Case study to document the condition of McConnell creek and the effect of redcedar revetments

by

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Abstract

Rivers are complex bodies of water under constant stress and factors such as land management increase the rate in which the channel is modified. Changes in land cover/land use are capable of modifying the hydrology of a site, accelerating the natural erosion rates of the stream banks and decreasing water quality. This case study was conducted to document overall creek condition at McConnell Creek in Wichita, Kansas and estimate the effect of streambank stabilization installations. The effects of the revetments were determined through two factors, first erosion/deposition rates on site, and second a bioassessment of macroinvertebrates. Erosion/deposition rates are measured through three different techniques. One method relied on dendrogeomorphology using exposed roots to quantify erosion for the previous 5-15 years based on the age of the roots, and when they were exposed. The macroinvertebrate bioassessment provides a better understanding of water quality, its degree of organic pollution and changes in biodiversity. The creek condition was determined through the use of the Rapid Assessment Along Stream Length (RASCAL) protocol which provided relevant background information of the creek's ecological processes. Erosion/deposition rates on Revetment One (R1) showed a migration of upper sections of the cut bank being captured on the lower segments of the bank by the revetment. Macroinvertebrate sampling showed increased populations in areas where revetment installations where located but overall biodiversity decreased due to the presence of a dominant family *Dogielinotidae*. The RASCAL protocol yielded stream condition ratings on 64 reaches both on federal and private land. The RASCAL results show which areas treatment should be focused. Long term monitoring should be conducted to document the effects of the revetment.

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Chapter 1 - Introduction

Rivers and streams are complex bodies of water under constant stress and factors such as land management increase the rate at which the channel is modified. Though bank erosion is integral to the functioning of river ecosystems, human impact has altered this natural process (Florsheim et al., 2008). Changes in land cover/land use are capable of modifying hydrology, water quality, soil erosion and biological community structure (Pilgrim et al., 2014). The increase in impervious surfaces result in higher volumes of water more quickly reaching the stream at a given point. Increased runoff causes a decrease in water quality through erosion due to its carrying of contaminants and sediment. Surface water bodies with high loads of sedimentation can be impaired which leads to the need for restoration (USEPA, 2007).

Having a basic understanding of the stream conditions proves essential for restoration project efforts. A protocol utilized to provide preliminary qualitative data of the overall condition of a stream is the Stream Visual Assessment Protocol (SVAP) developed by the Natural Resources Conservation Service (U.S. Department of Agriculture, 2009). The SVAP is most functional as an initial screening of a wadable and low-order stream, assessing its ecological health (Bjorkland et al., 2001). Another protocol utilized for stream assessment is the Rapid Assessment of Stream Conditions Along Length (RASCAL) which is being derived from the SVAP and has most of it benefits. RASCAL includes of Global Positioning Coordinates respective to each data point collected as well as less complex variables to reduce the time needed for data collection. RASCAL results provide various uses of the data which can further result in management recommendations. Analysis from RASCAL can result in the categorization of the different stream reaches which indicates common conditions in a stream facilitating the recommendation of a treatment (Wendt, 2007). Once areas of interest are determined restoration efforts can be then put in place.

Restoration can be done through different methodologies and usually are referred to as stream restoration projects (SRP). SRP aim to improve degraded streams by re-establishing some of its natural form and structure. This can be done through applying a series of restoration principles that include the restoration of the natural structure, ecological integrity or natural function of the stream (USEPA, 2000). Restoration efforts should also be implemented in areas which management has made previous monitoring efforts and deemed the restoration relevant (Schmidt et al., 1998). SRP achieves its goals through different efforts and a relevant technique is through the installation of revetments to stabilize the streambanks.

Streambank stabilization projects aim to control bank erosion. However bank erosion is a normal process of alluvial streams and it is recommended that erosion may be reduced substantially but not halted (Yochum & Reynolds, 2020). By working on streambank stability, bank erosion as one of the major sources of sedimentation in watersheds is reduced (Wilson et al., 2008). Streambank stabilization structures aim to act as deflectors or/and dissipaters of energy. This is done through the use of different project designs and materials which are both organic and inorganic in nature. The stabilizing structures can also be accompanied with vegetation as it is a natural way of protecting the bank which is both easy to implement and aesthetically pleasing (The Federal Highway Administration, 2009). A project design that implements both organic material and vegetation are redcedar revetments.

In the 1970's after previous efforts of controlling streambank erosion through channelization failed, conservationist gravitated towards natural or artificial methods of stabilization like redcedar revetments (Weins et al., 1997). The revetments primary function is to stabilize the bank with the use of anchored eastern redcedar (*Juniperus virginiana L.)* until trees and shrubs have established behind the revetment. This is possible because the trees anchored at the toe of the bank slow the current of water reducing erosion and promoting sedimentation during high flow events (Goard, 2006). The redcedar revetments are capable of dissipating energy during high flow events because of the branches and fine twigs, which water is forced to go through. Eastern redcedar also is considered a microbial resistant species which makes it ideal for extending the duration of the revetment (Hemmerly, 1970). Tree revetments have also been established with other trees of the *Juniperus* genus such as *Juniperus osteosperma* which according to Sheeter & Claire (1989) with proper management can protect a bank for 20 years. Even though restoration efforts with redcedar revetments have been done for more than four decades few monitoring efforts have been made which are necessary to provide insight on different outcomes and best practices to implement (Naisargi & Mittelstet, 2017).

Monitoring SRP through the years has been scarce though as many restoration projects take place on a small scale, monitoring should be implemented in the design process to evaluate the long term effect of the installations(dos Reis Oliveira et al., 2020). One of the few studies that aimed to evaluate different SRP methodologies such as rock jetties, rock-toe protection, slope reduction/gravel bank, retaining wall, rock vanes, and tree revetments used spatial imagery. It was concluded that rock jetties installed in the stream had a 70% success rate making them the most cost-efficient out of all the methodologies (Naisargi & Mittelstet, 2017). With insight on success rates and what SRPs are working it is relevant to include monitoring efforts to further understand the effectiveness of a project. SRPs should be evaluated with five clear elements in mind, having clear objectives, baseline data, good study design, commitment to the long term and willingness to acknowledge failure (Kondolf, 1995).

Monitoring erosion is one of the several ways to provide insight on the effectiveness of an installation**.** To provide baseline information on erosion rates of streams a dendrogeomorphic approach was developed by combining the study of trees with the study of the surface of the earth. Dendrogeomorphology is done through the observation of the relative position of an exposed root to the soil and the analysis of anatomical changes within the annual rings providing a rate of erosion (Gärtner, 2007). Root analysis proved to not differ statistically from popular photogrammetric techniques though the presence of trees is necessary for this analysis (Stotts et al., 2014). Dendrogeomorphology provides accurate, simple and quick results being deemed as a relevant tool to provide baseline data for stream erosion rate. To monitor on-site erosion or deposition once a revetment is installed rebar can be used as erosion pins for future evaluations. The pins are inserted horizontally to the bank and the site is revisited periodically to determine the amount of protrusion which defines the erosion that occurred locally (Thorne, 1981).

Another way of monitoring SRPs is through the sampling of macroinvertebrate populations which can be associated with water quality, habitat quality and diversity. The use of macroinvertebrates for biomonitoring offer certain advantages such as their abundance and the range of responses it can generate. Also macroinvertebrates count with life cycles that can span through several years which provide temporal changes in a population (Mandaville, 2002). Redcedar revetments provide shelter and structure, monitoring changes in macroinvertebrates could help further understand the effectiveness of this SRP. There is evidence that the introduction of woody debris alters the biota present in an area resulting in changes of resources present in the food web (Thompson et al., 2018).

Purpose of case study

This study was funded by the U.S. Fish and Wildlife Service with the objective of monitoring, and documenting the overall stream health and condition, and estimating the effectiveness of redcedar revetments on McConnell Creek on the McConnell Air Force Base in Wichita, KS. The effectiveness of the revetments was assessed through two major factors which include macroinvertebrate analysis and erosion/deposition rates. Erosion/deposition rates were monitored at the sites of the revetments to improve our understanding of the effectiveness in capturing and reducing the erosion locally. Historical erosion rates were documented through dendrogeomorphology analysis, providing a better understanding of overall stream behavior. Additionally, the RASCAL procedure was utilized to provide an overall stream health assessment of McConnell creek both on the base and adjacent private lands.

Chapter 2 - Material and Methods

Site Description

The McConnell Creek is located south of the airstrip at McConnell Air Force Base in Wichita, Kansas. The Air Force Base provides a strong impact on the stream it feeds into. The impervious surface that is created by the airstrip reduces the amount of water that is infiltrated by the soil. This leads to an increase in the volume of water that reaches the stream in a short period of time which may have adverse effects. Another scenario created by the presence of the runway is the use of de-icing fluid. This chemical is used for the prevention of snow, frost and ice accumulation on aircrafts and runway. This de-icing fluid manages to reach the stream due to its highly water soluble nature increasing the chemical demand of oxygen (COD)(Air Force Center for Environmental Excellence, 1998)(Cryotech, 2014). The field that the creek flows through is an area that the Air Force considers an emergency crash landing zone which provides for special management consisting of frequent mowing to any tree establishment.

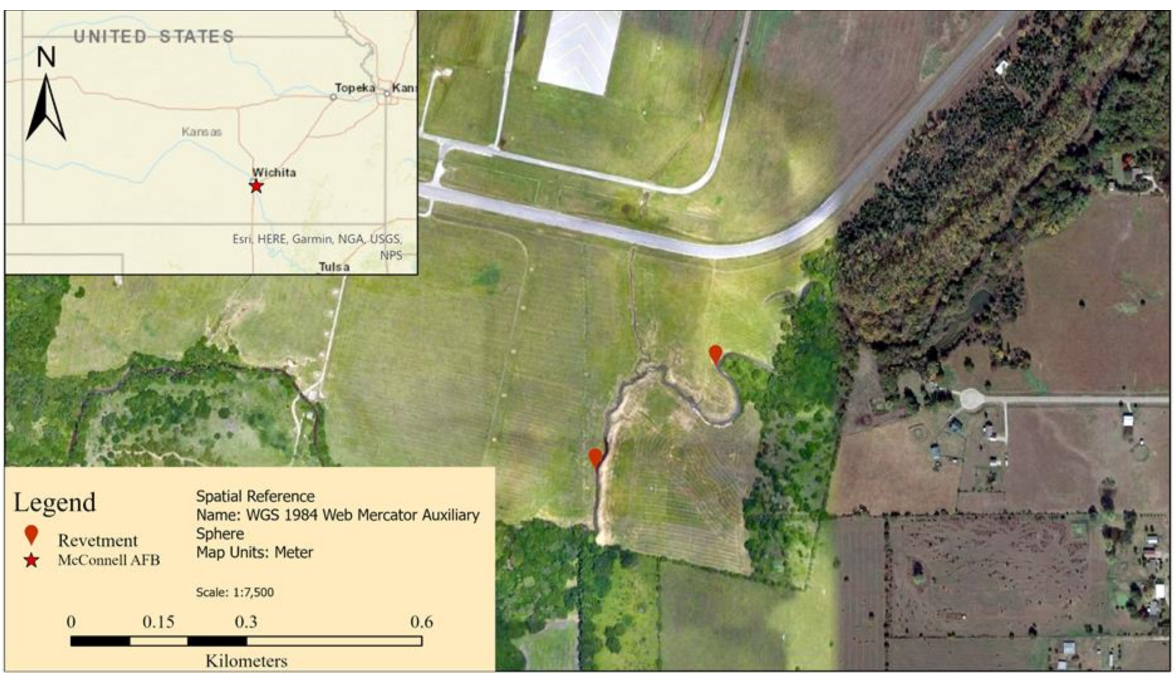

Figure 1. Study area at McConnell Airforce Base

The McConnell creek had two redcedar revetments installed in June of 2020 and March of 2021. Both were located in the emergency crash landing zone (Figure 1). Revetments covered between 25-30 meters of the cutbank with 10-15 trees. The number of trees was dependent on the size of trees available at the site. The installation process for each revetment took 2 work days with crews of 5-6 people.

Redcedar Revetment Installation

The first redcedar revetment installation took place in June of 2020, which was delayed originally from March due to Covid-19 restrictions. The second revetment was installed during March of 2021 as scheduled. The sites were previously marked and monitored to determine if they were suitable for an installation. These sites were selected for revetment installation as they appeared to have the most vertical, eroding banks, with little vegetative cover in the area of interest. The installation process was adapted from U.S. Department of Agriculture (2002) and Goard (2006). The revetment length is determined by beginning and ending the revetment in the areas in which the streambank was not eroding as evidenced by well-established vegetation. The installation process started from downstream with the trees base facing upstream. The trees selected averaged a height of 4.5-6 meters. Trees were anchored at the toe of the eroding bank at water base flow level. Once a tree was located in the desired position (Figure 2) it was secured with duckbill anchors that had attached a steel cable of 1.8 meters long. The anchoring was done with the use of a jackhammer with which the duckbill anchor was inserted 1.5-1.6 meters into the soil. The end of the cable was then wrapped around the trunk and secured with clamps at the base of the trunk and the crown of the next tree with cable clamps providing two holding points for each tree. Once the revetment was installed behind the tree line sandbar willow (*Salix interior)* cuttings were inserted into the soil to accelerate revegetation. Sandbar willow is commonly used for conservation projects and for a greater survival rates it is recommended to plant close to the minimum water level (Randall, 2015).

Figure 2. Second redcedar revetment installation during early spring with low water levels (before/after)

Macroinvertebrate Assessment

Macroinvertebrate assessments were conducted in each of the revetment sites during May and June both before and after installation. This was done through an adapted procedure in the Volunteer Stream Monitoring Training Manual (Hoosier Riverwatch, 2015). This procedure consisted in the collection of macro invertebrate samples in the stream for 15 minutes, both in the pool and cut bank of the stream. Only the pool was sampled since there was no presence of riffles or runs but if they were present besides the areas of installation they would be monitored separately. Samples were collected with the use of two types of nets, a bottom kick net for the pools and a D-net for the banks edge each having a 500 µm mesh. For the edge of the stream we would brush the nets on the branches of the cedar trees located underwater. On the pool two individuals would make the samplings one up front scraping the sediments with their boots and the person behind them catching the invertebrates with the net. Once the samples were collected they were placed in bottles with a 50/50 ratio of water and ethyl alcohol for their preservation. The samples then were transported to the lab to be identified with the use of a stereoscope and the Bioindicators of Water Quality Quick-Reference Guide by Purdue University (Speelman & Carrol, 2012). The macroinvertebrates were identified and tabulated by genus or family and presence to later calculate the following biotic and diversity indices.

Biological Monitoring Working Party (BMWP)

The BMWP method consisted of arranging the known families in each site with their respective score which is associated with pollution tolerance (Table 1). Once this is done a site score is obtained by summing the individual scores of all families present (Armitage et al., 1983). Higher scores are associated with pollution sensible macroinvertebrates, which can provide the relative pollution level in the site.

Table 1. The BMWP score system taken from Armitage et al., (1983).

FAMILIES	SCORE
Siphlonuridae, Heptageniidae, Leptophlebiidae, Ephemerellidae, Potamanthidae, Ephemeridae, Taeniopterygidae, Leuctridae, Caprniidae, Perlodidae, Perlidae, Chloroperlidae, Aphelocheridae, Phryganeidae, Molannidae, Beraeidae, Odontoceridae, Leptoceridae, Goeridae, Lepidostomatidae, Brachycentridae, Sericostomatidae.	10
Astacidae, Lestidae, Agriidae, Gomphidae, Cordulegasteridae, Aeshnidae, Corduliidae, Libellulidae	8
Caenidae, Nemouridae, Rhyacophilidae, Polycentropidae, Limnephilidae	7
Neritidae, Viviparidae, Ancylidae, Hydroptilidae, Unionidae, Corophiidae, Gammaridae, Platycnemididae, Coenagrionidae	6
Mesoveliidae, Hydrometridae, Gerridae, Nepidae, Naucoridae, Notonectidae, Pleidae, Corixidae, Haliplidae, Hygrobiidae, Dytiscidae, Gyrinidae, Hydrophilidae, Clambidae, Helodidae, Dryopidae, Elmidae, Chrysomelidae, Curculionidae, Hydropsychidae,Tipulidae, Simuliidae, Planariidae, Dendrocoelidae	5
Baetidae, Sialidae, Piscicolidae	4
Valvatidae, Hydrobiidae, Lymnaeidae, Physidae, Planorbidae, Sphaeriidae, Glossiphoniidae, Hirudidae, Erpobdellidae, Asellidae	3

Table 1. Continue.

FAMILIES	SCORE
Chironomidae	2
Oligochaeta (whole class)	1

Biotic Index

Tolerance to pollution for the species used in the biotic index was established by Speelman & Carroll from the Bioindicators of Water Quality Quick-Reference guide of Purdue University (2012). First each families tolerance value was multiplied by the number of specimens found, providing the family tolerance score. This was done with all the orders present at the site to later calculate the biotic index with the following formula:

Biotic index = [Sum of all family tolerance score] / [total number found]

The score provided then can then be interpreted as a water quality rating (Table 2).

Table 2. Water quality rating for the biotic index (Speelman & Carroll, 2012).

Biotic Index	Water Quality Rating	Degree of Organic Pollution
0.00-3.75	Excellent	organic pollution unlikely
3.76-4.25	Very Good	slight organic pollution possible
4.26-5.00	Good	some organic pollution probable
5.01-5.75	Fair	fairly substantial pollution likely
5.76-6.50	Fairly Poor	substantial pollution likely
6.51-7.25	Poor	very substantial pollution likely
7.25-10.0	Very Poor	severe organic pollution likely

Alpha diversity Shannon-Wiener and Simpson scores

These two scores were calculated with the use of R® to provide a better understanding of possible changes in diversity at each site.

Shannon-Wiener: $H' = \sum_{i=1}^{S} p_i \ln(p_i)$ Simpson: $\lambda = \sum p_i^2$

Where:

p_i= Proportion of abundance of the species.

S= Total number of species.

$\sum$= summation

Erosion/Deposition Estimation Techniques

Short term erosion and deposition was measured through the use of chaining pins 35cm long or rebar 60 cm long which were inserted perpendicular to the bank with flagging to make them easy to find again. The amount of pins placed varied from 3 to 4 depending the height of the bank and were placed equidistant from each other starting from the edge of the water (Couper et al., 2002). This was done in order to provide subsequent information on the bank erosion and deposition at the different heights. This information was later graphed for each revetment and provided a visual interpretation of the bank behavior.

Revetment deposition was estimated by measuring the length, width and depth of the new sediments deposited in the revetment. The new sediments were determined with the use of a ruler or rebar which was inserted to the soil and if it presented resistance to penetration it was considered part of the original soil present on the site. If the ruler or rebar easily penetrated the soil, the depth which the resistance increased was recorded as the depth. The length and width of the subsection was recorded providing the volume of the sediments in one of the subsections behind the revetment. After recording data for the entire length of the revetment all the subsections were added to estimate the deposition for the site.

Historical medium erosion was measured through the macro analysis of exposed tree roots. The criteria necessary for the samples are that it needs to be living tissue with the distal portion of the root still attached to soil, distant enough from the trunk to minimize ring distortion and 5-10 cm in diameter (Stotts et al., 2014). Before the samples were cut, in-situ details were recorded both on the root and a data workbook including location, species, orientation in relation to the bank and the species (Benitez, 2019). The length of lost soil at each location was measured using a meter stick measuring horizontal distance from the river side of the root. The samples were then air dried for 2 months, cut into 2cm sections with a hack saw and sanded until desired smoothness with successively finner sand papers from grit 150 to 400. The sample was then viewed through a stereoscope to determine years since the root was exposed by counting the number of annual rings. Indicators of the roots exposure were markings left on the root derived from injury during high flow events or drastic changes in ring patterns or cell-wall thickening and lignification processes (Schweingruber et al., 2007).

Once the data was recorded erosion was calculated using the following equation modified by Stotts et al. (2014) from Corona et al. (2011). Which is further detailed in figure 3.

$$E_r = E_x - (Gr1) + \frac{(B1 + B2)}{2}$$

$$E_{ra} = E_r / NRex$$

Where:

E_r: Corrected length of the eroded bank.

$Gr1$: Root growth after exposure (Figure 14).

E_x: Average distance between the riverside edge of the root and the current bank position.

$\frac{(B1+B2)}{2}$: Average bark width.

E_{ra}: Annual erosion.

NRex: number of years the root has been exposed

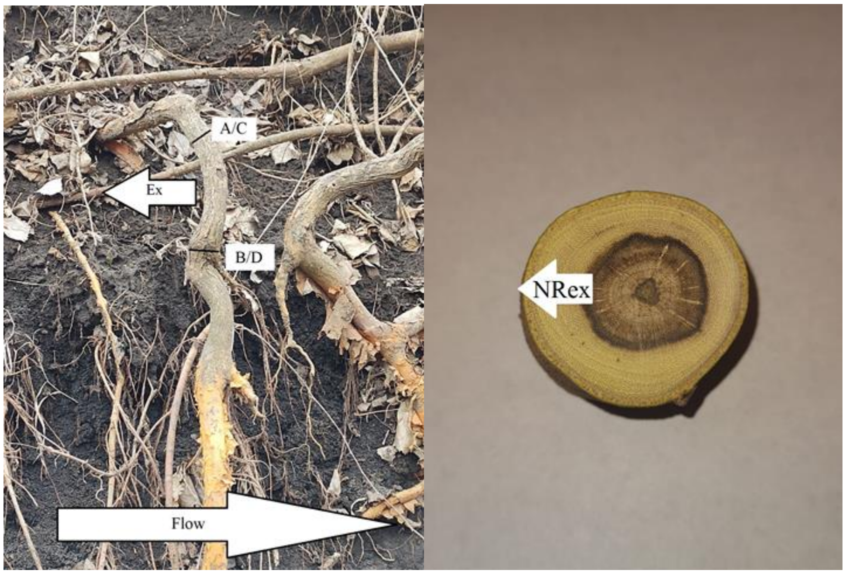

Figure 3. Macro analysis of exposed tree roots(A) downstream top, (B) upstream top, (C) downstream bottom, and (D) upstream bottom

RASCAL Protocol

The RASCAL Protocol is derived from the Stream Visual Assesment Protocol from the Natural Resources Conservation Service (U.S. Department of Agriculture, 2009),(Keil, 2010). The aim of this protocol was to provide a basic level stream health or condition assessment based on qualitative descriptions to determine the condition of stream habitats located on the property. The stream assessment was conducted on foot by walking down the creek channel through multiple visits. The stream was evaluated upstream to avoid any disturbance of the areas being surveyed. To enter the privately owned segments of the creek outside of the base landowners were contacted for permision to conduct the survey. The data was collected by reaches where there was a visible change in substrate, bank stability or distance of 50m (Wendt, 2007). On each of the reaches GPS coordinates were taken and the assessment variables were evaluated. Variables consisted of physical aspects such as canopy cover, bank vegetation, and bank erosion which are closely related to visual indicators in the SVAP(U.S. Department of Agriculture, 2009). Once the stream was surveyed the assessment provided GPS coordinates with relative stream condition which were later mapped to provide further understanding of the stream condition.

Comparison

The data collected on both macroinvertebrates and deposition/erosion at each site were compared between data before installation as well as after installation. A control site was also established to provide baseline information about the creek's behavior at a similar site to where the revetments where installed. Also, data from Little Grasshopper Creek and Plum Creek streams with the same redcedar revetment design installed were compared to McConnell Creek's behavior. This was done to provide a better understanding of the effects of cedar revetments on each site such as deposition rates and changes in macro invertebrate diversity.

Chapter 3 - Results and Discussion

The following chapter will present the results for data collected on McConnell Creek from April of 2019 until September of 2021. For ease of communication the revetment installed in June of 2020 will be refered to as R1 and the revetment installed in March of 2021 will be referred to as R2.

Short term Erosion/Deposition

Short term erosion/deposition through erosion pins was measured with different time lapses between the two revetments therefore their data will be presented separately to provide a better understanding of each cut banks behavior.

R1 counted with data previous to the installation of 1 year and 5 months and after installation the pins data was last recorded 1 year and 3 months after installation. Since installation of R1 it has been estimated that 3.32 cubic meters of sediment have been deposited behind the revetment.

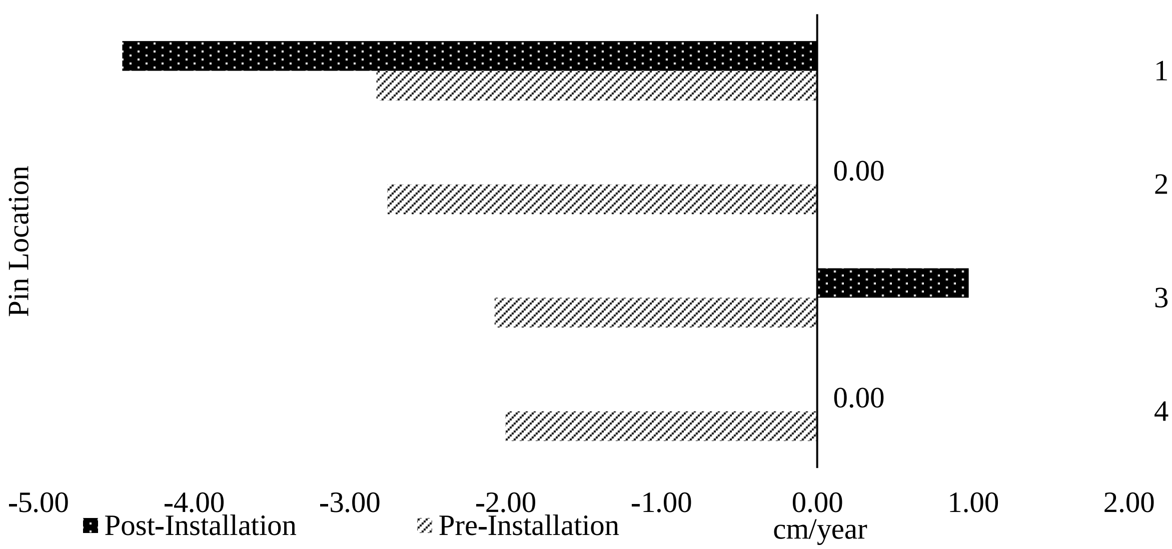

Figure 4. Streambank erosion estimates from reinforcement bars at McConnell Creek R1 both pre and post installation, monitored for 17 and 15 months respectively. Negative values indicate erosion, 1 in pin location indicates top of the bank

The chaining pins by being placed slightly protruding from the bank made simple measuring erosion but once deposition started taking place the lower two pins' data became unavailable. In Figure 4 the pins 3 and 4 being on the lower part of bank got buried by sediments post installation, with pin 4 averaging 0cm/year deposition/erosion. Pin 2 also didn't present any erosion or deposition during the monitored time.

As seen in Figure 4 the cut bank the year before the redcedar revetment was installed presented uniform erosion/deposition rates ranging from -2 to -3 cm/year. Once the revetment was installed there where instances of both erosion/deposition at the bank. The upper bank presented erosion/deposition rates of -5cm/year while the lower bank as previously discussed had deposition rates unaccounted for in a time period of 5 months.

Figure 5. High flow event in McConnell Creek on June of 2021 in R1

According to Couper et al., (2002) deposition could be generated by several phenomena such as expansion of the soil mass with increased moisture contents, human intervention and displacement from upper bank to lower parts of the bank. Figure 5 displays R1 during a high flow event where there is a clear display of upper bank collapsing and getting trapped by the revetment on the lower part of the bank.

R2 counted had data prior to the installation of 2 years and 3 months and after installation the pins data was last recorded 5 months after installation. Due to the short period of post-installation measuring erosion/deposition on R2 the data was standardized to erosion in cm/month instead of yearly. It is estimated that R2 has captured 2 cubic meters of sediment behind the revetment.

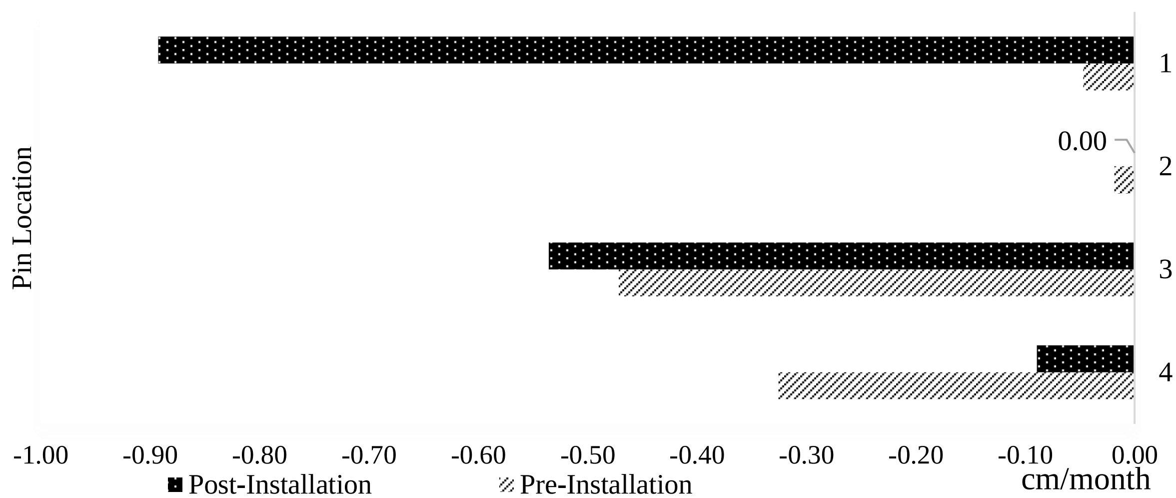

Figure 6. Streambank erosion estimates from reinforcement bars at McConnell Creek installation of R2 both pre and post installation, monitored for 27 and 5 months respectively. Negative values indicate erosion, 1 in pin location indicates top of the bank

R2 had only negative values which translate to erosion at this site. Both before and after the revetment installation the overall erosion at this site was low with values less than a centimeter a year. Erosion rates in R2 in comparison to R1 are lower though this is likely due to the morphology of the stream on each site. R1 is located on a meander which is known to have higher erosion rates because of its bends (Crosato, 2009). Erosion did increase slightly once the revetment was installed but this data only covers 5 months' time post-installation to better understand a trend more data needs to be collected.

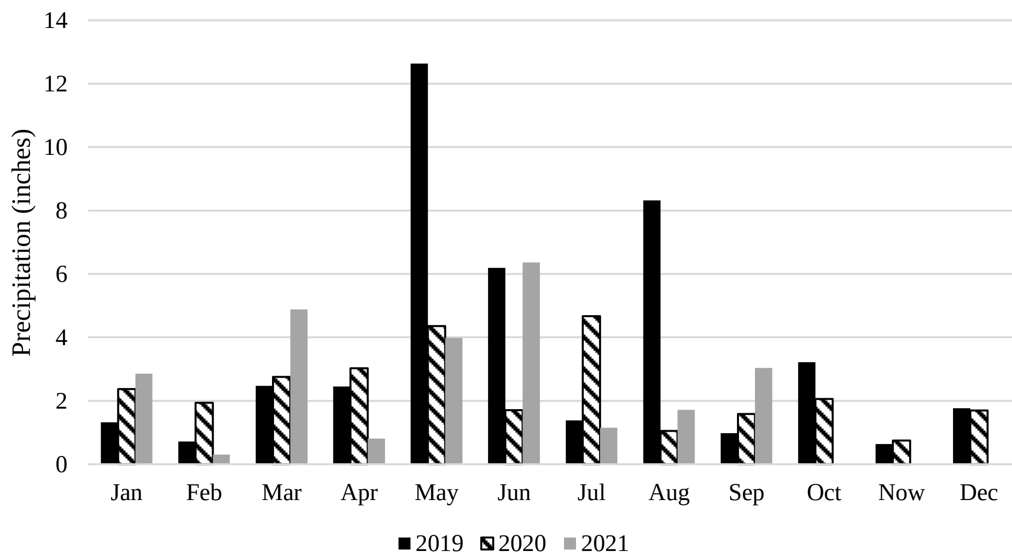

Figure 7. Monthly total precipitation 2019-2021 for Wichita Area, KS. Source: NOAA

There were two precipitation events of interest previous to the installation of the revetments during the presence of the erosion pins on R1 and R2. May and August of 2019 had precipitation events of greater than 2 inches (Figure 7). 2020 was characterized by having no high precipitation events meaning that R1 during its first year of installation presented fewer opportunities to capture sediments. Both R1 and R2 were installed for the single high precipitation event that occurred during June of 2021.

A control site located between R1 and R2 was also monitored for a period of 1 year and 7 months. It is important to emphasize that pins only are capable of providing proper erosion rates at the exact locations of pins, extrapolating data between pins and transects can result in erroneous conclusions (Jugie et al., 2018).

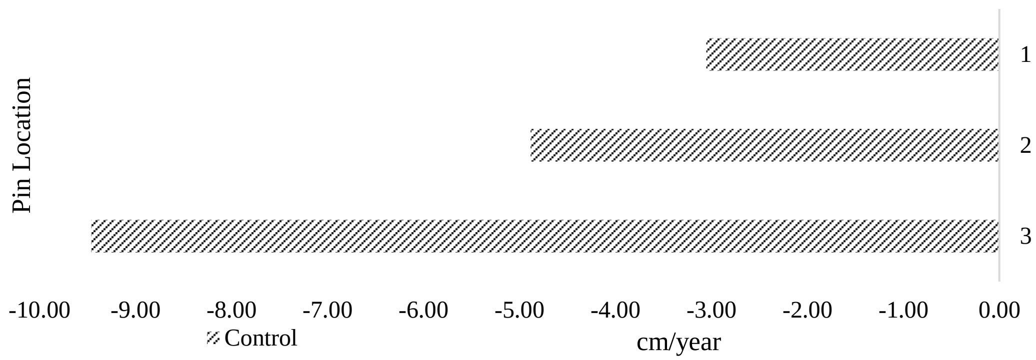

Figure 8. Streambank erosion estimates from control site at McConnell Creek monitored for 19 months. Negative values indicate erosion, 1 in pin location indicates top of the bank

In Figure 8 the rates of erosion/deposition are drastic in a short period of time specially on lowest pin which had an average of -9.46cm/year. High erosion rates can be attributed to a lack of cover. Jugie et al., (2018) presented similar results in which banks with 40% of vegetation cover were very stable and bare banks presented erosion rates of several centimeters/year.

Little Grasshopper Creek Erosion/Deposition

For comparison purposes longer term erosion pins were monitored at another site, Little Grasshopper Creek which is located in Atchison County, originally monitored by Benitez & Barden (2019). R1 and R2 redcedar revetments have a length of approximately 25 meters while Little Grasshopper has a length of 115 meters. Little Grasshopper revetment also had high precipitation events near the time of installation creating bankfull flows ideal for capturing sediments. The data collected from this revetment accounts for erosion/deposition rates since September 2018 until September of 2021. There is no historical data prior to the revetment installation therefore control sites were established and monitored.

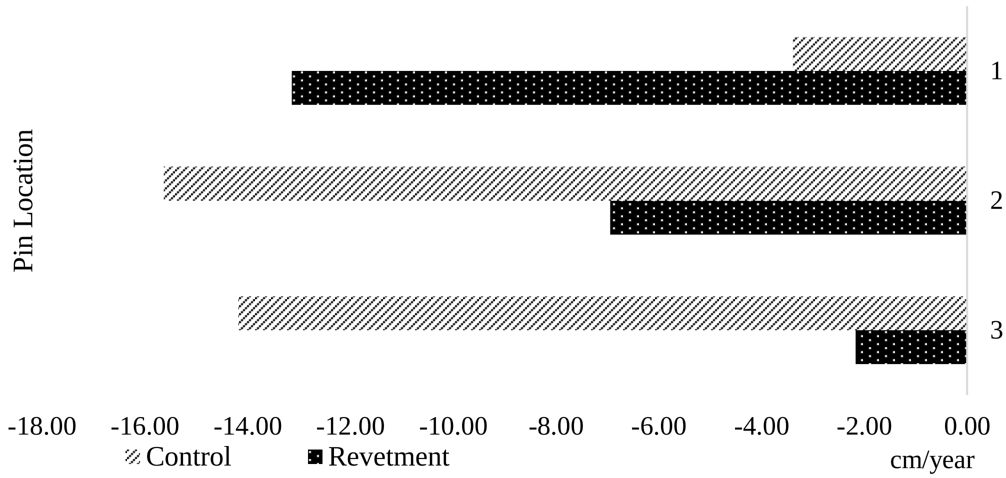

Figure 9. Streambank erosion estimates from reinforcement bars at Little Grasshopper Creek both revetment and control both monitored for 36 months. Negative values indicate erosion, 1 in pin location indicates top of the bank

Benitez (2019) originally observed erosion in the lower areas of the bank with some deposition in the middle and upper part of the bank for both control and redcedar revetment. The data now reflects a different behavior in which the control sites have higher erosion rates on the lower parts of the cut bank. The revetment presents its highest erosion rates at the upper parts of the cut bank similar trend observed behind the revetments on McConnell Creek (Figure 9). The control site in both McConnell Creek and Little Grasshopper Creek present similar tendencies in which the lower half of the bank is exposed and presents the greatest erosion rates. The McConnell Creek R1 could present similar erosion rates four years post the installation as Little Grasshopper's revetment now has developed higher erosion rates at the upper part of the bank and the now well established vegetation protects lower portion of the bank.

Data provided by the erosion pins best describe the areas where the pins were installed making extrapolations hard to achieve (Jugie et al., 2018) therefor each site was evaluated separately. Both revetments need longer monitoring times of erosion rates as it is necessary to establish well the trends of the cut bank (Arnold & Toran, 2018). R1 exhibited a clear erosion event of displacement from upper bank to lower parts of the bank (Couper et al., 2002). The cause of the erosion event was described well by Lawler (1995) and Laubel et al., (2003) in which there is a weakening of the lower bank causing a bank failure in the upper segment.

Historical erosion using exposed tree roots

During the conduct of the RASCAL procedure survey of 4.6 km of McConnel Creek during which we the selected and sampled 13 tree roots for dendrogeomorphologic analysis.

Table 3. Erosion rates through Dendrogeomorphological analysis at McConnell Creek

Common Name	Tree Species	Erosion estimates (cm/year)	Years exposed (Nrex)	Coordinates N	Coordinates W
Osage Orange	*Maclura pomifera*	2.63	7	37°36'10.2"	97°15'52.5"
Hackberry	*Celtis occidentalis*	3.68	4	37°35'55.4"	97°16'19.7"
Hackberry	*Celtis occidentalis*	3.86	7	37°35'52.7"	97°16'22.5"
Hackberry	*Celtis occidentalis*	3.74	5	37°36'02.6"	97°16'37.8"
Green Ash	*Fraxinus pennsylvanica*	5.68	11	37°36'54.2"	97°15'33.2"
Honey Locust	*Gleditsia triacanthos*	5.92	3	37°36'08.2"	97°15'53.9"
Mullberry	*Morus rubra*	11.33	3	37°35'55.2"	97°16'16.2"
Mullberry	*Morus rubra*	4.59	5	37°36'06.2"	97°15'56.0"
American Elm	*Ulmus americana*	2.96	4	37°36'14.6"	97°15'47.9"
American Elm	*Ulmus americana*	10.90	3	37°36'15.5"	97°15'47.1"
American Elm	*Ulmus americana*	1.08	6	37°35'53.1"	97°16'26.9"
American Elm	*Ulmus americana*	5.33	7	37°35'58.1"	97°16'48.0"
American Elm	*Ulmus americana*	4.48	5	37°36'27.4"	97°15'39.4"
	Mean:	5.09			

Throughout the surveyed area the average erosion rate was of 5.09 cm/year. With the highest erosion rate being 11.33cm/year located south of emergency crash landing zone on the border of base property. The lowest erosion rate was of 1.08 cm/year located south of the emergency crash landing zone in an area with dense riparian forest.

The erosion pins and dendrogeomorphology analysis of roots provides data at a given point and extrapolating the data could be accounted if heterogenous erosive processes can be determined (Scuderi, 2017). Erosion rate estimate through dendrogeomorphology analysis were capable of providing a good estimate of erosion rates in the banks present in McConnell Creek. This technique of erosion monitoring was also used by Benitez (2019) where they were able to sample roots exposed for 18 years prior sampling while in McConnell Creek the oldest exposure had occurred 11 years before sampling. One of the downsides of this erosion estimation technique was a lack of trees to sample in the emergency crash landing zone. Stotts et al., (2014) considered tree cover along the evaluated stream a necessary aspect for more precise results.

Macroinvertebrates

Macroinvertebrates results in R1 count with data previous to the installation as well as two samples done after the installation took place. Before the revetment was installed the most abundant family was *Chironomidae* once the revetment was installed the most prevalent family found was *Dogielinotidae*.

Table 4. Summary of biotic and diversity indices in R1 in McConnell Creek

	Pre-revetment		Post-revetment			
	Pool	Cut bank	Pool(1)	Cut bank(1)	Pool(2)	Cut bank(2)
BWMP	24	7	14	26	13	24
Biotic Index	7.65	8.79	7.00	8.15	7.50	8.25
Simpson	0.70		0.33		0.34	
Shannon-Wiener	1.35		0.85		0.80	

The overall water quality is estimated to be poor in this urban creek. During the short course of the study there were no clear changes of tendency of either BMWP or the Biotic Index (Table 4). BMWP low values indicate presence of pollution tolerant families at the site. With the Biotic Index all of the values fall under the category “severe organic pollution likely” except for the pool in the first sample post installation which had still a poor quality rating of 7.00.

Diversity indices in R1 did vary over the time of study. First the Simpson diversity score previous to the revetment installation was of 0.70 and after the installation took place values were around 0.33. This tells us that before the installation if two individuals were taken it was more likely that these were of different families. This is likely due to the high amounts of *Dogielinotidae* found during the sampling post installation affecting the evenness. The Shannon-Wiener diversity index had similar results to those of the Simpson diversity index. As the Shannon-Wiener takes into account mainly the eveness of the sample the overall diversity decreased after the installation from a 1.35 to a 0.80.

R2 counts with two samplings done after the installation took place but but doesn't count with data previous to the installation. Therefore its data can be compared to the control site which was sampled once during the first sampling of R2 post installation as well with R1 pre-revetment sample accounting for all the samples taken without a revetment.

Table 5. Summary of biotic and diversity indices in R2 and controll site in McConnell Creek

	Control		Post-revetment			
	Pool	Cut bank	Pool(1)	Cut bank(1)	Pool(2)	Cut bank(2)
BWMP	20	33	13	25	21	34
Biotic Index	7.75	8.33	8.09	7.89	7.90	7.85
Simpson	0.81		0.27		0.31	
Shannon-Wiener	1.89		0.69		0.76	

The overall water quality in the creek continues to be considered poor throughout the various samples taken. R2 and the controll site display similar patterns to what was found in R1 which was poor quality of water. Both indicated by the low values of BWMP and the high values received by the Biotic Index (Table 5).

The diversity index display a similar pattern to that of R1 in which a lack of revetment displays higher values of diversity in both indixes. This pattern is also due to the high amounts of *Dogielinotidae* present in the sampling where there are revetments. The high amount of

Dogielinotidae increased the total sample size of the site but since there is a clear dominant family the eveness is drasticly reduced affecting both diversity indices.

Benitez (2019) also evaluated biotic indices as well as diversity indices in Plum Creek located on the Kickapoo reservation in Brown County Northeast Kansas which had its revetment installed originally in 2010. Even though the creek has better apparent water quality than McConnell Creek, the influence by the revetment on water quality organisms seems to vary with the control site. This effect was not evident in McConnell Creek since all the organisms present in the samplings were associated with poor water quality yielding values associated with contaminated areas.

Table 6. Average Macroinvertebrate Indices, BMWP, Shannon-Wiener and Simpson Biodiversity Indices from Plum Creek site in stabilize and control reaches. Adapted from (Benitez, 2019)

	Revetment			Control		
	Riffle	Cut bank	Pool	Riffle	Cut bank	Pool
BWMP	165	85	61	84	38	51
Biotic Index	4.4	4.99	5.65	4.91	4.44	4.81
Simpson	0.88	0.74	0.55	0.81	0.74	0.76
Shannon-Wiener	2.51	1.87	1.40	1.98	1.56	1.89

The diversity in Plum Creek varied between control and revetment though this trend wasn't as clear as the one found in McConnell Creek (Table 6). In Plum Creek the riffle's diversity in the revetment site increased in comparison to that of the controll but the pool's diversity decreased. While in McConnell Creek as previously discussed the diversity decreased due to the large increase of a dominant species.

Figure 10. Freshwater amphipod of the genus Dogielinotidae found in McConnell Creek

As previously stated individuals sampled overall increased betweween samplings with revetment to those with no revetment installed. R1 pre-revetment sampled 39 individuals between the pool and cut bank, once the revetment was installed the first visit yielded 239 individuals being sampled. Overall richness in R1 increased from 5 families pre-revetment to 12 families post revetment. Though the increase wasn't even as the great majority of sampled individuals were of the family *Dogielinotidae* (Figure 9). With R2 and control site the results are similar, the control site yielded 75 individuals R2's first sample yielded 236 individuals. Overall richness was very similar as the control site had 11 families and R2 had 10 families. In both cases there is an increase in individuals present per sampling. Richness only had an aparent increase when comparing R1's pre and post revetment data. When comparing richness between control and revetments the number of families sampled were similar.

The overall relative water quality scores throughout the sampling in McConnell Creek were considered poor. This was due to the presence of pollution resistant families like *Chironomida* which according to Odume & Muller (2011) could be used as indicators of water quality impairment. Benitez (2019) and Zeybek et al. (2014) used indicators such as BMWP and Biotic index to determine water quality effectively in different streams. One of McConnell

Creek's possible contamination source could be the de-icing fluid utilized on the runway and airplanes which according to Ariyajunya et al. (2018) its usage is closely related to oxygen demand in waterways. Another possible source of contamination are the agricultural activities like cultivation that take place in surrounding areas of the creek which are a known source of contamination for water sources (Lian et al., 2019). Diversity did present clear changes from areas where there was a revetment installed. This is likely due to the increase in woody debri into the site creating refuge and a source of food for many species. Similarly Thompson et al. (2018) was capable of demostrating a positive relationship between large woody debri introduction and ecological responses. *Dogielinotidae* the main family which population increased drastically is a primary consumer which according to Camacho & Thacker (2013) population is dependant of algae for predator protection like the one found on the branches of the revetments located underwater. The increse in population of *Dogielinotidae* may lead to changes in structure of the enviornment as primary consumers (Huntly, 1995).

RASCAL Protocol

McConnell Creek was surveyed through the RASCAL protocol which yielded 64 survey reaches over 4.6 kilometers. The survey took place through several visits from February to April of 2021. RASCAL protocol consists in the collection of data of numerous metrics that enable the researcher to take accurate decisions and have a better understanding of a creek or river that is wadable. The ten variables that were collected for McConnell Creek consist of streambank material, streambank stability, bank erosion, bank vegetation, adjacent land use, riparian zone cover, canopy cover, embeddedness, dominant substrate and habitat. Variables that can be grouped together for comparison.

Table 7. Surveyed variables with their respective percentage at McConnell Creek related to bank stability, protection and overall habitat quality.

Survey Variable	Categories				
Streambank Stability	Stable	Moderately Stable	Moderately Unstable	Unstable	Artificially Stable
	17	31	37	6	9
Bank Vegetation	Overhanging only	Dislodged	Partially Established	Well Established	
	2	9	45	44	
Bank erosion	None	Both Banks	Alternate Banks	Random	
	8	16	67	9	
Habitat	Excellent	Average	Poor		
	11	78	11		

The surveyed stretch of McConnell Creek banks were characterized by mainly being stable with 58% of the banks being moderately stable or better (Table 7). Only 11% of the bank vegetation was categorized within categories associated with severe erosion process. Bank erosion throughout the evaluated stretch was mostly on an alternating pattern with 67% of the surveys falling under this category. The habitat of the creek was mainly characterized as being average with 78% of the surveys falling under this category.

Table 8. Surveyed variables with their respective percentage at McConnell Creek related to canopy cover and adjacent land use

Survey Variable	Categories				
Canopy cover	0-10%	10-25%	25-50%	50-75%	75-100%
	20	30	31	17	2
Riparian zone cover	Grass	Trees	Woody/Herbaceous Mix	Other	
	13	70	14	3	
Adjacent Land Use	Grass	Trees	Woody/Herbaceous Mix	Other	
	51	45	2	2	

Another interesting agrupation of metrics that can be made relates to vegetation cover adjacent to to the stream as well as the canopy cover it can provide (Table 8). For McConnell Creek 81% the canopy cover estimates fall in the category of 50% of cover or less. The main riparian zone cover consist of trees with a 70% of the evaluated stretch falling under this category. Adjacent land use was interesting as it varied mostly from riparian forest to grass with a small percetage of other in which the stream was parallel to the street.

Table 9. Surveyed variables with their respective percentage at McConnell Creek for streambank material dominant substrate and embeddedness

Survey Variable	Categories						
Dominant substrate	Bedrock	Boulder	Cobble	Gravel	Sand	Clay/ Hard Pan	Silt/ Mud
	2	2	11	23	17	15	30
Embeddedness	Completely Exposed	Partially Exposed	Mostly Embedded	Completely Embedded	NA		
	8	25	35	30	2		
Streambank Material	Rock/Rip Rap	Cobble/G ravel	Sand	Soil/Silt			
	2	2	0	96			

McConnel Creek is mainly characterized by a diverse subtrate composition in which the dominant channel substrate is silt/mud with 30% of stretch falling under this category (Table 9). The dominant embeddedness of the channel surface 66% of the time fell under the category of mostly embedded or completely embedded. Not surprisingly the streambank material mainly consisted 97% of soil/silt.

One advantage of the RASCAL protocol is that all the surveys have associated GPS coordinates which provide a way of visualizing the desired data easier. The decision makers can make a series of maps and visualize the data they see fit for their purposes and determine what areas they would want to work on. For interest of the project the variables which got mapped through ArcGis Pro were habitat quality and bank stability.

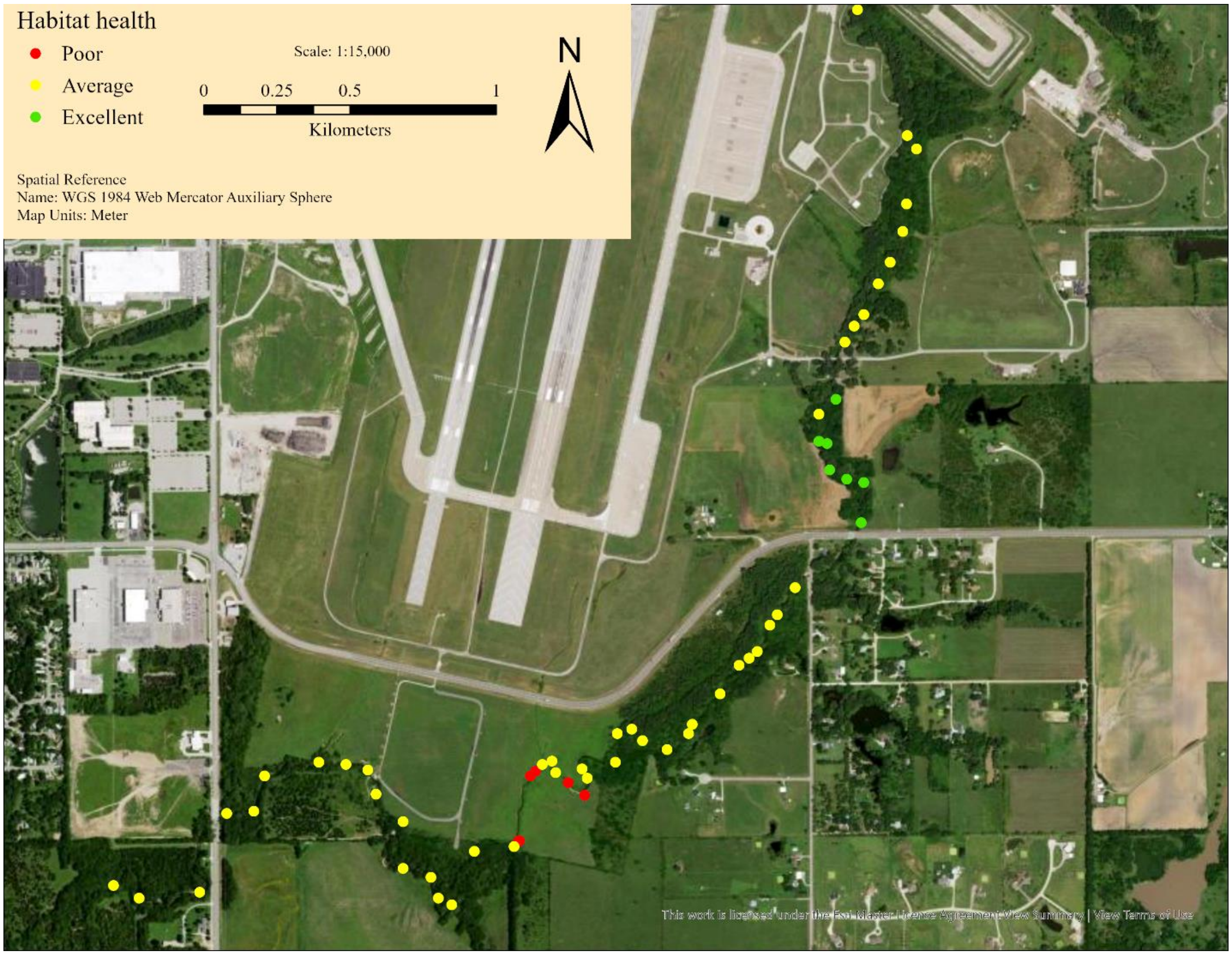

Figure 11. Evaluated McConnell Creek segment classified by Habitat health

Overall the RASCAL protocol is a valuable tool capable of providing information of a creek or river with great detail. Spatially identifying possible areas of interest in which efforts could be directed towards easier. This tool also allows researchers or land managers to draw conclusions of lengths evaluated on the stream. On McConnel Creek there are two segments which are clearly differentiated when ploting the habitat health points. The areas located in the on the emergency crash landing zone were charactized mainly as having por habitat quality (Figure 9). While outside of the base property there was a stretch which had excellent habitat an area which shows the creeks maximum potential. Wendt (2007) used the RASCAL protocol to evaluate larger portions of a watershed which provide a sense of scalability and potential of this tool.

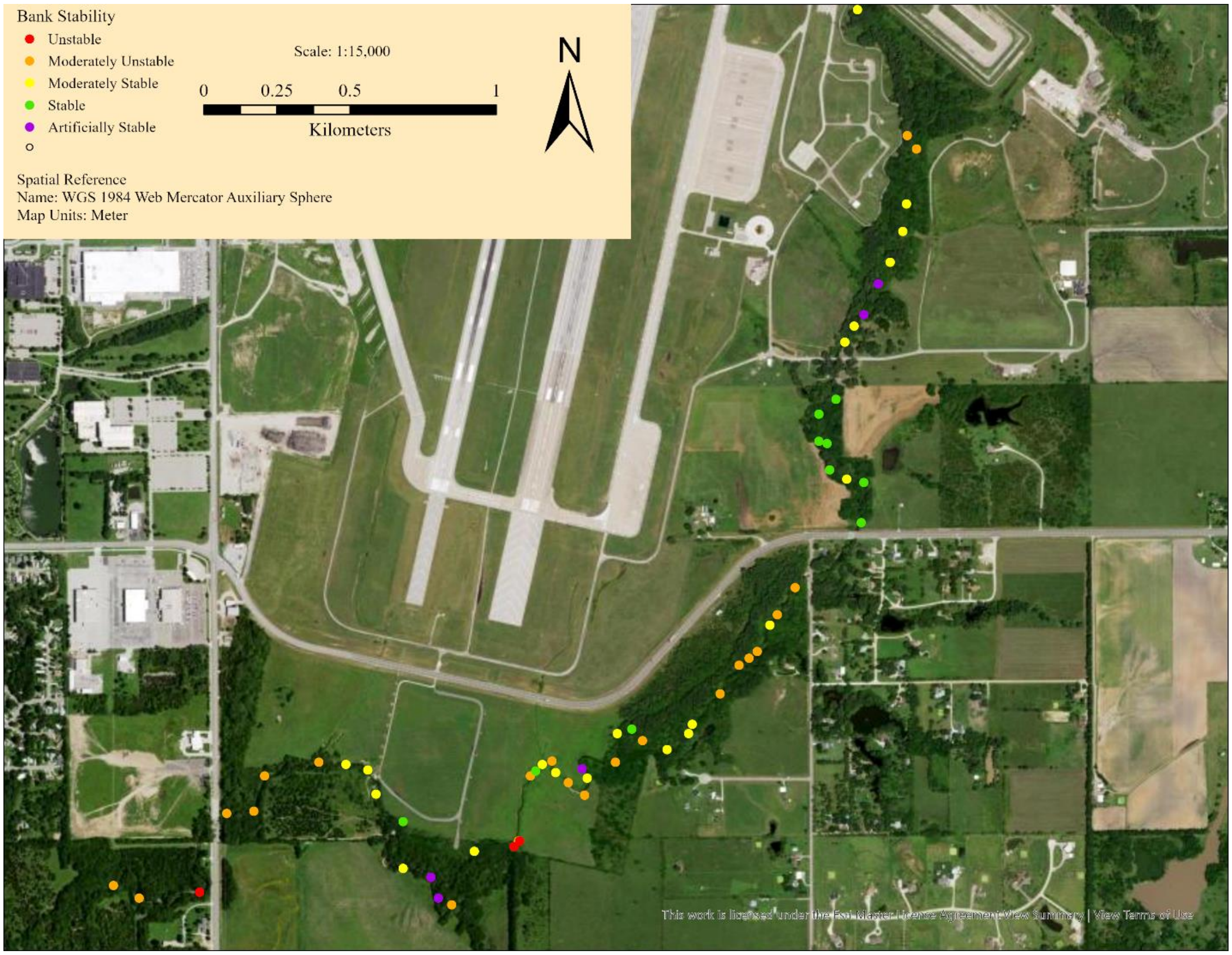

Figure 12. Evaluated McConnell Creek segment classified by Bank Stability

Plotting more variables might help land managers lead efforts towards problems of interest. When comparing the bank stability with habitat quality there was an overlap in which an extent of stable banks also had the best habitat quality (Figure 12). RASCAL also has been used in watershed management plans to define possible points of pollution which efforts were directed towards to (Northeast Iowa Resource Conservation & Development, 2012).

Chapter 4 - Conclusions and Recommendations

Both revetments for the short period since installation have been successful in capturing sediments during high flow events with R1 capturing 3.32 cubic meters and R2 capturing 2 cubic meters of sediments. Erosion rates in McConnell Creek's redcedar revetment sites have been recorded for two years and eight months. During this period of time erosion patterns differed between sites. R1 was characterized by having an erosion pattern post installation described by Couper et al., (2002) in which the upper section of the bank moves to the lower segments of the bank. A similar pattern was also present in Little Grasshopper Creek, a revetment originally evaluated by Benitez (2019). R2 displayed erosion rates less than 1cm/year before and after installation in contrast to the control site's lower bank presenting a rate of erosion of 9.46cm/year. The data provided by the pins best describes the points in which they were installed though more monitoring is necessary to provide a better understanding of the erosion trends (Arnold & Toran, 2018)(Jugie et al., 2018). Dendrogeomorphological analysis of roots also estimated a historical average erosion rate of 5.09 cm/year. Though segments of the stream were not evaluated as they lacked trees which are essential to determine erosion rates (Stotts et al., 2014).

Macroinvertebrate sampling in McConnell Creek defined the water quality of the stream as poor. This was due to the presence of pollution resistant families like *Chironomida.* Both Biotic index and the BWMP yielded scores associated with streams of high organic pollution. High organic pollution in the stream could be associated with the base's use of de-icing fluids as well as argricultural activities in the surrounding areas (Lian et al., 2019) (Ariyajunya et al., 2018). Overall biodiversity indices were higher in the sites with no revetmets. The biodiversity change was due to an increase in individuals sampled mainly being part of the family

Dogielinotidae reducing the eveness of the samples. The increase of *Dogielinotidae* can be associated with the revetments creating a source of refuge and food (Camacho & Thacker, 2013). This increase in primary consumers may lead to changes in other trophic levels (Huntly, 1995). To provide a better understanding of the revetments effect on the stream habitat more macroinvertebrate sampling sites are necessary for a statistical analysis.

Additional monitoring sites could be located in native prairie and monitored for changes in macroinvertebrate populations. This would allow comparing the effects of native vegetation in the Wichita area with that present in McConnell Airforce Base emergency crash landing zone. This would improve the understanding of what are the possible differences between an urban creek with a revetment and a naturally vegetated creek.

RASCAL protocol is an effective tool to evaluate the stream quality with little experience needed. 64 surveys were conducted in McConnell Creek on a reach of 4.6 kilometers. The ten variables surveyed provide valuable data for characterizing areas of interest for future decision making. When mapping variables such as habitat health and bank stability areas which had ideal conditions could be identified as well as those scored poorly and that work is needed on. RASCAL protocol has also been also implemented at the watershed level in other studies proving its scalability (Northeast Iowa Resource Conservation & Development, 2012).

Bibliography

Air Force Center for Environmental Excellence. (1998). *Air Force Aircraft and Airfield Deicing/Anti-icing* (Issue May 1998, pp. 1–7). https://p2infohouse.org/ref/01/00593.pdf

Ariyajunya, B., Tarun, P. K., Chen, V. C. P., & Kim, S. B. (2018). Modeling the impact of airport deicing and anti-icing activities on dissolved oxygen levels in the receiving waterways. *Journal of Water Management Modeling*, *2018*, 2–9. https://doi.org/10.14796/JWMM.C441

Armitage, P. D., Moss, D., Wright, J. F., & Furse, M. T. (1983). The performance of a new biological water quality score system based on macroinvertebrates over a wide range of unpolluted running-water sites. *Water Research*, *17*(3), 333–347. https://doi.org/10.1016/0043-1354(83)90188-4

Arnold, E., & Toran, L. (2018). Effects of bank vegetation and incision on erosion rates in an urban stream. *Water (Switzerland)*, *10*(4). https://doi.org/10.3390/w10040482

Benitez, D. M. (2019). *Monitoring the Effectiveness of Streambank Stabilization Projects in Northeast Kansas*. Kansas State University.

Bjorkland, R., Pringle, C. M., & Newton, B. (2001). A stream visual assessment protocol (SVAP) for riparian landowners. *Springer*, *68*(2), 99–125. https://doi.org/10.1023/A:1010743124570

Camacho, F. A., & Thacker, R. W. (2013). Predator cues alter habitat use by the amphipod Hyalella azteca (Saussure). *Freshwater Science*, *32*(4), 1148–1154. https://doi.org/10.1899/12-176.1

Corona, C., Lopez Saez, J., Rovéra, G., Stoffel, M., Astrade, L., & Berger, F. (2011). High resolution, quantitative reconstruction of erosion rates based on anatomical changes in exposed roots at Draix, Alpes de Haute-Provence - critical review of existing approaches and independent quality control of results. *Geomorphology*, *125*(3), 433–444. https://doi.org/10.1016/j.geomorph.2010.10.030

Couper, P., Stott, T., & Maddock, I. (2002). Insights into river bank erosion processes derived from analysis of negative erosion-pin recordings: Observations from three recent UK studies. *Earth Surface Processes and Landforms*, *27*(1), 59–79. https://doi.org/10.1002/esp.285

Crosato, A. (2009). Physical explanations of variations in river meander migration rates from model comparison. *Earth Surface Processes and Landforms*, *34*(March), 613–628. https://doi.org/10.1002/esp

Cryotech. (2014). *Type I Aircraft Deicing / Anti-icing Fluid: Safety Data Sheet* (p. 15).

dos Reis Oliveira, P. C., van der Geest, H. G., Kraak, M. H. S., Westveer, J. J., Verdonschot, R.

C. M., & Verdonschot, P. F. M. (2020). Over forty years of lowland stream restoration: Lessons learned? *Journal of Environmental Management*, *264*, 110417. https://doi.org/10.1016/j.jenvman.2020.110417

Florsheim, J. L., Mount, J. F., & Chin, A. (2008). Bank erosion as a desirable attribute of rivers. *BioScience*, *58*(6), 519–529. https://doi.org/10.1641/B580608

Gärtner, H. (2007). Tree roots - Methodological review and new development in dating and quantifying erosive processes. *Geomorphology*, *86*(3–4), 243–251. https://doi.org/10.1016/j.geomorph.2006.09.001

Goard, D. (2006). *Installing a Tree Revetment*. www.kansasforests.org

Hemmerly, T. E. (1970). Economic uses of eastern red cedar. *Economic Botany*, *24*(1), 39–41. https://doi.org/10.1007/BF02860632

Hoosier Riverwatch. (2015). Volunteer Stream Monitoring Training Manual 2015. In *Business* (pp. 14–25).

Huntly, N. (1995). How Important are Consumer Species to Ecosystem Functioning. In *Linking Species & Ecosystems*. Springer, Boston, MA.

Jugie, M., Gob, F., Virmoux, C., Brunstein, D., Tamisier, V., Le Coeur, C., & Grancher, D. (2018). Characterizing and quantifying the discontinuous bank erosion of a small low energy river using Structure-from-Motion Photogrammetry and erosion pins. *Journal of Hydrology*, *563*(June), 418–434. https://doi.org/10.1016/j.jhydrol.2018.06.019

Keil, A. (2010). *Rapid Assessment of Stream Conditions Along Length (RASCAL) Protocol* (pp. 1–7). Iowa Department of Natural Resources, Des Moines, IA. http://jaicwc.org/current_web_site/watersheds/muddy_creek/rascal/docs-rascal-mc/RASCAL_Procedure_DRAFT.pdf

Kondolf, G. M. (1995). Five Elements for Effective Evaluation of Stream Restoration. In *Restoration Ecology* (Vol. 3, Issue 2, pp. 133–136). https://doi.org/10.1111/j.1526-100X.1995.tb00086.x

Laubel, A., Kronvang, B., Hald, A. B., & Jensen, C. (2003). Hydromorphological and biological factors influencing sediment and phosphorus loss via bank erosion in small lowland rural streams in Denmark. *Hydrological Processes*, *17*(17), 3443–3463. https://doi.org/10.1002/hyp.1302

Lawler, D. M. (1995). The impact of scale on the processes of channel-side sediment supply: a conceptual model. *Effects of Scale on Interpretation and Management of Sediment and Water Quality. Proc. Symposium, Boulder, 1995*, *226*(May), 175–184.

Lian, Q., Yao, L., Uddin Ahmad, Z., Lei, X., Islam, F., Zappi, M. E., & Gang, D. D. (2019). Nonpoint source pollution. *Water Environment Research*, *91*(10), 1114–1128. https://doi.org/10.1002/wer.1205

Mandaville, S. M. (2002). Benthic Macroinvertebrates in Taxa Tolerance Values , Metrics , and Protocols. *The Use of Biotic Index as an Indication of Water Quality*, *5*, 85–98.

Naisargi, D., & Mittelstet, A. R. (2017). Quantifying effectiveness of streambank stabilization practices on Cedar River, Nebraska. *Water (Switzerland)*, *9*(12), 1–13. https://doi.org/10.3390/w9120930

Northeast Iowa Resource Conservation & Development. (2012). *Yellow River Headwaters Management Plan* (pp. 1–120).

Odume, O. N., & Muller, W. J. (2011). Diversity and structure of Chironomidae communities in relation to water quality differences in the Swartkops River. *Physics and Chemistry of the Earth*, *36*(14–15), 929–938. https://doi.org/10.1016/j.pce.2011.07.063

Pilgrim, C. M., Mikhailova, E. A., Post, C. J., & Hains, J. J. (2014). Spatial and temporal analysis of land cover changes and water quality in the Lake Issaqueena watershed, South Carolina. *Environmental Monitoring and Assessment*, *186*(11), 7617–7630. https://doi.org/10.1007/s10661-014-3953-9

Randall, C. (2015). *Survival & Growth of Sandbar Willow , Salix interior , in Bioengineering Projects , and the Implications for Use in Erosion Control in Manitoba By Christopher Randall A thesis submitted to the Faculty of Graduate Studies of The University of Manitoba in p*. 113.

Schmidt, J. C., Webb, R. H., Valdez, R. A., Marzolf, G. R., & Stevens, L. E. (1998). Science and Values in River Restoration in the Grand Canyon. *BioScience*, *48*(9), 735–747. https://doi.org/10.2307/1313336

Schweingruber, F. ., Börner, A., & Schulze, E.-D. (2007). *Atlas of Woody Plant Stems Evolution, Structure, and Environmental Modifications*. Springer.

Scuderi, L. A. (2017). Quantification of long-term erosion rates from root exposure/tree age relationships in an alpine meadow catchment. *Geomorphology*, *283*, 114–121. https://doi.org/10.1016/j.geomorph.2017.01.029

Sheeter, G. R., & Claire, E. W. (1989). *Juniper for Streambank Stabilization in Eastern Oregon*. 420–423.

Speelman, J., & Carroll, N. (2012). *Bioindicators of water quality quick-reference guide*. 1–6.

Stotts, S., O'Neal, M., Pizzuto, J., & Hupp, C. (2014). Exposed tree root analysis as a dendrogeomorphic approach to estimating bank retreat at the South River, Virginia. *Geomorphology*, *223*, 10–18. https://doi.org/10.1016/j.geomorph.2014.06.012

The Federal Highway Administration, F. (2009). *HEC 23 - Bridge Scour and Stream Instability Countermeasures: Volume 1*. *1*(23).

Thompson, M. S. A., Brooks, S. J., Sayer, C. D., Woodward, G., Axmacher, J. C., Perkins, D.

M., & Gray, C. (2018). Large woody debris “rewilding” rapidly restores biodiversity in riverine food webs. *Journal of Applied Ecology*, *55*(2), 895–904. https://doi.org/10.1111/1365-2664.13013

Thorne, C. R. (1981). Field measurements of rates of bank erosion and bank material strength. *Erosion and Sediment Transport Measurement. Proc. Florence Symposium, June 1981, (International Association of Hydrological, Sciences, IAHS-AISH Publication 512), 133*, 503–512.

U.S. Department of Agriculture. (2002). *Streambank and Shoreline Protection Manual*. Chicago Metro Urban and Community and Assistance Office.

U.S. Department of Agriculture. (2009). Stream Visual Assessment Protocol Version 2. *National Biology Handbook, December*.

USEPA. (2000). *Principles for the Ecological Restoration of Aquatic Resources* (pp. 1–2).

USEPA. (2007). *Total Maximum Daily Loads with Stormwater Sources: A Summary of 17 TMDLs*.

Weins, J. R., Guy, C. S., & Lee, C. D. (1997). *Streambank revetment* (pp. 1–8). Kansas State University. https://krex.k-state.edu/dspace/bitstream/handle/2097/21736/KSUL0009KSREODPUBSMF2294a.pdf?sequence=1&isAllowed=y

Wendt, A. A. (2007). Watershed planning in central Iowa: An integrated assessment of the Squaw Creek Watershed for prioritization of conservation practice establishment. *ProQuest Dissertations and Theses*, 94. http://sfx.scholarsportal.info/guelph/docview/304855404?accountid=11233%255Cnhttp://sfx.scholarsportal.info/guelph?url_ver=Z39.88-2004&rft_val_fmt=info:ofi/fmt:kev:mtx:dissertation&genre=dissertations+%2526+theses&sid=ProQ:ProQuest+Dissertations+%2526+Theses+A%25

Wilson, C. G., Kuhnte, R. A., Bosch, D. D., Steiner, J. L., Starks, P. J., Tomer, M. D., & Wilson, G. V. (2008). Quantifying relative contributions from sediment sources in Conservation Effects Assessment Project watersheds. *Journal of Soil and Water Conservation*, *63*(6), 523–532. https://doi.org/10.2489/jswc.63.6.523

Yochum, S. E., & Reynolds, L. V. (2020). *Guidance for Stream Restoration*. *September*.

Zeybek, M., Kalyoncu, H., Karakaş, B., & Özgül, S. (2014). The use of BMWP and ASPT indices for evaluation of water quality according to macroinvertebrates in Değirmendere Stream (Isparta, Turkey). *Turkish Journal of Zoology*, *38*(5), 603–613. https://doi.org/10.3906/zoo-1310-9