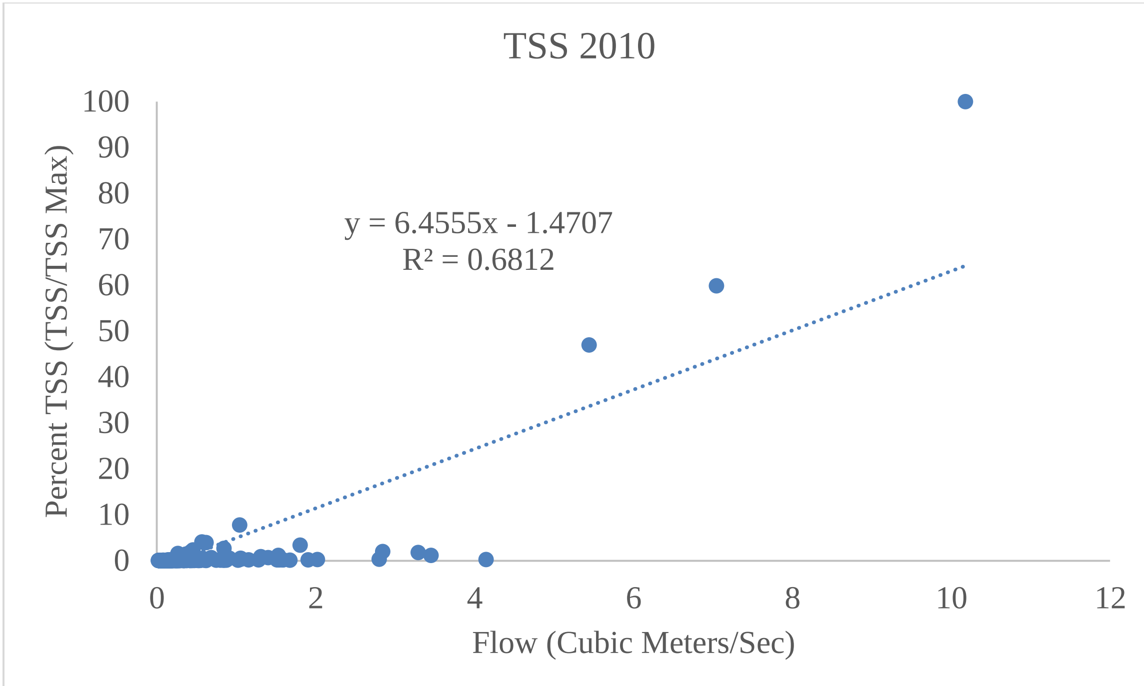

Figure A.45 Load estimation correction graph for TSS 2010

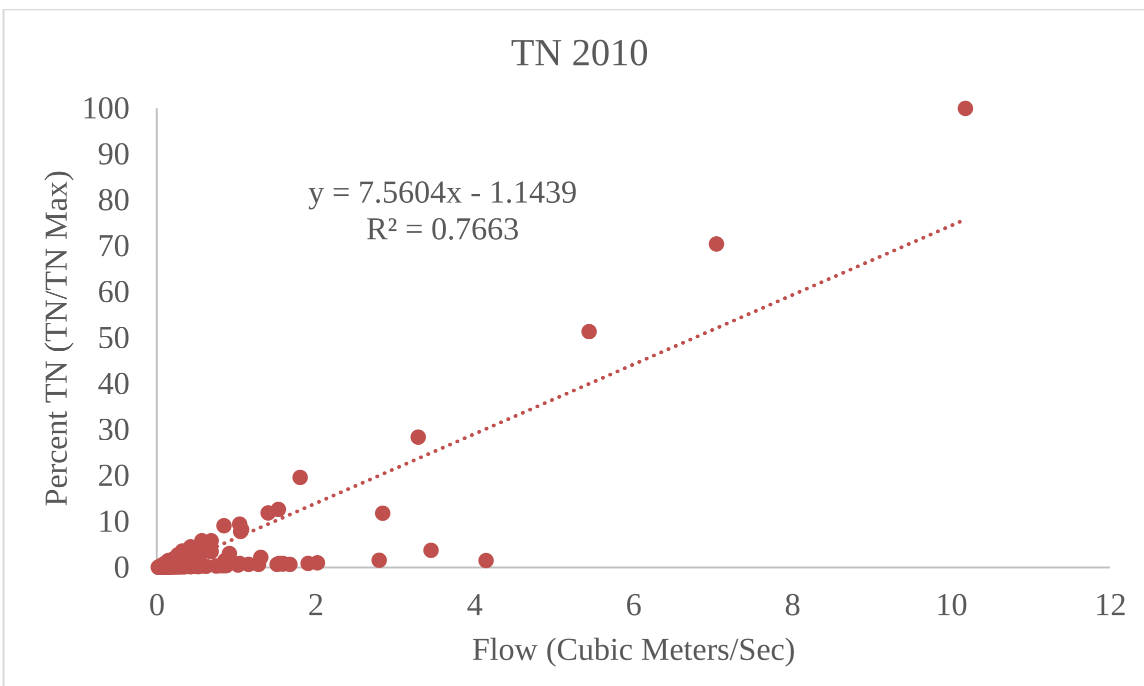

Figure A.46 Load estimation correction graph for TN 2010

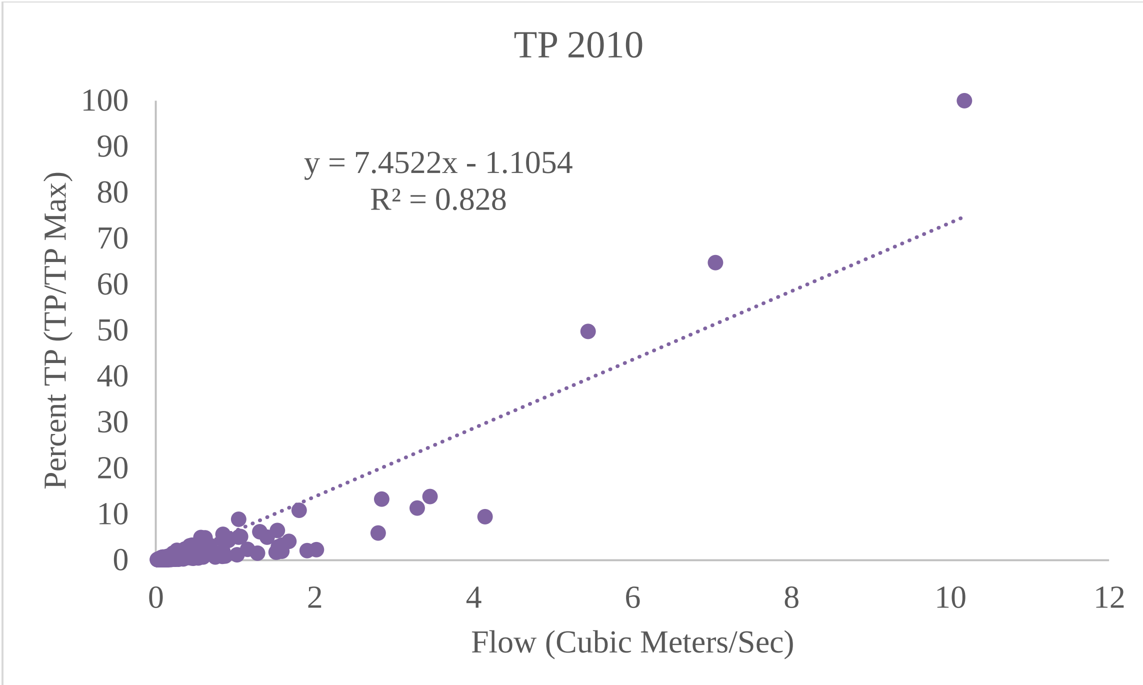

Figure A.47 Load estimation correction graph for TP 2010

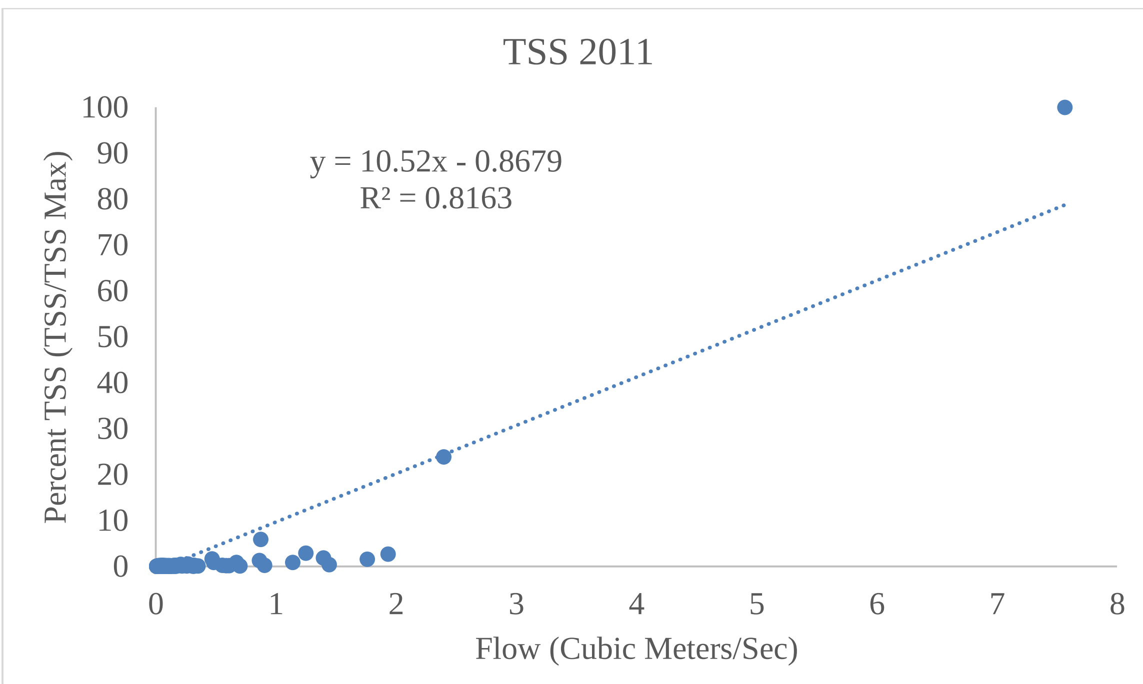

Figure A.48 Load estimation correction graph for TSS 2011

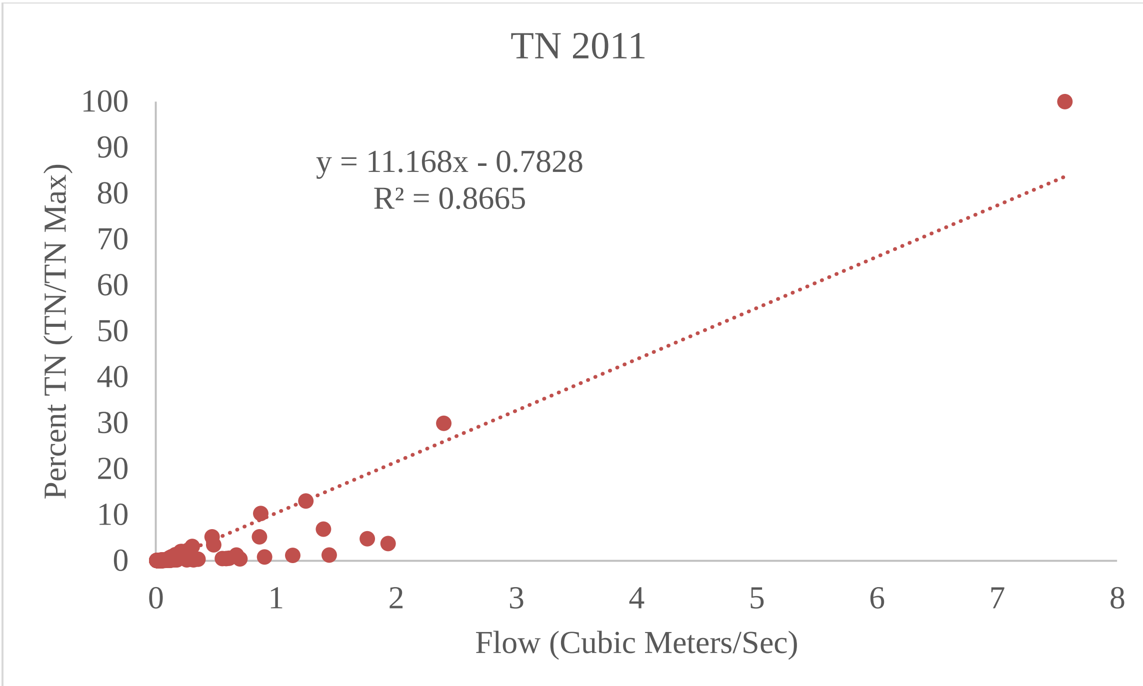

Figure A.49 Load estimation correction graph for TN 2011

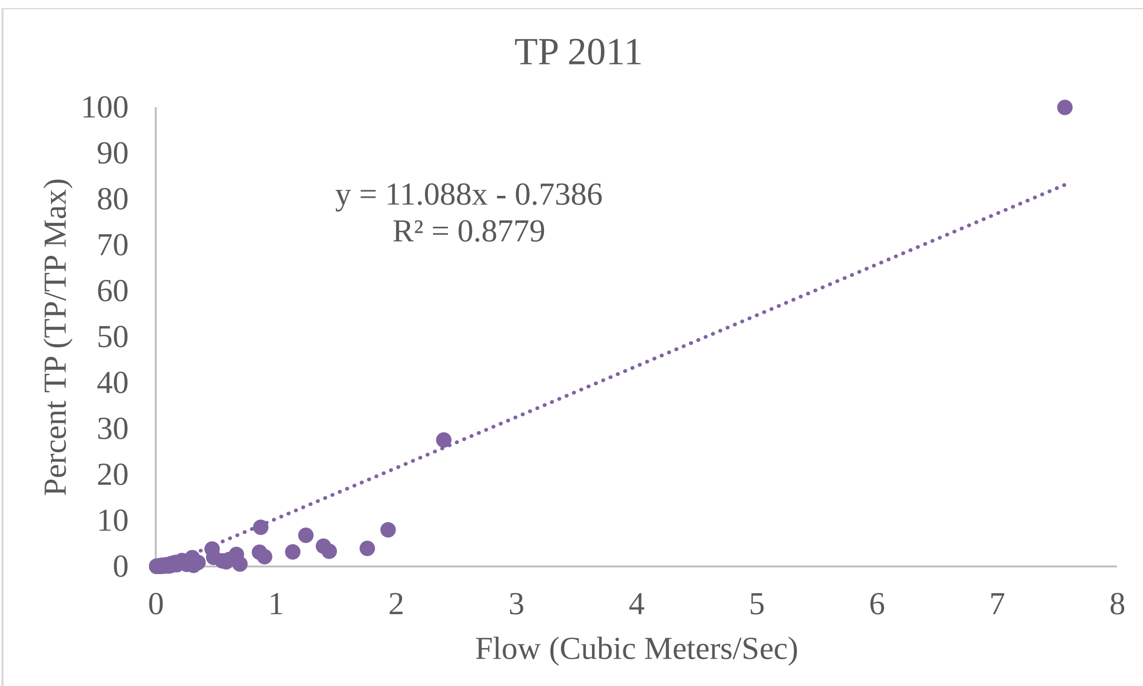

Figure A.50 Load estimation correction graph for TP 2011

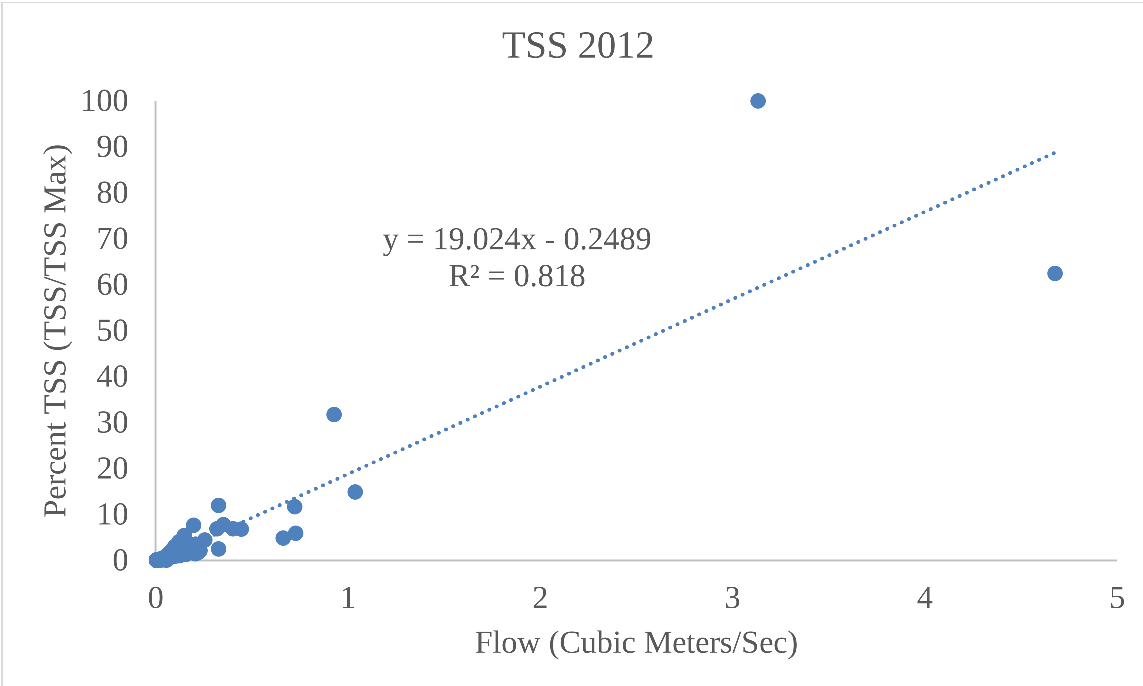

Figure A.51 Load estimation correction graph for TSS 2012

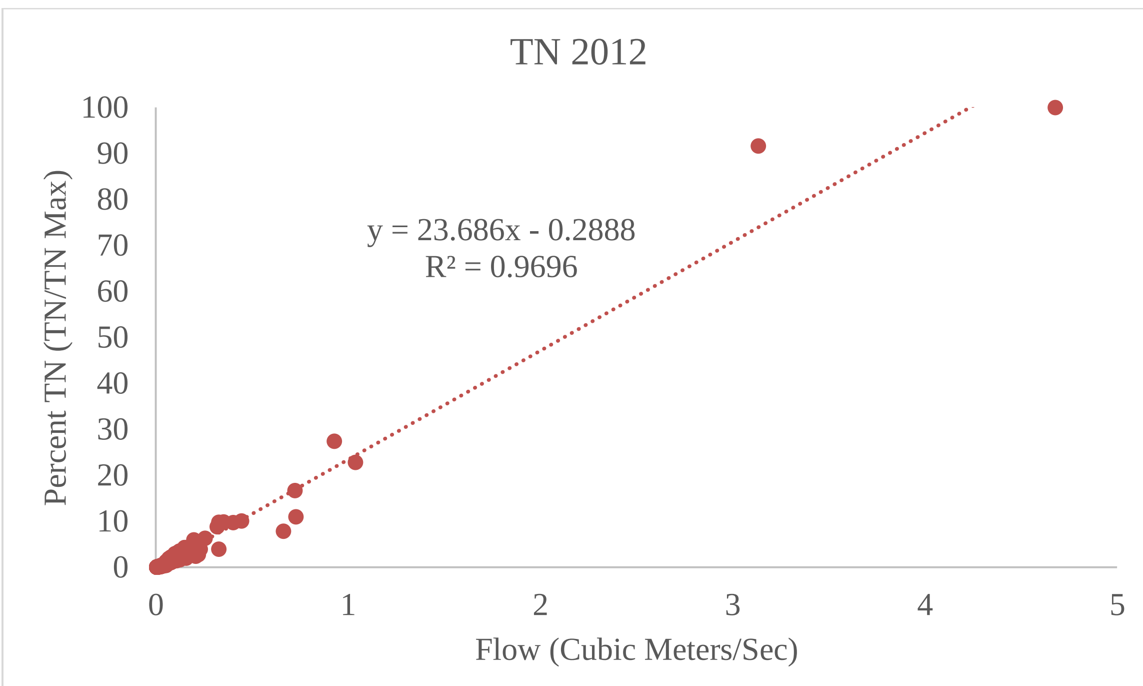

Figure A.52 Load estimation correction graph for TN 2012

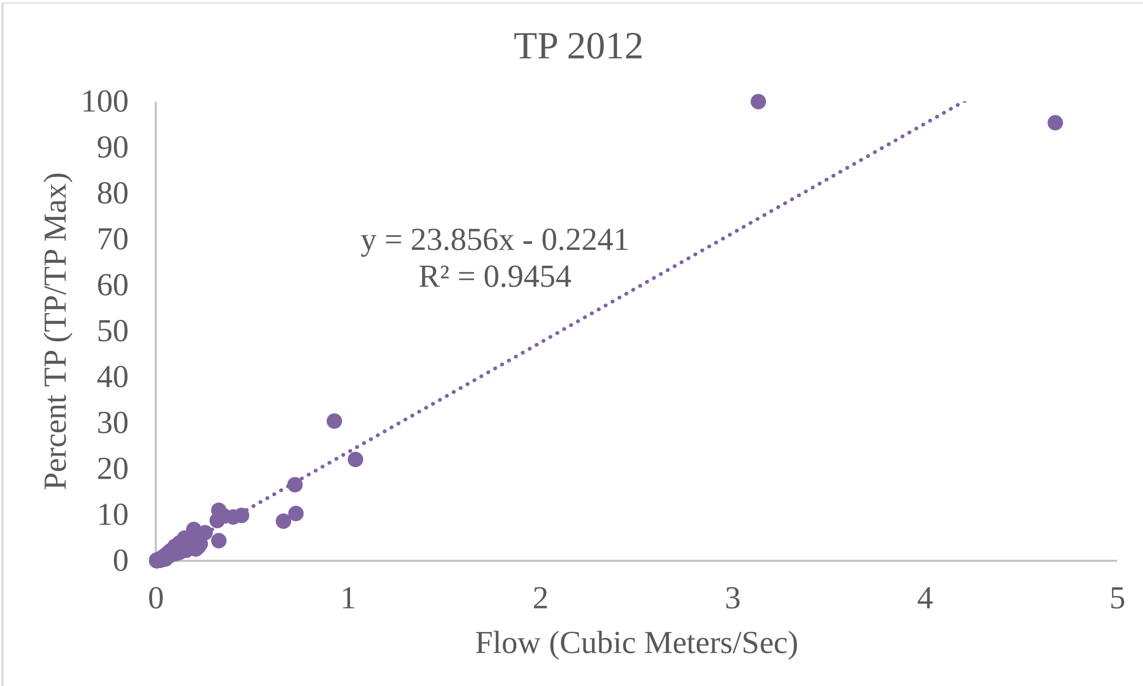

Figure A.53 Load estimation correction graph for TP 2012

Survey Data Profile

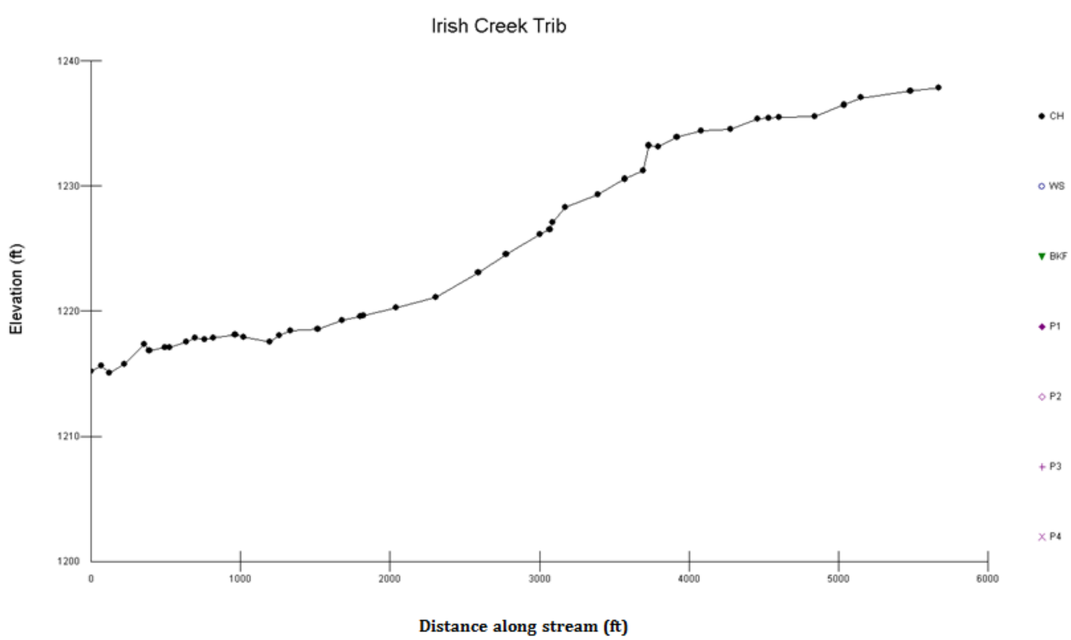

Figure A.54 Irish Creek survey data profile