QUANTIFYING SEDIMENT TRANSPORT IN MODIFIED STREAMS IN THE UPPER MACKINAW RIVER, IL

Andrew T. Sergeant

41 Pages May 2012

This thesis reports the results of a two year study determining quantitatively whether or not there is a relationship between stream modification and sediment transport.

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Stream modification, the widening, deepening, straightening, and alteration of channel geometry, is common in Illinois to drain water from fields to enhance agricultural production. Natural stream restoration begins immediately following stream modification as sediment is deposited and the stream reverts to a natural form. The objective of this work was to determine whether or not there is a relationship between sediment transport and stream modification. Three stream segments within the Mackinaw River watershed (IL) that have been modified at different intervals were chosen to assess how sediment transport varies as streams return to a natural form. Frog Alley (FA) was modified 11 years ago, Bray Creek (BC) was modified 34 years ago, and Crooked Creek (CC) is unmodified. Scour markers, suspended sediment concentrations, stream cross-sections, shear stress calculations and Stream Power Indices were used in this study. The results from the scour markers indicate that the more recently modified streams have lower amounts of scour and sedimentation due to a lack of sediment in the stream. FA had the lowest amount of scour and sedimentation, BC had slightly more scour and sedimentation, and CC had the highest levels of scour and sedimentation. The

average scour per recording for FA, BC, and CC was 0.15, 0.23, and 0.78 cm respectively. The average sedimentation per recording for FA, BC, and CC was 0.12, 0.12, and 0.6 cm respectively. The stream cross sections indicated a change in channel geometry throughout the study period. The theoretic shear stresses indicate that during baseflow, the d_{85} particles will not move, but the d_{50} particles were always mobile at Bray and Crooked. At Frog, there were periods when the d_{50} would not be mobile. The results show sediment deposition and scour is more closely related to available sediment in a stream rather than strength of stream flow.

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ANDREW T. SERGEANT

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Fulfillment of the Requirements
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ANDREW T. SERGEANT

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A. T. S.

CONTENTS

TABLES

FIGURES

CHAPTER I

INTRODUCTION

Background

Central Illinois was once a marshy wetland that was unsuitable for the agriculture. Prior to settlement, it is estimated that 50% of Illinois was a natural wetland (Rhoads and Herricks, 1996). Draining the marshy areas made the land suitable for agriculture. In order to drain the land, stream modification took place. Virtually all Illinois headwater streams have been straightened, widened, and deepened (Mattingly et al., 1993).

Straightening a stream prevents the stream from naturally meandering, which allows it to drain an area more quickly. As a stream is straightened the sinuosity, a measure of stream straightness, is lowered. Sinuosity is calculated using the following equation:

$$\text{Sinuosity} = \frac{Distance\ along\ the\ stream\ between\ 2\ points}{Straight\ line\ distance\ between\ 2\ points} \qquad \text{Equation 1}$$

The lowest possible sinuosity is 1, which represents a stream flowing in a straight line. Any stream that has a sinuosity greater than 1.5 is considered to be meandering (Allan, 1995). A straighter stream will have a greater discharge (more energy), which allows the stream to erode and transport more sediment. Stream modification is important because it affects the surrounding environment in many ways. In addition to aiding drainage, streams form many boundaries such as property lines, county lines, or state boundaries. In order for these boundaries to function effectively they must remain constant. Straightening a stream and preventing it from meandering is one way to keep stream location constant.

Modifying the stream geometry alters the stream from a natural form to a modified shape (Figure 1). The modified geometry forms a trapezoidal stream shape with steep banks on both sides of the stream. Widening and deepening a stream involves the removal of the stream's substrate and any stream vegetation. The modified geometry with limited vegetation along the slopes will eventually lead to erosion of the bottom of the bank. As the bottom of the bank is eroded away, bank failure will occur. The mass wasting will deposit bank sediment onto the stream bed, resulting in a transition back towards a natural geometry for the stream.

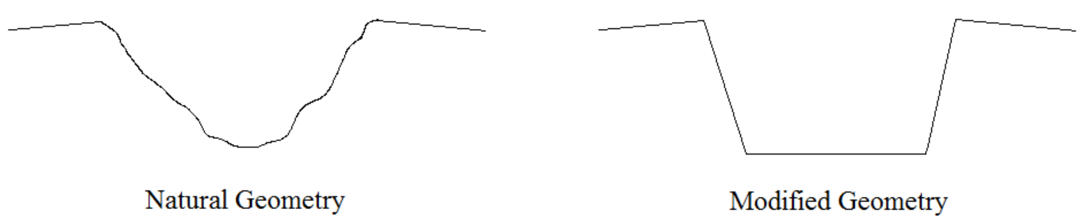


Figure 1-Generalized Cross Section of a Stream with a Natural Geometry and a Modified Geometry

As soon as streams are modified, the natural restoration process begins. Modified streams are constantly progressing towards a natural state. There are six stages of stream restoration or channel evolution (Simon and Rinaldi, 2000). Stage I is considered pre-modification. In stage I the stream will have a natural geometry, erosion and deposition will occur and there should be vegetation along the banks and possibly within the stream Stages II-IV are characterized by degradation of upstream segments due to erosion of the stream bank and aggradation in downstream segments as sedimentation occurs. Stage II is characterized by a trapezoidal geometry and the removal of vegetation. Stage III is characterized by basal erosion of stream banks and pop-out failures. Stage IV is also characterized by basal erosion of stream banks, pop-out failures and the development of riparian vegetation. Stages V and VI are characterized by continued aggradation as eroded sediment is deposited along the stream. During stage V, a meandering thalweg will start to develop, there will be pop-out failures, and the deposition of point bars will begin. Stage VI is characterized by the further development of a meandering thalweg, deposition of point bars, basal erosion along the outside banks of bends, some pop-out failure may still occur, and vegetation should be reestablished. The newly restored stream will not be exactly the same as it was pre-modification, but the stream will reach new equilibrium conditions.

While modifying streams enhances the drainage of fields, the draining of soil water introduces potential environmental problems. An increase in nutrients within stream water is linked to the installation of tile drains. Tile drain installation is common in Illinois due to the importance of agriculture in the state. Many farmers utilize tile drainage systems to keep their fields dry enough to grow crops. A tile drainage system is a series of PVC or clay/brick pipes placed beneath a field to drain water from the field to a stream flowing along the edge of the field. The PVC pipes are pierced to allow water to enter the pipes but keep soil out. The water that is drained from a field is typically high in nitrates and other nutrients (Nangia *et al*., 2010). These agriculturally derived chemicals in the water are not removed due to the loss of stream sediment and stream vegetation during the modification process.

The hyporheic zone (HZ) is the area beneath a stream where surface water mixes with groundwater (Jones and Mulholland, 2000). The HZ plays many roles in stream ecology and is affected by stream modification (Jones and Mulholland, 2000). In addition to stream vegetation, the HZ also helps to remove nutrients from stream waters. As stream modification occurs and the stream's substrate is removed, the HZ is effectively gone. The area that groundwater and surface water mix is negligible. The effective loss of the HZ, as well as the removal of stream vegetation, results in the inability of a stream to remove nutrients from stream water and causes a buildup of nutrients at the stream's mouth. For example, it is estimated that 30% of the nitrates in the Gulf of Mexico near the mouth of the Mississippi River are from Illinois (Scott *et al*., 2007).

Research has previously been conducted on low order modified streams in the Upper Mackinaw River Basin. Harris (2008) conducted her M.S. thesis research in the spring and summer of 2008 examining the effect stream modification has on the denitrification ability of hyporheic sediment. She concluded that restored streams have a greater denitrification potential than modified streams because of the restoration of the HZ in restored streams. The lack of hyporheic sediment leads to a reduced residence time for stream water in the HZ and contributes to a decrease in denitrification potential (Harris, 2008).

During restoration the HZ will be restored. Sedimentation will take place and as sediment is deposited and the stream substrate is reformed, the HZ will be reestablished. However, low gradient streams limit the restoration rate (Urban and Rhoads, 2003). Due to low energy levels stream banks are eroded slowly, and thus, sediment deposition rates are low. Higher gradient streams with more energy will be able to erode more sediment and restore the HZ faster.

Research Question

This research addresses the following question:

What effect does stream modification and natural restoration have on sediment transport in the Upper Mackinaw River?

Hypothesis

The following hypothesis has been proposed:

Streams that have been modified more recently will carry less sediment than those that have been modified earlier or not at all. Or, in other words, as a stream returns to a natural state, more sediment is transported

Site Description

Three different streams were used to test the proposed question and hypothesis. The streams are part of the Mackinaw River Basin located east-northeast of Bloomington, IL near the town of Colfax, IL (Figure 2).and are low gradient, low order streams. The three streams are Crooked Creek, Bray Creek, and Frog Alley. Frog Alley has a gradient of 0.00215, Bray Creek has a gradient of 0.00138, and Crooked Creek has a gradient of 0.00163. These streams have been modified at varying times so that the progression of stream restoration can be determined. Crooked Creek is unmodified, Bray Creek was modified 34 years ago, and Frog Alley was modified 11 years ago. These streams flow through agricultural areas and serve as drainage for the surrounding fields. The studied segment of Frog Alley has a sinuosity of 1.014, Bray Creek has a sinuosity of 1.033, and Crooked Creek has a sinuosity of 1.083.

The three streams are developed within the Wedron Formation. which is comprised of glacial till and moraine deposits from the Wisconsin glaciations The Wisconsin glaciation was the last glaciation event to cover Illinois and occurred from 75 to 13.5 thousand years ago (Nelson & Weibel, 2009). The stream beds are composed of sand and gravel, while the banks are silt and clay. Subsequently, all three streams have stream beds that are characterized as very poorly sorted.

Table 1-Site Statistics

	Frog Alley	Bray Creek	Crooked Creek
Time since Modification	11 years	34 years	Unmodified
Sinuosity	1.014	1.033	1.083
Gradient	0.00215	0.00138	0.00163

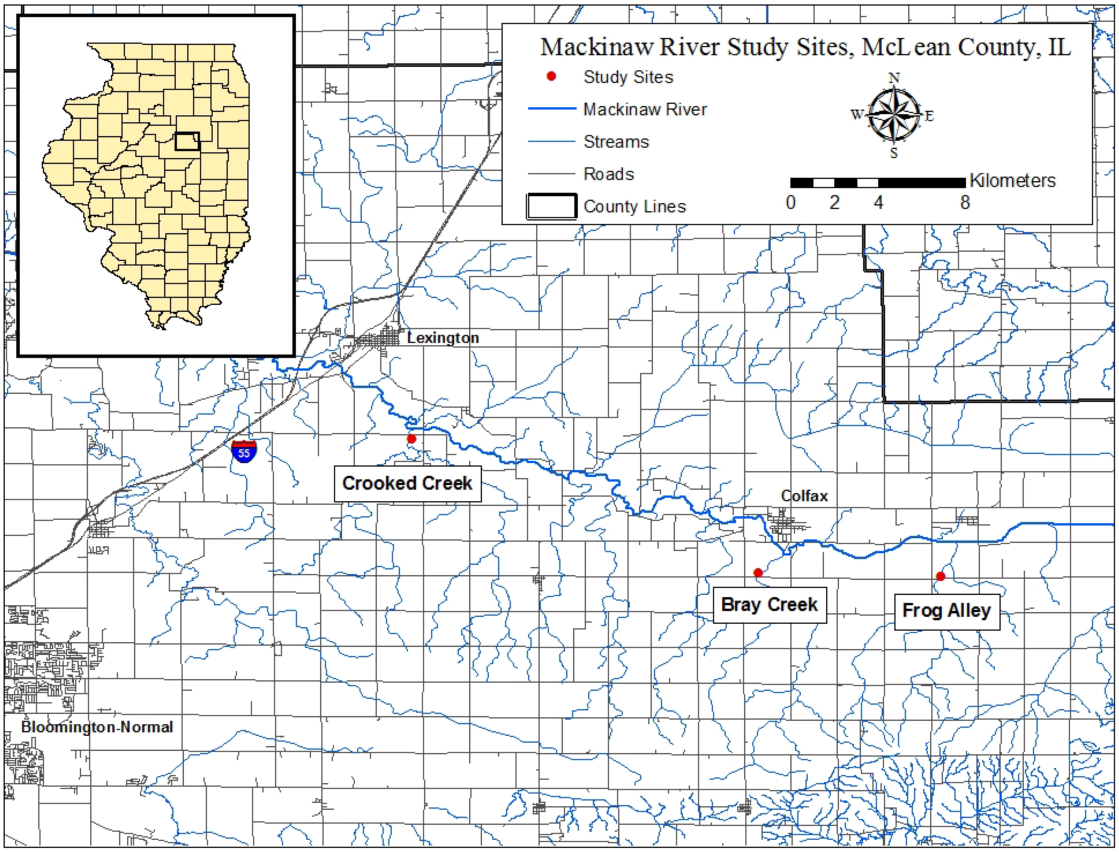


Figure 2-Locations of study sites within McLean County, IL

CHAPTER II

METHODS

Five different methods were used to address the question and hypothesis. These included the installation and monitoring of scour markers, the monitoring of stream cross-sections, the monitoring of the suspended sediment concentrations, the determination of theoretical basal and critical shear stresses, and the determination of Stream Power Indices for the study streams. The methods were used on the same 100 meter stretches used by Joyce Harris and Joe Becker in previous studies. These methods reproduce the work Joseph Becker conducted on the same stretches of streams in 2008. His data included amounts of sediment deposition and scour in the modified stream segments. The previous data will provide additional data sets to use in my research.

Scour Markers

Scour markers were used to quantify the amount of sediment deposited or eroded along the stream bed. The scour markers consisted of rebar inserted vertically into the streambed with washers placed around the rebar resting on the stream bed. As sediment is deposited, the washers were covered and the amount of deposited sediment was measured based on the depth the washers are buried at. In the case of erosion, it was measured how far the washers fell to get an idea of how much sediment was eroded. Five scour markers were installed along the thalweg of each stream segment with the five markers placed in line along a 100 meter stretch of the stream channel at 25 meter intervals. Data were recorded following precipitation events.

The data collected were analyzed to determine how sediment transport varies between the different intervals of stream modification. The sediment deposition data was used to determine average sediment deposition amounts per data collection and the standard deviations of each recording.

Suspended Sediment

Suspended sediment concentration was measured and recorded to determine how much sediment is entrained in the stream flow. Once a known sample of stream water is obtained, the entrained sediment was filtered out and dried at 105 °C. The sediment was then weighed to determine the suspended sediment mass (Maidment, 1993). The amount of water and the mass of sediment collected was used to calculate the sediment concentration using the following formula.

$$\text{Sediment Concentration} = \frac{Mass\ of\ Sediment}{Volume\ of\ Water} \qquad \text{Equation 2}$$

Sediment concentration samples were collected using a siphon sampler. The siphon samplers (or single stage samplers) were constructed using 500 and 710 mL plastic bottles. Two holes were drilled into the cap of each of the bottles using a ¼ in drill bit and ¼ in clear vinyl tubing was inserted into each hole approximately 1 cm into the bottle. The area around the tubing was sealed with sealant to ensure that water would not leak into the bottle and to prevent the tubing from sliding in and out of the bottle cap. Five bottles with were fastened to a fencepost with plastic cable ties. The inlets for the samplers were at varying depths of 10, 30, 50, 70, and 80 cm from the top of each fence post (Figure 3) so that sediment samples from different heights within the water column could be collected.

Once suspended sediment samples were collected, the samples were filtered using a hand pump filter. The filters used had a pore size of 0.45 µm. The weight of the filter paper was measured prior to filtering. The amount of water being filtered was also measured. After the sediment was filtered out of the sample, the sediment and filter paper were placed on a crucible and placed in an oven and baked for 24 hours at approximately 105 degrees Celsius to remove water from the sediment. After 24 hours the filter paper with sediment was removed from the oven and weighed. The mass of sediment could then be determined by subtracting the initial filter weight from the weight of the dried sediment and filter. It was assumed that the amount of water in the filter initially was negligible. Once the weight of the sediment and the volume of water filtered were determined, Equation 2 was used to calculate the suspended sediment concentration.

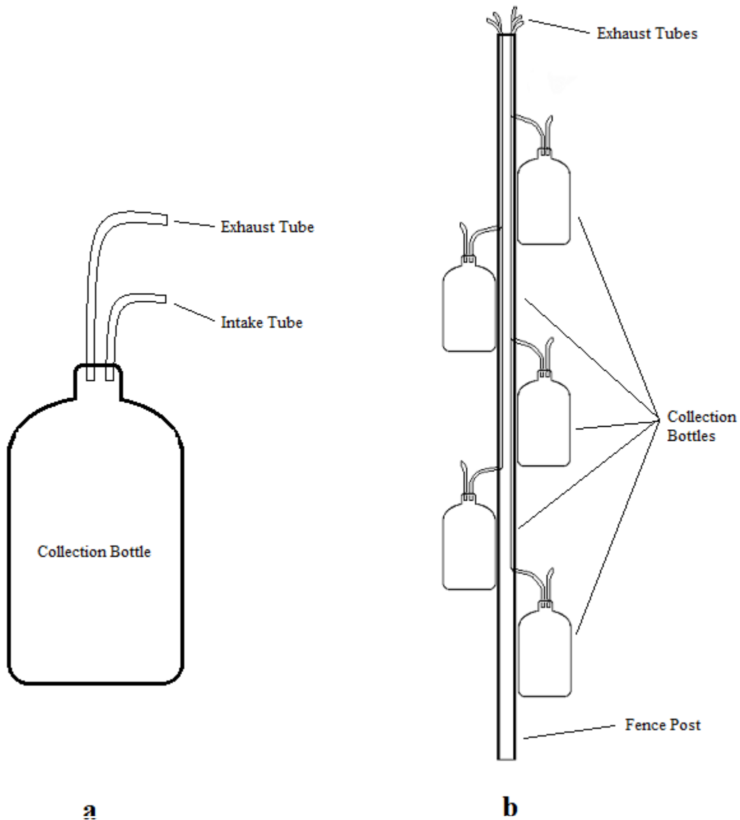


Figure 3-Suspended sampler diagram. (a) represents a single collection bottle with intake and exhaust tubes, (b) represents the assembled device with five collection bottles attached to a fence post. The depths of the bottles in figure b are the distances from the top of the fence post to the intake tube.

Stream Cross-Sections

Stream cross sections were surveyed by hand with a stadia rod and measuring tape to determine the depth of water. The assumption was made that the water surface was horizontal, thus making the water depth an accurate approximation for channel geometry. Because the water depth varied each time a cross section was recorded, a correction had to be made so the cross sections could be compared. The change in water depth between measurements was determined and that change in depth was either added or subtracted from the measured depths so the data corresponded with the original cross sections.

The cross sections of each of the three streams helped to show how the stream geometry has changed throughout the restoration process. As previously mentioned, modified streams will erode over time and a stream's modified geometry will return to a natural geometry. Detailed cross sections were used to monitor changes in stream geometry following high flow events. Cross sections were taken at two set locations at each stream segment. Cross sections were resurveyed at a varying interval dependent on sediment deposition rates. If the scour marker results indicated significant sediment deposition or scour had occurred, new cross sections were surveyed and if the scour markers did not indicate significant deposition or scour, cross sections were not resurveyed.

Stream Power Index

The Stream Power Index (SPI) was used to show the potential for sediment erosion. SPI combines the stream gradient with the flow accumulation of a stream segment. The stream gradient will represent the energy of stream flow based on the assumption that a steeper gradient results in higher energy stream flow. Flow accumulation shows how much water will flow across the land surface. Greater amounts of flow will result in a greater potential for sediment erosion. ESRI *ArcMap* 10 was used to create SPI maps. A 30m Digital Elevation Model (DEM) of the study site was downloaded from the USGS Seamless viewer website (http://seamless.usgs.gov/website/seamless/viewer.htm), and McLean County stream and road layers were downloaded from the Census Bureau/TIGER website, (http://www.census.gov/geo/www/tiger/tgrshp2010/tgrshp2010.html). The streams and roads layers were used to help identify the locations of the study sites.

The process for creating a SPI map is outlined in the following steps and is taken from Dogwiler *et al.* in WRC Report 2010-02. Keep in mind it is important throughout the process that the outputs for each step are given appropriate names so that their purpose can be identified.

The first step in creating a map of SPI in eastern McLean County is to import the DEM, stream, and roads layer into a new ArcMap document. If necessary, fill the DEM using the fill tool located in the hydrology folder of the spatial analyst tools. Fill is necessary if there are sinks, depressions in the land surface that water could not flow out of, in the DEM. Sinks typically result from errors in the DEM. Next derive a flow direction raster using the flow direction tool located in the hydrology folder of the spatial analyst tools. The input for the flow direction tool is the DEM (filled or unfilled) and the output will be a raster indicating the direction water will flow out of each cell in the raster. Next generate a flow accumulation raster using the flow accumulation tool located in the hydrology folder of the spatial analyst tools. The input for flow accumulation is the previously derived flow direction raster and the output is a raster indicating the total number of cells that flow into a given cell. Next a slope raster is generated using the slope tool found in the surface folder of the spatial analyst tools. The input for the slope tool is the filled or unfilled DEM, the output measurement is Percent_Rise, and the z-factor used is 1. The z-factor is used to compare the units of elevation with distances along the ground. The z-factor is similar to vertical exaggeration. Because the ground units and elevation units are the same, the z-factor used is 1. Percent rise indicates that the slope output is a percentage rather than in degrees. The output raster indicates the slope of the land in percent with 0 being flat and 100 being a 45 degree slope. Next, using the raster calculator located in the map algebra folder of the spatial analyst tools, enter the expression "[Slope_Raster] / 100", where Slope_Raster is the name of the slope raster file, and click evaluate. This presents the slope in decimal form rather than as a percentage. Make the calculation permanent by right-clicking on the new raster in the table of contents and selecting "Data, Make Permanent." Next, select the reclassification tool from spatial analyst tools. The input is the previously derived flow accumulation raster. In the dialog window in the "Set Values to Reclassify" box, shift-select everything except the "No Data" row. Click the delete entries button to delete the selected data. Click on the first and only entry under the "New Values" column and enter 0. If a warning box pops up select yes. Make the resulting raster permanent by right clicking on the raster in the table of contents and selecting "Data, Make Permanent." The purpose of this step is to give all cells without data a value of zero. If any of these cells fall within the study area the data should be examined more closely. Next, open up the raster calculator again and enter the expression: "([FlowAcc_Reclass] + 0.001) * ([SlopeRecalc] + 0.001)", where FlowAcc_Reclass is the name of the reclassified flow accumulation raster file and SlopeRecalc is the name of the recalculated slope raster file.

The 0.001 values are added in case the slope or flow accumulation is zero in any of the cells, which would inaccurately cause the value of the cell's SPI to be zero. The resulting raster shows raw SPI values. Make the resulting raw SPI raster permanent by right clicking on the raster in the table of contents and selecting "Data, Make Permanent." Next, using the raster calculator located in the spatial analyst toolbar, enter the expression "Ln([RawSPIraster])", where RawSPIraster is the previously derived raw SPI raster file. The Ln function can be found by clicking the "log" button in the "logarithms" group. Click evaluate and make the resulting raster permanent. The Ln function normalizes the SPI values for the final raster.

Survey data acquired with either a total station or a Trimble GPS unit were used to determine which segments of the study streams intersected which cells in the SPI raster. The cells of the SPI raster that were intersected by segments of the study streams were used for analysis. The average SPI value for each study site was calculated and the results were compared between the three sites.

Shear Stress Calculations

Theoretical shear stresses were calculated using data measured at the study sites. Shear stress calculations will help to identify the sediment entrainment potential at each of the four stream segments. The first equation is for basal shear stress, which represents the force required to entrain sediment (Dogwiler and Wicks, 2004), and is found using the following equation:

$$\text{Basal Shear Stress } (\tau_b) = 9800hS \qquad \text{Equation 3}$$

where h is equal to the depth of water (m), S is the channel slope (m/m, dimensionless), and τ_b is in units of N/m^2 (Dogwiler and Wicks, 2004). The water depth was measured in the field and the channel slope was determined using data acquired with a Trimble GPS device.

The second equation is for critical shear stress. Critical shear stress represents the force required to begin eroding sediment (Dogwiler and Wicks, 2004), and is found using the following formula:

$$\text{Critical Shear Stress } (\tau_c) = \Theta_{cc}(\gamma_s - \gamma)d \qquad \text{Equation 4}$$

Where Θ_{cc} is the critical dimensionless shear stress (Shield's parameter), which is equal to .044 for fully turbulent flow, γ_s is the weight density of sediment in N/m^3, γ is the weight density of water in N/m^3, d is particle diameter in m, and τ_c is in units of N/m^2. The particle size was determined based on the results of suspended sediment calculations. After the suspended sediment was baked average grain size was determined. Using known values Equation 4 can be rewritten as:

$$\text{Critical Shear Stress } (\tau_c) = 713d \qquad \text{Equation 5}$$

which also is in units of N/m^2 and shows that critical shear stress is dependent upon particle size. These two equations were be used to show how easily sediment was entrained and how it varies throughout the stream restoration process. The data was plotted and compared to a 1:1 basal to critical shear stress line to determine conditions favorable for sediment transport.

CHAPTER III

RESULTS

Results were collected from 6/23/2011 to 3/30/2012 and the data collection dates are summarized in the following table:

Table 2-Dates of Data Collection

Data Collection Frequency Installation- 6/23/2011		
Scour Markers	Suspended Sediment	Cross-Sections
6/30/2011	6/30/2011	
7/28/2011	7/28/2011	7/28/2011
9/6/2011	9/6/2011	
9/29/2011		9/29/2011
11/1/2011		
11/5/2011		
11/15/2011		
1/31/2012		
3/15/2012		
		3/30/2012

Scour markers and suspended sediment data were collected (if possible) following storm events. Cross sections were recorded following significant changes in channel geometry.

Scour Markers

The scour markers indicated that Crooked Creek had the largest amount of sedimentation and scour compared to Frog Alley and Bray Creek. Frog Alley had an average scour of 0.15 cm per data collection period and an average sedimentation of 0.18 cm per data collection period. Bray Creek had an average scour of 0.23 cm per data collection period and an average sedimentation of 0.12 cm per data collection period. Crooked Creek had an average scour of 0.78 cm per data collection period and an average sedimentation of 0.6 cm per data collection period.

Table 3- Summary of scour marker results. Results show mean scour/sedimentation and standard deviation in centimeters. A positive mean indicates sedimentation occurred while a negative mean indicates scour occurred.

Scour Marker Results (cm)						
	Frog Alley		**Bray Creek**		**Crooked Creek**	
Date	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
6/30/2011	0.15	0.32	-0.2	0.60	-1.1	3.13
7/28/2011	-0.05	0.15	-0.1	0.20	1.25	3.04
9/6/2011	0.0	0.32	-0.3	0.40	-0.15	0.39
9/29/2011	-0.05	0.27	-0.1	0.30	0.0	0.22
11/1/2011	-0.05	0.15	0.05	0.27	-0.2	0.64
11/5/2011	-0.1	0.20	0.0	0.00	-0.05	0.27
11/15/2011	-0.1	0.20	0.0	0.00	-0.1	0.30
1/31/2012	0.05	0.35	0.05	0.42	-0.45	3.24
3/15/2012	0.0	0.43	0.1	0.37	0.0	0.39
Average	-0.02		-0.06		-0.09	
Standard Deviation	0.05		0.13		0.61	

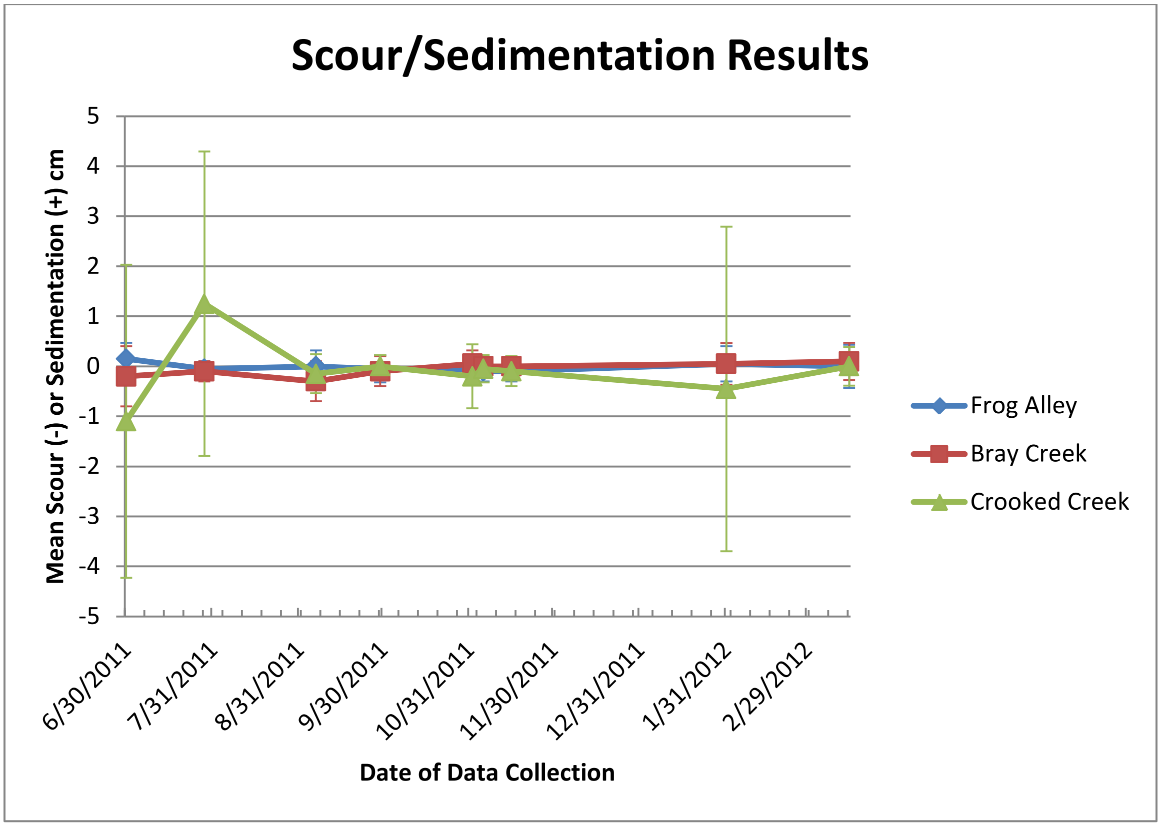


Figure 4-Results from scour markers. Positive values indicate sedimentation while negative values indicate scour. Error bars representing standard deviation are present

Suspended Sediment

Bray Creek and Crooked Creek had higher suspended sediment concentrations than Frog Alley. Bray Creek had a suspended sediment concentration of 6.32×10^{-5} g/mL and Crooked Creek had a suspended sediment concentration of 4.47682×10^{-5} g/mL.

Frog Alley had an average suspended sediment concentration of 1.90665 x 10^{-5} g/mL. Six quality samples were taken from Frog Alley while only one sample each was taken from Bray Creek and Crooked Creek. Only the lowest samplers at Bray Creek and Crooked Creek collected samples. At Frog Alley samples were collected from the lowest two depths.

The farthest upstream sampler at Frog Alley had the lowest average suspended sediment concentration, which was 4.53981 x 10^{-6} g/mL. The middle sampler at Frog Alley had the highest average suspended sediment concentration of 5.9492 x 10^{-5} g/mL. The farthest downstream sampler at Frog Alley had an average suspended sediment concentration of 1.52759 x 10^{-5} g/mL. Across all the samplers at Frog Alley, the samplers of the lowest depth had an average sediment concentration of 2.73633 x 10^{-5} g/mL and the next highest depth had an average suspended sediment concentration of 2.47294 x 10^{-6} g/mL.

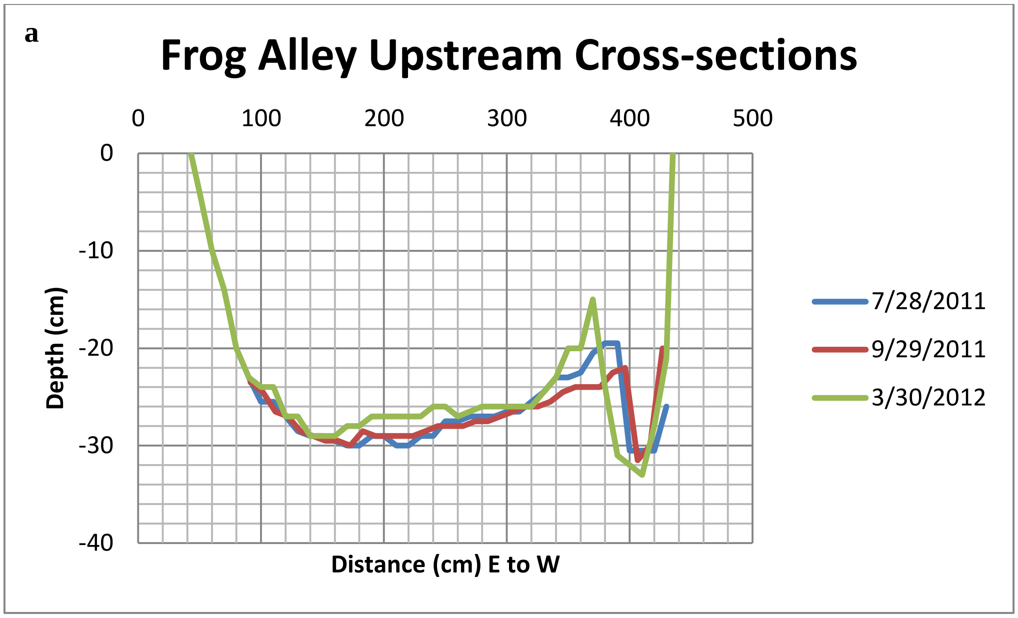
Table 4-Suspended Sediment Results

Suspended Sediment (g/mL)		
Study Site	**Mean**	**Standard Deviation**
Frog Alley		
6/30/2011		
Depth-70 cm	$2.47*10^{-6}$	$1.89*10^{-6}$
Depth-80 cm	$2.18*10^{-5}$	$2.36*10^{-5}$
7/28/2011		
Depth-80 cm	$3.27*10^{-5}$	$3.78*10^{-5}$
Bray Creek		
6/30/2011		
Depth-80 cm	$6.32*10^{-5}$	
Crooked Creek		
6/30/2011		
Depth-80 cm	$4.48*10^{-5}$	

Stream Cross-Sections

The stream cross sections indicate that the stream geometry does not remain constant; however, change is not drastic. The upstream Frog Alley cross section indicates that scour occurred during the study period. The downstream Frog Alley cross section indicates only slight scour of the stream bed. The upstream Bray Creek cross section indicates slight scour, while the downstream Bray Creek cross section indicates little change in channel geometry. The upstream Crooked Creek cross section shows no significant change in channel geometry as well.

Frog Alley shows the expected trapezoidal geometry of a modified stream. The west side of the Frog Alley upstream cross-section is influenced by a boulder located approximately 50 cm from the west bank. This is indicated by the sharp increase in stream bed elevation. Bray Creek is starting to show a V-shaped geometry that is expected of natural streams. Crooked Creek also shows the V-shaped channel geometry in both cross sections.



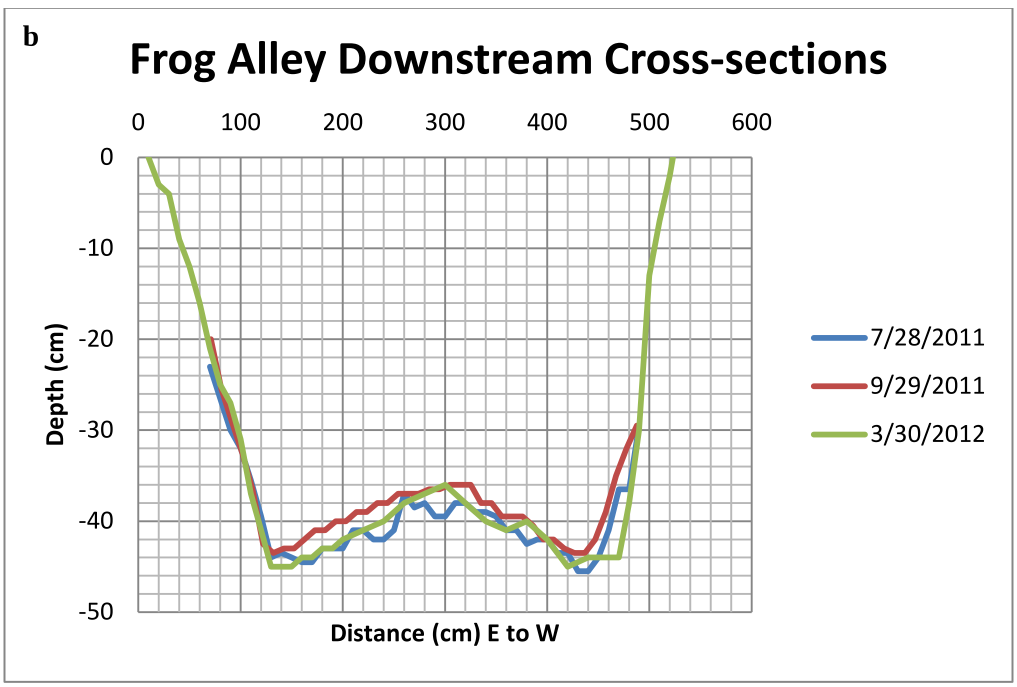
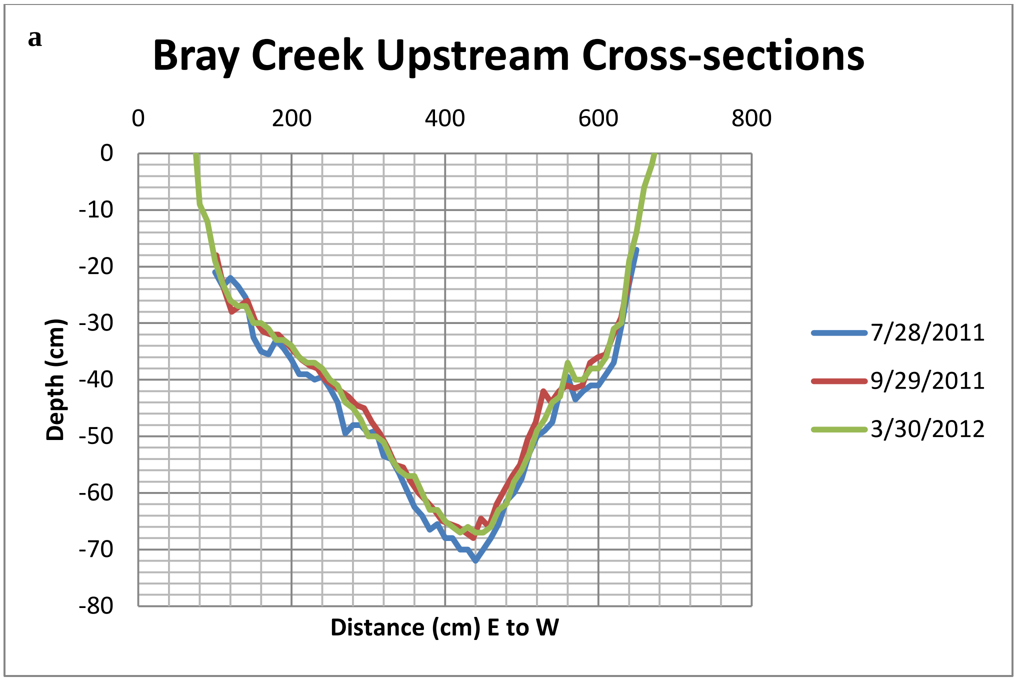


Figure 5-Cross-sections of Frog Alley. 11 years since modification (a) upstream cross-sections, (b) downstream cross-sections



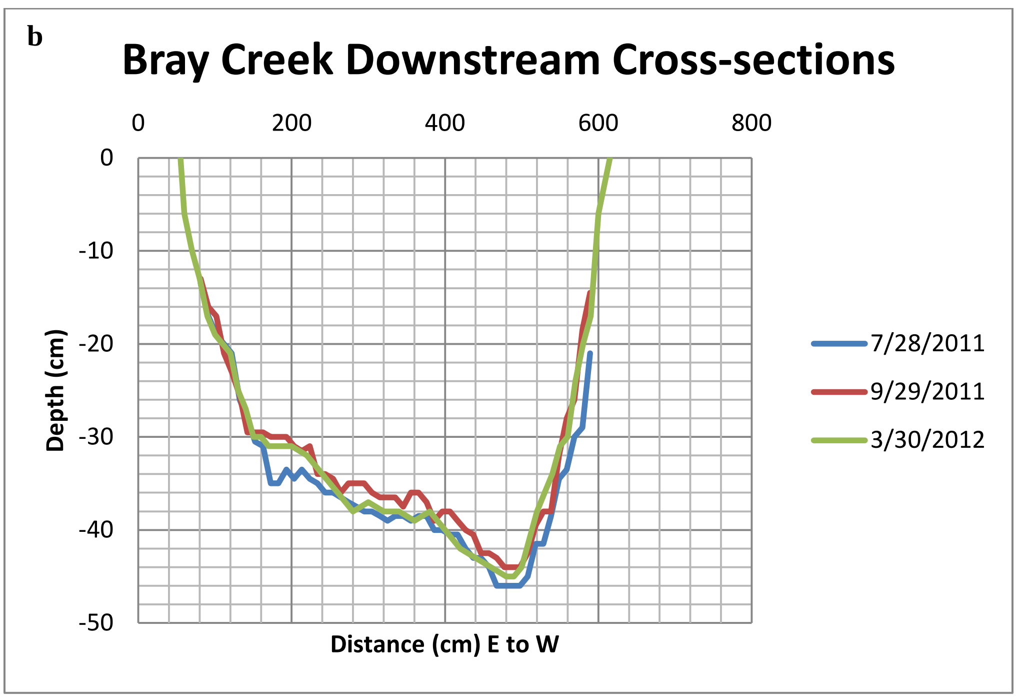
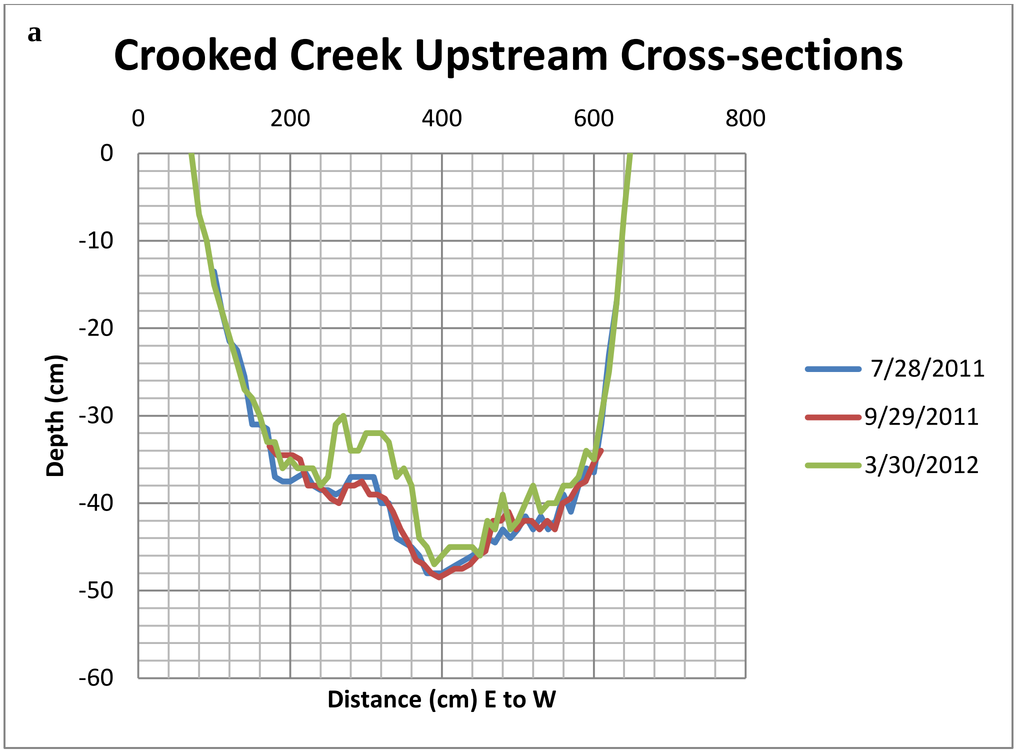


Figure 6- Cross-sections of Bray Creek. 34 years since modification, (a) upstream cross-sections, (b) downstream cross-sections



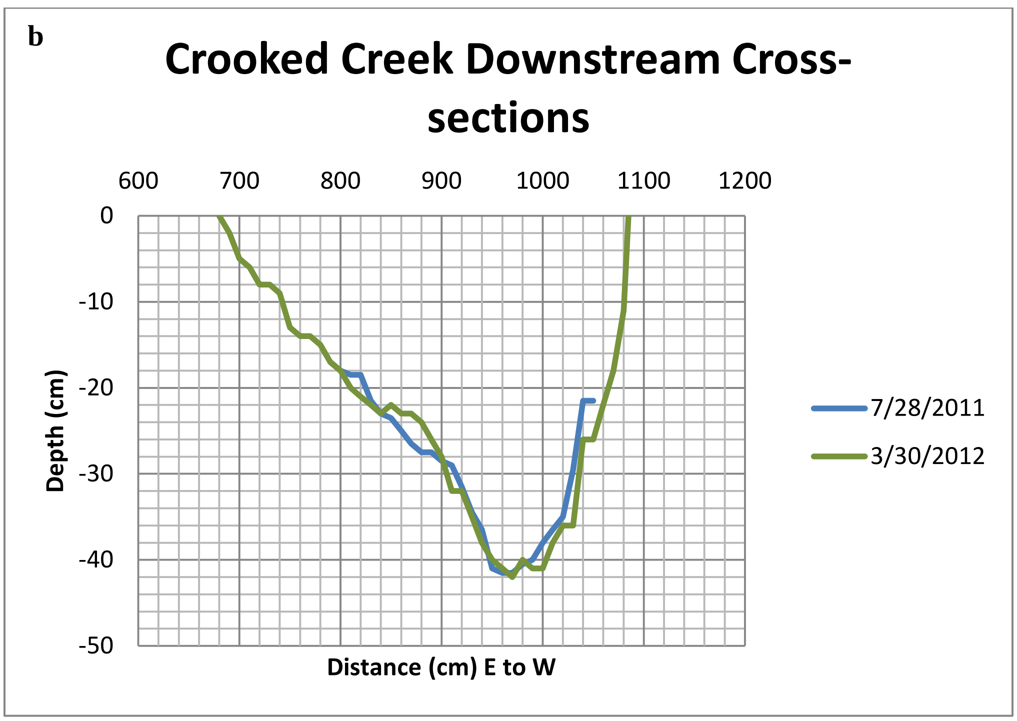


Figure 7-Cross-sections of Crooked Creek. Unmodified, (a) upstream cross-sections, (b) downstream cross-sections. A cross-section was not measure downstream on 9/29/2011 due to low water level

Stream Power Index

Each study stream segment intersects five cells of the SPI raster. Since the analysis is of the SPI of the study sites, only the five cells that each site intersects with were used in the analysis. The results of the SPI analysis indicated that Crooked Creek had the highest SPI value. Crooked Creek had an average SPI of 28.08 while Frog Alley had an SPI of 27.57 and Bray Creek had an SPI of 26.98. The results from SPI analysis were tested using an ANOVA with an alpha value of 0.05 and an initial hypothesis that all samples are from the same distribution. The ANOVA resulted in a p-value of 0.0712. Because the p-value is greater than the alpha value used, the initial hypothesis is accepted (Table 4).

Table 5-Results of ANOVA analysis on SPI data

SPI ANOVA Results						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Frog	5	137.86	27.57	1.185		
Bray	5	134.88	26.98	0.172		
Crooked	5	140.41	28.08	0.028		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3.065778	2	1.532889	3.319279	0.071222	3.8852938
Within Groups	5.541767	12	0.461814			
Total	8.607546	14				

The variances of both Bray Creek and Crooked Creek indicate that Bray and Crooked have more uniform SPI values than Frog Alley. Such a high variance of data at Frog Alley indicates that the SPI values vary along the study stream segment. The lack of samples used in the ANOVA also indicates that the values should be used with caution. More samples would result in more accurate results and conclusions drawn from the results would be more reliable

Shear Stress Calculations

Basal shear stress (τ_b) calculations were performed for two locations at each stream and for three different dates. The Frog Alley upstream τ_b was 3.16 N/m^2 on July 28, 2011 and the downstream τ_b was 0.67 N/m^2 on the same day. The Frog Alley upstream τ_b was 2.53 N/m^2 on September 29, 2011 and the downstream τ_b was 6.21 N/m^2 on the same day. The Frog Alley upstream τ_b was 6.10 N/m^2 on March 30, 2012 and the downstream τ_b was 9.26 N/m^2 on the same day. The Bray Creek upstream τ_b was 8.10 N/m^2 and the downstream τ_b was 5.13 N/m^2 on July 28, 2011. On September 29, 2011 the upstream τ_b of Bray Creek was 7.29 N/m^2 while the downstream τ_b was 4.59 N/m^2. On March 30, 2012 the upstream τ_b for Bray Creek was 9.05 N/m^2 while the downstream τ_b was 6.08 N/m^2. The upstream τ_b for Crooked Creek was 6.25 N/m^2 on July 28, 2011 while the downstream τ_b was 4.32 N/m^2. On September 29, 2011 the upstream τ_b of

Crooked Creek was 2.96 N/m^2 and a downstream τ_b was not calculated due to lack of data. On March 30, 2012 the upstream τ_b was 7.21 N/m^2 while the downstream τ_b was 6.57 N/m^2.

Table 6-Basal Shear Stresses

Basal Shear Stress		
Date	**Frog Alley**	**Stress (N/m^2)**
7/28/2011	Upstream	3.16
	Downstream	0.67
9/29/2011	Upstream	2.53
	Downstream	6.21
3/30/2012	Upstream	6.10
	Downstream	9.26
	Bray Creek	
7/28/2011	Upstream	8.10
	Downstream	5.13
9/29/2011	Upstream	7.29
	Downstream	4.59
3/30/2012	Upstream	9.05
	Downstream	6.08
	Crooked Creek	
7/28/2011	Upstream	6.25
	Downstream	4.32
9/29/2011	Upstream	2.96
3/30/2012	Upstream	7.21
	Downstream	6.57

Critical Shear Stress (τ_c) was calculated based on previously recorded d_{50} and d_{85} particle sizes (Becker, unpublished data). The d_{50} τ_c for Frog Alley was 4.01 N/m^2 while the d_{85} τ_c was 78.72 N/m^2. The d_{50} τ_c for Bray Creek was 3.14 N/m^2 while the d_{85} τ_c was 46.30 N/m^2. The d_{50} τ_c for Crooked Creek was 1.32 N/m^2 and the d_{85} τ_c was 504.93 N/m^2.

Table 7-Critical Shear Stresses

Critical Shear Stress	
Frog Alley	**Stress (N/m2)**
D_{50}(m)	4.01419
D_{85}(m)	78.7152
Bray Creek	
D_{50}(m)	3.1372
D_{85}(m)	46.29509
Crooked Creek	
D_{50}(m)	1.31905
D_{85}(m)	504.93234

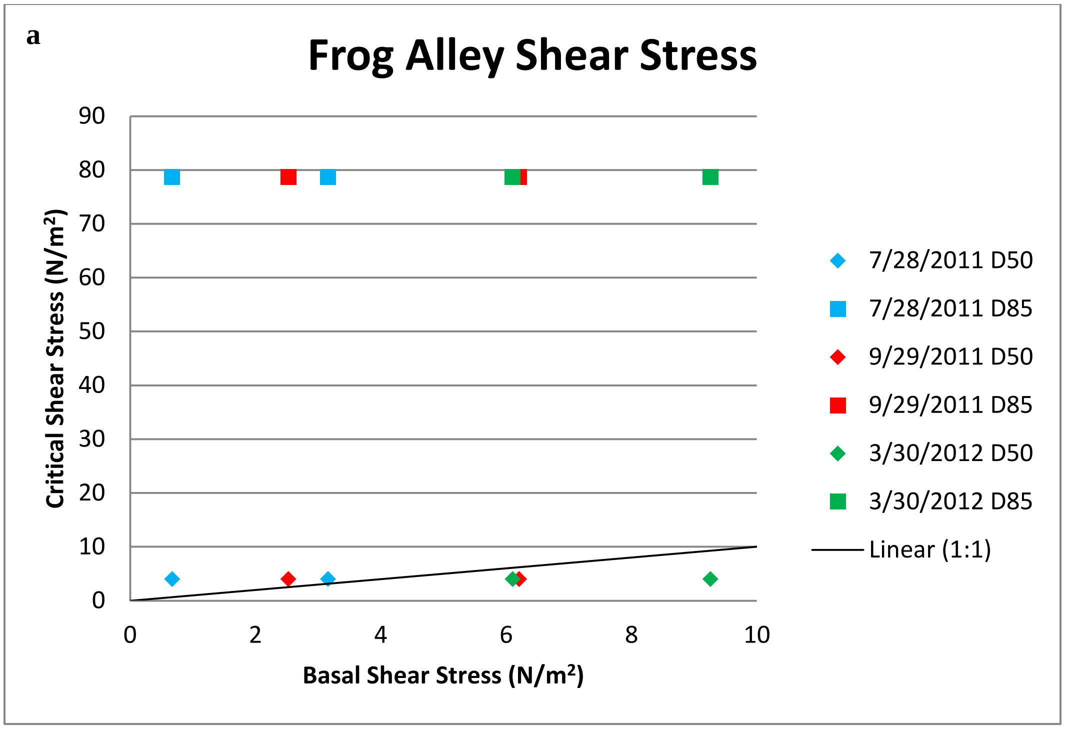
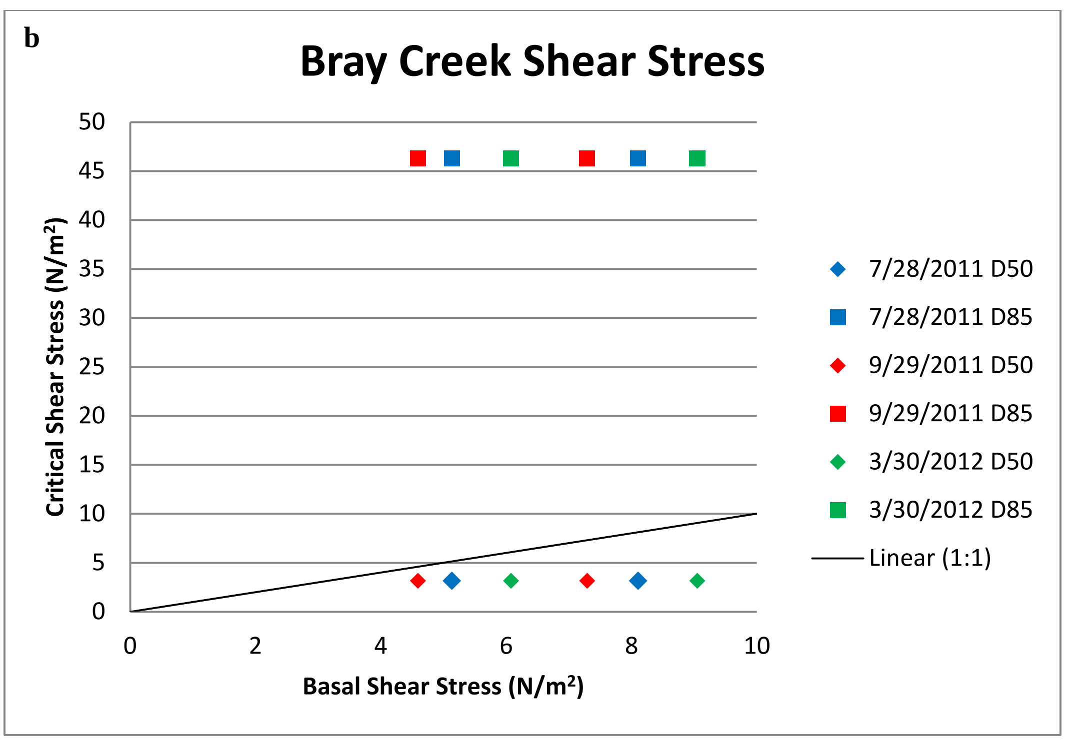


Figure 8-Results of theoretic shear stress calculations of d_{50} and d_{85} particles. (a) Frog Alley, (b) Bray Creek, and (c) Crooked Creek. Points falling below the line indicate conditions favorable for sediment transport



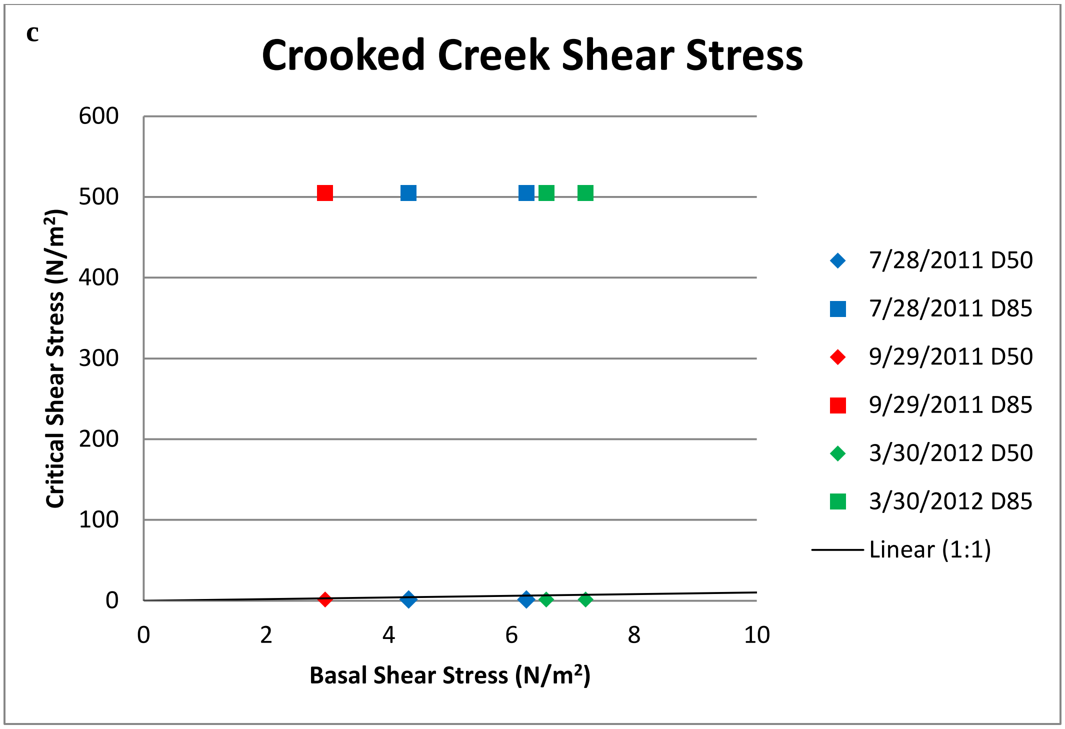


Figure 8 Continued

The shear stresses for d_{50} and d_{85} particles were plotted against a line of 1:1 ratio (Figure 8). The area beneath the line indicates conditions favorable for sediment transport. For all three stream segments at every date of data collection, d_{85} particles would not be transported. The d_{50} particles would be transported at Frog Alley under high flow conditions while under low flow, the particles would not be transported. The d_{50} particles would always be transported at Bray Creek and Crooked Creek.

CHAPTER IV

DISCUSSION

The purpose of this study was to determine whether or not a relationship exists between stream modification and sediment transport. There is a relationship present and is most evident in the scour/sedimentation data. Crooked Creek had the most scour and sedimentation while Frog Alley had the least scour and sedimentation. This confirms the hypothesis that more recently modified streams transport less sediment. Frog Alley, Bray Creek, and Crooked Creek had average amounts of scour and sedimentation of 0.15, 0.18, 0.23 and 0.12, 0.78, 0.60 cm per data collection period, respectively. Frog Alley had the least amount of sediment scour while Crooked Creek had the most scour. Crooked Creek also had the largest average amount of sedimentation.

Higher sediment transport, as evidenced by the results of the scour markers, is also supported by theoretic shear stress calculations. The calculated shear stresses indicate that d_{85} sediment will not be transported at any of the three study sites at baseflow conditions. At Crooked Creek and Bray Creek, d_{50} particles will always be transported while at Frog Alley d_{50} particles will only be transported during high flow conditions. The d_{50} particle sizes at Frog, Bray, and Crooked are 5.63, 4.4, and 1.85 mm respectively. The d_{85} particle sizes at Frog, Bray, and Crooked are 110.4, 64.93, and 708.18 mm respectively. According to the Wentworth scale, the d_{85} particle sizes at Frog and Bray are cobbles while Crooked is boulder. Using the same classification scale the d_{50} particles at Frog and Bray are fine gravel while Crooked is very coarse sand. The particle sizes indicate that Crooked Creek has the largest variation in grain size, varying from 1.85 mm to 708.18 mm. Modified streams have a reduced ability to transport sediment, while unmodified streams have a greater ability to transport larger sediment particles and thus more sediment.

Stream cross-sections indicate that there was a change in channel geometry at all three study sites throughout the data collection period. There were not any major changes in channel geometry, only small scour and sedimentation events that correspond to scour and sedimentation events recorded by the scour markers. The cross-sections from Frog Alley (Figures 5a and 5b) show a trapezoidal geometry that is common among modified streams (Figure 1). The trapezoidal geometry of the upstream cross-section of Frog Alley is disrupted by a boulder near the west bank. The boulder has diverted water towards the west bank and has resulted in increased scour near the west bank. Bray Creek as well as Crooked Creek show V-shaped channel geometries that indicate Bray Creek is returning to a natural form.

SPI indicated that Crooked Creek had the highest potential for sediment erosion followed by Bray Creek and then Frog Alley. Frog, Bray, and Crooked had average SPI values of 27.57, 26.98, and 28.08 respectively. The ANOVA performed on the SPI data indicated that the three sites have SPIs that are statistically the same. The ANOVA also indicated that the SPI values of Frog, Bray, and Crooked have variances of 1.185, 0.172, and 0.028 respectively.

The SPI is dependent upon the stream gradient and flow accumulation within the stream. It is assumed that stream gradient and flow accumulation are proportional to discharge (Wilson and Gallant, 2000). Stream gradient and flow accumulation are determined from a DEM. The accuracy of the SPI is then directly related to the resolution of the DEM being used. A DEM with greater resolution will lead to more accurate calculations for stream gradient and flow accumulation.

The quality of data used in the SPI process is partly responsible for all the streams having statistically equal SPI values. Using a 30 meter DEM did not provide enough resolution for calculating an accurate SPI. LiDAR data (1 meter DEM) would provide adequate resolution and provide a more accurate calculation of SPI. The flattened topography in Illinois is why a DEM with greater resolution is required. Small changes in elevation across the study sites and study site watersheds could not be properly identified, and thus, SPI was not as accurate as it could be.

Suspended sediment data were limited but indicate that Frog Alley, the most recently modified stream, has the least amount of suspended sediment. Because only one suspended sediment sample each was collected from Bray Creek and Crooked Creek, an accurate comparison of suspended sediment concentrations cannot be made. The samples that were collected from Frog Alley do indicate that there is at least ten times more suspended sediment at a depth of 80 cm than 70 cm below the top of the fence post. This is expected because the distribution of sediment particles is coarser at the bed of a stream and finer near the surface. As particles fall out of suspension and mix with the particles being stirred near the stream bed the sediment concentration increases (Maidment, 1993).

The rates at which the HZ is being restored at Frog and Bray are limited due to the low gradients of the streams. The low gradients limit the amount of sediment that can be transported. A steeper gradient stream will have a higher energy stream flow and be able to transport more sediment.

This relationship between sediment transport and stream modification is a result of sediment availability rather than strength of stream flow. A more recently modified stream should have stronger flow and a greater potential to erode sediment due to channelization, but the greatest average scour amounts were located in Crooked Creek, an unmodified stream. Crooked Creek has a higher sinuosity and weaker stream flow, yet still has greater amounts of scour. The fact that scour was greater at Crooked Creek than the other two sites indicates that there is more sediment available to be scoured at Crooked Creek than the other sites. Because SPI is only dependent upon stream gradient and flow accumulation the effects of sediment grain size are ignored. Grain size and availability is an important factor for stream modification. While the energy of stream flow is important for determining stream erosion potential, the characteristics of the sediment being eroded is also important. Because Frog Alley and Bray Creek have been modified, those streams have less sediment available for transport than an unmodified stream such as Crooked Creek. As streams are modified and the substrate is removed, any available sediment to be deposited or scoured is also removed.

Because more sedimentation occurred at Crooked Creek, it is expected that Crooked Creek has a greater potential to remove nutrients. It is expected that the HZ is greater at Crooked Creek than the other two streams due to the greater amount of sedimentation that occurred during the study period and because it is an unmodified stream. A thicker HZ means that more nutrients can be removed from stream flow as stream water infiltrates through the HZ (Urban and Rhoads, 2003).

Crooked Creek behaves as an unmodified stream should and it appears that Bray Creek is approaching similar conditions. The channel geometry of Bray Creek is becoming the V-shape that is expected of unmodified streams. Both Bray Creek and Crooked Creek exhibit enough shear stress to transport d_{50} particles. Scour and sedimentation is less at Bray Creek than Crooked Creek, but is also greater than what was observed at Frog Alley. Frog Alley was modified too recently to see large changes in stream characteristics. Frog still shows a trapezoidal geometry and has the least amounts of scour and sedimentation of the three streams. The shear stresses also indicate that under low flow conditions d_{50} particles are not transported.

The upstream and downstream cross-sections of Frog Alley show trapezoidal channel geometries which indicate that Frog Alley is a Stage II or constructed stream. The lack of vegetation also supports this classification. Frog Alley may be a stage III or degradation stream but erosion and undercutting is not prominent enough to support this conclusion. Bray Creek is a Stage III or degradation stream. There is vegetation starting to develop within the stream and a cut bank present along the east bank of the stream that indicates erosion is occurring. Pop-out features as described by Simon and Rinaldi (2000) are also present at Bray Creek indicating a stage III stream.

CHAPTER V

CONCLUSIONS

There is a relationship between stream modification and sediment transport. While a cause-effect relationship cannot be proven from the collected data, the relationship that is present is identified. The proposed hypothesis was that a more recently modified stream will carry less sediment than a natural or unmodified stream. The hypothesis was supported with sediment availability. As streams are modified, sediment along the substrate and stream banks is removed. As a stream returns to a natural form sediment accumulates. The accumulated sediment can then be eroded if stream flow is strong enough.

Frog Alley exhibits characteristics of a recently modified stream, including low sedimentation and scour, trapezoidal channel geometry, and low shear stresses. Because of this it would be classified as a stage II or constructed stream. Bray Creek exhibits characteristics of a Stage III or degradation stream. The characteristics exhibited by Bray Creek include V-shaped channel geometry, increased amounts of sedimentation and scour, and increased shear stresses.

SPI analysis is a useful tool if quality data is available. Due to the limited relief of central Illinois a high resolution DEM, such as LiDAR, is required for accurate SPI calculations. SPI also only examines the potential for stream erosion and does not take into account sediment particle size.

Suspended sediment data are useful and can help to determine the amount of sediment carried by streams. Siphon samplers need to be placed in locations so that accurate samples can be taken regularly. A preliminary investigation to determine baseflow is necessary to determine at what depths each sample bottles should be placed.

Further research into the potential cause-effect relationship between stream modification and sediment transport and the effects stream modification has on sediment availability could be undertaken. Looking at stream segments upstream from the study sites to determine whether there are changes in sediment transport along a stream would be useful in determining from where sediment is being eroded. The acquisition of LiDAR data would be useful in determining accurate SPI values for streams of ranging lengths of time since modification. Stream modification is a common practice and due to its potential environmental consequences should be studied further to determine how humans can reduce our impact on the environment.

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