2016

Stream Energy Impacting Sediment Transport through Low-Gradient Agricultural Streams

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Recommended Citation

Pryor, Paula Jane, "Stream Energy Impacting Sediment Transport through Low-Gradient Agricultural Streams" (2016). *Theses and Dissertations*. 539.
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STREAM ENERGY IMPACTING SEDIMENT TRANSPORT THROUGH LOW-GRADIENT AGRICULTURAL STREAMS

Paula J. Pryor

78 Pages

Water quality can be severely impacted by increased sediment transport, particularly agriculturally-dominated systems like those found in central Illinois. Many low-gradient sediment studies focus on the fine material transported in suspension. However, coarse-material transport can be equally important for understanding sediment loads to surficial reservoirs for local drinking water. To address a general gap in knowledge of coarse-sediment transport through agricultural streams, seasonal changes and watershed differences in sediment transport were examined in a low-gradient system. This was accomplished through the installation of bedload traps, scour-fill markers, and bank erosion pins at two streams, Six Mile Creek and Money Creek located in different, but geographically similar, watersheds. After record-breaking amounts of precipitation in the early summer, it was found the two streams transported different mass of sediment and different grain sizes during the spring and summer. Six Mile Creek transported large grains (maximum d84 = 17.25 mm) while Money Creek was dominated by finer material (d84 = 3.35 mm). Overall, the two watersheds have different slopes and areas, and one stream cuts through a ground moraine and the other an end moraine. Changes in slope, parent material, and watershed area may result in dramatically different sediment transport in two geographically similar watersheds. In a system where fine material erosion and transport is considered the dominant process, this study shows how important bedload transport can be to sediment transport models.

KEYWORDS: Agricultural, bedload, low-gradient, sediment transport

STREAM ENERGY IMPACTING SEDIMENT TRANSPORT THROUGH LOW-GRADIENT AGRICULTURAL STREAMS

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A Thesis Submitted in Partial
Fulfillment of the Requirements
for the Degree of

MASTER OF SCIENCE

Department of Geography-Geology

ILLINOIS STATE UNIVERSITY

2016

STREAM ENERGY IMPACTING SEDIMENT TRANSPORT THROUGH LOW-GRADIENT AGRICULTURAL STREAMS

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ACKNOWLEDGMENTS

I would like to thank my committee for their time, patience, and comments throughout the entire project. My chair, Dr. Catherine O'Reilly, was pivotal in helping me meet my aggressive timeline goals and ensuring a quality end product. I would also like to thank the City of Bloomington, especially Mr. Rick Twait, for support and assistance. Much of this story would be incomplete without the efforts of the summer sampling team, including Audra Hanks, Tyler Rothschild, Allyson Hanlin, and Victoria Heath. During my absence in the summer they collected data from the streams and it proved to be well worth the effort and time. The thanks extends to all of the people who have helped me in the field and lab throughout this project, as well as the Research Group for their draft comments and edits. Lastly, I would like to thank my friends and family for their support and love throughout my tenure as a graduate student. Countless times they have served as sounding boards for my problems, and this accomplishment would have been a lot more difficult without their help. Thank you all.

P. J. P.

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CHAPTER I

INTRODUCTION

Sediment transport processes carry great implications for surficial water quality. In agricultural settings, soil lost from fields or from lateral bank migration is dramatically increasing due to farming practices and changing climates (Montgomery, 2007). Streams are the initial recipients of the increased sediment loads, which can negatively impact fish (Minella et al., 2008) and microbes (Fraley et al., 2009; Wildhaber et al., 2012). Over time, artificial reservoirs used for potable water and recreation can be filled in with increased sediment (Graf et al., 2010; Stall et al., 1958). Increased sedimentation is one of the common causes of impaired stream quality (USEPA, 2000). Previous studies have focused on the transport of fine-grained sediment, but not necessarily on sediment moving as bedload.

In low-gradient alluvial systems, bedload transport is not considered a significant factor due to the low energy nature of the streams. Bedload studies are commonly performed in alpine, high-gradient streams where the energy can mobilize particles with median grain sizes exceeding 50mm (Wang and Zhang, 2012). Bedload transport through low-gradient systems is not commonly found, but a study in Maine showed that a stream with slope 0.6% averaged grain sizes of 5mm, or fine pebbles (Barrier et al., 2015). Bedload studies in low-gradient karst conduits reveal transport of 8.3mm (d50) and 18.4mm (d85) during bankfull conditions (Dogwiler and Wicks, 2004). Peterson et al.

(2008) studied bedload in a low-gradient agricultural system and found that by mass, the amount of bedload moved is greater than alpine areas because smaller particles are easier to entrain. In alpine areas, the bedload transport is largely influenced by the stream gradient. Spatially, minor topographic differences and changes to slope can enhance sediment transport dramatically (Fox and Gibson, 2010; Miller et al., 1993). The slope is not the only driver for bedload transport, the source of sediment and precipitation amounts may also play important roles.

Seasonal changes in precipitation can change the sediment transport dynamics within low-gradient streams. In humid continental areas, the weather can vary widely from one year to the next, with drought conditions being replaced by record-breaking rainfalls. The impacts of precipitation on sediment transport have been extensively documented (Gimenez et al., 2012; David et al., 2010; Oeurng et al., 2010; Delpla et al., 2011; Araujo et al., 2012). While it generally follows that with more precipitation, more sediment will be transported, the timing of maximum sediment transport is contested. A study by Araujo et al. (2012) showed that a majority of sediment transport to streams occurs following single-flood events rather than after a period of frequent high-magnitude flood events (Oeurng et al., 2010). Streams generally respond the same way regardless; increased precipitation will increase stream discharge. This is exacerbated by the presence of tile drains, which are perforated pipes installed in the subsurface along fields to improve subsurface drainage and prevent crops from flooding (Li et al., 2010; Kiesel et al., 2013). The tiles rapidly and efficiently drain water into streams, which is just one way anthropogenic impacts can potentially alter sediment transport.

Agricultural systems are prone to extensive modification and alteration. Within watersheds, increased sediment transport has been observed with channel dredging, shoring, and straightening (Rinaldi and Johnson, 1997). Stream channels are modified with heavy machinery to improve drainage from agricultural fields. Natural streams in low-gradient areas tend to meander, and over time modified streams are continuously working to return to a more natural state. Channel straightening results in an increased capacity to transport sediments through the system because natural pools and low velocity areas where sediment can be deposited are removed (Lenhart et al., 2012). Additionally, agricultural fields are regularly disturbed with tilling, planting, and harvesting crops. When crops are not present, the soil particles are not held together and more sediment can be mobilized during precipitation events (Meyer et al., 1999; Minella et al., 2008). Extensive modifications culminate in greater sediment transported, largely derived from three distinct sources of sediment.

Sediment Sources

Overall, the natural and anthropogenic influences on sediment are defined by three distinct sources of sediment: bank sources, surface sources, and bed material. The bank sources are influenced also by three main processes that act to limit the stability of sediments (Grove et al., 2013). Grove et al. (2013) studied many components regarding sediment stability. Along the banks, the sediment size, packing, and overall sequence and clay content can act to aid sediment transport through fluvial entrainment, or scour. The stream itself can also contribute to bank instability through undercutting the slopes in stream meanders, which can result in mass slope failures (Lamba, 2015). The contribution of the banks to sediment is difficult to measure quantitatively, but from the

Grove et al. (2013) study, qualitative measurements are possible. Qualitative data could include pins installed in the bank to measure retreat (Gordon et al., 2005; Lamba et al., 2015), field surveys to study undercut banks, vegetation that is bowed and bent due to creep, or overall bank retreat over a long term period (Grove et al., 2013). Bank erosion is a dominant source of sediment to meandering streams (Lamba, 2015). When compared to two other sources of sediment, the surface and bed material, bank erosion potentially contributes the same magnitude of sediment (Fraley et al., 2009).

The second source of sediment involves the contribution of the land surface within the catchment. Soil loss from fields and the land surface is significant to the long-term sustainability of fields and crop land, and intense storms produce the highest rates of sediment loss (Nu-Fang et al., 2011). One component of the source of sediment from the land surface is the infiltration rate and how much water can be drained into the soils as opposed to overland flow processes. The infiltration rate is largely dependent on the lithology of the particles, the size and sorting, how much vegetation is present, the intensity of the precipitation event, the degree of sediment saturation, and the slope (Wainwright, 1996). Overall, these factors can play a significant role in dictating how much and how quickly sediments are transported from land sources to the streams. The interplay of these factors dictate when storm events are likely to transport the most sediment, such as during high intensity, high frequency storms during low vegetation times (Nu-Fang et al., 2011). In the Midwest, the floodplain acts as an important storage basin of sediment when large floods mobilize large quantities of sediment that were previously relatively stagnant through the system (Fraley et al., 2009). The dominant particle size is fine grained material in agricultural systems because erosion is not directly into bedrock in most cases and these regions are dominated by glacial till.

The third and final primary source of sediment is what exists within the stream already as bed material. In down-cutting streams, the bed material plays a large role in the entrainment and size of particles observed. Many systems have a bed material consisting of bedrock, but regions dominated by glacial tills find that the streams cut into or through end moraines, ground moraines, or outwash areas. End moraines may have a greater number of gravel lenses compared to ground moraines, which may impact the size of material eroded (Patterson et al., 2003). The bed material in these settings can be easier to entrain because of the unconsolidated nature of the material. However, in many instances dual layers can be found as part of the bed material (Gordon et al., 2005). By this, Gordon et al. indicates that an armor layer can be found in some streams that will inhibit the movement of coarser grains, and instead a finer sediment layer is more easily mobilized as suspended particles are brought into and out of suspension. The material underneath this would be more representative of the material the stream is cutting into, if the stream is down cutting at all. In streams that are extensively anthropogenically modified, the bed material can be disturbed through heavy machinery, which can have an impact on this sediment source. In addition, streams can be altered by humans depositing garbage into the streams, disrupting the dynamics of the system and preventing the bed material from being mobilized.

Once incorporated into the stream processes, the sediment is differentiated and sorted primarily based on grain size. Within the channel, pools or riffle areas can indicate if deposition or erosion is taking place, with smaller sediment sizes being deposited either at the bed margins or low-flow areas. Sediment can be transported either in suspension, common with the finer particles, or as bedload pushed along the stream bed. It is expected that increased rain, therefore stream stage, would have direct impacts on the sediment transported. While bedload transport is primarily a function of stream power (Schneider, 2014), particle movement has also been described as being dependent on the particle size and protection (Peterson et al., 2008). Despite this, the peak discharge has a large impact on the distribution and movement of individual particles (Schneider, 2014). In low-gradient streams, it has been found the maximum volume of bedload transported was moved shortly after the peak discharge on a hydrograph (D'Agostino, 1999). While only one component of a multi-faceted system, understanding the grain sizes can provide information regarding stream flow and competence to mobilize that particular grain size. Critical sheer stresses and the friction between particle, bed material, and the water all contribute to the ability to mobilize a sediment grain.

Streams found in low-gradient, agriculturally dominated regions are not a focus of coarse-material transport studies. Gomez (1991) applied a definition of bedload as any particle larger than 0.2 mm that moves by rolling or saltating along the stream bed. The threshold of 0.2 mm was applied because of the preponderance of particles smaller that immediately go into suspension when disturbed. The definition of bedload is a dynamic definition, because something that is considered bedload at one point in a stream may settle out and fall under the bed material definition (Emmett, 1981; Recking et al., 2012). With this definition, bedload studies can be significant when applied to low-gradient regions. In particular, bedload movement impacts the channel morphology and erosion from both the stream bed itself and the banks (Gomez, 1991). Within sand-bed streams, which dominate low-gradient regions, the mobilization of coarse material may prompt a significant change in the balance of the streams and erosion from the channels. Understanding the mechanisms that would result in coarse-load transport (d84 of pebbles or gravels) should be emphasized and studied better than it has been previously. Controlled flume studies modeling low-gradient sand-dominated systems have shown that bedload transport rates can be largely influenced by increasing discharge (Stall et al., 1958; Xu, 2013). In order to study how flume results translate to a real-world scenario, bedload transport through low-gradient systems ought to be better understood.

Geology and Soils

This study focuses on low-gradient, agriculturally-dominated watersheds and the primary streams that drain them. Central Illinois, in the Midwestern portion of the United States, is dominated by glacial deposits, which are the largest component of the surficial geology. Because of this, the overall topographic relief is low, with a slope between 1 and 4% (Lake Bloomington Watershed Management Plan, 2008). Approximately 150 meters beneath the surface lies the Pennsylvanian-aged sandstone-shale-limestone units, but the dominantly visible and significant features are the Quaternary deposits from the glaciers (Lake Bloomington Watershed Management Plan, 2008). At the conclusion of the Wisconsonian glaciation, about 12,000 years ago, the ice sheets deposited large moraines as they retreated. During the glaciation, ice retreated and advanced multiple times, occasionally overriding previously deposited moraines (Patterson et al., 2003). Evergreen Lake overlies materials of the Batestown Member, while Lake Bloomington overlies the Batestown with Peoria Silt cover, both of which are part of the Lemont Formation (Patterson et al., 2003). The Batestown Member is a till with sand and gravel lenses and the Peoria Silt cover consists largely of fine silts and loess deposits (Patterson et al., 2003; Kolata and Nimz, 2010). The key interpretation is that the Batestown Member represents an end moraine (Patterson et al., 2003). The Normal Moraine is the largest moraine and runs through Evergreen Lake Watershed. Additionally, the moraine contains more gravel and sand lenses because it is an end moraine (Figure 1; Lake Bloomington Watershed Management Plan, 2008). The geologic differences will play a key role in the sediment transport processes between the two watersheds.

The Quaternary deposits are very rich in silts and clays, and result in soils that are silt loams and silty clay loams (Soil Survey of McLean County, 2002). Agricultural practices dominate this region and are successful largely due to the nature of the soils, which have been defined as very fertile and high in organic content, as well as drought-resistant and poorly draining (Soil Survey of McLean County, 2002). Overall, the streams will transport large amounts of this sediment and can be easily influenced by various anthropogenic impacts.

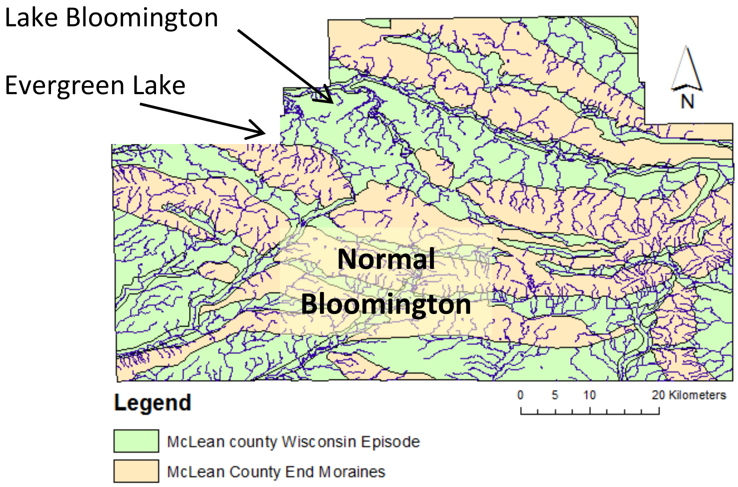


Figure 1: Locations of End and Ground Moraines in McLean County.

Research Objective

This research studied the sediments of two agricultural streams to understand transport through the system. Previous research on these streams has examined the suspended sediment transport through two watersheds in central Illinois as part of a paired watershed study started by Laura Hanna (2013). Data were collected from a drought year, with fewer storm events and lower precipitation values (Hanna, 2013). The following study was performed during one of the wettest summers on record; precipitation amounts in June were the highest since 1926 and total precipitation for the summer was over 58 centimeters (NOAA, 2015). While this study will follow along a similar tract to Hanna's work (2013), the focus is on the bedload component of sediment transport and how stream energy can influence the movement of sediments. Over the course of the spring, summer, and fall, baseflow bedload, suspended sediment concentrations, discharge, and scour measurements were measured. This project's goal is to identify bedload movement through two streams. This project can assist the City of Bloomington with an approximation of bedload contribution to the reservoirs, Lake Bloomington and Evergreen Lake, and to understand the differences between two similar watersheds that exhibit different sediment transport dynamics. Additionally, surficial water management plans to reduce the sediment load into the two lakes as well as improve channel ecosystems and overall health can be more comprehensive.

Hypotheses

The focus of this study is sediment transport dynamics through low-gradient agricultural streams and if coarse-material (gravels, pebbles) can be mobilized. To address this sediment transport question, the following hypotheses have been proposed:

1. There will be a seasonal change with the bedload transported and scour from the bed and banks, with more being mobilized in the spring compared to the fall (Figure 2).
   - The spring will see higher consistent discharges. Decreased precipitation and increased vegetation during the summer and fall will reduce sediment transport.

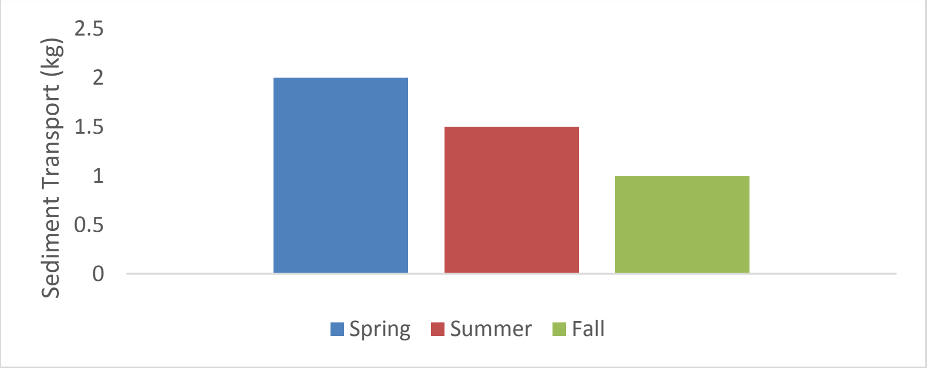


Figure 2: Hypothesized Seasonal Changes in Sediment.

2. There will be no significant difference between the two watersheds with respect to the amount of sediment transported and to the grain size distribution of sediment (Figure 3).
   - Geologically and geographically similar sub-watersheds ought to have similar transport dynamics. Each will receive similar precipitation amounts, have similar slope values, and similar geologic units that the streams cut through, implying that the total sediment loads and grain size distributions will be the same.

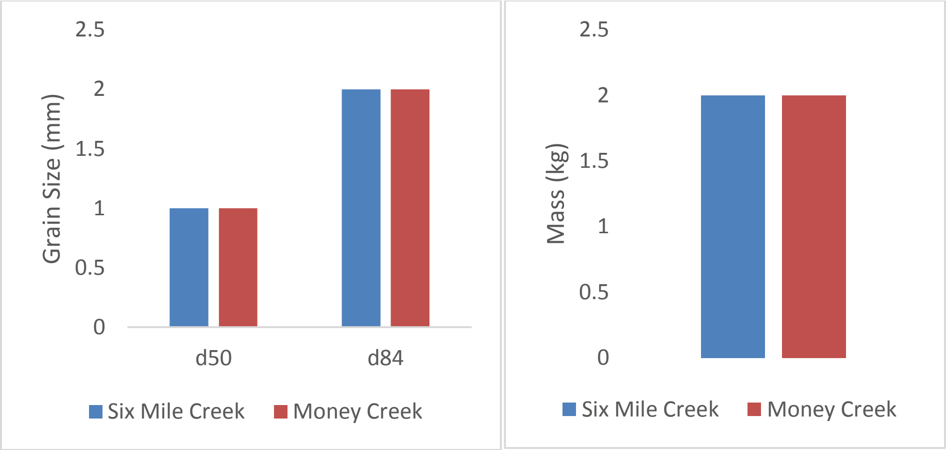


Figure 3: Hypothesized Watershed Similarities in Overall Grain Size and Mass.

CHAPTER II

METHODS

Site Description

The study area is located in central Illinois, in a region known for agriculture (Figure 4). Two streams, Money Creek and Six Mile Creek, flow into Lake Bloomington and Evergreen Lake, respectively. These two lakes are important because they are the sources of drinking water for residents in the City of Bloomington, so the overall health, quality, and lifespan of these reservoirs is of utmost concern (Hanna, 2013). The two watersheds have slightly different characteristics. Lake Bloomington has an overall greater area and 70% larger drainage area compared to Evergreen Lake (STREAMS, 2006). The lake surface area is smaller for Lake Bloomington, and the overall storage capacity (volume) is less than Evergreen Lake (STREAMS, 2006). Money Creek has more stable channels and a lower gradient compared to Six Mile Creek's incised channels and higher gradient (STREAMS, 2006). Both streams overlie and erode directly into glacial till, however, Money Creek overlies a ground moraine while Six Mile Creek overlies end moraine deposits. Both watersheds are dominated by agricultural production of corn and soybeans (Hanna, 2013). The impact of watershed differences on sediment transport is not known. These subtle differences will be taken into consideration when examining the sediment loads within the two stream systems.

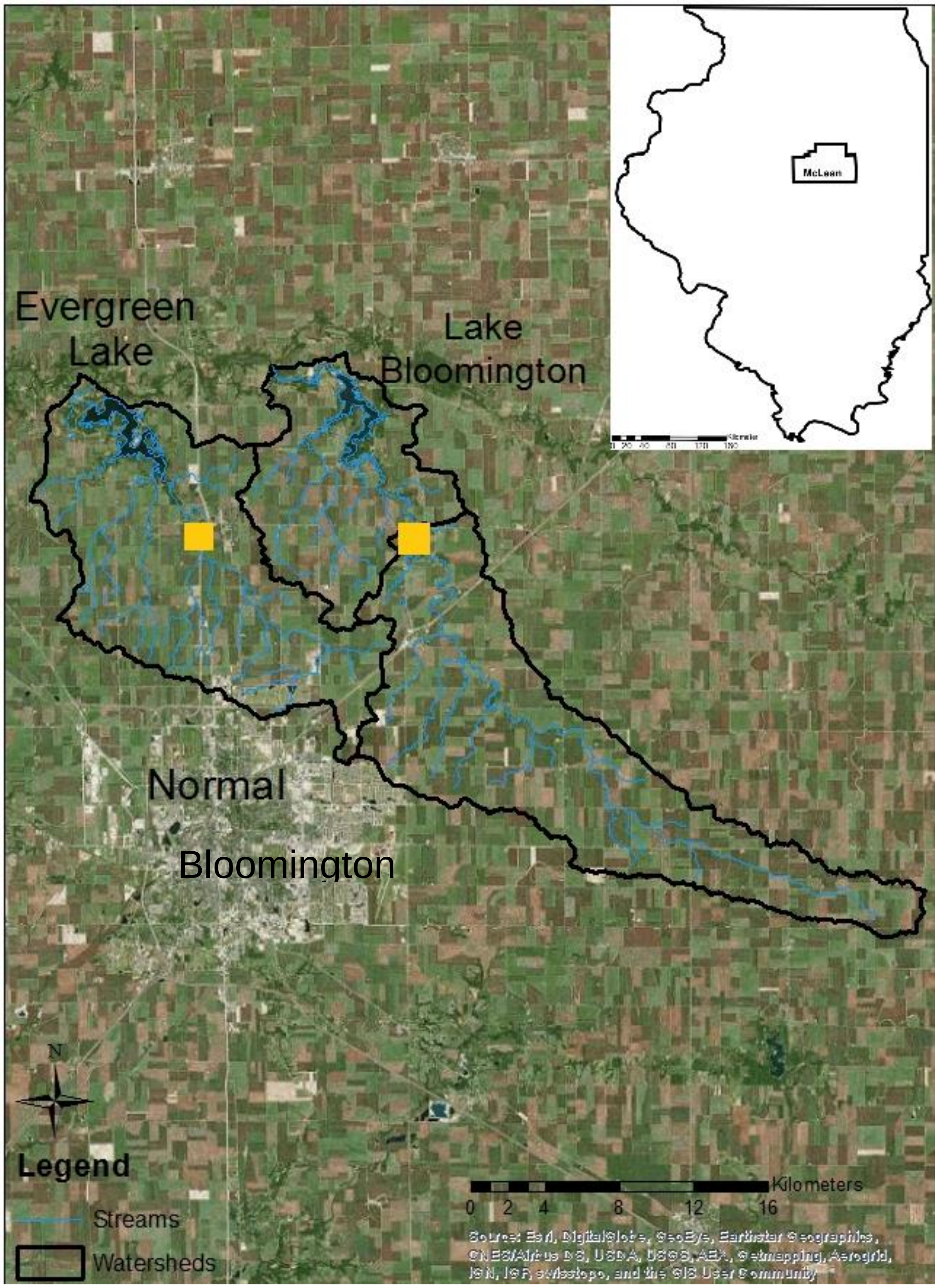


Figure 4: Watersheds Located just North of Normal, IL in McLean County, IL. Study Sites Indicated by Yellow Squares.

Study Sites

The study sites were located along a section of Six Mile Creek (Evergreen Lake) and Money Creek (Lake Bloomington, Figure 4). These sites are used in conjunction with a paired watershed study, a water chemistry study looking at nitrates in surface and tile-drained waters. Along Six Mile Creek, the site is located just off of I-39 along Route 12 (40°36’18.96”N 89°0’10.38”W). The Money Creek site is located along County Road 1975 E (40°35’38.57”N 88°53’19.50”W). The selected sites were optimal because of their proximity to public bridges.

The surrounding land use and some channel characteristics are similar between the two streams. Both streams are bordered by lands farmed for corn and soybeans, and the immediate zone surrounding the streams has established vegetation, including trees, shrubs, bushes, and tall grasses. The two study sites are located relatively close to where the streams enter the lake. Within both channels, the thalweg of the streams are off-centered, as would be expected with more natural and unmodified stream channels. The two sites have a dominance of fine-grained particles such as silts and clays closer to the banks. Both streams showed evidence of anthropogenic modification through dumping of gravels, tires, and junk into the stream, but this was not considered a factor because it occurred close to the bridges and was downstream from the sampling location.

The overall texture and characteristic bed material differs among the two streams. The sediment consists of both larger particles, from coarse sands to pebbles, and fine material including clays and silts. Money Creek had a thicker covering along the bed of finer silts and clays that masked any coarser particles. One obvious difference was the channel morphology between the two sites. At Six Mile Creek, the banks were taller and steeper (Figure 5). Money Creek had banks that gently sloped away from the stream and were less than a meter taller than the stream water at baseflow (Figure 6). Money Creek was also wider, averaging 9.5±1.9 meters throughout the entire study period, while Six Mile Creek averaged 5.1±1.3 meters.

Figure 5: Photograph of Six Mile Creek Study Site. Stream Width is Approximately 5.1 Meters.

Figure 6: Photograph of Money Creek Study Site. Stream Width is Approximately 9.5 Meters.

Field Measurements

Sampling

Data were collected generally every two weeks, beginning in the spring on May 7, 2015 (Table 1). Spring collection occurred during the period from initial installation through June 6, 2015, with complete (or as best as possible) sampling events that occurred on May 7th, 16th, 18th, 21st, and June 4th. Summer collection was after June 6th through July 31st, with specific sampling events occurring on June 18th, July 2nd, 16th, and 30th. Following the reinstallation of equipment on September 3rd, fall sampling dates included September 17th, October 1st and 15th, with storm and partial sampling taking place on September 10th. Storm event sampling was the exception to the biweekly sampling schedule, with April 28th and September 10th being “unscheduled” post-storm measurements.

Table 1: Dates of Sampling Events and the Corresponding Season.

Season	Sampling Date
Spring	4/28/2015*
Spring	5/7/2015
Spring	5/16/2015
Spring	5/21/2015
Summer	6/4/2015
Summer	6/18/2015
Summer	7/2/2015
Summer	7/16/2015
Fall	9/10/2015*
Fall	9/17/2015
Fall	10/1/2015
Fall	10/15/2015

*Refers to samples collected out of the biweekly schedule.

Stage and Discharge

Stage was continuously monitored using pressure transducers installed within the stream. The transducers were secured to rebar using zip-ties through the loop at the top of the transducer and one at the bottom to ensure the sensor was not free-floating in the stream. The rebar was then hammered vertically into the stream bed until the transducer, positioned approximately 15 centimeters below the top of the rebar, was touching the stream bed. The transducers were installed on May 16, 2015 at Six Mile Creek and Money Creek and were removed on August 20, 2015 and September 2, 2015, respectively. The transducer data were downloaded and then one transducer reinstalled at Six Mile Creek on September 10, 2015 for the fall sampling period (pulled on October 15, 2015). All of the transducers were installed off-center in the streams, but not in the deepest portion of the stream.

Stream discharge was collected during each of the sampling days, if flow conditions permitted safe wading. To ensure consistent measurements, a singular cross-sectional transect line was established at each study site. Discharge was taken using a Sontek Flowtracker, which collects a minimum of 20 point-velocity measurements across a cross-sectional transect. Velocity was measured at 18 centimeters above the stream bed. Using the velocity and the measured depth at each point, the system calculates discharge (Q) using velocity-area calculations, reporting the amount of water moving through the cross-sectional area. Discharge was measured in cubic feet per second (cfs or ft^3/s) but is reported in m^3/s (Appendix A). In some cases during the summer, the stream was too high to permit safe wading, and in those instances the depth was read from the staff gauge and the stream width measured. A rating curve was generated by plotting stream stage and discharge. During high flow events when discharge was not measured, the stage values from the transducers can be used to interpolate stream discharge from this rating curve.

Suspended Sediment and Turbidity

Suspended sediment and turbidity were collected to better understand the overall sediment transport processes through these streams. Water samples were collected using 1-liter sampling bottles that were rinsed three times in the stream. Samples were collected from about the center of the stream, approximately every two weeks. Back in the laboratory, I measured turbidity using a Hach 2100P Portable Turbidity meter, reported in Nephelometric Turbidity Units (NTU). Suspended sediment was measured by filtering a known volume of water through pre-combusted, weighed Whatman 934-AH microfiber filters (diameter 4.7 cm, retention of 1.5 μm) with a vacuum filtration system. Filters were dried in a 108°C oven for at least 24 hours. The mass of sediment on the filters was divided by the volume of water filtered, which provides a suspended sediment concentration (mg/L). Previous studies have shown a relationship between suspended sediment and turbidity, where turbidity can be plotted as the response variable to suspended sediment concentrations (Hanna, 2013; Salant et al., 2008). If a relationship exists, turbidity can be used as a proxy for suspended sediment.

In addition to turbidity and suspended sediment concentrations, I calculated the suspended sediment load. In order to do this, stream discharge at the time of sampling needs to be known. In most cases, this discharge was the value that was directly measured with the Flowtracker. For the days when discharge was not directly measured, the rating curve produced using stage and discharge was used to interpolate the discharge with known stage. To calculate suspended sediment load, the discharge in m^3/s was multiplied by sediment concentration and a conversion factor of 1000. To obtain a seasonal load of sediment, this was converted then to kilograms per day, then multiplied by 90 days to define the season. Sampling occurred only over a 45-day interval during each season, so the results are an extrapolation over time:

$$Q\left(\frac{m^3}{s}\right) \times SSC\left(\frac{mg}{L}\right) \times 1000 \times = SSL\,(\frac{mg}{s}) \qquad \text{Eq. (1)}$$

The suspended sediment load is useful for a more direct comparison among the streams. Sediment concentration will change based on the volume of water, and dilution of sediment mass is common. Greater water volume as a result of more stream discharge may result in the same concentration, despite an increase in sediment mass. The sediment load essentially normalizes the mass to the volume of water, and the mass per time value can be compared between the two streams.

Bank Pins

To identify the sediment contribution into the streams due to bank erosion, I installed pins in the banks at each study site (Gordon et al., 2005). These pins were stainless steel threaded rods purchased at the Home Depot (Model # 802497) with a 1 cm diameter and 91 cm in length. Each rod was cut in half and measured approximately 45 cm. These were installed horizontally into the right and left banks and flagged with tape. The pins were aligned in a singular, vertical column positioned towards the top of the bank (“upper”), the middle (“middle”), and near the water surface (“lower”, Figure 7). The pins were not always found due to high flows, which also may have been responsible for washing away and burying some pins during the summer. Money Creek was particularly susceptible to lost pins due to flow conditions, with all of the pins being buried during the summer, but uncovered during the fall. On September 3, 2015, missing pins were replaced and new initial measurements collected. The length of pin exposed, measured as the end of the pin to the intersection with the bank, was measured biweekly using a ruler.

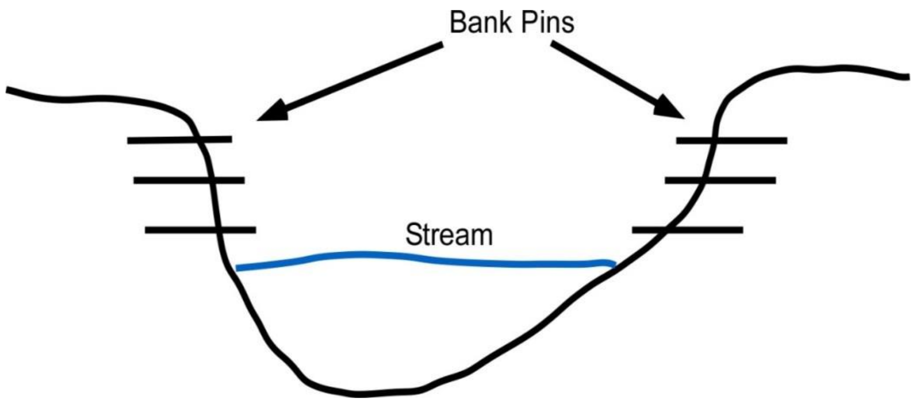


Figure 7: Cartoon Drawing of the Bank Pins and their Position within the Stream.

The bank pins are used to determine if there is more erosion or deposition along the stream banks. Despite being measured every two weeks, the ultimate goal was to see if there were seasonal changes in erosion and deposition along the banks. To answer this question, the initial and final bank pin measurements were the only ones used in the final analysis. The biweekly measurements were used to qualitatively understand small-scale changes to the banks, such as slope failures. To obtain the seasonal change at each site, the final pin length was subtracted from the initial length for each of the six pins. Negative values indicate erosion away from the banks and positive values represents deposition. A one-way ANOVA test was used to determine if there was a significant difference among the seasons at each site, and between each site.

Scour-Fill Markers

Scour-fill markers were installed to help understand the sediment deposition or erosion in the stream during high-flow events like storms. To accomplish this, rebar stakes were hammered into the stream bed at three different locations across the stream

(Sergeant, 2012). One stake was installed near each bank, and the last stake in the center of the stream, dividing each stream approximately in thirds. To reduce the chance that vegetation could get hung up on the rebar, the stakes were positioned diagonally across the stream, slightly upstream from the established cross-sectional transect. Between 15 and 30 centimeters remained above the bed, and two or three washers (6.5 cm outside diameter, stainless steel) were placed on the rebar, dropping onto the stream bed. The initial depth from rebar top to the washer resting along the bed was measured, and after a storm event, the distance to the bed surface was measured, the sediment removed, and depth to washer measured (Figure 8). The depth to the bed marked the amount of sediment that was deposited during the falling limb of the hydrograph, when the stream would be returning to baseflow conditions. The depth from the top of the rebar to the washer indicates the amount of erosion that took place during the rising limb of the hydrograph. The initial measurements used for the next storm event were the depth to the washer, which is the "reset" system level.

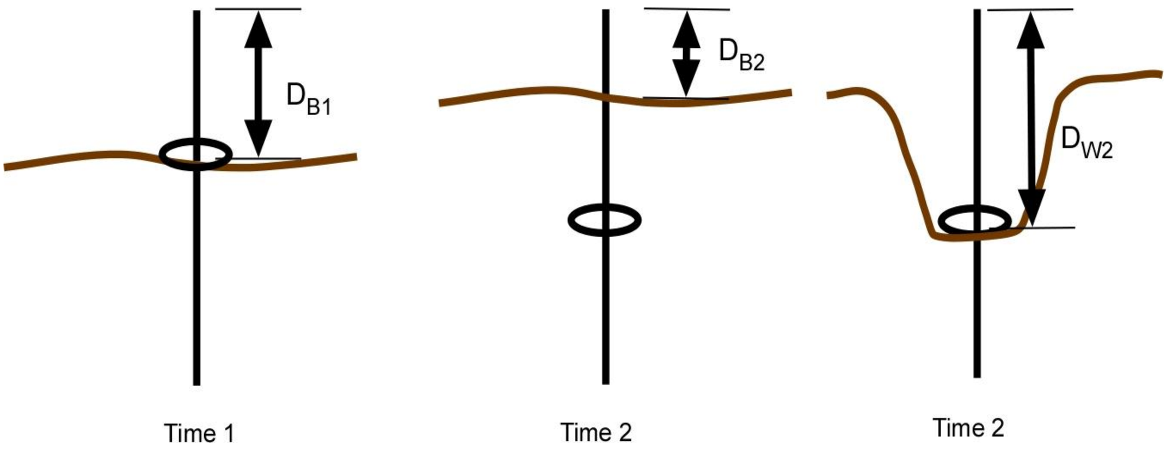


Figure 8: Schematic of the Scour-Fill Markers and their Design.

Data analysis for the scour-fill markers included obtaining the mean erosion and deposition per site, then the same parameters analyzed between seasons (Sergeant, 2012). For each sampling event, the amount of fill and scour were calculated using the following equations:

$$Fill = D_{B1} - D_{W2} \qquad \text{Eq. (2)}$$

$$Scour = D_{B2} - D_{W2} \qquad \text{Eq. (3)}$$

Where D_{B1} is the depth to bed from the previous or initial time, D_{W2} is the depth to the washer from the current sampling period, and D_{B2} is the depth to bed at the current sampling time (Figure 8). The scour and fill data were then averaged together for each sample date, which indicates if erosion or deposition dominated. A one-way ANOVA test was used to identify significant differences among the seasons at Six Mile Creek and then Money Creek. For each site, the data were grouped over the entire sampling interval, and a paired t-test used to analyze watershed differences.

Bedload Traps

Bedload traps are designed to be pit traps that are set flush with the stream bed so that particles moving along the stream bed transported as bedload will fall into the trap. Three traps were installed along the cross-sectional transect at each stream, and divided the stream up approximately into thirds. The trap was constructed using plastic storage tubs measuring 35 cm x 21 cm x 12 cm that had a storage volume of 5.7 L. To ensure the traps remained in the stream bed, 61 cm long rebar pieces were hammered into the bed until about 30 cm remained above the bed (Figure 9). Each trap was punctured near the upper corner to allow for the insertion of zip-ties. The ties were then secured around the rebar and tightened to the point that the trap could still be removed for easy sampling but that they would keep the trap secured in place. A shovel was used to dig out the bed material to place the traps flush with the bed surface. The traps were oriented with the long axis parallel to the flow direction to ensure that the traps were aligned and "natural" with the flow. Large, heavy rocks were placed within the plastic bins to ensure they remained in position and not mobile or floating above the bed (Gordon et al., 2005, Sear, 2003). The traps were left to collect sediment for at least two weeks. High flow conditions prevented sampling in some cases for up to a month (Appendix B). During sampling, the traps were removed from the stream bed and the sediment emptied into labeled sample bags.

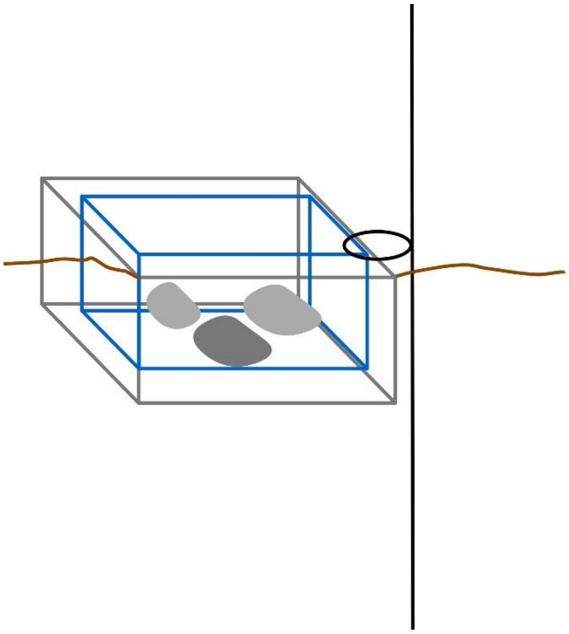


Figure 9: Cartoon Conceptualizing the Bedload Trap Installation. The blue is the Plastic Bin and the Black is the Rebar.

In the laboratory, bedload sediment was placed into aluminum baking pans and oven dried for between 12 and 24 hours until completely dry. During the drying period, sediment would consolidate together. This overestimated the coarse material present in high-clay content samples because the grains would get baked together. The more sands and gravel-sized grains present, the easier it was to break apart. For clay-rich samples, a mortar and pestle was used to break apart the material. A trial run was performed to perfect the technique to eliminate the chance that grains would get further broken down and therefore underestimate the actual grain sizes. Individual grains were examined with a hand lens to see if there was a large amount of grains that remained as consolidated clays. Loose sediment was sieved into different fractions using either both or one of the following shakers: Rx-86 Sieveshaker and the Derrick Test Sieve Vibrator. The sieve sizes used were: 16mm, 4.0mm, 2.0mm, 1.0mm, 600µm, 500µm, 250µm, and a pan to collect grains <250µm. Prior to placement within the sieve, the initial mass was measured. The sediment was machine-sieved for at least 30 minutes. Each fraction was bagged, weighed, and the mass in grams recorded.

Analysis of the bedload samples began with the grain size distribution. Each fraction's mass (g) was entered into Excel, then the particle diameters separated into grain classifications according to the Wentworth scale, and summarized in Table 2. In order to determine if the overall distribution of the grain sizes was normal, the mass of sediment was plotted against the classifications to observe the patterns. The individual traps were summed over each season and compared between the two sites.

Table 2: Grain Size Classification Used for this Study.

Size (mm)	Classification
4.0 – 64.0	Pebble / Gravel
2.0 – 4.0	Granule / Gravel
1.0 – 2.0	Very Coarse Sand
0.500 – 1.0	Coarse Sand
0.250 – 0.500	Medium Sand
<0.250	Fine sand, silt, clay

For each bedload trap, the d50 and d84 particle diameters (mm) were interpolated from grain size distribution curves. The d50 represents the median of the sample, and the d84 is used to represent the coarser sediment within the sample (Folk and Ward, 1957; Holmes, 2010). To calculate the d-values, each fraction's weight was divided by the total mass of sediment and multiplied by 100, which gives the mass retained percent. Then the cumulative weight percent retained was calculated by adding the previous cumulative weight to that specific fraction's mass retained. The cumulative weight values were then subtracted from 100, which the cumulative weight of the smallest fraction should equal, and this provided a percent finer value. The fraction size was plotted against the percent finer values, and a curve was drawn to show the grain size distribution curve. The d50 and d84 grain sizes are then interpolated from where the 50% or 84% intersects the curve. To calculate the mean (M) and standard deviation (σ) of each sample, the d5, d16, and d95 were found as well and used in the following formulae (Folk and Ward, 1957):

$$M = \frac{\emptyset 16 + \emptyset 50 + \emptyset 84}{3} \qquad \text{Eq. (4)}$$

$$\sigma = \frac{\emptyset 84 - \emptyset 16}{4} + \frac{\emptyset 95 - \emptyset 5}{6.6} \qquad \text{Eq. (5)}$$

The bedload d50 and d84 values were then averaged per season and an ANOVA test used to identify significant seasonal differences. A t-test was performed for differences between the two sites, after the d50 and d84 values were grouped by site.

Calculations

Shear Stresses

The potential for sediment entrainment can be calculated using basal and critical shear stress values. The basal shear stress values represent the competence of the stream and the forces available for particle motion. The basal stresses (τ_b) are a function of the water depth (stage) and the slope of the stream. They are calculated using the following equation

$$\tau_b = \gamma_w h S_c \qquad \text{Eq. (6)}$$

where γ_w is the specific weight of the fluid (assumed 9,800 N/m^3), h is the water depth (m), and the S_c is channel slope (m/m). The transducer values (stage) were used as the water depth values. In order to accurately represent the stage levels during the time interval the bedload traps were collecting material, the geometric mean of the stage was used. This was used as opposed to the mean because the geometric mean uses the product of the values, following the central tendency of the data as opposed to just the value sum. The channel slope was not directly measured, which may introduce error in the calculations. Slope for both streams was found from previous channel surveys. The slope for Six Mile Creek was 0.00136 m/m (STREAMS, 2005) and Money Creek was 0.00077 m/m (STREAMS, 2006).

The critical shear stress values represent the point at which entrainment theoretically can begin. There are many factors that influence the point at which a grain is mobilized, one of which is how the grains are arranged on the bed surface. If larger grains overlie smaller ones, then the ability for the small grains to be entrained is limited. The armoring of the bed and how grains are aligned will alter particle motion. Regardless, the critical stresses are a function of grain size. The larger the grain, the more energy required to initiate movement and transport. Critical shear stress (τ_c) is calculated as:

$$\tau_c = \theta(\gamma_s - \gamma_w)d \qquad \text{Eq. (7)}$$

where θ is the “Shield’s parameter”, γ_s is the specific weight of the sediment (26,000 N/m^3), γ_w is the specific weight of water, and d is the particle diameter (m). The Shield’s parameter value used was 0.06, following the work and justification of Peterson et al. (2008), who worked in a geologically similar system located near this study in an adjacent watershed. The d84 for each sampling interval was used as the particle diameter in order to calculate the stress required to mobilize the representative coarse material. Because there were three traps at each site, the largest d84 for that time was used as opposed to the average. The maximum grain size was used because the goal was to calculate the upper stress limit required for grain motion.

A common way to analyze and compare the shear stress values is to compare them as a 1:1 ratio, of τ_b/τ_c. If the ratio is greater than one, then the basal values have exceeded the critical shear stresses and particle motion is possible. Less than one indicates the particle is likely not entrained at that depth of water. The two stresses can also be set equal to each other, to calculate the height of water required for movement of that grain size. Because water depth is available for the study period, except for Money Creek during the fall (after 9/3/2015), the actual and required water heights were compared as a ratio, Ha/Hr. If the required height exceeded the actual height, then theoretically grain movement occurred.

Additional Sites

Sediment transport dynamics within a stream become more representative of the entire system when multiple locations are studied. During the spring and parts of the summer, bedload data were collected at two additional sites upstream from the two sites reported here. These two sites were located in the primary trunks of Six Mile Creek and Money Creek, but they were identified to be representative of modified channels (Figure 10). Modified channels would be defined as those anthropogenically channelized, straightened, and dredged to improve field drainage. Unmodified channels are sinuous and have established vegetation along the banks, as well as natural areas within the stream of sediment accumulation and storage. The streams directly drained the farm fields with no buffer zone between field and stream. Neither modified stream section had a definitive thalweg present; in general, they exhibited a trapezoidal cross-section. The bedload data collected were not robust enough for statistical comparisons and they were collected in different seasons. Instead, the data can be used to qualitatively explore spatial dynamics.

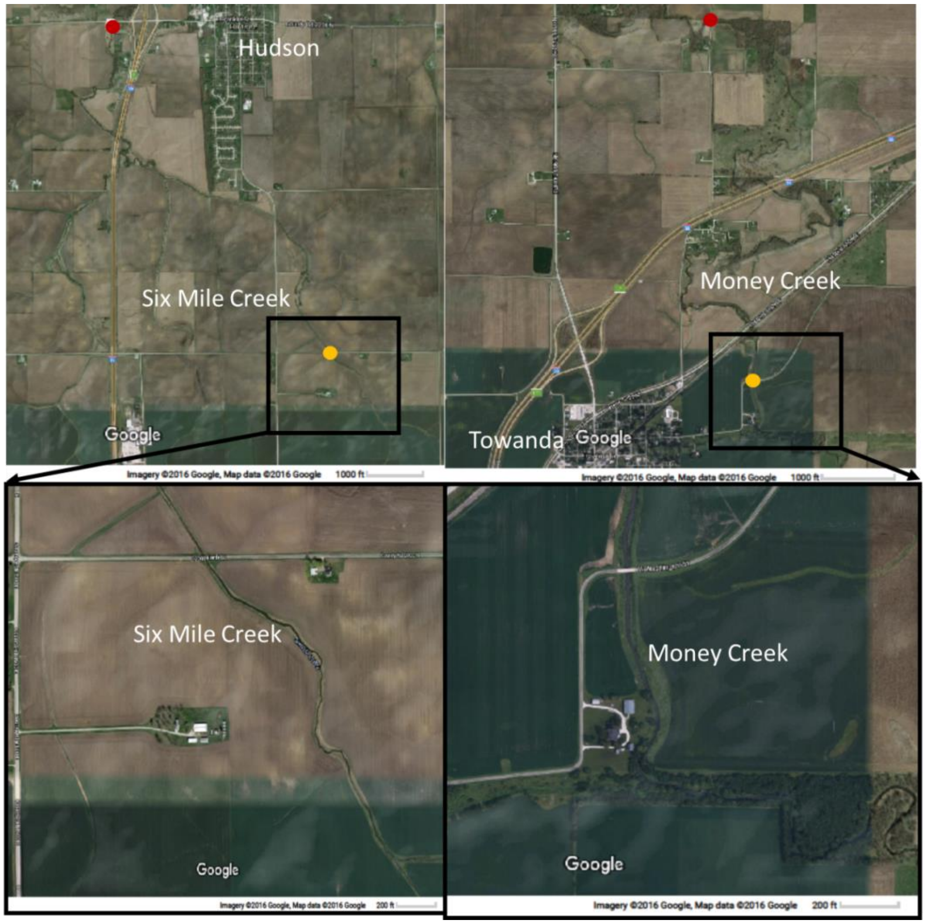


Figure 10: The Locations of the Two Additional Study Sites (Yellow Dots). Red Dots are Original Sites.

CHAPTER III

RESULTS

Precipitation and Stream Data

For this study, each season was defined by a date not necessarily matching with the official calendar dates for that season. Spring was slated as the time from the beginning of installation (4/23/2015) through 6/6/2015. Summer was defined as 6/6/2015 through 9/1/2015, and fall as 9/1/2015 through 10/15/2015. Precipitation data were downloaded from rain gauges in Bloomington, IL. The storm events increased in frequency and magnitude towards the end of the spring and extended through mid-summer (Figure 11). As expected, the streams responded to the storm events through increased stage (Figures 12 & 13). Stage levels were higher overall at Money Creek compared to Six Mile Creek, despite the shallower banks that overfilled during intense flooding events. Peak stage occurred on the same day at both streams, with Money Creek reaching 3.38 meters and Six Mile Creek 1.20 meters on 7/9/2015. The maximum discharge for Money Creek was measured on 5/16/2015 as 1.84 m^3/s. On 7/2/2015, the discharge was measured at 1.77 m^3/s, but was not able to be measured during the highest stage levels on 7/16/2015. However, for Money Creek there was a strong correlation with stage and discharge ($R^2 = 0.97$, $n = 5$; Figure 14). Using the regression equation with known stage level, the discharge for Money Creek was calculated for the days no sampling could take place (Table 3). The measured discharge was compared to values calculated with the rating curve and had a good overall fit (Table 4). The maximum measured discharge at Six Mile Creek was 1.02 m^3/s on 6/4/2015.

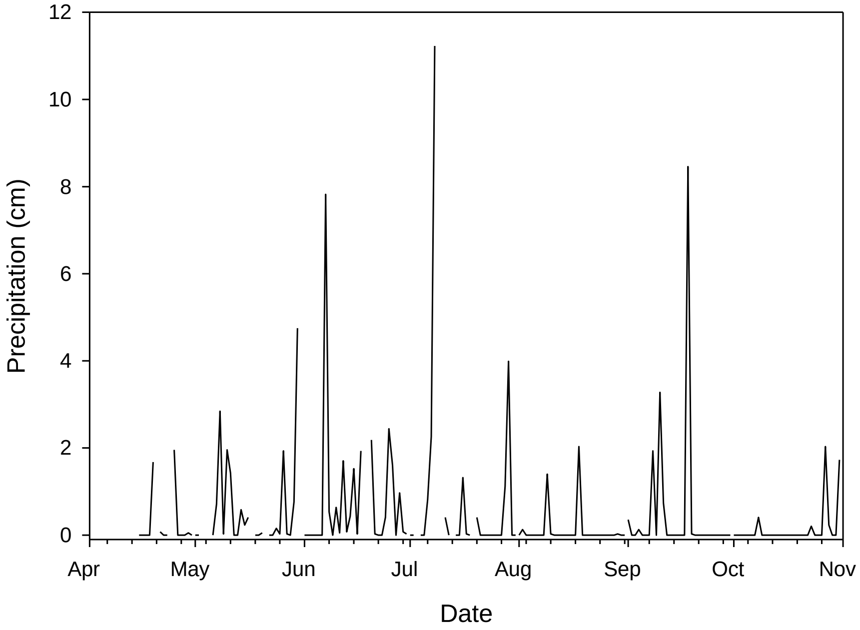


Figure 11: Daily Precipitation during the Study Period.

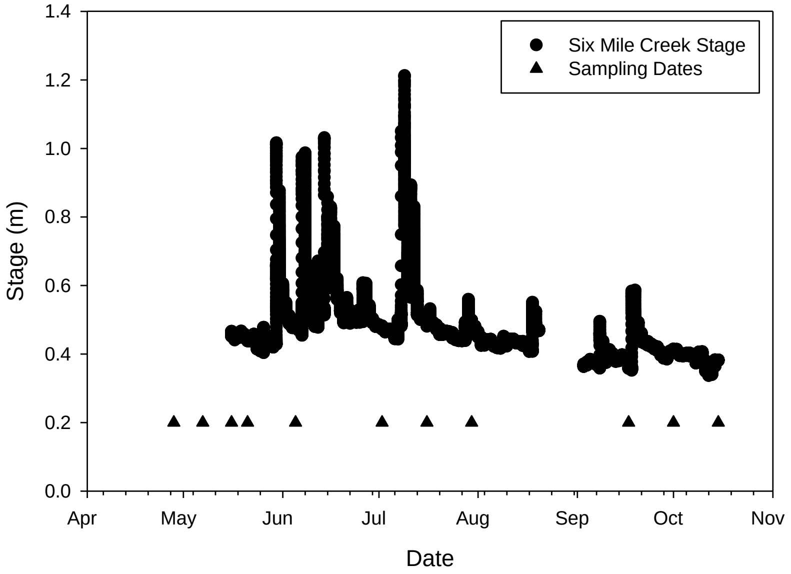


Figure 12: Six Mile Creek Stage and Sample Dates.

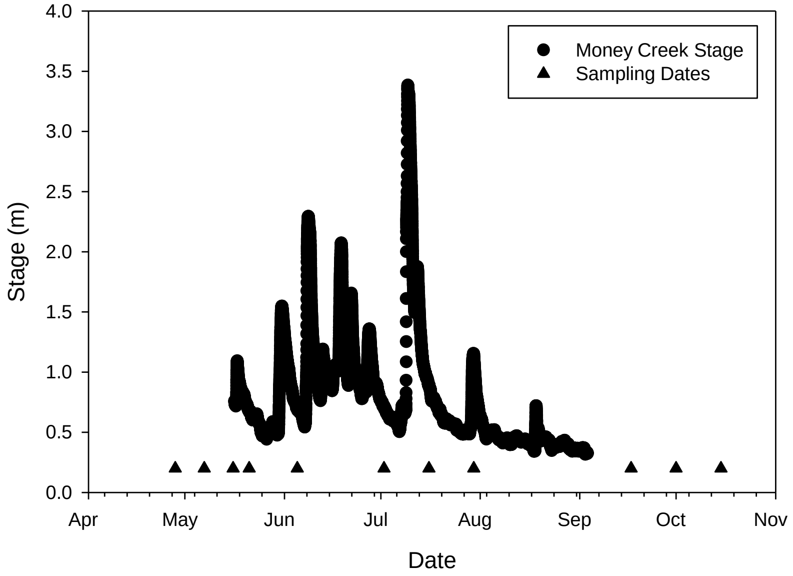
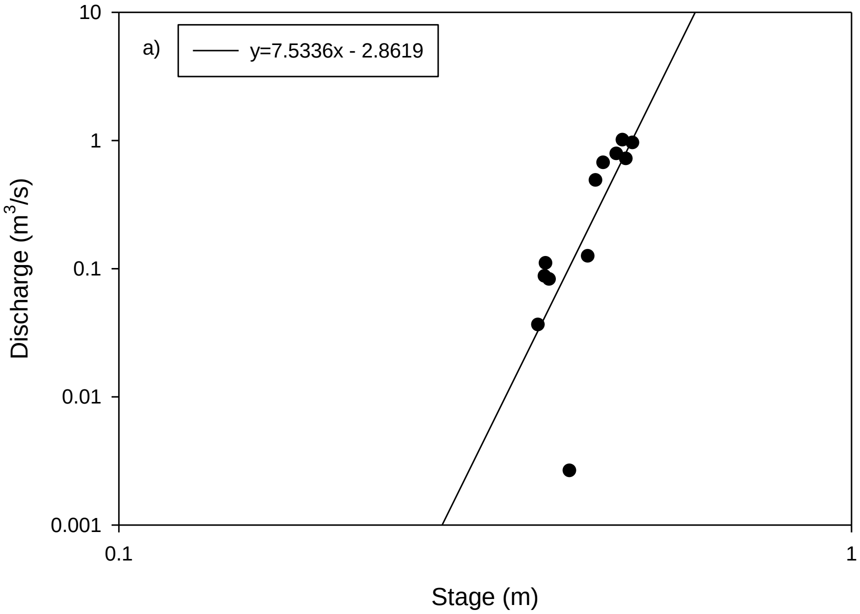


Figure 13: Money Creek Stage with Sample Dates.

Table 3: Stream Width and Measured Discharge on Sampling Dates.

Date	**Six Mile Creek** **Width (m)**	**Discharge (m^3/s)**	**Money Creek** **Width (m)**	**Discharge (m^3/s)**
5/7/2015	5.3	0.22	8.8	1.16
5/16/2015	5.6	0.67	9.7	1.84
5/21/2015	5.3	0.49	9.0	1.29
6/4/2015	5.2	1.02	9.8	1.71
6/18/2015	*N.A.*	*N.A.*	14.6	1.78*
7/2/2015	5.2	0.79	9.4	1.77
7/16/2015	5.4	0.96	10.1	1.65*
7/30/2015	5.5	0.73	13.1	1.74*
8/13/2015	5.2	0.13	9.1	0.20
8/27/2015	5.1	0.10	8.4	0.07
9/10/2015	5.7	*N.A.*	7.6	0.07
9/17/2015	6.2	0.11	7.5	0.03
10/1/2015	5.6	0.04	7.6	*N.A.*
10/8/2015	5.1	0.00	9.5	0.18
10/15/2015	5.8	0.05	7.5	0.11



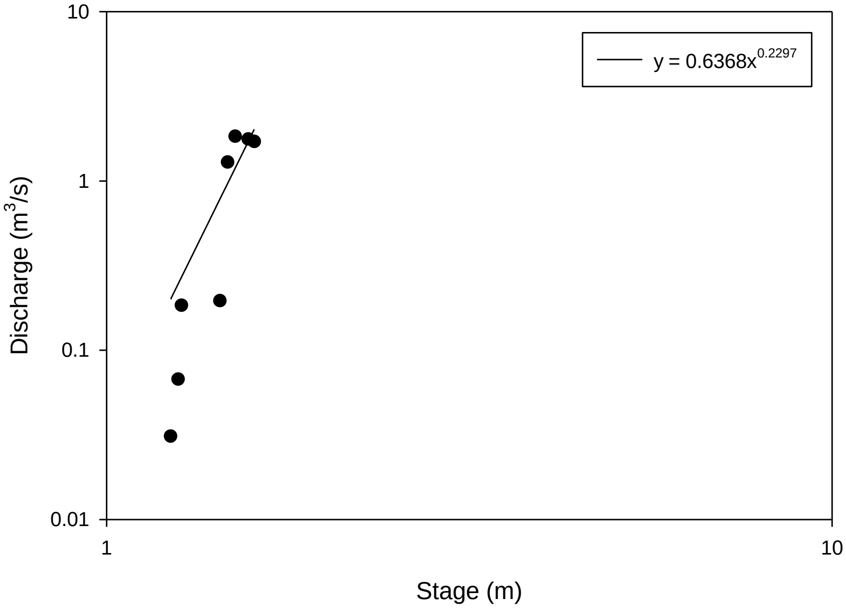


Figure 14: Rating Curve for Six Mile Creek ($R^2 = 0.86$) (a) and Money Creek ($R^2 = 0.97$) (b).

Table 4: Comparison of Field Discharge to Rating Curve for Six Mile Creek (Top) and Money Creek (Bottom).

Date	**Stage (m)**	**Actual Discharge (m3/s)**	**Calculated Discharge (m3/s)**
5/7/2015	*N.A.*	0.22	*N.A.*
5/16/2015	0.46	0.67	0.59
5/21/2015	0.45	0.49	0.51
6/4/2015	0.49	1.02	0.81
7/2/2015	0.48	0.79	0.74
7/30/2015	0.49	0.73	0.85
9/17/2015	0.37	0.04	0.02
10/1/2015	0.41	*N.A.*	0.24
10/15/2015	0.38	0.09	0.01

Date	**Stage (m)**	**Actual Discharge (m3/s)**	**Calculated Discharge (m3/s)**
5/7/2015	*N.A.*	1.16	1.16
5/16/2015	0.76	1.84	1.57
5/21/2015	0.66	1.29	1.52
6/4/2015	0.74	1.71	1.56
7/2/2015	0.69	1.77	1.54
9/17/2015	0.30	0.03	0.95
10/1/2015	0.43	0.18	1.05
10/15/2015	0.39	0.11	1.02

Sediment Movement

Bank Pins

The mobility of sediment along the stream banks gives a sense for how the channels respond over time. At Six Mile Creek, bank erosion dominated all seasons and was highest during the spring and lowest during the fall (Figure 15). Field observations noted a bank failure event during the spring (May 16th) and summer (August 20th), which were gradually eroded away and confirms the overall net erosion from Six Mile Creek. The seasons were not significantly different from each other at Six Mile Creek ($n = 16$, $p > 0.05$). Direct seasonal comparisons could be made between the spring and fall at Money Creek, but not the summer. Half of the pins at Money Creek were entirely buried by sediment during the summer, but the buried pins were exposed again during the fall. The summer was estimated through the assumption that sediment must have been deposited in a quantity enough to completely conceal the pin. During the spring and summer at Money Creek, sediment was deposited on the banks (Figure 15). The fall had erosion of sediment from the banks. Erosion during the fall is supported by the exposure of the buried pins. The spring and fall at Money Creek were significantly different ($n = 12$, $p < 0.05$).

The total change in sediment was compared between the two streams by grouping all of the seasons. At the Six Mile Creek study site, erosion was the dominant process along the stream banks. In contrast, Money Creek had net deposition of sediment. The summer estimate was included in the total sediment analysis for Money Creek. The two streams were significantly different from each other ($n = 12$, $p < 0.05$).

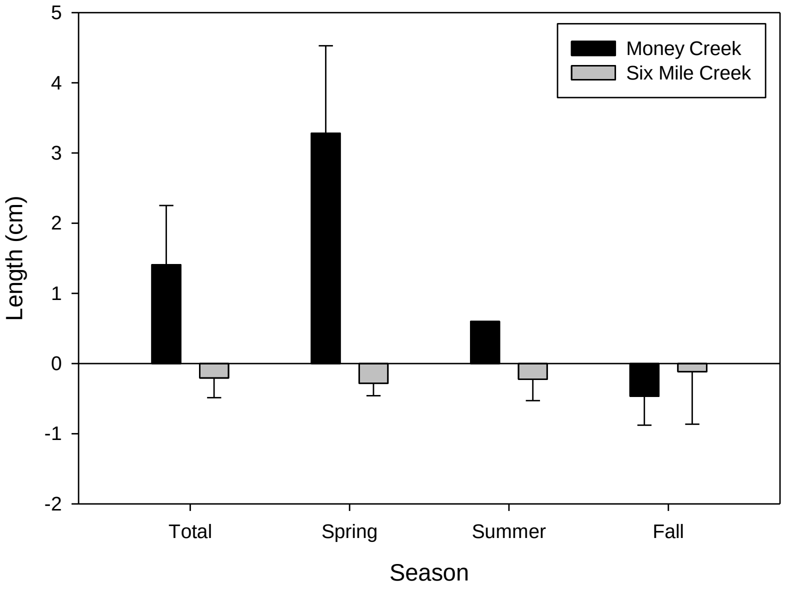


Figure 15: Mean Bank Pin Results. The Error Bars are the Standard Error.

Scour-Fill Markers

The active layer of the stream bed was measured using scour-fill markers that record sediment deposited or eroded during storm pulses. Scour (erosion) is marked by negative length values, whereas fill (deposition) will be indicated by positive values. Due to high stream levels in the summer, measurements were collected only during the spring and fall. Neither Six Mile Creek nor Money Creek had significant differences between the spring and fall (n = 39, p > 0.05). Both sites had deposition of sediment on the stream bed as the dominant process (Figure 16). Net erosion occurred once at each stream, both during the fall but on different days (Table 5). In total, the two streams were not significantly different (n = 39, p > 0.05).

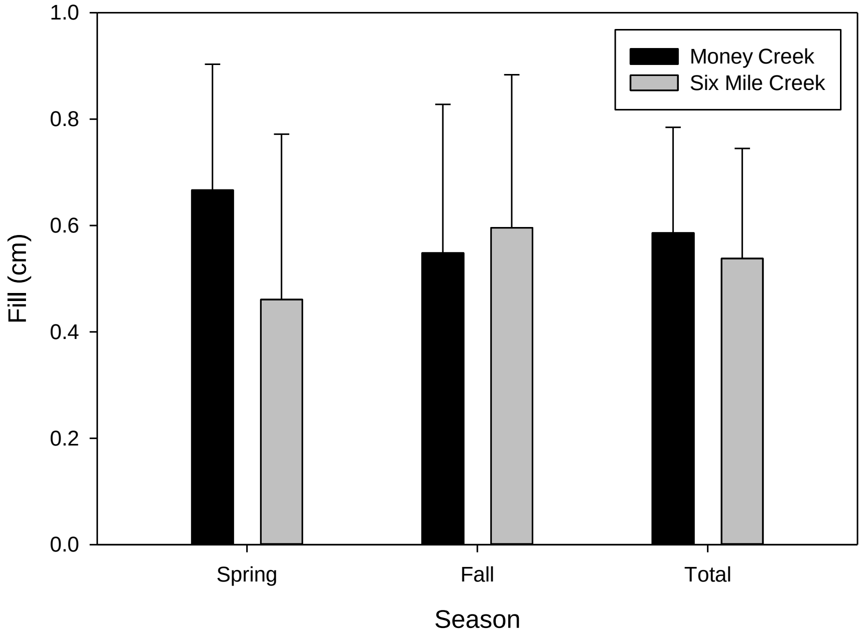


Figure 16: Average Change in Length Recorded with the Scour-Fill Markers.

Table 5: Mean and Standard Deviation for Scour-Fill Markers.

	Six Mile Creek		**Money Creek**	
Date	**Mean (cm)**	**Standard Deviation (cm)**	**Mean (cm)**	**Standard Deviation (cm)**
4/28/2015	0.12	0.86	0.63	1.14
5/7/2015	1.07	2.86	0.7	1.18
5/16/2015	0.2	0.98	*N.A.*	*N.A.*
9/10/2015	1.85	2.76	-0.07	1.33
9/17/2015	0.25	0.67	0.65	1.43
10/1/2015	0.33	0.27	1.1	2.43
10/15/2015	-0.05	0.27	0.5	0.80
Total	0.54	0.68	0.59	0.38

The scour-fill marker results reflect a large amount of uncertainty. This could be due to human error when measuring the depth to bed and washer, or by stepping on the washers during sampling. The washers may not have been heavy enough to fall down the rebar during scour events. Lastly, rip-rap caught on the rebar could disrupt the flow conditions of the water and potentially reduce the scour recorded. The large discrepancies in the data make it difficult to confidently discern patterns and trends between the sites and seasons.

Particle Sizes

Suspended Sediment and Turbidity

The finest particles in suspension were measured as the sediment concentration (SSC), suspended sediment load (SSL), and turbidity. Six Mile Creek and Money Creek had a linear relationship between SSC (mg/L) and turbidity (NTU) (Figures 17). Money Creek had a stronger relationship ($R^2 = 0.986$, $n=16$, $p < 0.05$) compared to Six Mile Creek ($R^2 = 0.793$, $n=13$, $p < 0.05$). There was no significant relationship observed between discharge and SSC or turbidity. At Six Mile Creek, the highest concentration of suspended sediment was in the spring and the lowest in the fall, but no significant difference was found (n = 13, p > 0.05; Figure 18). Money Creek had the highest SSC during the summer and lowest in the spring, but again no significant difference was found among the seasons (n = 16, p > 0.05).

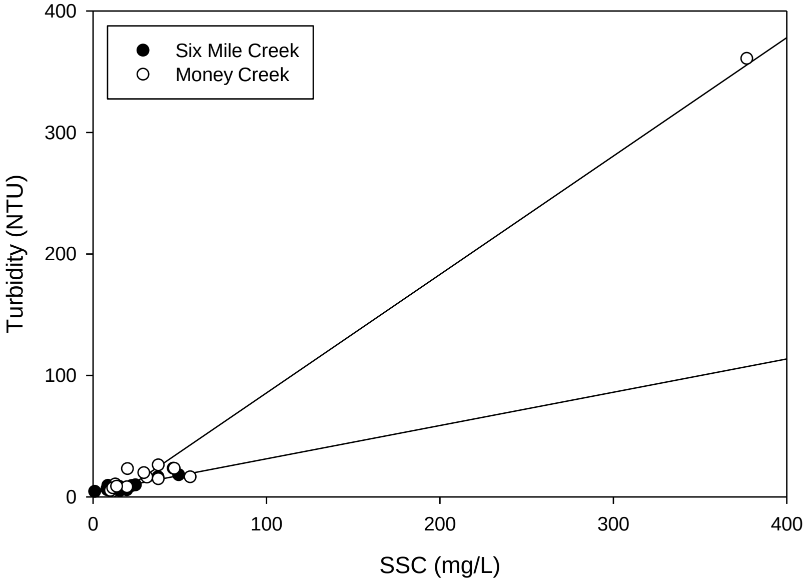


Figure 17: Relationship between Turbidity (NTU) and Suspended Sediment Concentration (mg/L). Six Mile Creek $R^2 = 0.79$, Money Creek = 0.98.

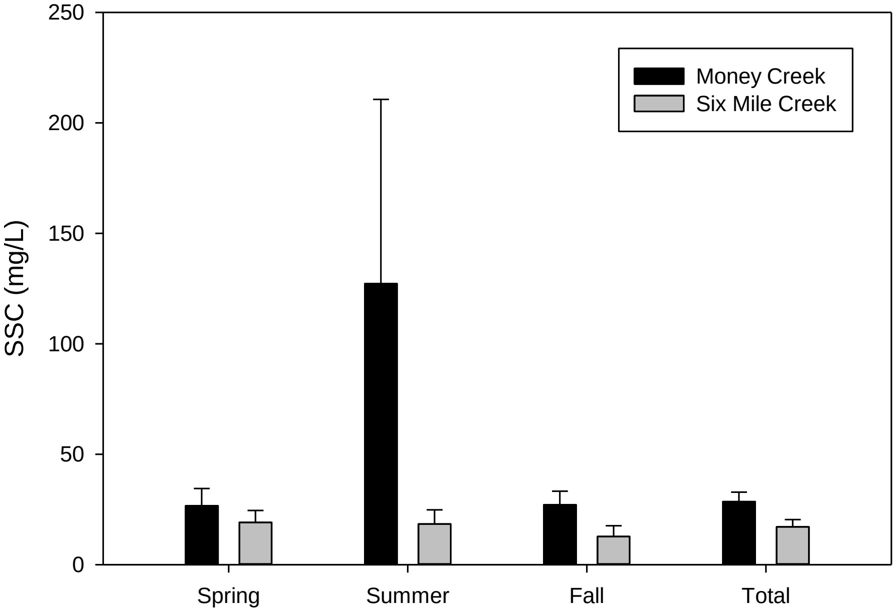


Figure 18: Average Suspended Sediment Concentration for each Season on Six Mile Creek and Money Creek.

The SSC at Six Mile Creek ranged from a low of 0.89 mg/L during the fall to a maximum of 49.3 mg/L during the summer. Money Creek was overall higher with SSC, ranging from 10.0 mg/L during the spring to 377 mg/L during the summer. The two watersheds had significantly different SSC, in total ($n = 15$, $p < 0.05$).

The SSL showed interesting trends within the two streams (Figure 19). At both Six Mile Creek and Money Creek, the spring had the highest average SSL and the fall was the lowest. Over time, the average seasonal (load per 90 days) SSL decreased (Table 6). At Six Mile Creek, the spring and summer were close to, but not statistically different ($n = 10$, $p = 0.0713$). The fall at Six Mile Creek was significantly different than spring and summer ($p < 0.05$). However, the fall at Money Creek was not significantly different from the spring and summer ($n = 10$, $p > 0.05$). When all of the data were averaged together, the two sites showed no significant difference ($n = 10$, $p = 0.077$).

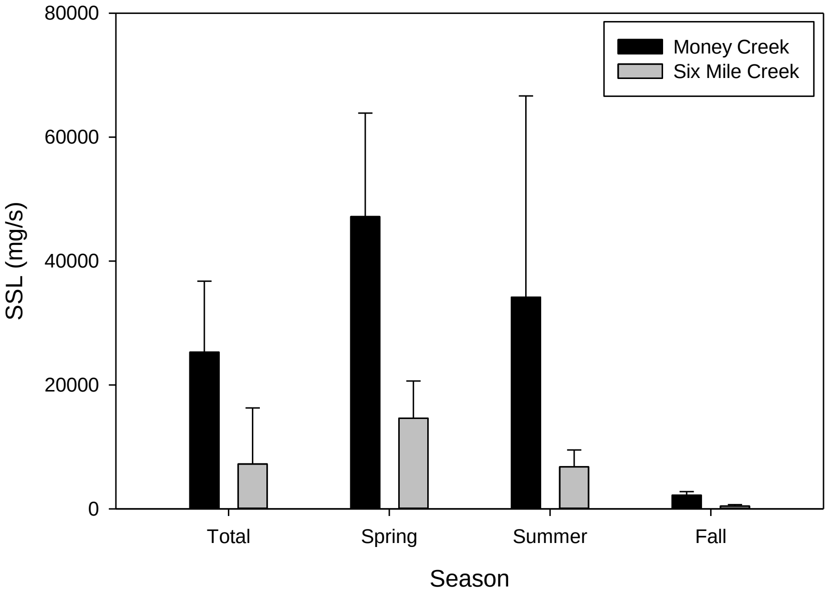


Figure 19: Average Suspended Sediment Loads for each Stream and Season. Error Bars Represent the Standard Error.

Table 6: Average Suspended Sediment Load (SSL) (kg).

Season	Six Mile Creek		Money Creek	
	Mean	**St. Deviation**	**Mean**	**St. Deviation**
Spring	1.1×10^5	$\pm 9.0 \times 10^2$	3.7×10^5	$\pm 2.0 \times 10^3$
Summer	5.3×10^4	$\pm 4.7 \times 10^2$	5.9×10^5	$\pm 3.5 \times 10^3$
Fall	3.4×10^3	$\pm 3.4 \times 10^1$	1.7×10^4	$\pm 8.4 \times 10^1$

The turbidity at Six Mile Creek was consistent throughout the entire sampling period; there was no significant difference among the seasons (n = 15, $p > 0.05$; Figure 20). Money Creek was overall greater compared to Six Mile Creek (n = 14, $p > 0.05$). The summer at Money Creek had the highest turbidity, at 73.1 NTU, while the spring averaged 14.6 NTU and the fall at 18.2 NTU. The two watersheds, though, showed a significant difference ($p < 0.05$), with Six Mile Creek averaging 8.50 NTU and Money Creek at 35.3 NTU for the entire study period. When the individual seasons were compared between sites, the fall was the only season significantly different ($p < 0.05$) but the spring was almost different ($p = 0.0987$) as well as the summer ($p = 0.0528$).

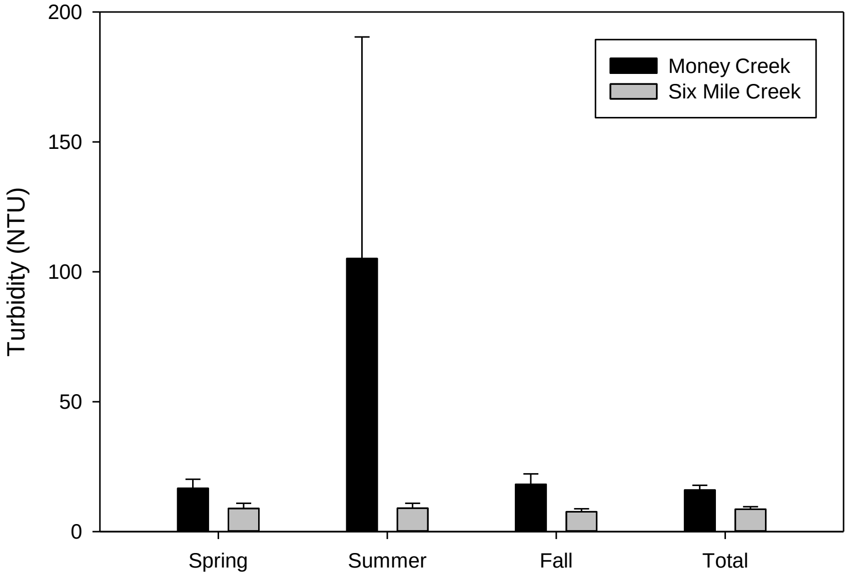


Figure 20: Average Turbidity for each Season and Site. Error Bars Represent the Standard Error.

Bedload

The bedload samples were used to understand coarse sediment transport. At Six Mile Creek the grain size varied between seasons, but within the season was relatively consistent (Appendix C). During spring and summer, 40% of the sediment was pebble-sized, while 52% of the total sediment during the fall was fine-grained (Figure 21). In contrast, Money Creek had fine sediment dominate all seasons, with 45% of the sediment comprised of the finest particles during the spring and fall. The summer had medium sands as opposed to fine sands, silts, and clays comprise a large portion of the total mass (46%, Table 7). Very little coarse material was transported in all seasons at Money Creek. In total, Six Mile Creek transported twice as much sediment than Money Creek.

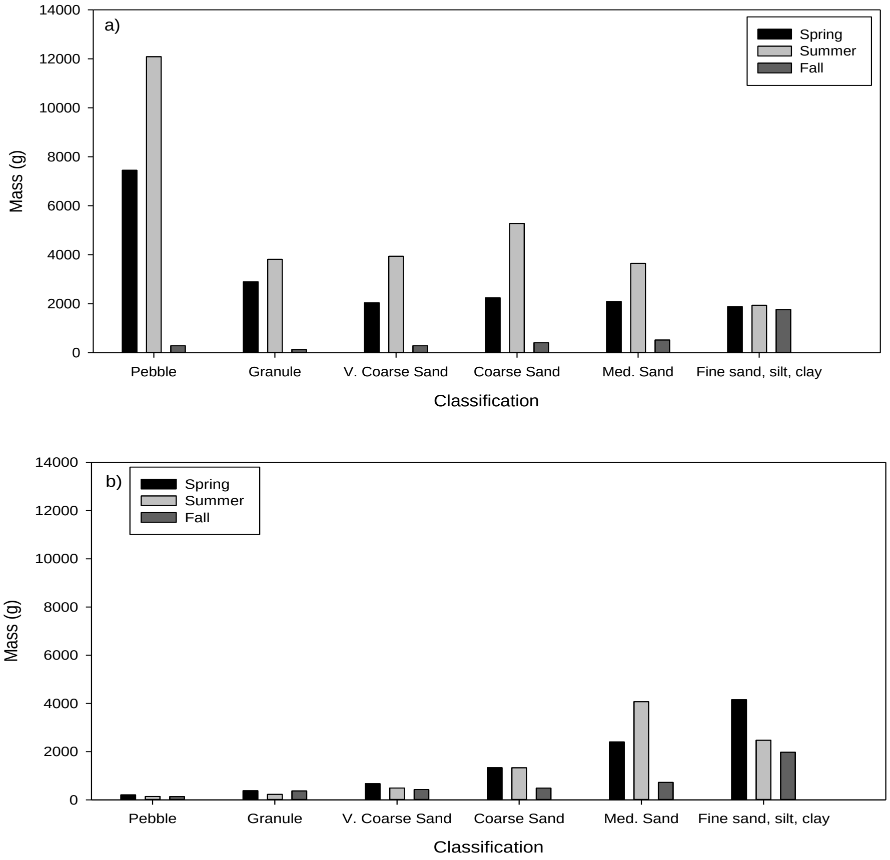


Figure 21: Distribution of Sediment Mass According to Wentworth Classification. a) Represents Six Mile Creek and b) is Money Creek.

Table 7: Grain Size Relative to the Total Mass. Left Column is Six Mile Creek. Right is Money Creek.

Grain Classification	**Spring (%)**		**Summer (%)**		**Fall (%)**		**Total (%)**	
Pebble / Gravel	40.1	2.2	39.4	1.6	8.4	3.2	37.6	2.2
Granule / Gravel	15.6	4.1	12.4	2.6	3.9	9.0	13.0	4.4
Very Coarse Sand	11.0	7.3	12.8	5.6	8.3	10.4	11.9	7.2
Coarse Sand	12.1	14.6	17.2	15.2	12.0	11.8	15.0	14.3
Medium Sand	11.2	26.2	11.9	46.7	15.4	17.6	11.9	32.7
Fine sand, silt, and clay	10.1	45.4	6.3	28.3	52.0	48.0	10.6	39.1

Post-sieving, a cumulative weight curve was used to determine the median and coarse sediment sizes (Appendix D). At Six Mile Creek, the summer season transported the coarsest particles and the fall transported the smallest (Figure 22). While the spring had coarse sediment as well, the seasons were all significantly different ($p < 0.05$). In contrast to Six Mile Creek, the coarse sediment at Money Creek was comparatively small grain sizes (Figure 22). The spring transported the coarsest (medium sands) d84 grain size at Money Creek and the fall was the smallest grain size. None of the seasons were significantly different than the other ($p > 0.05$). The median grain size (d50) followed the same trends as the d84 (Figure 23). Six Mile Creek was largest during the summer and smallest during the fall, while Money Creek was the largest during the spring and smallest in the fall. The spring and summer were not different, but the fall was significantly different at Six Mile Creek ($p < 0.05$). However, Money Creek was not significantly different between seasons ($p > 0.05$).

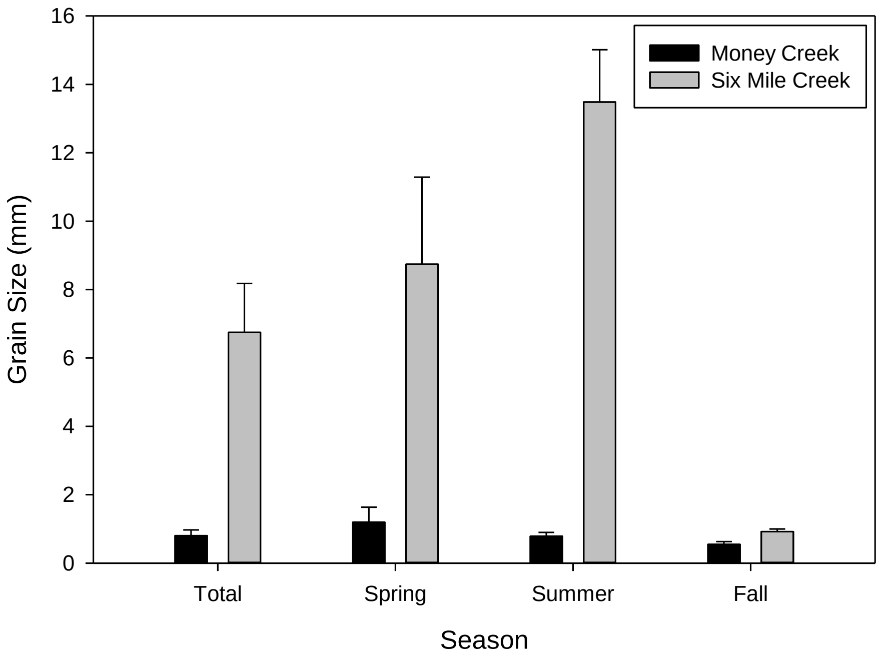


Figure 22: Mean d84 Grain Sizes for Six Mile Creek and Money Creek. The Error Bars are Standard Error.

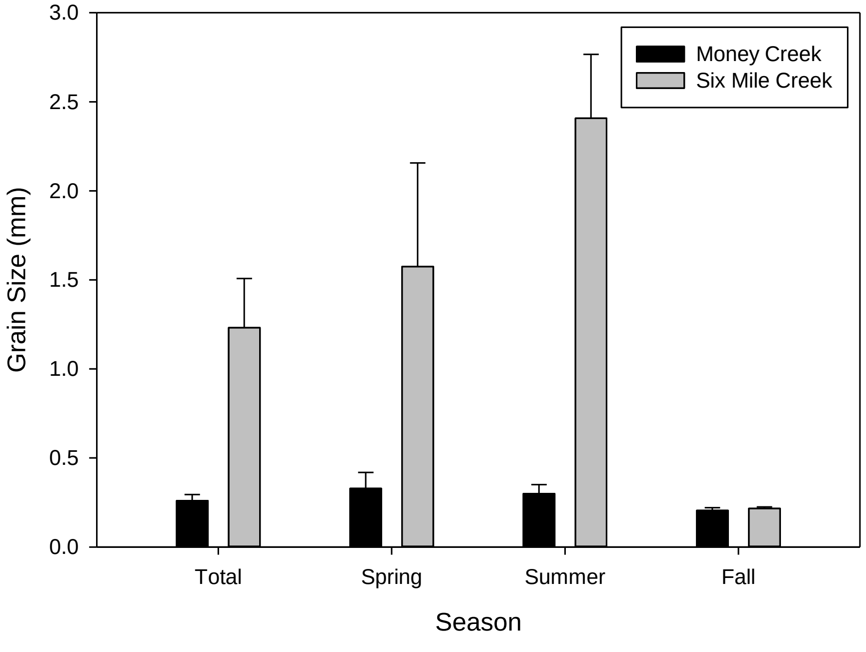


Figure 23: Mean d50 Grain Sizes at Six Mile Creek and Money Creek.

The two streams exhibited vastly different grain sizes transported. At Six Mile Creek, the average d84 grains transported in total were pebbles (gravels). More than half of the total mass of sediment transported were gravel-sized (Table 7). However, the average d84 grain size at Money Creek consisted of coarse sands and only 6.6% of the mass was gravel. The difference in grain sizes transported were significant ($n = 21$, $p < 0.05$). The median sizes transported were also significantly different, with Six Mile Creek transporting a median size of very coarse sand while Money Creek had fine sands, silts, and clays ($n = 16$, $p < 0.05$).

As a comparison, theoretical particle entrainment is studied using basal and critical shear stress values. The highest force available for transport (basal shear stress) at both streams was during the summer, when stage was the greatest (Table 8). Calculations for Money Creek were completed by calculating missing stage from the rating curve. The critical stress (τ_c) is influenced by grain size, not stage or slope as basal stress is. Six Mile Creek, therefore, had the highest critical stress during the summer and least during the fall. While Money Creek also had low critical stress during the fall, the spring had the highest critical stress. Overall, Money Creek had higher basal stresses and lower critical stresses compared to Six Mile Creek. The results of the basal and critical stresses show that at Six Mile Creek, the grains transported during the spring and summer theoretically could not be transported because the basal stress did not exceed the critical (Figure 24). However, the calculations from Money Creek show that theoretical entrainment was achieved every time except on 5/7/2015 (Figure 24). The basal stress for that date, however, was calculated using the rating curve and is an estimate, rather than the actual.

Table 8: Calculated Basal and Critical Sheer Stress Values for Both Streams. The * Indicates Values Calculated Using the Rating Curve.

	Six Mile				Money Creek			
Date	**τ_b (N/m^2)**	**τ_c (N/m^2)**	**H_a (m)**	**H_r (m)**	**τ_b (N/m^2)**	**τ_c (N/m^2)**	**H_a (m)**	**H_r (m)**
5/7/2015	*N.A.*	15.5	*N.A.*	1.17	3.23*	3.3	*N.A.*	0.43
6/4/2015	6.5	12.6	0.47	0.95	5.4	0.97	0.72	0.13
7/2/2015	7.0	15.2	0.79	1.14	7.5	0.87	0.99	0.12
7/16/2015	7.3	16.8	1.6	1.26	7.6	*N.A.*	*N.A.*	*N.A.*
9/17/2015	5.2	1.0	0.39	0.05	1.40*	0.97	*N.A.*	0.13
10/1/2015	5.6	1.3	0.42	0.09	2.10*	0.63	*N.A.*	0.08
10/15/2015	5.1	1.0	0.39	0.07	1.89*	0.87	*N.A.*	0.12

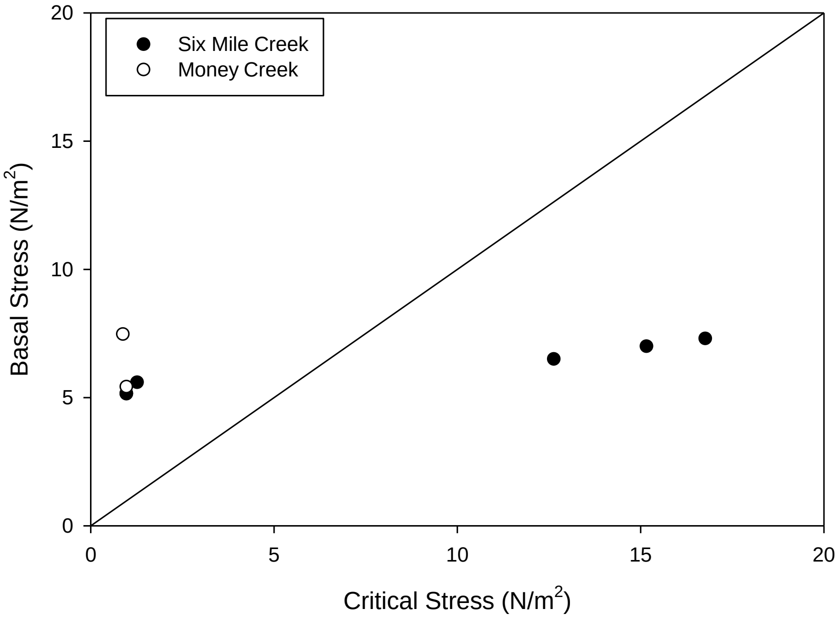


Figure 24: Basal and Critical Stresses Calculated for Theoretical Particle Entrainment. The Line Represents a 1:1 Ratio.

The required water height to mobilize the d84 particles was also calculated. The results were similar to the stress calculations (Table 8). At Six Mile Creek, two points lie below the line indicating the required height was not met (Figure 25). However, this is likely due the use of geometric mean to determine actual water height. Stage values of 1.2 m were observed in this study, and likely allowed for the transport of d84 sizes at Six

Mile Creek. In contrast, Money Creek always exceeded the required height of water, where a very shallow depth of water can theoretically entrain the d84 grain size.

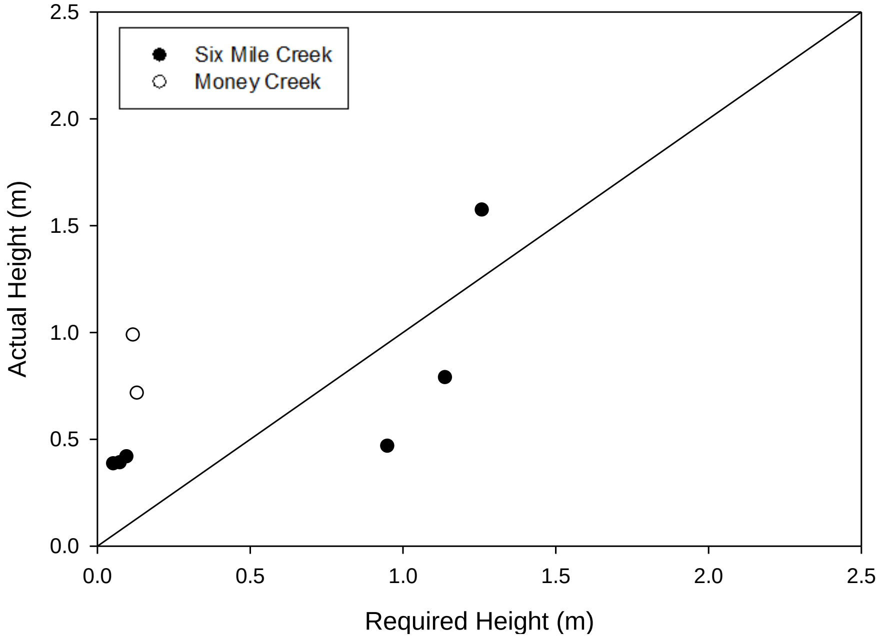


Figure 25: Actual and Required Water Depths for Particle Entrainment. The Line Represents the 1:1 Ratio.

Additional Study Sites

The two upstream sites were used to evaluate qualitative spatial changes in sediment transport. At both Six Mile Creek and Money Creek, the grain size was dominantly fine-grained (Figure 26). A majority of the total sediment mass at both sites was comprised of fine sand, silt, and clay sized grains (Table 11). No statistical comparisons could be made between the two, however, overall they appear very similar to each other. At Money Creek, the overall dominance of fine-grained sediment is similar to the downstream site. However, Six Mile Creek exhibits a different trend than the downstream counterpart; upstream, fine particles dominate the sample composition.

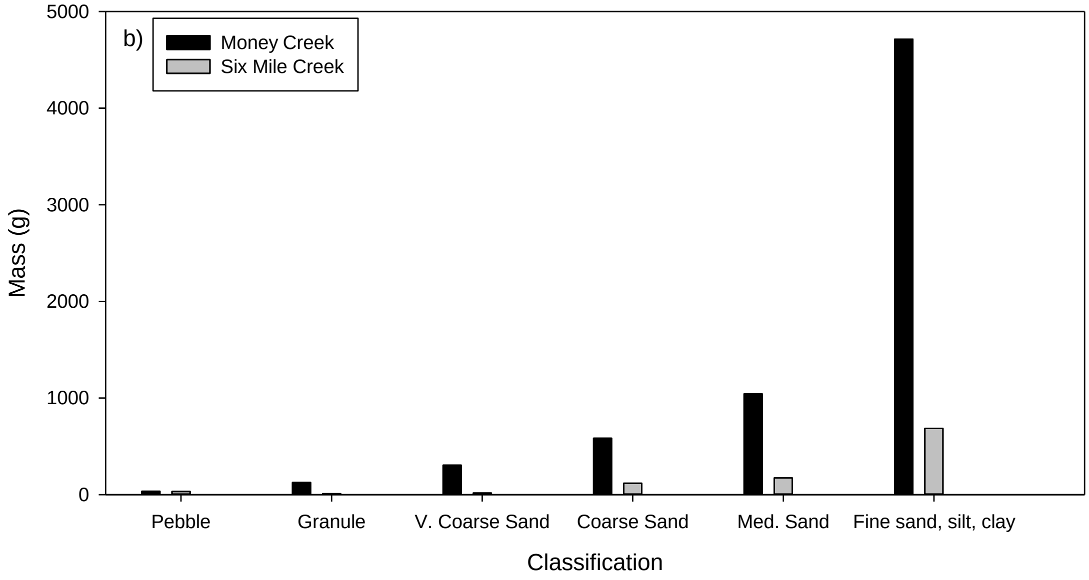


Figure 26: Grain Size Distributions for the Modified Six Mile Creek and Money Creek Sites.

Table 9: Percent of the Total Sample Mass for Upstream Sites.

Classification	**Six Mile Creek (%)**	**Money Creek (%)**
Pebble / Gravel	3.1	0.5
Granule / Gravel	0.8	1.8
Very Coarse Sand	1.6	4.5
Coarse Sand	11.4	8.6
Medium Sand	16.7	15.3
Fine Sand, Silts, Clays	66.3	69.3

CHAPTER IV

DISCUSSION

Seasonal Patterns

The flow conditions at Six Mile and Money Creeks were enhanced due to uncharacteristic precipitation events. The month of June went on record as the highest precipitation month since 1926 (Angel, 2016), and the effect of precipitation was evident within the two streams as seasonal changes in particle sizes transported (Figures 22 and 23). The streams began the sampling season roughly at baseflow levels (0.22 m^3/s for Six Mile Creek and 1.16 m^3/s for Money Creek), but rapidly increased with the increased precipitation, and by mid-summer they were at higher discharge values (maximum 1.01 m^3/s and 1.87 m^3/s). Towards late July into August, the rain events decreased and the streams returned to baseflow conditions. The extensive precipitation resulted in bankfull conditions during the summer for Money Creek, but not Six Mile Creek. Baseflow conditions dominated throughout the fall, but occasional storm events during the sampling period provided higher stage and discharge values. Overall, periodic storms produced unsteady flow conditions throughout the early portions of the study period, which has been shown to enhance bedload transport (Gomez, 1991; Graf and Suszka, 1985; Paul and Dhillon, 1987).

One potential factor for sediment transport in addition to seasonal differences in precipitation is the impact of activities on the farm fields. During the spring months, the fields are tilled and prepared for planting. The farmers with fields adjacent to the study sites do not use cover crops, so the fields are tilled and barren from post-harvest (mid-September) to the late spring (May). During the summer, the crops would be expected to hold the soil particles together. Trees and established vegetation increase the contribution of sediment from the stream banks, while greater land area devoted to crops increases overland flow (Lamba et al., 2015). The fields were harvested late this year in the fall (early-mid October), which coincided with the end of data collection. Because so much of the land surface is disturbed seasonally, one would expect the sediment from the fields to be a large component of the sediment transported (Basile, 2010; Duvert, 2011; Montgomery, 2007). This is consistent with the sediment patterns at Six Mile Creek. The fall transported significantly less material, and the material was smaller in diameter, compared to spring and summer. While the storm events were fewer in number and small in magnitude during the fall, the subdued stream response may be partially attributed to vegetation on fields. The stream baseflow levels were lower during the fall as well, which may be tied seasonally to precipitation. However, at Money Creek, no difference in seasons was observed with the amount and size of sediment transported between the spring and summer versus the fall. The lack of a seasonal difference at Money Creek may be related to the stream bank morphology, which showed both erosion and deposition, so the activities on the farm fields may still impact seasonal sediment transport.

The spring and summer seasons exhibited similar patterns in sediment transported at Six Mile Creek. In general, coarse material was transported during both the spring and summer (Figure 21). The two seasons can be differentiated because the spring transported finer material compared to the summer. The grain size distributions showed the summer months had coarse material transport dominate the system. The metrics used to study fine-grained material, i.e. suspended sediment load and the bank pins, confirm the seasonal difference. Compared to the fall, the spring and summer were vastly different in most aspects of sediment transport; there was less sediment in suspension, less as bedload, and less eroded. One caveat is regarding the sampling period, which began halfway through the spring season. If snowmelt has an impact on sediment transport, then sampling would need to be conducted closer to the freeze-thaw cycles indicative of early spring. In the current study, the spring transported more sediment compared to the fall, but the summer season proved to be the greatest season of variation. Similar low-gradient bedload work found that the greatest transport occurs between February and July, which is consistent with the results of this study (Milzow et al., 2010).

The surrounding farm fields represent one of two possible external sediment sources, the overland flow component. While this was not directly measured, it could potentially account for some of the finer grained sediments being mobilized through the system. In similar low-gradient agricultural systems, the land area devoted to crops resulted in a general increase in the overland flow of sediment (Lamba et al., 2015; Florsheim et al., 2011). The uncharacteristically high precipitation events (24 centimeters of rain in June alone; Angel, 2016) largely occurred during the late spring, when the plants were not necessarily well-established in the soils. The lower suspended sediment and overall lower sediment mass transported during the fall could indicate that the crops were sufficient during storms to reduce the overland flow of sediment into the streams. However, the presence of tile drains may play a significant impact on the sediment derived from overland surfaces. Tile drains are installed to improve subsurface drainage so the roots of crops are not flooded by the rise of the shallow water table. If the tile drains are efficient, then less water will drain directly off the fields from sheet flow, thereby reducing the contribution of sediment from surrounding fields. Fine, suspended sediment in the streams is more likely derived from bank erosion.

Bank erosion is a second potential sediment source, and one that may play a large role in low-gradient systems. These streams are characterized by meanders that move laterally through extensive bank erosion and deposition. Agricultural systems are extensively modified, and stream channels are continuously working to return to natural, meandering conditions. Because of this, bank erosion and lateral channel migration dominate the erosion processes (Lamba et al., 2015; Florsheim et al., 2011). In this study, the bank erosion pins showed net erosion at Six Mile Creek, where steep, actively eroding banks characterize the stream. In contrast, the stream banks at Money Creek reflected deposition along the shallow banks when the floodwaters recede followed by erosion during the fall. At Money Creek, the seasonal differences in precipitation were potentially the controlling factor for sediment derived from the banks. While the results here cannot be entirely conclusive regarding the dominance of bank erosion versus overland flow, it is likely that bank erosion dominates as a source of sediment because extensively tiled fields will see subsurface drainage dominate rather than sheet flow.

Watershed Differences

There were surprising differences between the two watersheds (Table 10). Stream responses to the same precipitation events differed between the two sites (Figures 11-13). The peak discharge values at Six Mile Creek were less than Money Creek, yet Six Mile Creek mobilized much coarser particles (maximum 20.5 mm at Six Mile Creek compared to 4 mm at Money Creek). Six Mile Creek also transported twice as much bedload sediment than Money Creek. With increased discharge and stream stage, there should be more and coarser material transported as bedload (Schneider, 2014; Gomez, 1991). Observations of the bed material in each stream showed that both have coarse material present, and the streams would be classified as bimodal sand-gravel streams with silts and clays comprising the bed margins (Gomez, 1991; Folk and Ward, 1957). However, Money Creek did have fewer coarse materials compared to Six Mile Creek. The amount of sediment moved through the seasons and the size of particles (Figure 22), mass transported (Table 7), and the SSL and turbidity metrics for the suspended load (Figures 19 and 20) were remarkably different.

Table 10: Summary of Results.

Component	**Six Mile Creek**	**Money Creek**
Stage	Lower	Higher
Discharge	Lower	Higher
Bank Pins	Net erosion	Net deposition
Suspended Sediment	Less	More
Bedload: Mass	More	Less
Bedload: Particle size	Gravels	Medium-Fine Sands

Despite the apparent similarities in land use and gradient, the sediment transport dynamics were extraordinarily different between the two streams. The most striking difference was with the transport of coarse material as bedload. Six Mile Creek showed that coarse-grained sediments as large as 20.5mm were transported, whereas grains coarser than 4.0mm were not commonly transported in Money Creek. Previous work on sediment transport within Money Creek revealed 67% of the bed material was characterized by grains as large as 9.4mm (Stall et al., 1958). For Money Creek, the d84 grain sizes are small compared to other low-gradient systems; some report minimum d84 values of 62mm (Snyder et al., 2008), and another study in McLean County, IL revealed a minimum d85 of 11mm along the Little Kickapoo Creek (Peterson et al., 2008). The Six Mile Creek sediment sizes are consistent with the previous work in Little Kickapoo Creek. In contrast, Money Creek is not similar in sediment size, but appropriate for the sediment size established by Stall et al. (1958).

Because grain size studies were not performed on the formation the streams cut through, it is difficult to discern if the differences between Six Mile Creek and Money Creek are a result of the source of sediment or the mechanics behind sediment transport. However, the surficial geology reveals slight differences in the material the streams are cutting through (Figure 1). Some of the tributaries of Six Mile Creek overlie the Normal moraine, an end moraine, while all of Money Creek and its tributaries overlie the ground moraine of the Lemont Formation. The differences in coarse material transport could be attributed to the difference between the two moraines. This implies that coarse material transport in low-gradient systems will depend spatially on the surficial geology and nature of sediment deposition.

At first glance, it appears suspended sediment transported exhibited different trends than the bedload. The suspended load through Six Mile Creek was significantly less than at Money Creek (Table 6). These results fit with previous studies during a drought year on the two streams by Hanna (2013). However, Six Mile Creek transported more sediment as bedload than Money Creek. One explanation for the discrepancy in sediment transport between suspended sediment and the bedload is the size of the watersheds. While not directly accounted for in this study, the results from Hanna (2013) can be applied to look at suspended sediment per drainage area. Hanna found that Six Mile Creek transported more sediment in suspension per drainage area than Money

Creek. Overall, it can be determined that the suspended sediment results from a stormy year are comparable and fit with previous work from a drought year. The trends observed are similar, but the magnitude of sediment increased. There are also spatial considerations at work; the smaller area of Evergreen Lake Watershed is an important factor.

The stream differences extend to the morphology of the banks. The contribution from the banks was greater at Six Mile Creek, where the banks are much steeper and have visible erosion surfaces that contribute sediment to the streams. The bank pins showed net erosion from the banks, which confirm observations made in the field that mass wasting events occurred frequently throughout the study period. This happened during the spring and summer, when the higher stream discharges would erode bank material. Due to the steepness of the banks at Six Mile Creek, the recession limbs of the hydrographs would rarely deposit sediment on the banks. This was not the case at Money Creek; the gentle slopes of the banks meant that when the stream was at bankfull, the water flowed onto the floodplain. In this scenario, when the waters receded and returned to baseflow, sediment was deposited on the stream banks. This was confirmed by the burying and subsequent rediscovery during fall of the bank pins at this stream. The difference in channel morphologies at these streams can potentially lead to interesting implications for the dynamics of sediment transport. While representing only one point in a spatially extensive watershed, steeper, eroding banks characterize a larger portion of Six Mile Creek (STREAMS, 2005).

The spatial extent of the stream differences is difficult to discern. The data collected at the two additional sites show a different story than the primary stream segments. The particles are dominantly fine-grained for both of the modified sites at Six

Mile Creek and Money Creek (Figure 27). This differs from the typical stream dynamics expected; in most systems, the higher slopes upstream will result in grain size decreasing downstream. The explanation for this could be that the two systems are recently and continuously being anthropogenically modified, which alters the dynamics (Knox, 2001). The streams become so streamlined and capable of transporting water and sediment downstream, that pools where sediment can be stored are lost (Knox, 2001). The bedload moving downstream is transported in pulses as wave forms, and these forms are influenced by the bed morphology and particle size (Gomez, 1991; Iseya and Ikeda, 1987; Whiting et al., 1988; Ferguson et al., 1989). When streams become modified and altered, the sediment transport dynamics can vary widely (Knox, 2001). Instead of the fining-out sequence, coarser particles are more likely to be transported downstream from the stream headwaters.

Spatial patterns are consistent with previous work, particularly in the Evergreen Lake watershed. Previous work on Six Mile Creek has noted that 90% of the erosion and transport occurs within 4 miles of Evergreen Lake (STREAMS, 2005). The Six Mile Creek study site in this study is within this distance, whereas the modified site is located near the headwaters of the stream. Their study also revealed that the surrounding fields are positioned lower than the channel of the stream at the study site location (STREAMS, 2005). This could potentially play a role in the overland flow component of sediment transport, where the fine-grained sediment cannot efficiently drain into the stream channel. Without an addition of fine-grained sediment, the stream could be sediment starved, making it easier to pick up and transport sediment grains, hence the dominance of the coarse-grained material.

Across the watershed, a majority of Six Mile Creek is eroding. The STREAMS (2005) study reported that along Six Mile Creek, 61% of the stream channels are actively down cutting and incising into the parent material. The down cutting would indicate the primary source of sediment for transport in Six Mile Creek is derived from the bed material. The larger d50 and d84 particles mobilized a greater quantity of sediment found in this study would potentially confirm STREAMS (2005) findings. Bank erosion has been rated as severe for Six Mile Creek (STREAMS, 2005), and the bank pins results would support that (Figure 15). Unfortunately, the scour-fill data are not adequate to address whether scour or deposition within the stream dominated (Figure 16). Theoretically, with the installation of the dam and subsequent upstream flooding, Six Mile Creek should not be incising into the bed material, but rather be laterally cutting into the banks. The results here suggest that the watershed dynamics within Six Mile Creek are unusual and warrant further study to understand the processes dominating the system.

Money Creek exhibits different trends than Six Mile Creek. Unlike Six Mile Creek, it was determined that Money Creek was not actively down cutting, making the primary source of sediment the lateral migration of the banks (STREAMS, 2006). In many low-gradient agricultural systems, the dominant sources of sediment will be derived from the banks and overland flow (Florsheim, 2011). The bank erosion data presented here does not support a greater lateral migration of the streams, but the uncharacteristically high stage levels from the rain events perhaps are to blame. In addition, the difference in bank morphology could play a role due to the ability of Money Creek to deposit sediment on its banks when the flood waters recede. Bank erosion would contribute smaller particles (Lamba et al., 2015; Florsheim et al., 2011). The higher proportion of fine-grained sediment in Money Creek could mean the stream is not sediment starved, and therefore not actively down cutting. This is supported by the higher turbidity, suspended sediment load, and suspended sediment concentration values found at Money Creek throughout the study period. However, there are no data to support that Money Creek is completely sediment starved.

Bedload Contribution Downstream

Estimates can be determined regarding the bedload contribution to the two lakes. A 1958 effort to quantify the sediment deposited in Lake Bloomington used the Schoklitsch formula to calculate the tons of bedload moving through the stream (Stall, 1958). This formula has been utilized by the USGS in subsequent sediment studies throughout other low-gradient, agricultural systems in Illinois. There are two equations for the Schoklitsch formula, one quantifying the bedload from a relatively uniform sand sample (Equation 9), and the other for mixed bedload samples (Equation 10; Stall, 1958).

$$G = \frac{86.7}{\sqrt{d}} S^{1.5} B(q - q_0)$$

$$q_0 = \frac{0.00532d}{S^{1.33}} \qquad \text{Eq. (9)}$$

Here, G is the bedload mass (kg day^{-1}), d is the grain size (mm), S is the slope, B is bed width (m), q is discharge (m^3/s), and q_0 is the discharge at which movement begins (m^3/s).

$$G_t = aG_a + bG_b + cG_c + \cdots + mG_m \qquad \text{Eq. (10)}$$

In Equation 10, G_t is the total bedload for a mixture of particles, G_a is the mass of a particular grain size (kg), a is the percent weight of that diameter, and m is the number of sediment fractions (from sieving). The bedload from Money Creek was uniform and approximately sand sized. Stall (1958) characterized the bed material of Money Creek and found the particles ranged from 0.05mm to 9.4mm, which is consistent with the data from this study.

Bedload estimates were calculated four times, two different ways for each stream. First was to use the equation for sands (Equation 9). The slopes used in Equation 9 were the same as used in the basal and critical stress calculations. The diameter used was the calculated d84 grain size from each sampling interval. The mass collected over the 14 to 30 day intervals was not used for the calculation. Instead, the d84, stream discharge, and stream width were used to determine a daily rate. Discharge was calculated for all stage values measured by the transducer using the rating curve of stage versus discharge. Over the time interval, the geometric mean was calculated for discharge. Because the bed width was not measured continuously, the width used was the average of the measured width at the start and end of the interval. At Six Mile Creek, the bank morphology prevents a large variance in stream width, so the results will not be sensitive to width. However, the calculations for Money Creek will be more sensitive to width because it varied widely with stage. After solving for q_0 (part of Equation 9), the bedload in kg per day (G) was calculated for each sampling date. This number was multiplied by the length of a season, 90 days, to obtain an extrapolated seasonal bedload mass (Table 13).

Table 11: Kg of Bedload Transported using Schoklitsch Formulas for Sand and Mixed Material.

Season	**Money Creek**		**Six Mile Creek**	
	Sand (kg)	Mix (kg)	Sand (kg)	Mix (kg)
Spring	$4.3\text{x}10^5$	$9.1\text{x}10^3$	$2.2\text{x}10^4$	$7.0\text{x}10^4$
Summer	$6.3\ \text{x}10^5$	$1.0\text{x}10^4$	$3.8\text{x}10^4$	$5.1\text{x}10^4$
Fall	$3.4\text{x}10^4$	$6.4\text{x}10^3$	$2.8\text{x}10^4$	$1.5\text{x}10^4$
TOTAL	$1.1\text{x}10^6$	$2.4\text{x}10^4$	$6.4\text{x}10^4$	$1.4\text{x}10^5$

The second step was to calculate the bedload using the equation for mixed sediment composed of sands plus gravels or clays. Using Equation 10, the bedload was calculated for every collected trap. The percent finer values were calculated as described above in the Methods section. Each fraction was summed for that trap and averaged together to obtain a mass for that sampling interval. The intervals were then averaged together and multiplied by 90 days to calculate the bedload mass per season. The total mass was calculated by summing the seasons together; however, because winter was not sampled, the total does not represent the yearly bedload mass.

When the two methods were compared, there are distinct differences in the estimated bedload mass transported per season. Money Creek estimates using the sand equation are considered most accurate because Stall et al. (1958) found it estimated bedload to an accuracy of 31%, compared to the two other methods that were 225% higher than the measured amount. The Money Creek mixed sediment equation results were used to compare the difference between the two formulas. However, the Six Mile Creek results show less bedload is being transported than Money Creek, which does not agree with the results of this study. This could potentially be due to the inaccuracies with the mixed sediment equation, which does not incorporate as many stream-related variables. The sand equation for Money Creek also may be overestimated due to slope inaccuracies, bed width, or the geometric mean of discharge.

While there are many uncertainties with the bedload results presented, they can provide a general understanding of how much sediment moves through Six Mile Creek and Money Creek. According to the STREAMS reports, Six Mile Creek contributes 1.9×10^6 kg of sediment per year to Evergreen Lake (2005) and Money Creek transports

9.5×10^5 kg to Lake Bloomington (2006). The sediment loads per year were based on one-time qualitative surveys of bank erosion throughout the watersheds. A certain severity rating equated to a mass of sediment per length. If these bedload results are accurate, then despite the unexpectedly large grain sizes from Six Mile Creek, the bedload contribution to the lakes would be 7% of the total estimated sediment load. One caveat is that winter is not incorporated to the total sediment calculation in the current study. At Money Creek, the bedload exceeds the total sediment estimated by the STREAMS study. This may imply the calculated seasonal bedload is an extreme overestimate for this study, or far more sediment is contributed to Lake Bloomington than originally thought.

The spatial and temporal component of sediment transport is important to consider. The STREAMS study calculated the total sediment loads to the reservoirs different than the methods in this study. In the STREAMS study, they incorporated the spatial component but not the temporal. However, in this work, the bedload estimates represent one spatial point and many points incorporated over a temporal range. With bed material defined as a separate source of sediment than bank erosion, it is possible the annual sediment contribution established by the STREAMS study is in fact an underestimate. This is important for management practices and predictions for sediment loading into reservoirs used for drinking water and recreation. While further studies are needed to confirm and improve these estimates, these results should be considered in other low-gradient stream systems that do not incorporate bedload to sediment transport calculations.

Further Research

There are many avenues of research that can be done to further this study and improve its conclusions. Methodologically, comparing the sediment transport captured by a hand-held bedload sampler or installing bedload traps that extend the whole way from one stream bank to the other would improve the knowledge of sediment mass and particle size moving through the system. In addition, adding more sampling periods and decreasing the interval of time in between sampling would aid in observations of when the pulse of sediment is mobilized through the system. Storm sampling of bedload could also be incorporated to understand at which point in the hydrograph the streams are most actively eroding. Lastly, the stark differences between the two watersheds pose a few different questions. Another study could be to examine the effect of scale; the two watersheds studied here are portions of the larger Mackinaw River Watershed. Are the watershed scale discrepancies observed here even significant to discuss and pursue when pushed out to a larger scale? This study also controls the spatial distribution of the sampling points while the temporal factor is dynamic and changing. Future studies could examine the spatial changes of sediment transport, observing the movement of materials from headwater to discharge. Further research would help answer these questions, and aid in understanding the complexities of sediment transport in low-gradient agricultural streams.

CHAPTER V

CONCLUSION

The objectives of this study were to study sediment transport dynamics through two low-gradient agricultural streams. Two hypotheses were proposed that stated there would be seasonal differences in the various components of sediment transport studied, including bedload transport, suspended sediment and turbidity, scour-fill, and bank erosion. The second hypothesis stated there would be no differences between two sub-watersheds located within the same watershed.

With regard to seasonal discrepancies, it was found that the summer transported the most sediment as opposed to the spring and fall for Six Mile Creek, but with no significant difference among seasons at Money Creek, it is difficult to discern one season as greater than the other. There was also greater erosion during the early portions of the study, which was largely due to uncharacteristically large magnitude precipitation events.

The watershed differences, were exacerbated by the extensive precipitation during the late spring and early to mid-summer. The particles were larger and greater in quantity and erosion was greater for the Evergreen Lake Watershed compared to Lake Bloomington-Blue Mound Watershed. Additionally, the streams were spatially variable between upstream and downstream locations. Potential explanations for this could be the differences in parent material grain distributions, slope, land-use, unstable channels, and Six Mile Creek being more sediment-starved and more competent at mobilizing sediment. The largest system control is the presence of the end moraine in Evergreen

Lake Watershed, with more sand and gravel lenses.

As climate continues to change and precipitation events become more unpredictable, sediment transport processes become more important to understand. Because these two streams flow into artificial reservoirs used as a source of drinking water, the long-term health and sustainability of the reservoirs is of the utmost importance. Increased sedimentation has already reduced storage capacity, and will continue to do so. As freshwater sources become more scarce and in-demand for a growing world, their preservation and health is critical. The results of this study are a stepping stone into understanding the geomorphological processes affecting two local freshwater sources.

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APPENDIX A

STREAM WIDTH AND DISCHARGE CONVERSIONS (METRIC TO STANDARD)

Six Mile Creek				
Date	**Width (m)**	**Width (ft)**	**Discharge (m^3/s)**	**Discharge (ft^3/s)**
5/7/2015	5.3	17.5	0.22	7.9
5/16/2015	5.6	18.5	0.67	23.8
5/21/2015	5.3	17.5	0.49	17.4
6/4/2015	5.2	17	1.02	35.8
6/18/2015	*N.A.*	*N.A.*	*N.A.*	*N.A.*
7/2/2015	5.2	17	0.79	28.0
7/16/2015	5.4	17.75	0.96	34.1
7/30/2015	5.5	18	0.73	25.6
8/13/2015	5.2	17	0.13	4.4
8/27/2015	5.1	16.7	0.10	3.7
9/10/2015	5.7	18.75	*N.A.*	3.9
9/17/2015	6.2	20.5	0.11	1.3
10/1/2015	5.6	18.5	0.04	0.1
10/8/2015	5.1	16.8	0.00	2.9
10/15/2015	5.8	19	0.05	3.1

Money Creek				
Date	**Width (m)**	**Width (ft)**	**Discharge (m^3/s)**	**Discharge (ft^3/s)**
5/7/2015	8.8	29	1.16	40.849
5/16/2015	9.7	31.7	1.84	64.827
5/21/2015	9.0	29.5	1.29	45.643
6/4/2015	9.8	32	1.71	60.407
6/18/2015	14.6	48	*1.78**	*62.86**
7/2/2015	9.4	30.75	1.77	62.539
7/16/2015	10.1	33	*1.65**	*58.27**
7/30/2015	13.1	43	*1.74**	*61.45**
8/13/2015	9.1	30	0.20	6.932
8/27/2015	8.4	27.5	0.07	2.601
9/10/2015	7.6	25	0.07	2.379
9/17/2015	7.5	24.5	0.03	1.095
10/1/2015	7.6	25	*N.A.*	*N.A.*
10/8/2015	9.5	31.2	0.18	6.501
10/15/2015	7.5	24.5	0.11	3.89

APPENDIX B

SAMPLING SUMMARY TABLE

	Six Mile Creek					Money Creek				
Sampling Date	S-F	BP	SSC	DIS	BLD	S-F	BP	SSC	DIS	BLD
4/23/2015	INSTALLATION DAY									
4/28/2015	X	--	--	--	--	X	--	--	--	--
5/7/2015	X	X	X	X	X	X	X	X	X	X
5/16/2015	🟨	X	X	X	--	--	--	🟨	--	--
5/18/2015	--		--	--	--	--	🟨	--	X	--
5/21/2015	--	--	X	X	--	--	🟨	X	X	--
6/5/2015	🟨	🟨	X	X	X	--	🟨	X	X	X
6/18/2015	--	--	X	--	--	--	--	X	--	--
7/2/2015	🟨	🟨	X	X	X	--	--	X	X	🟨
7/16/2015	🟨	🟨	X	X	X	--	--	X	--	--
7/30/2015	🟨	🟨	X	X	🟧	--	--	X	--	--
8/13/2015	--	--	--	X	--	--	--	--	X	--
8/27/2015	--	--	--	X	--	--	--	--	X	--
9/3/2015	RE-INSTALLATION DAY									
9/10/2015	X	X	X	X	--	X	X	X	X	--
9/17/2015	X	X	x	X	X	X	X	x	X	X
10/1/2015	X	X	x	x	X	X	X	x	x	X
10/15/2015	x	x	x	x	x	x	x	x	x	x

--	no samples
🟨	1 sample missing / PARTIAL
🟧	2 samples missing
X	all samples
S-F	Scour Fill
BP	Bank Pins
SSC	Suspended Sediment
DIS	Discharge
BLD	Bedload (traps)

APPENDIX C

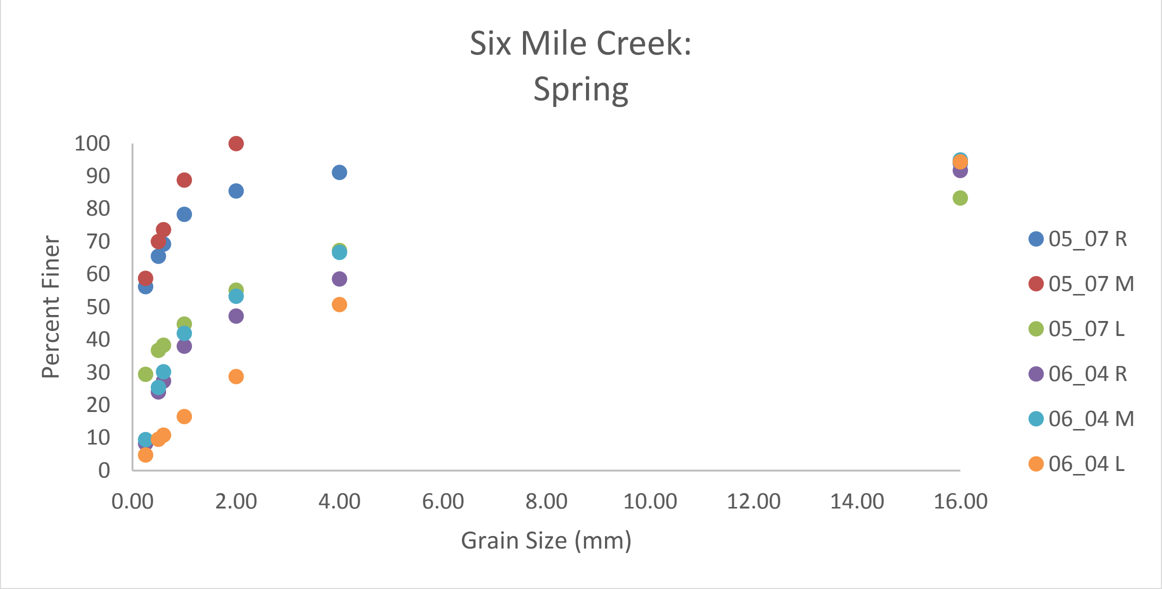
BEDLOAD TRAPS

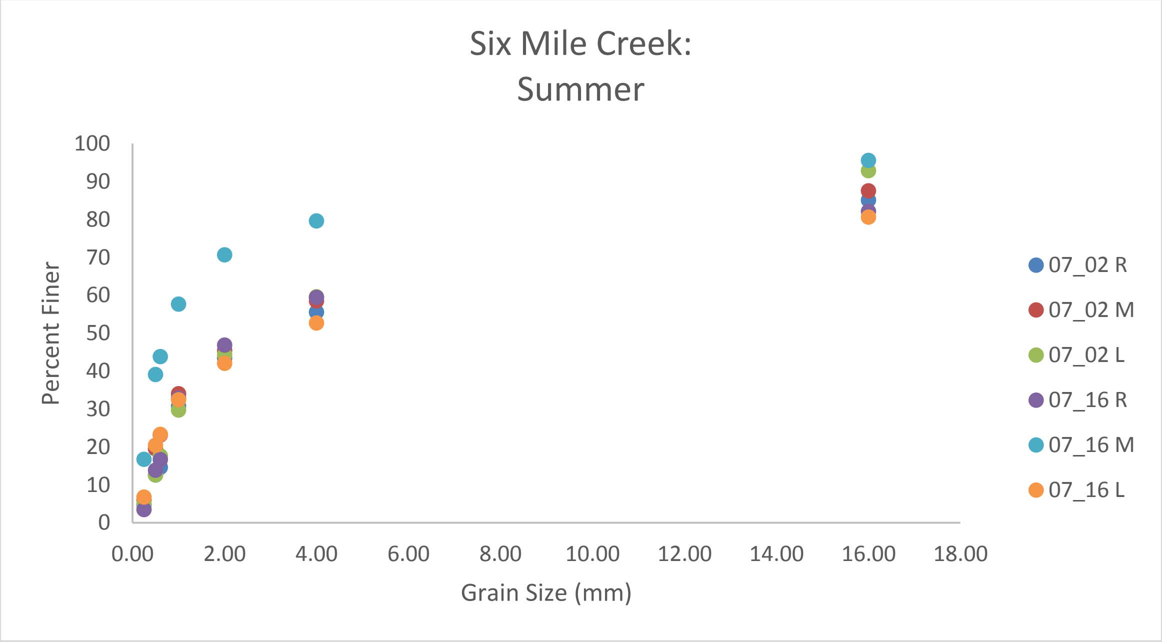
Date	Trap Position	Six Mile Creek (g)	Money Creek (g)	Time Collecting (days)
5/7/2015	A	379.03	653.48	14
	B	496.37	1029.7	
	C	532.28	798.1	
	Total	*1407.68*	*2481.28*	
6/4/2015	A	5600.17	1400.67	28
	B	6886.84 [a]	3425.73	
	C	4865.1	1845.59	
	Total	*17351.44*	*6671.99*	
7/2/2015	A	5962.02	2583.32	27
	B	7307.79 [a]	6228.31	
	C	3735.42	*N.A.*	
	Total	*17005.23*	*8811.63*	
7/16/2015	A	1521.88	*N.A.*	14*
	B	3814.1	*N.A.*	
	C	8341.95 [a]	*N.A.*	
	Total	*13677.93*	*N.A.*	
9/17/2015	A	221.5	232.5	14
	B	280.5	291.5	
	C	259.5	233.5	
	Total	*761.5*	*757.5*	
10/1/2015	A	622.5	590.5	14
	B	325.5	1671	
	C	1217.5	438.5	
	Total	*2165.5*	*2700*	
10/15/2015	A	113.5	211.5	14
	B	102.5	227	
	C	230.5	201.5	
	Total	*446.5*	*640*	

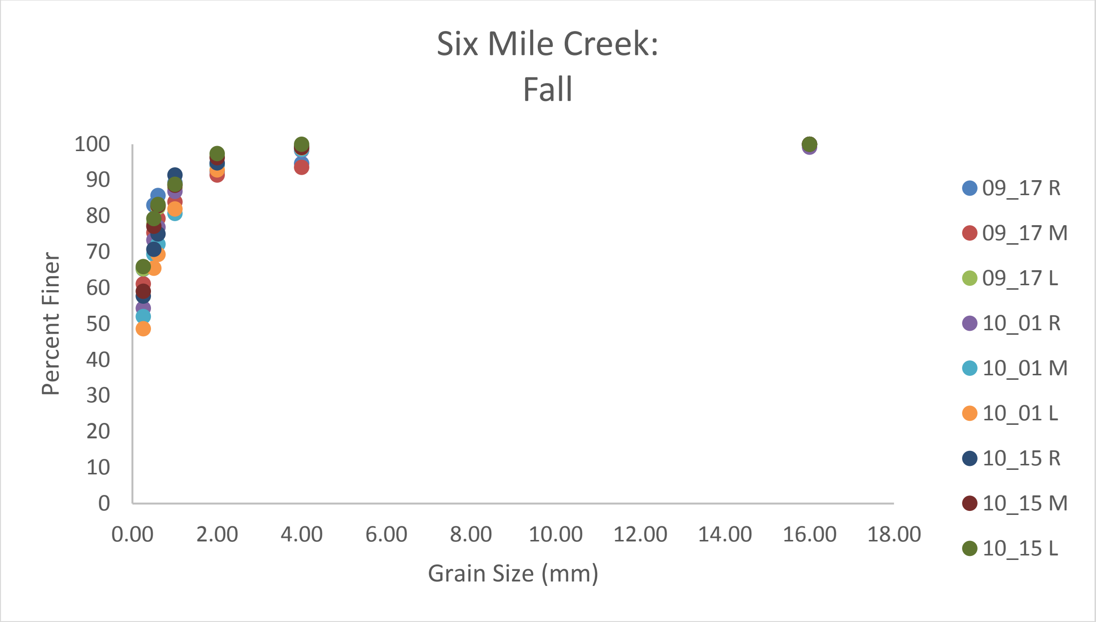
[a] While not directly recorded, these were instances where the capacity of the traps were either approached, met, or exceeded.
* Time collecting is only for Six Mile Creek; no sample was collected from Money Creek on that day due to high flow.

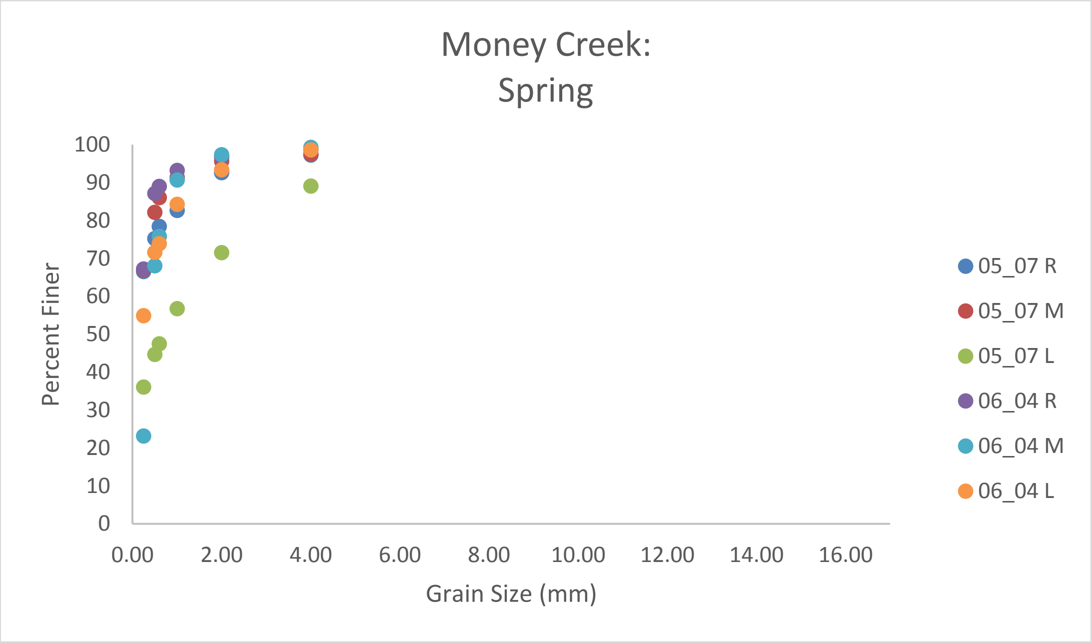
APPENDIX D

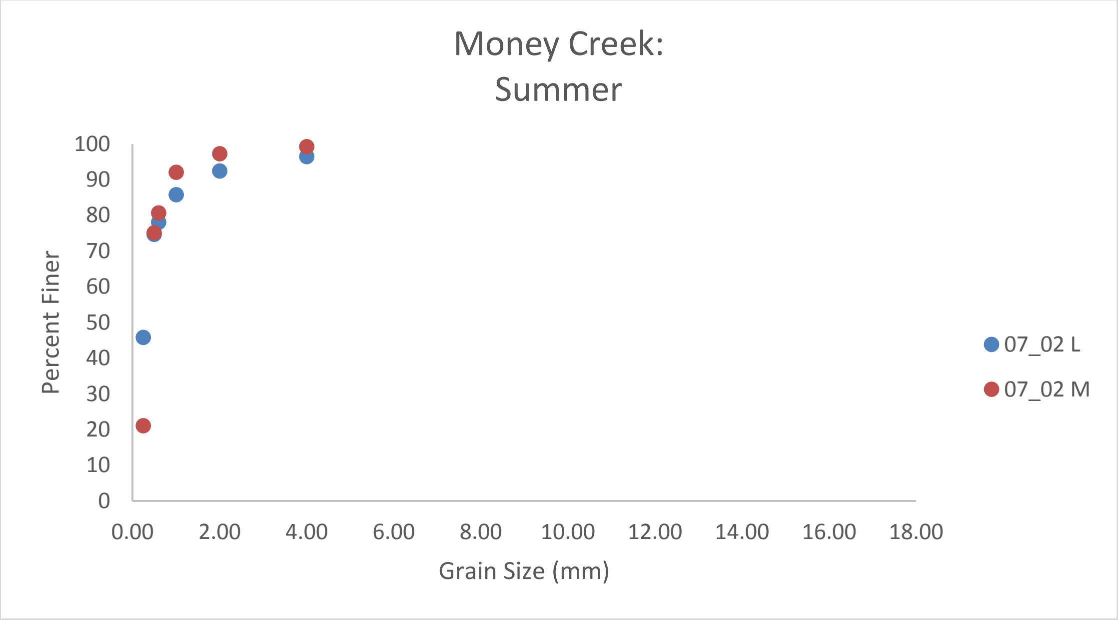
CUMULATIVE WEIGHT CURVES



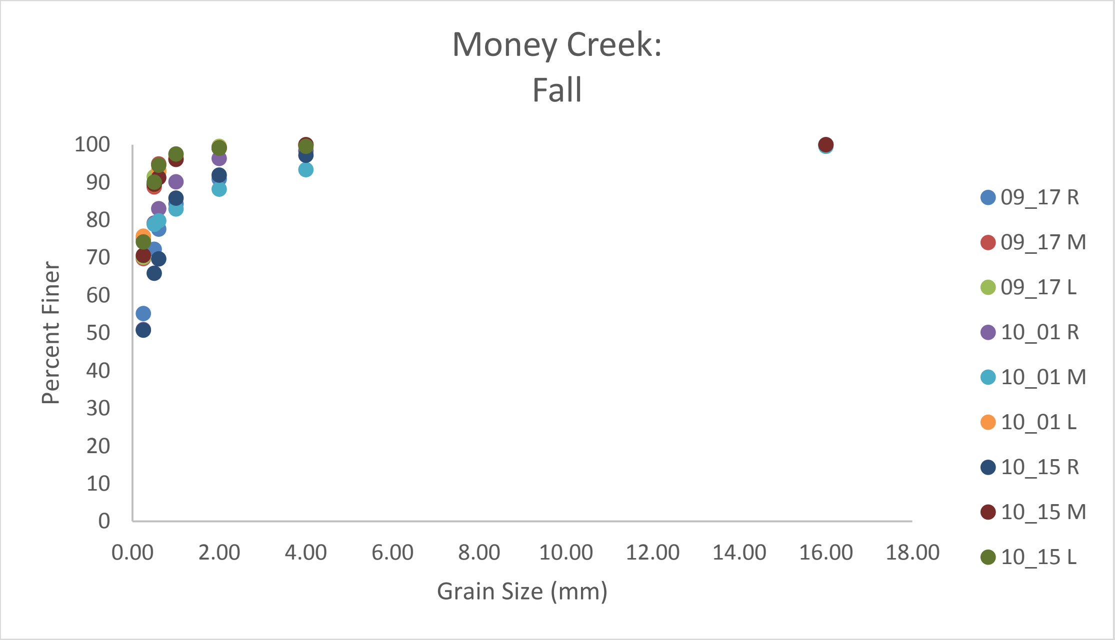



Six Mile Creek:
Fall
Percent Finer
100
90
80
70
60
50
40
30
20
10
0
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
Grain Size (mm)
● 09_17 R
● 09_17 M
● 09_17 L
● 10_01 R
● 10_01 M
● 10_01 L
● 10_15 R
● 10_15 M
● 10_15 L


Money Creek:
Spring
Percent Finer
100
90
80
70
60
50
40
30
20
10
0
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
Grain Size (mm)
● 05_07 R
● 05_07 M
● 05_07 L
● 06_04 R
● 06_04 M
● 06_04 L



Money Creek:
Summer
Percent Finer
100
90
80
70
60
50
40
30
20
10
0
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
Grain Size (mm)
● 07_02 L
● 07_02 M



Money Creek:
Fall
Percent Finer
100
90
80
70
60
50
40
30
20
10
0
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
Grain Size (mm)
● 09_17 R
● 09_17 M
● 09_17 L
● 10_01 R
● 10_01 M
● 10_01 L
● 10_15 R
● 10_15 M
● 10_15 L

APPENDIX E

BEDLOAD FRACTION RESULTS

SIX MILE CREEK

Season	**d50 (mm)**	**d84 (mm)**	**Mean**	**Standard Deviation**
Spring	0.2	1.65	0.65	1.19
Spring	0.2	0.92	0.41	0.43
Spring	1.25	16	5.80	5.23
Spring	2.2	12.2	4.92	4.70
Spring	4.0	16	6.00	4.19
Spring	1.6	8.7	3.55	3.31
Summer	2.8	15.6	6.33	6.82
Summer	2.4	13.4	5.40	6.21
Summer	2.6	12	5.03	5.56
Summer	3.45	17.25	7.03	7.52
Summer	0.8	6.85	2.62	4.07
Summer	2.4	15.8	6.23	7.11
Fall	0.2	0.6	0.30	0.73
Fall	0.2	1	0.43	1.22
Fall	0.2	0.7	0.33	0.42
Fall	0.2	0.9	0.40	0.65
Fall	0.25	1.2	0.52	0.65
Fall	0.25	1.3	0.55	0.69
Fall	0.25	1	0.45	0.52
Fall	0.2	0.8	0.37	0.43
Fall	0.2	0.8	0.37	0.43

MONEY CREEK

Season	**d50 (mm)**	**d84 (mm)**	**Mean**	**Standard Deviation**
Spring	0.25	1	0.45	0.69
Spring	0.16	0.55	0.27	0.38
Spring	0.75	3.35	1.40	1.62
Spring	0.2	0.45	0.25	0.33
Spring	0.39	0.82	0.46	0.41
Spring	0.22	1	0.44	0.63
Summer	0.25	0.9	0.40	0.68
Summer	0.35	0.67	0.41	0.32
Fall	0.25	1	0.45	0.71
Fall	0.2	0.45	0.25	0.16
Fall	0.2	0.4	0.23	0.19
Fall	0.25	0.65	0.33	0.41
Fall	0.1	0.3	0.17	1.26
Fall	0.2	0.4	0.23	0.19
Fall	0.25	0.9	0.42	0.68
Fall	0.2	0.4	0.23	0.21
Fall	0.2	0.4	0.23	0.16