Case study in erosion control at Mcconnell Air Force Base: redcedar streambank revetments, macroinvertebrates bio assessment, and runoff estimation

by

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Abstract

Water bodies are crucial ecosystems, they facilitate natural processes that create favorable conditions for biodiversity. This study aims to monitor and document the overall health condition of the watershed at McConnell Air Force Base in Wichita, Kansas, and assess the effectiveness of implementing redcedar revetments on the streambank to mitigate accelerated streambank erosion. The impact of the revetments was evaluated by measuring erosion and deposition rates periodically through rebar pins, conducting a bioassessment using macroinvertebrates, and the impact of impervious surfaces have on the creek with a runoff estimation. To measure erosion and deposition rates, vertical transects containing pieces of rebar were inserted into the eroding bank, with exposed rebar length or burial depth indicating the extent of erosion or deposition. Macroinvertebrate populations were sampled as they are indicators of water quality, habitat quality, and diversity. Various indices were calculated to estimate water quality, species richness, and biodiversity. The runoff estimation was conducted to document high percentages of impervious surfaces which can affect the infiltration and discharge of the nearby stream, and which conservation practices can mitigate. This research compared the results of two revetments previously monitored in a study by Molina (2021) and two recently added for this case study. Redcedar revetments effectively reduced erosion rates and captured sedimentation, enhancing streambank stability over time. Macroinvertebrate sampling reveals improved habitat quality, with revetments supporting increased species diversity. Visual evidence highlights vegetated areas and wildlife presence while implementing practices like rain gardens can further mitigate erosion and pollution from runoff.

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Chapter 1 - Introduction

Water bodies are certainly one of the most important attributes of an ecosystem; they represent a crucial point for developing natural processes that generate suitable conditions for different types of biodiversity (Ogoyi, 2022). Among the many benefits that water bodies can bring, they can affect directly and indirectly human activities in general providing services that can determine people's health.

Rivers are truly one of the most important water suppliers between water bodies in general, even though they just represent approximately 0.2 percent of fresh water on planet Earth, they directly bring nutrients, organisms, wildlife, gases, and of course, water, to communities across the world, (New Hampshire PBS, 2022).

Without consistent access to healthy rivers and watersheds, generations of people struggle to meet their basic needs and become trapped in poverty. But when river banks and wetlands are rehabilitated, a true transformation occurs. Rivers thrive, farmers have more area to farm, and fish species revive and diversify. (Sullivan, 2018)

The land cover and usage near a particular river can determine its quality, and urban and agricultural land can modify the natural state of the water body, these impacts can be documented by having a reference reach of pre-development conditions of the watershed (Water Resources Mission Area, 2019).

Sedimentation and erosion processes are key mechanisms through which pollutants can enter streams and pose significant challenges to water quality. Erosion refers to the wearing away and displacement of soil and rock materials by natural forces, such as wind and water according to the United States Environmental Protection Agency (EPA, 2019). When soil erosion occurs, sediments containing various pollutants, including heavy metals, pesticides, and nutrients, can be transported by runoff into nearby streams and water bodies (EPA, 2019). Sedimentation, on the other hand, involves the deposition of these eroded materials in streams, which can have detrimental effects on aquatic ecosystems and the quality of water resources (Fletcher et al., 2021). Studies have shown that sedimentation can contribute to elevated levels of suspended solids, increased turbidity, and the accumulation of pollutants, ultimately impacting the health of aquatic organisms and the overall ecological balance of stream ecosystems (Fletcher et al., 2015).

The connection between sedimentation, erosion, and pollutant transport in streams highlights the need for effective sediment and erosion control measures to safeguard water quality. Implementing erosion control practices in the watershed, such as the use of vegetative cover, and contour plowing, and terracing, can help minimize soil erosion by reducing the velocity of runoff and promoting sediment retention (EPA, 2019). Similarly, adopting proper land management practices, including the establishment of buffer zones and conservation tillage, can help mitigate the impacts of sedimentation and reduce the transport of pollutants into streams (Fletcher et al., 2019). Furthermore, strategies such as the implementation of sediment basins, sediment traps, and sediment ponds can be employed to capture and retain sediments before they reach sensitive water bodies, thereby reducing the potential for pollution (EPA, 2019). By focusing on sediment and erosion control measures, we can protect stream ecosystems and ensure the availability of clean water resources for both human and environmental well-being.

Streambank revetments are structures designed to stabilize and protect streambanks from erosion. Revetments are typically constructed using various materials such as riprap (i.e., large stones or rocks), gabions (i.e., wire mesh containers filled with stones), or concrete mats (U.S. Army Corps of Engineers, 2012). These structures are placed along the streambanks to provide support, reduce erosion, and protect against the erosive forces of flowing water (U.S. Army Corps of Engineers, 2012). By preventing the undermining and collapsing of streambanks, revetments help maintain the integrity of the stream channel, protect adjacent infrastructure, and preserve the stability of surrounding ecosystems. Additionally, revetments can contribute to the enhancement of habitat diversity by creating varied bank slopes and providing sheltered areas for aquatic organisms (U.S. Army Corps of Engineers, 2012). Streambank revetments serve as important tools in stream restoration and management, helping to mitigate the adverse impacts of erosion and maintain the ecological health of stream systems.

Streambank erosion is a natural process that plays an important role in shaping river ecosystems by depositing sediment and coarse material, which contribute to the formation of channel beds and riverbanks, enhancing habitat diversity for various species, including macroinvertebrates. (Florsheim, Mount, and Chin, 2008) However, anthropic activities often accelerate erosion rates, posing significant environmental concerns. Revetments serve as vital mitigation measures to counteract accelerated erosion caused by human intervention. Eastern redcedar trees (*Juniperus virginiana (L.)*) offer several qualities that make them potentially suitable for streambank revetments. These trees possess dense and durable wood, which can provide structural strength and stability when used in revetment construction (Dorsey, 2008). Redcedar wood has a natural resistance to decay and insect damage, making it long-lasting in moist environments such as streambanks (Dorsey, 2008). Furthermore, redcedar trees have a spreading growth habit with intertwining branches, dense foliage and fine twigs which can contribute to their ability to trap sediments and provide protection against streambank erosion even during high flow events (Klein, 2019).

Macroinvertebrate sampling and biotic indices serve as valuable tools in assessing water quality and the ecological health of aquatic ecosystems. Macroinvertebrates are organisms such as insects, crustaceans, mollusks, and worms that live in streams and rivers. These organisms are sensitive to changes in water quality and habitat conditions, making them excellent indicators of overall ecosystem health (Barbour et al., 1999). By collecting macroinvertebrate samples from a water body and analyzing their composition and abundance, scientists and researchers can gain insights into the water quality and potential impacts of pollution. Biotic indices, such as the Macroinvertebrate Biological Index (MBI) and the Biological Monitoring Working Party (BMWP) index, are derived from the analysis of macroinvertebrate data and provide a quantitative assessment of water quality (Barbour et al., 1999). These indices assign scores or rankings to different taxa based on their tolerance or sensitivity to pollution, enabling the classification of water bodies into different quality categories. In addition to biotic indices, diversity indices such as the Shannon and Simpson indices are used to complement the assessment of water quality. These indices evaluate the species diversity and evenness within a sample, providing additional information about the ecological condition and stability of the ecosystem (Barbour et al., 1999). Overall, the use of macroinvertebrate samples and biotic indices, along with diversity indices, offers a comprehensive approach for assessing water quality and monitoring the ecological integrity of aquatic systems.

Redcedar revetments, erosion control measures, and macroinvertebrate sampling are integral components of a comprehensive approach to enhance stream quality. Redcedar revetments provide structural stability and resistance against streambank erosion, reducing sediment and pollutant inputs into the stream (Dorsey, 2008). Erosion control measures, including vegetative cover, contour plowing, and sediment traps, mitigate soil erosion and minimize the transport of pollutants, thereby preserving water quality and stream ecosystem integrity (EPA, 2019).

Macroinvertebrate sampling, combined with the use of biotic indices, enables the assessment of water quality and the monitoring of ecological health by evaluating the composition and abundance of sensitive organisms (Barbour et al., 1999). Together, these approaches contribute to improved stream quality by reducing sedimentation, controlling erosion, and providing insights into the ecological condition of the stream. By implementing redcedar revetments, incorporating erosion control practices, and conducting macroinvertebrate sampling, stream restoration efforts can effectively address the challenges of sedimentation, erosion, and water quality, ultimately leading to healthier and more resilient stream ecosystems

Knowing the hydrological soil group can provide valuable insights into the, soil HSG is perhaps even more pertinent to watershed hydrology. The hydrological soil group classification categorizes soils based on their infiltration rates and drainage characteristics (Ross et al., 2018). Soils with higher infiltration rates, such as Group A, are typically well-drained and less prone to erosion, while soils with poor drainage, such as Group D, are more susceptible to erosion and instability (Ross et al., 2018). By identifying the hydrological soil group of the streambank area, restoration practitioners can better understand the soil's water-holding capacity, permeability, and susceptibility to saturation during precipitation events. This knowledge is valuable for selecting appropriate streambank stabilization methods, designing erosion control measures, and promoting effective and sustainable streambank management. These soil data also provide critical information for estimating runoff rates and volumes that are likely to flow to the channel during rainfall events.

Through runoff estimation, it's possible to have a better understanding of the situation at McConnell Creek and how the amount of runoff entering the creek can impact it, determining what actions have to be taken to improve the state of the water body exiting the AFB. Runoff estimation is a critical aspect of watershed management and planning, and it plays a vital role in protecting public health and safety, preserving the environment, and promoting sustainable development.

Purpose of case study

This study, funded by the U.S. Fish and Wildlife Service, aimed to comprehensively monitor and document the overall stream health and condition while assessing the effectiveness of redcedar revetments along McConnell Creek, situated on the McConnell Air Force Base (AFB) in Wichita, KS. The primary objective was to evaluate the impact of the redcedar revetments on streambank stability and erosion control. To achieve this, several key factors were assessed, including erosion/deposition rates, macroinvertebrate analysis, and a GIS assessment to determine the extent of impervious surfaces and estimate runoff volume. By integrating these diverse monitoring techniques, the study sought to provide a holistic understanding of the ecological response and effectiveness of the redcedar revetments in preserving streambank integrity and enhancing the overall ecological health of McConnell Creek. The findings from this research could enhance future stream restoration and management projects, particularly in terms of mitigation practices. The number of published researches based in this practice is still low, the present study aims to bridge this gap by addressing the need for comprehensive research in this area.

Chapter 2 - Materials and Methods

Description of the site

At McConnell Air Force Base (AFB), Wichita, KS, McConnell Creek originates just off the base and is part of the drainage area within the Arkansas River Watershed with a drainage area of 3,782 acres (Figure 3.1). The creek crosses by an emergency crash site in the southern area of the AFB. The area is only used in situations when aircraft cannot land by any circumstance in the original landing strip. For that reason, this area does not have any type of buildings or structure and is frequently mowed to clear the area from any potential obstacle that can interfere with an emergency landing. The creek is surrounded by grassland with a top soil of mainly "Elandco silt loam" (Web Soil Survey, 2024) that indicates a soil with a significant proportion of silt, a moderate amount of clay, and possibly some sand, with a moderate infiltration rate, and the banks height mainly from 2.5m to 4 m. The Air Force Base directly impacts the nearby stream, leading to runoff events that channel into the creek due to the urbanized nature of the base and the presence of impervious surfaces. Consequently, the volume of water that reaches McConnell Creek is significantly affected by these factors.

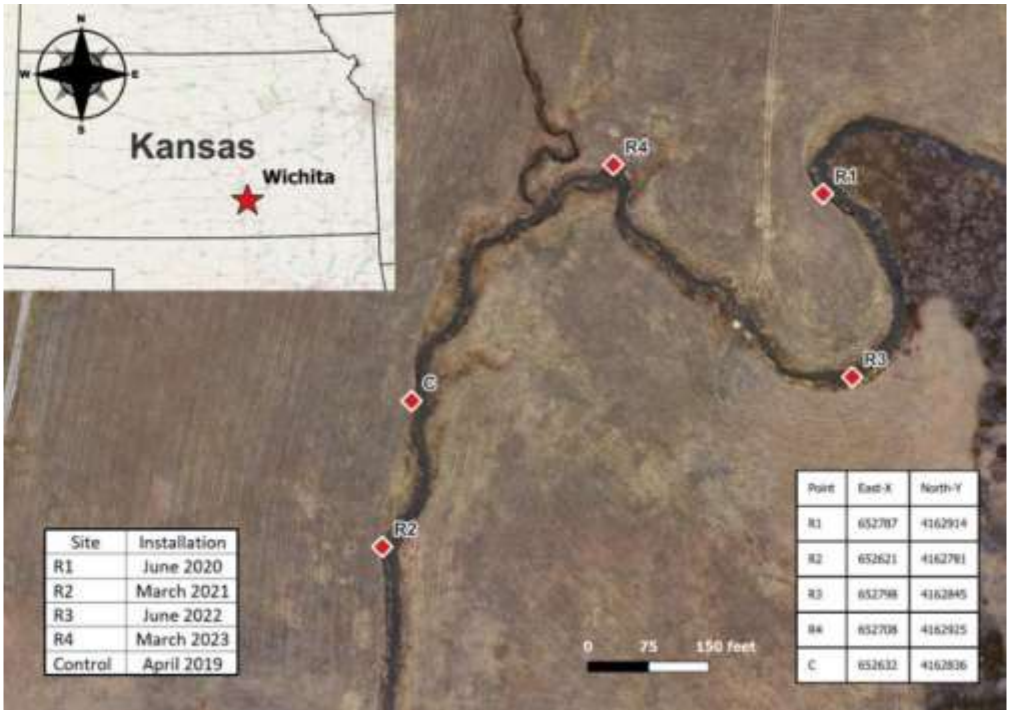

Figure 2.1 Study area at McConnell Air Force Base.

McConnell Creek had four redcedar revetments installed and a control site (C), the first (R1) was installed in June 2020, the second (R2) in March 2021, the third (R3) one on June 2022 and the fourth one (R4) in March 2023. All the revetments were located in the emergency crash landing area of the Air Force Base (Figure 2.1). They covered around 82 meters (R1: 24.46 m, R2: 18.76m, R3: 25.50 m, R4:12.90m) of the cutbank with 9-15 trees per revetment Figure. The number of trees was based on the size of trees available nearby and the length of the area to cover in the streambank. The installation process for each revetment took one to two work days with a team of 4-7 people and the sites were selected based in the meanders that had most severe erosion at the date of installation.

Redcedar Revetments

In the stream restoration project, cut redcedar trees were strategically anchored along the streambank area at four different sites as streambank revetments. This innovative approach involved anchoring the cut redcedar trees by securing the tip, base, and center of each tree. The process commenced by anchoring the tip of the first redcedar tree using duckbill anchors and insert them into the soil with a jackhammer, followed by anchoring its base in the same way. Subsequently, from the center of the first redcedar tree, the base of another redcedar tree was anchored. Figure 2.2 shows the installation of revetment 3 (R3), and R3 installed in the last picture.

Figure 2.2 Visual example of the installation of R3 anchoring redcedar trees using duckbill anchors and insertion to the soil with a gas jackhammer.

This sequential process was repeated until the entire streambank area of the designated sites, labeled as R1, R2, R3, and R4, the most unstable areas with pronounced erosion at the meanders were covered with redcedar revetments. Within the same creek segment where all of the revetments have been placed, the control location was selected based in the sinuosity of the meander, within the same creek, the control was established to compare how a bank without a pronounced curve can have bigger rates of erosion even if their counter parts have a more sinuous meander as long as they are protected by a revetment.

The implementation of cut redcedar tree revetments as described has shown promise in stream restoration and stabilization efforts. Redcedar trees possess durable and rot-resistant wood (Dorsey, 2008), making them well-suited for streambank revetments. Additionally, their extensive and fibrous branch systems aid in stabilizing the soil and reducing erosion by effectively anchoring the revetments (Benitez, 2019). Redcedar revetments have demonstrated the ability to mitigate streambank erosion, minimize sediment input, and protect against the erosive forces and capture sediment in high flowing water events (U.S. Army Corps of Engineers, 2012). Furthermore, redcedar trees can provide additional ecological benefits by creating varied bank slopes and sheltered areas for aquatic organisms (U.S. Army Corps of Engineers, 2012).

The innovative process of anchoring cut redcedar trees as streambank revetments, as described above, offers a promising and environmentally friendly approach to stream restoration. By utilizing the inherent characteristics of redcedar trees, such as their durable wood and robust branch and twigs systems, this method aims to improve streambank stability, minimize erosion, capture sedimentation and enhance the overall ecological health of the stream.

Figure 2.3 represent an aerial and transverse point of view of an installed redcedar revetments. The revetment must be installed in the streambank toe, the earth anchors inserted in the soil have an average depth of 3 feet, the chain of trees faces their base against the water current and it have to cover all the unstable area, where erosion occurs in the meanders.

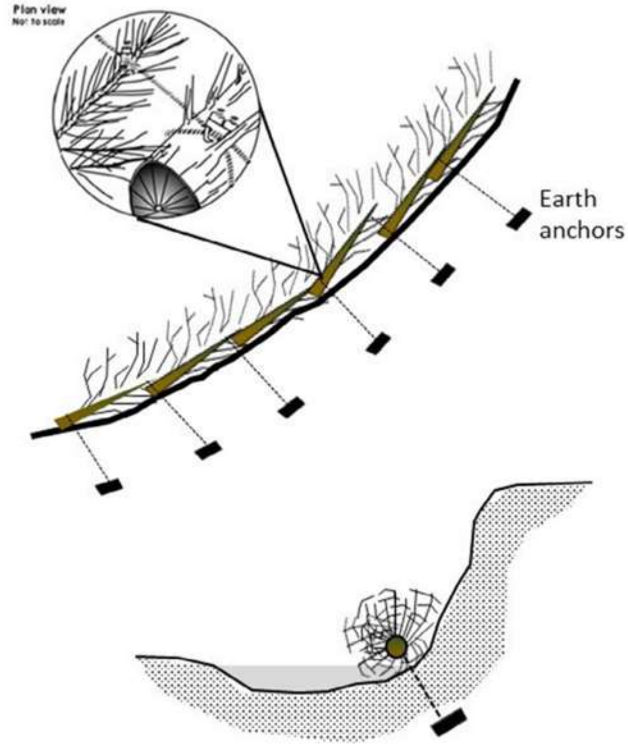

Figure 2.3 Modified illustration of a redcedar revetment.
(Shelley, Haring, and Chrisman, 2022)

Depending on the exposed area, the revetment varies for each site, Figure 2.4 highlights in different colors all revetment sites and their respective length, R3 was the site with the most length of bare soil due to erosion, so it is the one that covers more area with the revetment. Figure 2.4 also shows how the sites measure in height due to their different morphology, being R3 the one with the biggest height as well. The control doesn't count with a revetment because its function is to act as a buffer, however, its height of 3.5 m due to the importance that having bank height for evaluating bank stability, and understanding channel morphology.

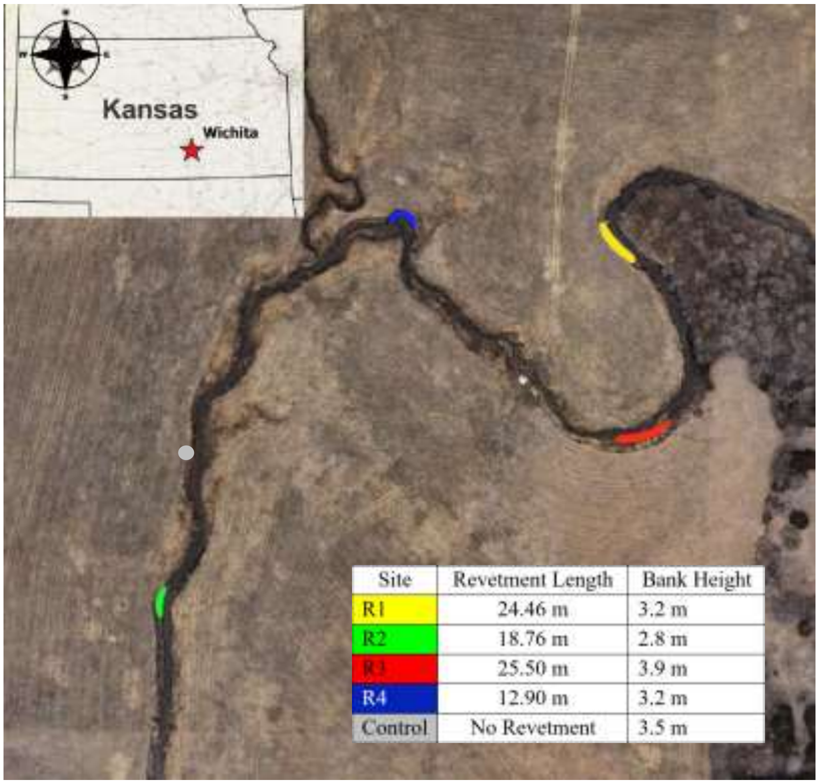

Figure 2.4 Map of the study sites with the length of the revetment and the bank height.

To assess the effectiveness of the redcedar revetments in stabilizing the streambank and reducing erosion, a monitoring method utilizing rebar pins was implemented across all sites, including R1, R2, R3, and R4. These rebar pins, pounded into the streambank area using a hammer as how is shown in Figure 2.5, served as erosion measurement markers, providing valuable insights into erosion dynamics over time (Jugie et al., 2018). During periodic site visits, the exposed length of the rebar pins above the ground surface was meticulously measured using a ruler. This quantitative measurement not only offered a clear indication of the amount of erosion that had occurred since the previous visit but also enabled a comparative analysis between the sites with redcedar revetments and the control site (DeFrancesco and Hansen, 2000). It's important to mention that sandbar willows (*Salix exigua* (Nutt.)) a deciduous shrub or small tree known for its slender, flexible branches, were planted in the experiment points except the control site, to boost vegetation growth in the desired area, this choice was made for revegetating the stream banks because of their resilience to flooding, and capacity to stabilize soils, and ability to grow swiftly in saturated conditions. (Miller-Adamany, Gerber, and Thomsen, 2017)

Figure 2.5 Rebar pins installed in the streambank revetment sites.

The use of rebar pins as erosion measurement markers is a widely recognized and reliable approach in streambank erosion studies (Ramirez et al., 2010). They were installed in transects of three to five depending on the height of the streambank, by monitoring the exposed length of the rebar pins, changes in erosion rates and patterns can be precisely quantified, providing essential data on the effectiveness of the redcedar revetments in mitigating erosion (Greenway et al., 2012).

The installation of rebar pins allows for a consistent and repeatable assessment, ensuring accurate comparisons and reliable evaluation of the streambank stabilization measures implemented at the study sites (Streambank and Shoreline Protection Manual, 2002). Furthermore, this monitoring method facilitates the identification of potential erosion hotspots and informs decision-making processes regarding further erosion control strategies (Greenway and Colwell, 2012)

For having a better perspective of the efficiency of the revetment as a method for capturing sediment a specific measurement was made in R1, that is the site with the most longevity. Initially, width and length of new sediment were measured using a metric tape to measure all the area covered by new deposition captured by the revetment, while the depth of the sediment was determined using a large ruler.

Given the varied units of sediment capture (feet for length and inches for width and depth), all measurements were converted to inches for uniformity in calculation. For measuring depth of the sediment accumulation, an insertion of the ruler into the central area of the revetment sediment zone was made until reaching roots in the soil.

Volume was calculated using the formula: Volume = Length * Width * Depth. To convert the final volume from cubic inches to cubic meters, the conversion factor of 1 cubic meter = 61023.7 cubic inches was applied.

The measurements were conducted in R1, targeting visually high levels of sedimentation. The results from these measurements were summed assess sediment accumulation in R1.

By incorporating the monitoring method utilizing rebar pins, this study aims to enhance the understanding of erosion dynamics along the streambank and provide valuable insights into the effectiveness of the redcedar revetments as a sustainable and ecologically friendly streambank stabilization measure.

Macroinvertebrate Sample

To evaluate water quality, a comprehensive macroinvertebrate sampling was conducted at all sites, including R1, R2, R3, R4, and the control site, following the procedures outlined in the Volunteer Stream Monitoring Training Manual (Hoosier Riverwatch, 2015). The collection of macroinvertebrate samples involved using nets to sample both the pool and cut bank areas of the stream for a duration of 15 minutes.

The collected macroinvertebrates were carefully transferred into water bottles filled with a solution comprising 50% water and 50% alcohol, ensuring their preservation for subsequent analysis in a laboratory setting (Hoosier Riverwatch, 2015). In the lab, the macroinvertebrates were examined to the Order to Family level using a stereoscope, with guidance from the Bioindicators of Water Quality Quick-Reference Guide by Purdue University (Speelman and Carrol, 2012). The process is summarized in Figure 2.6, where it shows the critter collection and their identification.

Figure 2.6 Macroinvertebrate sampling and identification.

The utilization of macroinvertebrate samples and the application of biotic indices offer a robust approach to assess water quality and monitor the ecological health of streams. Macroinvertebrates serve as valuable bioindicators, reflecting the impacts of pollution and habitat degradation on stream ecosystems (Barbour et al., 1999).

By analyzing the composition and abundance of macroinvertebrate communities, it is possible to determine the overall health of the stream and identify potential water quality issues (Barbour et al., 1999). The use of biotic indices, such as the Index of Biotic Integrity (IBI) or the Biological Monitoring Working Party (BMWP) score, further enhances the assessment process by providing a quantifiable measure of water quality based on macroinvertebrate community composition and tolerance to pollution (Speelman and Carrol, 2012).

These indices allow for the comparison of water quality among different sites and provide a standardized approach for evaluating the ecological condition of the stream (Speelman and Carrol, 2012).

Biotic Index

By following the macroinvertebrate sampling procedure outlined in the Volunteer Stream Monitoring Training Manual (Hoosier Riverwatch, 2015) and utilizing the Bioindicators of Water Quality Quick-Reference Guide by Purdue University (Speelman and Carrol, 2012), this study aims to evaluate water quality across different years in the study sites, providing valuable insights into the ecological health of the streams and the effectiveness of the stream restoration efforts through a Biotic index. This method assigns a tolerance score to macroinvertebrates from which the biotic index is calculated (Table 2.1).

Table 2.1 Biotic index water quality rating (Speelman and 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
7.26-10.0	Very Poor		Severe organic pollution likely

The Biotic Index is shown by executing the formula:

$$\sum = \left(\frac{Number\ of\ individuals\ of\ each\ species \times Pollution\ sensitivity\ score}{Total\ number\ of\ individuals}\right)$$

(2.1)

The data sampled was computed through Microsoft Excel, an example of the orders and families present in the different data points are shown in Table 2.2, showing how different families differ in pollution tolerances, even if they belong to the same order they do not share the same conditions.

Aquatic macroinvertebrates can endure various environmental conditions like aquatic ecosystems, influenced by biological and chemical factors, pose challenges for certain macroinvertebrates. These factors, including oxygen levels, water temperature, sediment, nutrients, and chemical contaminants, determine their habitat suitability. (Resh et al., 1996).

Macroinvertebrates exhibit a range of tolerance levels, typically rated from zero to ten, indicating their resistance to pollution and oxygen depletion. Species with low tolerance serve as indicators, as their survival rates reflect environmental conditions, potentially signaling pollution or low oxygen levels. (Dharan et al., 2010)

For this study, the tolerance values provided are only the ones that belongs to the macroinvertebrates found within the sampling points R1, R2, R3, R4 and the control site, other possible benthic macroinvertebrates, so it doesn’t represent the biodiversity of all the creek, just the one of the case studies.

The orders identified in this study were Mayflies, Caddisflies, Coleoptera, Diptera, Odonata, and Hemiptera, within those orders, just the families that posses a confirmed tolerance score was included for the calculation of the Biotic Index.

Table 2.2 Order Totals in R1 for determining the Biotic Index.

Order	Family	Tolerance Value
Mayflies	Prong-gilled Mayfly	2
	Small Square-gill Mayfly	7
	Small Minnow Mayfly	4
Caddisflies	Micro Caddisfly	4
Coleoptera	Whirligig Beetle (larvae)	4
	Water scavenger Beetle (Adult)	5
	Long-toed Water Beetle	5
	Water Scavenger Beetle (larvae)	5
	Riffle Beetle (Adult)	5
	Predaceous Diving Beetle (Adult)	5
	Crawling water beetle (adult)	7
Diptera	Non-biting Midge (red forms)	8
	Non-biting Midge (pale forms)	6
	Biting Midge	4
	Moth fly	10
	Marsh fly	6
	Aquatic dance fly	6
	Phantom midge	8
Odonata	Narrow winged damselfly	9
	Darner	3
	Common Skimmer	7
	Broad winged damselfly	5
Hemiptera	Broad-shouldered water strider	6
	Water Scorpion	8
	Water Boatman	9

Based on the specimens found within the study areas at the creek, tolerance values can vary from 10 to 2 depending of the critter family, with those values is possible to determine the family tolerance score by multiplying the number of a given family critter found times the tolerance value as how is shown in Table 2.3 , for this example, only data from the Mayfly order in R1 is shown for explaining the process to obtain the a Biotic index.

Table 2.3 Family tolerance scores for the Mayfly order in R1.

Mayflies			
Family	Tolerance value	Number Found	Family Tolerance Score
Prong-gilled Mayfly	2	0	0
Small Square-gill Mayfly	7	65	455
Small Minnow Mayfly	4	0	0
	Order Total	65	455

With the order total of all the orders, its possible to calculate the Biotic Index following the formula provided in Equation (2.1), a detailed example is shown in Table 2.4, where all the Order Totals are already presented for the ease of the example and it shows how the grand total of individuals found divided by the grand total of Order Tolerance can be computed in (2.1) to provide the Biotic Index of 7.5.

Table 2.4 Order Totals in R1 for determining the Biotic Index.

Order Total	Number Found	Order Tolerance
Mayflies	65	455
Caddisflies	0	0
Coleoptera	0	0
Diptera	2	12
Odonata	2	5
Hemiptera	36	324
Grand Total	105	796
	Biotic Index	7.5

Shannon-Wiener Index and Simpson Diversity Index

The Shannon-Wiener Index and Simpson Diversity Index are both commonly used measures of biodiversity. Having both indices in research allows for a deeper understanding of biodiversity richness and distribution. For this investigation, the following formulas for the indexes were executed through the programing software R.

Shannon-Wiener: $H = -\sum_{i=1}^{S} p_i \ln(p_i)$

(2.2)

S is the number of species

pi is the proportion of individuals belonging to the ith species

Simpson: $D = 1 - \sum_{i}^{S} p_i^2$

(2.3)

S is the total number of species

pi is the proportion of individuals belonging to the ith species

Having both indices in research allows a complete understanding of biodiversity within a community. According to Gotelli and Colwell (2011), methods for estimating species richness are discussed in the context of biological diversity assessment. The Shannon-Wiener Index show the overall species richness and evenness, while the Simpson Diversity Index focuses on dominance and the impact of abundant species. By using both indices together, it's possible to assess the complexity and health of ecosystems such as streams or similar water bodies.

Runoff Estimation

Data from the National Weather Service revealed that Wichita, KS experiences an average annual precipitation of approximately 30.53 inches (77.54 cm). Information retrieved from the Web Soil Survey website provided an overview of the diverse soil types within the expansive 3782-acre drainage area, categorizing them based on their hydrological soil group.

These groups, ranging from D (representing the worst drainage) to A (indicating the best drainage), play an important role in understanding the soil's water infiltration and drainage capacities. Figure 2.4 shows different infiltration rates within the boundaries of the base, those are the rates classified into levels from A to D sequentially, those levels are presented in the results section later in Table 3.3.

In Figure 2.7, the green line represents the boundaries of the Air Force Base, and the orange lines represent the different groups present in the area of interest (AOI), the numbers in orange are different codes that represent a unique map unit symbol, as how it was mentioned before, are the different unit symbols determine the Hydrological Soil Group ratings, for example 3911 is equal to D and 6052 represents B.

Figure 2.7 Image of the Air Force Base showing different infiltration rates, retrieved from WebSoilSurvey website.

The hydrological soil group data, combined with the average slope and flow length acquired from the Web Soil Survey, were integrated into the runoff estimation spreadsheet from the NRCS. This spreadsheet uses the Curve Number (CN) method to determine runoff volume and use the variables presented in Equation 2.4:

$$S = \frac{1000}{CN} - 10$$

(2.4)

S Max Soil Water Retention/Storage, inch

CN Curve Number from NRCS

Factors like the curve number (CN) and precipitation, allow for accurate runoff estimation and offer a valuable understanding of the extent of runoff within the study area. The study aimed to gain a comprehensive understanding of the hydrological dynamics, drainage patterns, and potential runoff in the drainage basin, thereby contributing to effective and informed stream management and conservation strategies.

Chapter 3 - Results and Discussion

Erosion/Deposition

The following data show erosion and deposition rates gathered in the previous research conducted by Molina (2021), values taken since April 2019 before the installation of the revetments, and the values gathered at the end of his program in September 2021, those rates were compared with the data compiled for the current research. R1 and R2 were the revetments with more observations, since they were installed at the beginning of the project so they were analyzed separately at first and compared with records from recent data in Figure 3.1 and Figure 3.2.

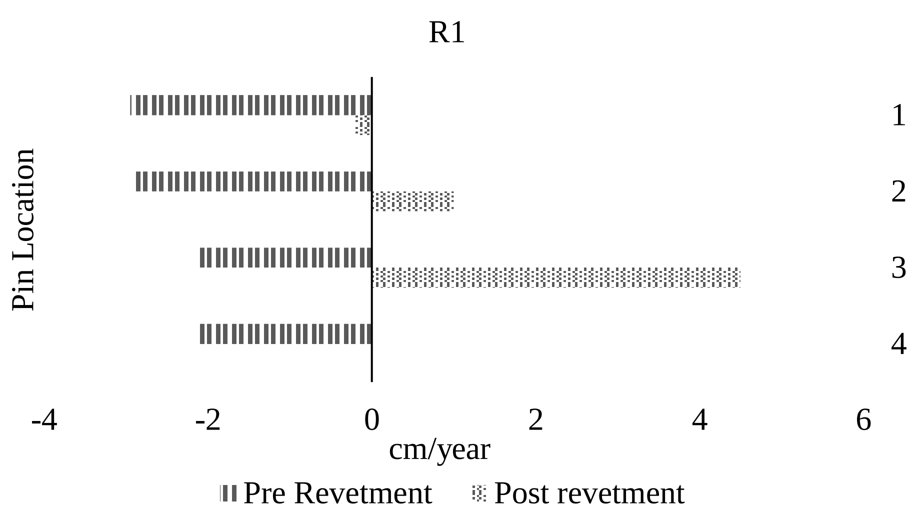

Figure 3.1 Average Streambank erosion estimates from rebars at McConnell Creek R1 from April 2019- November 2023

Figure 3.1 shows a comparison between the data gathered since 2019 from Molina (2021) previously to the installation of the erosion pins as “Pre-Revetment” and the averaged data from his results and the most recent data of this research in 2023 as “Post Revetment”. Negative values represent erosion rates, and positive values represent deposition or sedimentation captured by the revetment. The pin location is based on the placement of the rebars along the streambank studied, where pin one is the highest possible measurement point in the streambank and pin four is the lowest point. Compared with the pre-revetment graphs, the monitored data post revetment shows a great decrease in erosion, even capturing sediments in the cases of pin 2 and 3, with pin 3 showing a high quantity of 4.5 cm of deposition captured. Pin 4 was mainly buried during all the sampling dates so there is no exact record but comparing it with the data from higher pins in the streambank, the deposition captured is likely higher than 10 cm based in how deep the pin was. These results can be compared with ones reported by Molina (2021) which shows how the revetments installed in McConnell Creek had successfully trapped sediments and stabilized the bank by reducing erosion over the previous years.

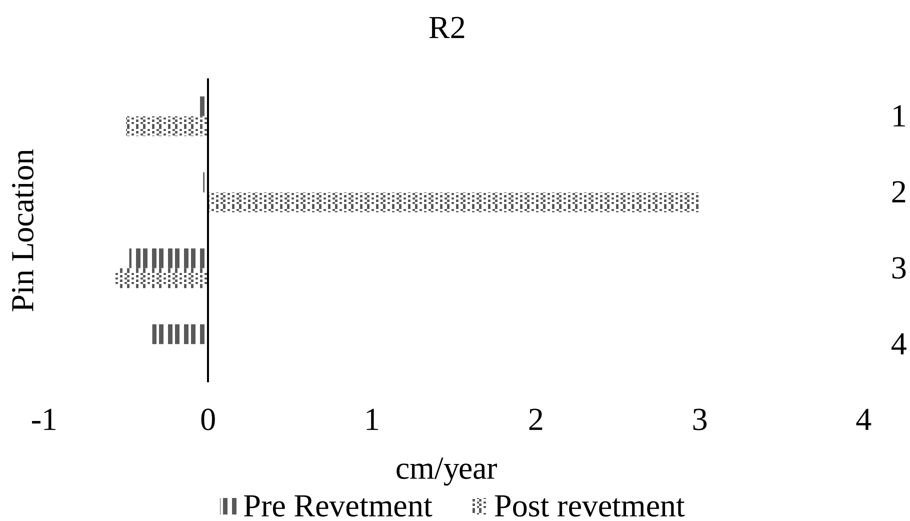

Figure 3.2 Average Streambank erosion estimates from rebars at McConnell Creek R2 through the recent investigations.

Figure 3.2 shown the comparison between pre and post-revetment in revetment 2 (R2), the highest point in the streambank indicated erosion was higher after the installation while the second pin show high rates of sediment capture, it's possible that the deposition of the first pin is being captured in the second pin or different water fluctuations over time eroded the bank at different elevations (Hupp, 2009), a similar case happens with the third and fourth pin where in the third one have slightly higher erosion rates than before installation but in the fourth, the pin was completely buried and covered with vegetation.

The following figures will show the data of each revetment over the previous and current research to show the streambank erosion and deposition rates over the years, from 2021 results of Molina (2021) to the last sampling in this research in November of 2023.

The main results in Figure 3.3 are that over the years there was a decrease in erosion rates in all the measured erosion pins, and the last observations between 2022 and 2023 show that sediment has been captured with the largest average recorded of 8.5 cm/year in the third pin.

The fourth pin was always buried since the installation of the redcedar revetments, because it was the lowest point in the streambank, all the sediments were highly accumulated there and among the branches of the redcedars installed, showing new vegetation.

As how it was stated by Bigham (2020) factors such as vegetation, shear strength, and hydraulic forces, can impact directly the state of the streambank. Revetments are a reliable option to protect them and aim to improve streams health, while providing better coverage and boosting vegetation growth.

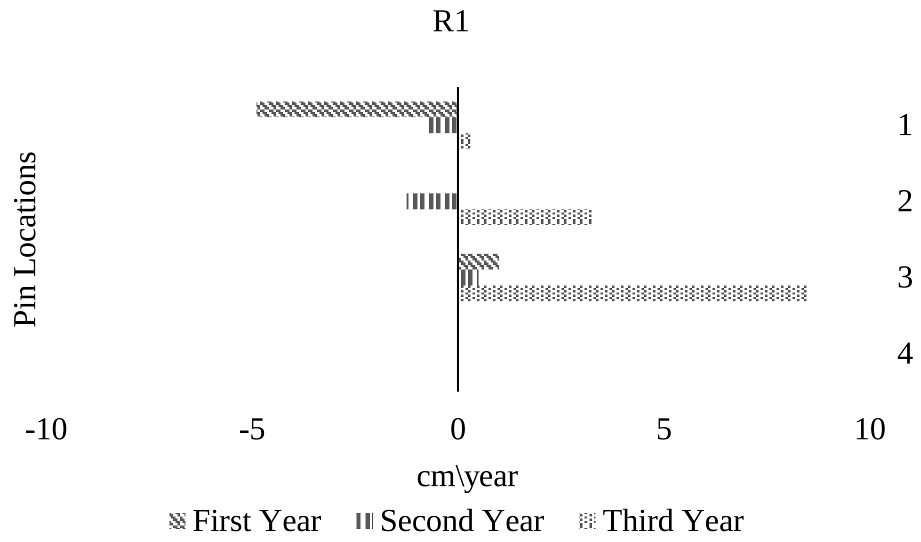

Figure 3.3 Erosion estimates from rebars at McConnell Creek R1

Data gathered in Figure 3.4 from the second revetment indicates great amounts of deposition captured on the second pin area by the third year. All data points show higher amounts of erosion in the second year of research, with a considerable increase in erosion cm in the fourth pin, but all those were compensated over time and decreased in the third year, where even the fourth pin was completely buried in the last sampling dates. This could be the result of a high precipitation event and the different erosion rates at different elevations represent the natural morphology of the streambank composition.

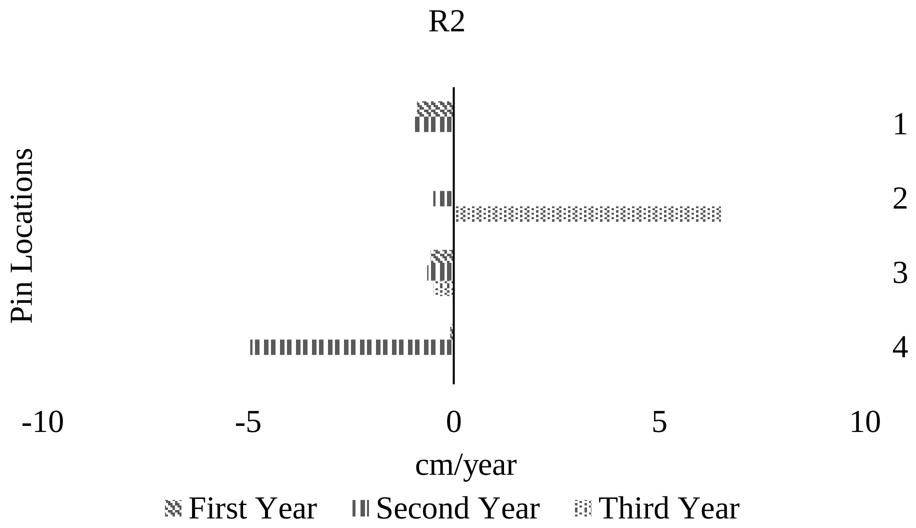

Figure 3.4 Erosion estimates from rebars at McConnell Creek R2.

The third revetment was installed in June of 2022 so Figure 3.5 compares the first and second years of the current project (2022-2023). The first year didn't show changes in the rebar exposed, and all pins did not indicate erosion or sedimentation, but the second year demonstrated that the redcedar revetment helped capture sediments along all the streambank. Due to the streambank morphology, it seems that all deposition of the second pin was retained in the third pin that had the higher rates of deposition captured showing an average value of 3.9 cm per year. The fifth pin was buried during the last sampling of the second year.

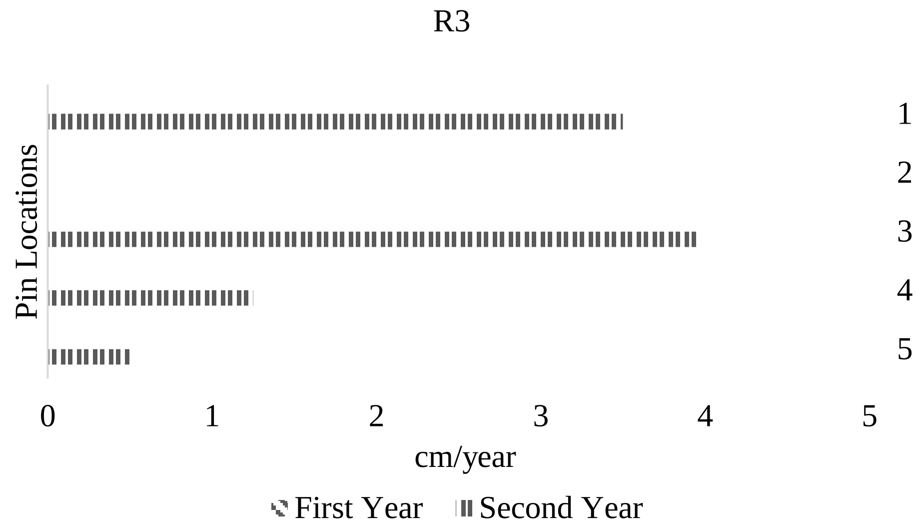

Figure 3.5 Erosion estimates from rebars at McConnell Creek R3.

Revetment 4 was installed in March of 2023, this is the most recent so the data gathered will only show the average rates of less than a year of sampling. The last measurements were collected in November of 2023, at that date, the erosion and deposition rates were the ones in reflected in Figure 3.6. The data show that there was sediment capture in the short term of this measured site, it only had an average erosion of 1.6 in the third pin but all other pins seem to have been capturing sediments, the highest rate is 0.5 cm of sediment captured in the first pin, what not a high quantity but future measurements are expected to confirm the trend.

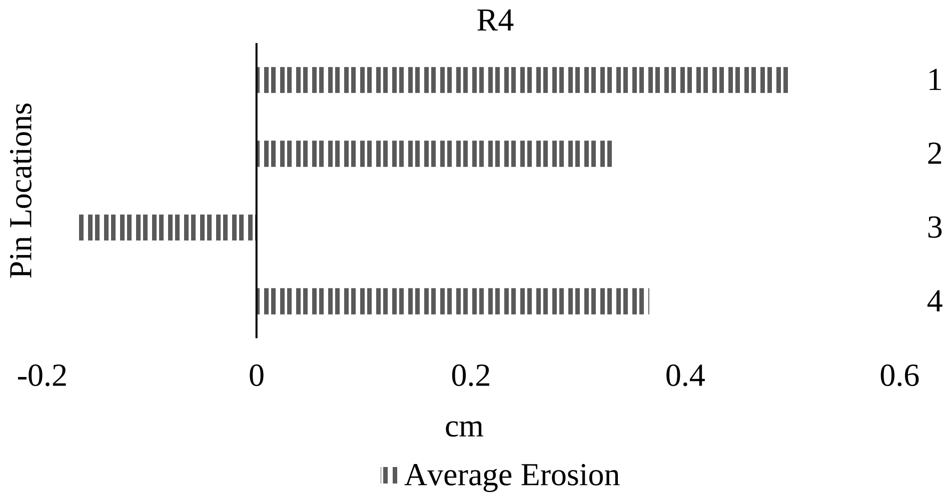

Figure 3.6 Erosion estimates from rebars at McConnell Creek R4 (March-November 2023).

A graphic depiction of the average annual erosion at the control site during the course of the project is shown in Figure 3.7. The data in the figure shows significant rates of erosion, especially in the bottom portion of the streambank. With an average erosion rate of 29 centimeters per year, the third pin site stands out as having a notable erosion rate. Higher quantities of soil exposed result in greater amounts of erosion and sedimentation washed into the stream, this can significantly affect stream health, higher nutrient concentration and reduction of aquatic wildlife habitat (Xenophon, Koch, and Fetter, 2022). Despite the fact that the control site wasn’t a pronounced meander as the rest of the sites, without being covered with any practice to mitigate erosion it was susceptible to higher erosion events than the rest of the sampling points, demonstrating the big difference that redcedar revetments can contribute for bank health.

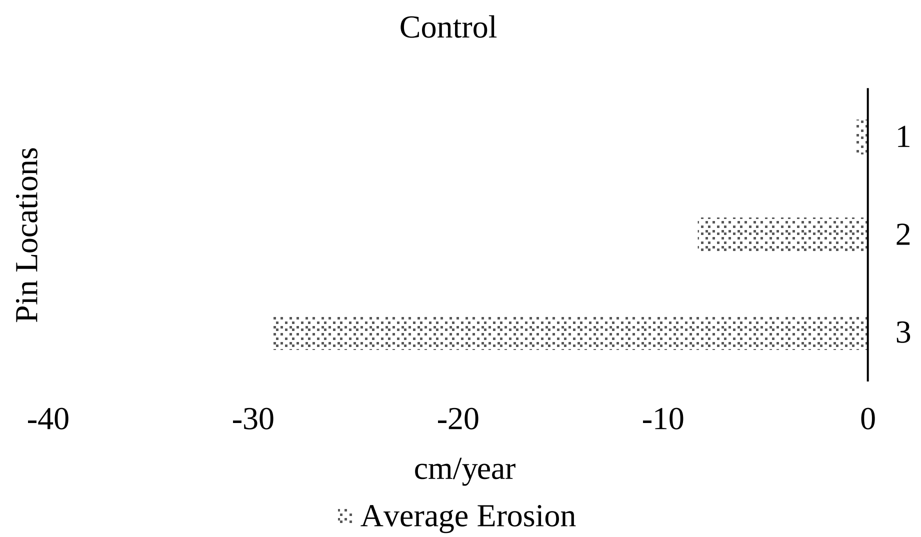

Figure 3.7 Erosion estimates at the control site in McConnell Creek (2022-2023).

The National Oceanic and Atmospheric Administration (NOAA,2024) can provide a clear insight of the precipitation events in Wichita, with Figure 3.7 showing how between May and July there were more incidences of precipitation in general. In the last year of the research during 2023, the highest amount of precipitation was during July and August, that can be correlated with the greater amounts of sediments captured by all the revetments during 2023. During 2022 the months of May and November were the ones with higher average of total precipitation, so the reduction of erosion rates during that year can be a good indicator of the efficacy of the red cedar revetments as a treatment for mitigating erosion.

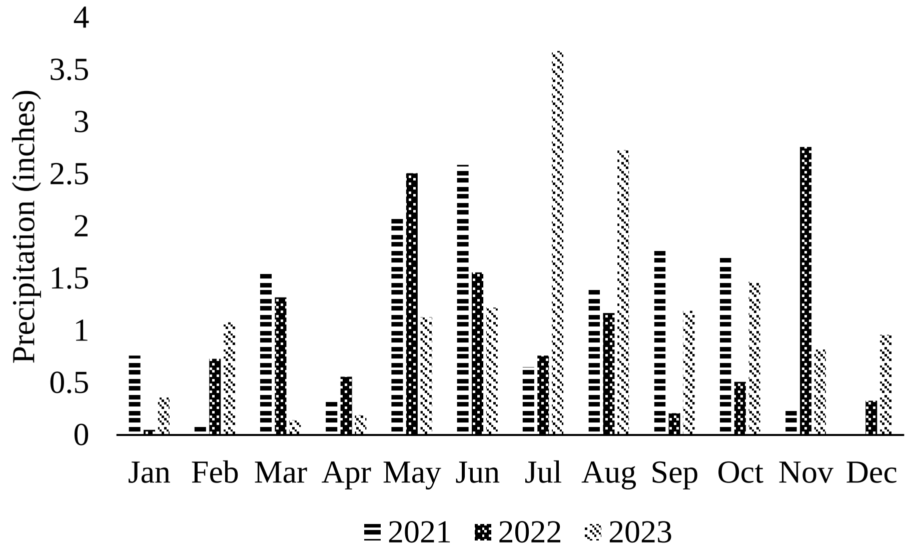

Figure 3.8 Monthly total precipitation 2021-2023 for Wichita, KS. (NOAA, 2024)

Macroinvertebrate Assessment

For comparison purposes, to identify the improvement of the quality of the water and habitat the data from this research is contrasted with the final results of the biotic index, and the two diversity indices (Shannon and Simpson) of the previous research by Molina (2021), this information will be provided through tables of biotic and diversity indices in the revetments situated in McConnell Creek through the recent investigations.

Table 3.1 compares the last data gathered by Jose Molina (2021) and data collected in 2022-2023 in the current research. This compilation only shows results from the first two revetments (R1 and R2) installed due to the longer data history from those points. There is enough evidence of the improvement of the quality of the water with previous values in ranges from 7 to 8 indicating very poor quality and the recent data collected showing values around 5 to 6 that can be interpreted as fair and fairly poor. It shows an improvement in water and habitat quality. Examining biodiversity indexes from present and historical data, notable improvements have been found in the environment under study. A more even distribution of organisms and a decline in species dominance are shown by the increase in the Simpson index, which rose from roughly 0.30 to 0.80. The Shannon index has also increased, going from approximately 0.8 to 2, indicating a substantial boost in species richness and evenness. These modifications imply better habitat conditions. These results demonstrate how installment of cedar tree revetments, improves the habitat quality by providing shade, shelter and acting as filter for pollutants (Bierman, 2021)

Table 3.1 Summary of biotic and diversity indices in the revetments situated in McConnell Creek through the recent investigations.

	2020-21				2022-23			
	R1		R2		R1		R2	
	Pool	Cut Bank	Pool	Cut Bank	Pool	Cut Bank	Pool	Cut Bank
Biotic Index	7	8.15	7.9	7.85	5.11	5.6	6	6.66
Simpson	0.34		0.31		0.82		0.79	
Shannon	0.8		0.76		2.04		1.79	

The last collection made in May 2023 shows the results displayed in Table 3.2, the cut bank area closer to where the redcedar revetments were installed shows better habitat quality than the pool area through the biotic index, with a range from 2 to 3 indicating an excellent to very good level of quality, and in the same way the values of the Simpson and the Shannon indexes are on average higher than the previous samples collected at the same points. The control acts as a reference for comparison, in the case of the cut bank area it shows that it has a better biotic index quality than the rest of the revetment counterparts, that result may be due to the pre-existing vegetation such as shrubs on the cutbank. Sediments washed into streams are one major cause of habitat quality degradation, it does not only reduce suitability for macroinvertebrate communities, but it does for fish and larger organisms as well (Myers, Rediske, and McNair, 2019). Redcedar revetments installed on the streambank area have demonstrated to upgrade the conditions in the cutbank, making it more suitable for lifeforms such as macroinvertebrates.

Table 3.2 Summary of biotic and diversity indices in the revetments and control situated in McConnell Creek in the last sample, May 2023.

	R1		R2		R3		R4		Control	
	Pool	Cut Bank	Pool	Cut Bank	Pool	Cut Bank	Pool	Cut Bank	Pool	Cut Bank
Biotic Index	7.5	3.4	7.2	2.3	7.3	3.6	5.6	2.2	7.3	1.2
Simpson	0.59		0.73		0.80		0.87		0.67	
Shannon	1.15		1.67		2.13		2.27		1.42	

The sites R1 and R2 have enough data to show a clear trend in habitat quality according to the scores provided by the Biotic Index formula, this formula was applied to the pool area, that was shallower and towards the central area of the creek, and also the cutbank area where the redcedars where anchored, the results of trends are displayed in Figure 3.9. There is a flat trend in the pool equivalent to constant state in the habitat quality. The cutbank area biotic index in both revetments were negative, what indicates that the pollution levels have been decreasing, the cutbank have developed vegetation such as shrubs and grass, that suits better conditions for fauna, including macroinvertebrates, to develop a larger population of species that indicates improvements in habitat quality.

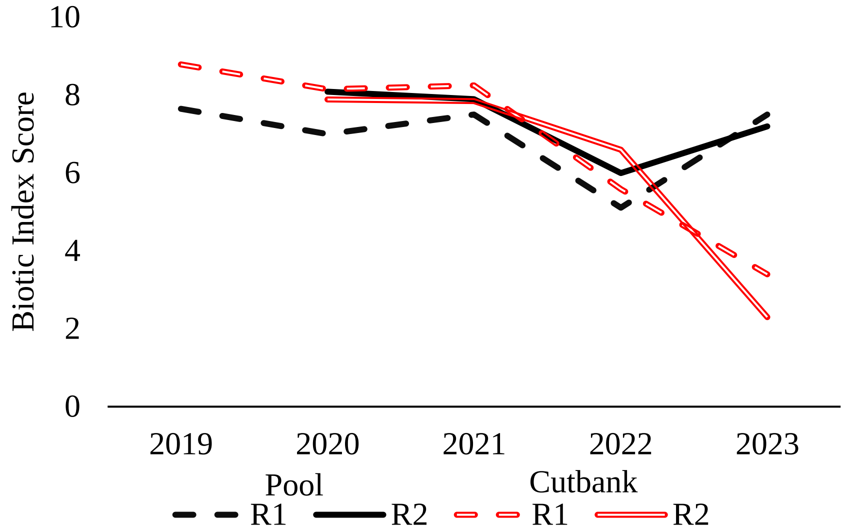

Figure 3.9 Trendline of the Biotic Index in R1 and R2.

Visual Improvement

This section provides a visual representation of the improvement of the sites studied in this research, revetments will be referred to as R 1- 4 respectively as how they were mentioned before in the document (R1, R2, R3, R4) and they will be compared with the control site.

R1 is the oldest of the points in the case study and is the one with the most vegetation to this date, providing shade and suitable habitat for different species, the last time that the place was visited, various species of frogs, fish, and some turtles were spotted, among all the sites, is the one with more biodiversity based in what can be casually observed

Figure 3.10 Picture of R1 taken in November (Left) and in May (Right)

In the same way as how it was witnessed at R1, R2 has been installed with anticipation, as there is a high amount of vegetation growing in the bank, and in Figure 3.12, the presence of sandbar willows can be appreciated in a better way, showing how well adapted this species are to growing under this condition.

Figure 3.11 Picture of R2 taken on November (Upper) and in May (Lower)

The pictures of R3 were taken before winter, so greener vegetation can be appreciated in the different perspectives provided, different species of grass, shrubs and forbs can be identified, as well as the planted sandbar willow. Despite the fact that it is a very rocky bank, vegetation regrowth is very noticeable at this sample point.

Figure 3.12 Picture of R 3 from different angles (ground and aerial).

Figure 3.13 show the last revetment installed so is more pertinent to show how it looked like before the installation and after its installation to demonstrate the area of bare soil that can be covered just by using the revetment. The area will likely be vegetated with time in the same way as it happened in the previous revetments; sandbar willows were planted at this point as well. The picture in the bottom of Figure 3.13 show how even if R4 is the newest installment, it is already capturing sediment allowing vegetation to regrow.

Figure 3.13 Picture of R4 site before and after the installment of the revetment.

The picture in Figure 3.14 serves as a comparison point to demonstrate how different are the areas covered with the revetments to an uncovered and exposed zone, erosion rates are higher in this spot, and vegetation in the streambank area is few to nonexistent, is a good highlight of the effectiveness that revetments can have as a positive impact for promoting biodiversity and stream health.

Figure 3.14 14 Picture of the Control site at McConnell Creek.

By summing up the volumes obtained from both sets of measurements in the two areas with high deposition captured in the same revetment, we found that the volume of new sediment captured by R1 is approximately 2.8 cubic meters. This comprehensive approach ensures a thorough understanding of the sediment volume, accounting for all relevant measurements and providing an accurate representation of the sedimentary deposition in the streambank.

Figure 3.15 Visual representation of the sediment captured in R1.

Runoff Estimation Results

According to the National Weather Service, the average annual precipitation in Wichita, KS is approximately 30.53 inches (77.54 cm). The website Web Soil Survey provides the different types of soil that exist in the drainage area of 3782 acres and also provides their hydrological soil group, this information is shown in Table 3.3.

Table 3.3 Hydrological Soil Group

Map unit name	Rating	Acres in AOI	Percent of AOI
Rosehill silty clay, 1 to 3 percent slopes	D	261.7	6.9%
Urban land-Irwin complex, 1 to 3 percent slopes	D	1,350.7	35.7%
Clime silty clay, 3 to 7 percent slopes	D	21.5	0.6%
Irwin silty clay loam, 1 to 3 percent slopes	D	694.7	18.4%
Irwin silty clay loam, 3 to 7 percent slopes	D	132.2	3.5%
Urban land-Farnum complex, 0 to 3 percent slopes	D	179.7	4.8%
Urban land-Tabler complex, 0 to 1 percent slopes	D	691.1	18.3%
Saltcreek and Naron fine sandy loams, 0 to 1 percent slopes	C	2.5	0.1%
Tabler silty clay loam, 0 to 1 percent slopes	D	49.3	1.3%%
Elandco silt loam, frequently flooded	B	59.6	1.6%
Elandco silt loam, occasionally flooded	B	62.3	1.6%%
Blanket silt loam, 0 to 1 percent slopes	C	2.4	0.1%
Milan loam, 1 to 3 percent slopes	C	269.1	7.1%
Pits	C	4.2	0.1%
Water	C	0.8	0.0%
Totals for Area of Interest		**3,782.0**	**100.0%**

Runoff Influence

McConnell Creek is significantly impacted by the Air Force Base. The amount of water that gets infiltrated into the soil is decreased by the airstrip's impervious surfaces. This causes an increase in the amount of water that enters the stream in an accelerated way through runoff, which has a negative impact on the state of the stream, reflected in the streambank areas subject to severe erosion. Decreasing runoff rates going into the creek to decrease stormwater impacts is one of the main goals in the area.

The usage of de-icing fluid and other chemical-related components can also result in an issue with water quality in the stream brought up by the runway's existence. This substance is used to stop snow, frost, and ice on the landing site. (Molina, 2021)

Runoff Estimation

Through a runoff estimation it is possible to have a better understanding of the situation at McConnell Creek and how the amounts of runoff entering the stream can impact it, and in that way determine what actions have to be taken to improve the state of the creek. Runoff estimation is a critical aspect of watershed management and planning, and it plays a vital role in protecting public health and safety, preserving the environment, and promoting sustainable development. In Table 3.3 we can use the data provided by the hydrological soil group to estimate runoff using the runoff estimation spreadsheet, with the slope acquired in Web Soil Survey the flow length, and the land use, all together provide the curve number shown in Figure 3.16. The information that Figure 3.16 provides is 24-hour rainfall events in different return frequency rates and peak discharges.

USDA
NRCS

Hydrologic Summary Sheet

KS-ENG-137b
Rev. 12/15

Name	McConnell Air Force Base	Practice	
Legal Desc		County	Sedgwick
Designed by	558	Date	4/30/23
Checked by	Jorge Serrano	Date	

Use "CN calc" sheet to enter acres and compute weighted CN.
Enter acres and weighted CN directly on this sheet.

Design Data:

Drainage Area	3781.8 acres	5.91 square miles
Weighted Curve Number, CN	88	
Flow Length	27,028.80 feet	
Watershed Slope	2.8 %	
Time of Concentration, Tc	3.36 hours	
Rainfall Type Zone	4	

Frequency (years)	2	5	10	25	50	100
Use site-specific 24-hour Rainfall (inches)						
24-hour Rainfall, P (inches)	3.38	4.24	4.98	6.05	6.92	7.83
Initial Abstraction, Ia (inches)	0.27	0.27	0.27	0.27	0.27	0.27
Ia / P	0.10	0.10	0.10	0.10	0.10	0.10
Runoff, Q (inches)	2.16	2.95	3.65	4.67	5.52	6.40
Unit Peak Discharge, qu (cfs/acre-inch)	0.24	0.24	0.24	0.24	0.24	0.24
Peak Discharge, Qp (cfs)	**1932**	**2642**	**3266**	**4182**	**4936**	**5728**

Figure 3.16 Runoff estimation spreadsheet displaying rainfall frequencies and peak discharges.

A curve number (CN) of 88 can be regarded as relatively high and may show that impermeable surfaces, such as paved surfaces, roofs, or compacted soils, dominate the land cover in the watershed. Increased runoff and decreased infiltration can result from this, which can have detrimental effects on watershed management by increasing the risk of flooding, eroding land, and deteriorating water quality. According to statistics, the probability of a 24-hour rainfall event with a total of 4.98 inches occurring in a periodicity of 10 years is 1 in 10, or 10%, for any given year. In other words, this is a 10-year-return period rainfall event. The amount of 4.98 inches of rain in a 24-hour period is a sizeable quantity of precipitation, and it can have a big impact on the watershed in terms of increased runoff, flooding, and erosion. Therefore, in order to lessen the effects of such events, this information can be helpful when planning and designing infrastructure and land use practices like stormwater management systems, erosion control measures, and land use zoning.

This event will have a return time of 10 years with a peak discharge of 3266 cubic feet per second (cfs). Peak flow, which refers to a river or stream's greatest discharge during a rainfall event, is frequently employed in hydrologic analysis and hydraulic structure design.

A peak discharge of 3266 cfs during a ten-year period is a comparatively high flow rate that may have serious effects on the watershed and places downstream, such as flooding and erosion and sedimentation processes.

ArcGis Assesment

ArcGIS can be a great tool for picturing the area of impervious surfaces in a watershed or other area. By using satellite imagery or aerial photographs, ArcGIS can be used to create a land cover map that shows impervious surfaces in the area, such as pavement, rooftops, and sidewalks. An ArcGIS assessment can show the total area of the site and the percentages of different land covers to evidence the percentage of impervious surfaces and green areas, etc. in the site. Figure 3.17 shows the area that the watershed drainage area covers within the AFB boundaries, and also the flood zone of the creek, with this image we have evidence of how the base covers almost entirely the watershed, and how it impacts directly the creek.

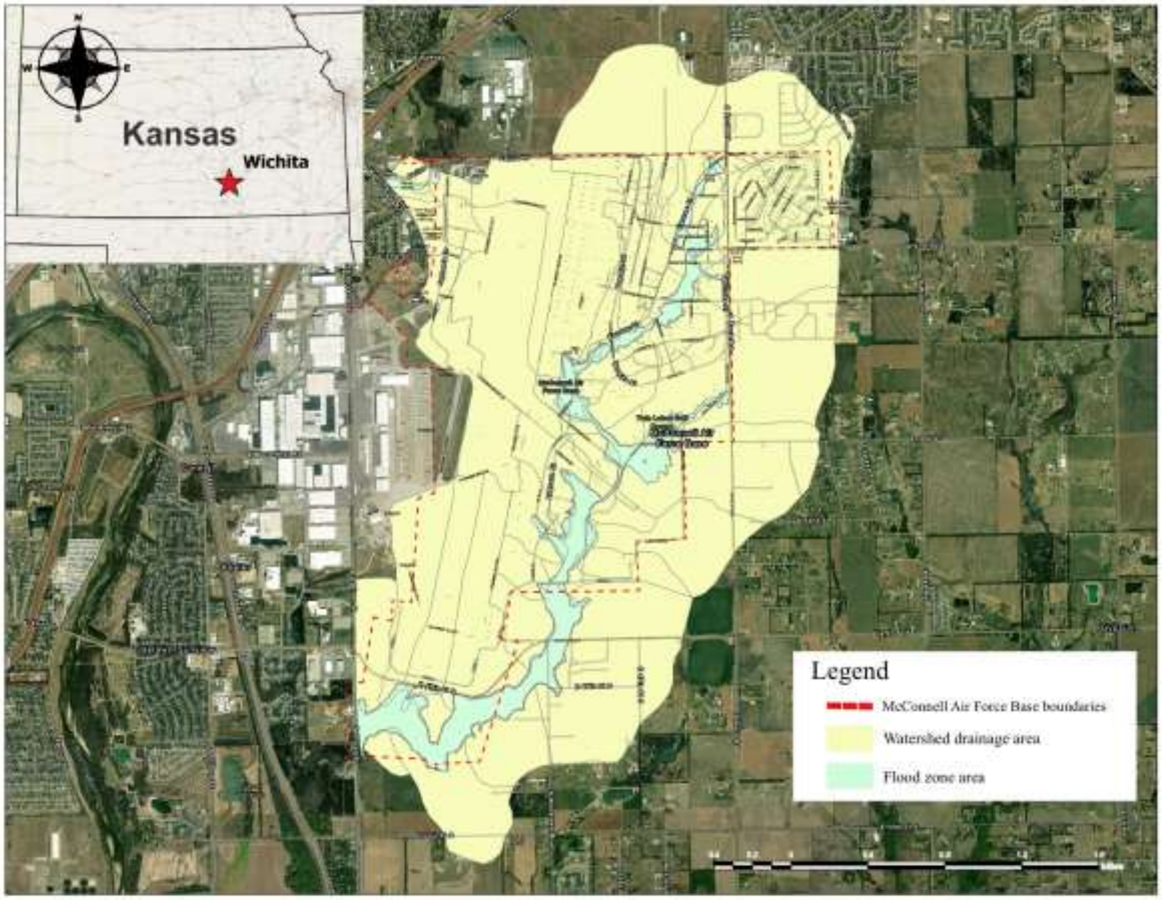

Figure 3.17 ArcGIS Pro map of McConnell AFB watershed drainage and flood zone area.

The map in Figure 3.18 shows the impervious cover that McConnell Air Force Base has, for practical purposes, the map is simplified to be easier to understand, the area of the Air Force Base is 3302 ac, according to the map an amount of 2412.3 ac is impervious surface such as buildings, paved roads, and sidewalks. that means that 73% of the total area is composed of impervious surfaces, the map also includes the study site to dimension the big influence that impervious surfaces can have in a creek of that proportions. This information indicates that the high quantity of impervious surfaces contributes to the high Curve Number that the watershed has and how this can lead to high runoff and flooding events. This can be compared with larger cities such as New York City, that is approximately 72% impervious surfaces with all the streets, parking lots, and sidewalks. (Valderrama, 2017). High percentages of impervious surface can drastically increase runoff, from 10% in natural conditions to 55% with impervious surface areas of 75%–100% (Jia, Yao, and Yu, 2013).

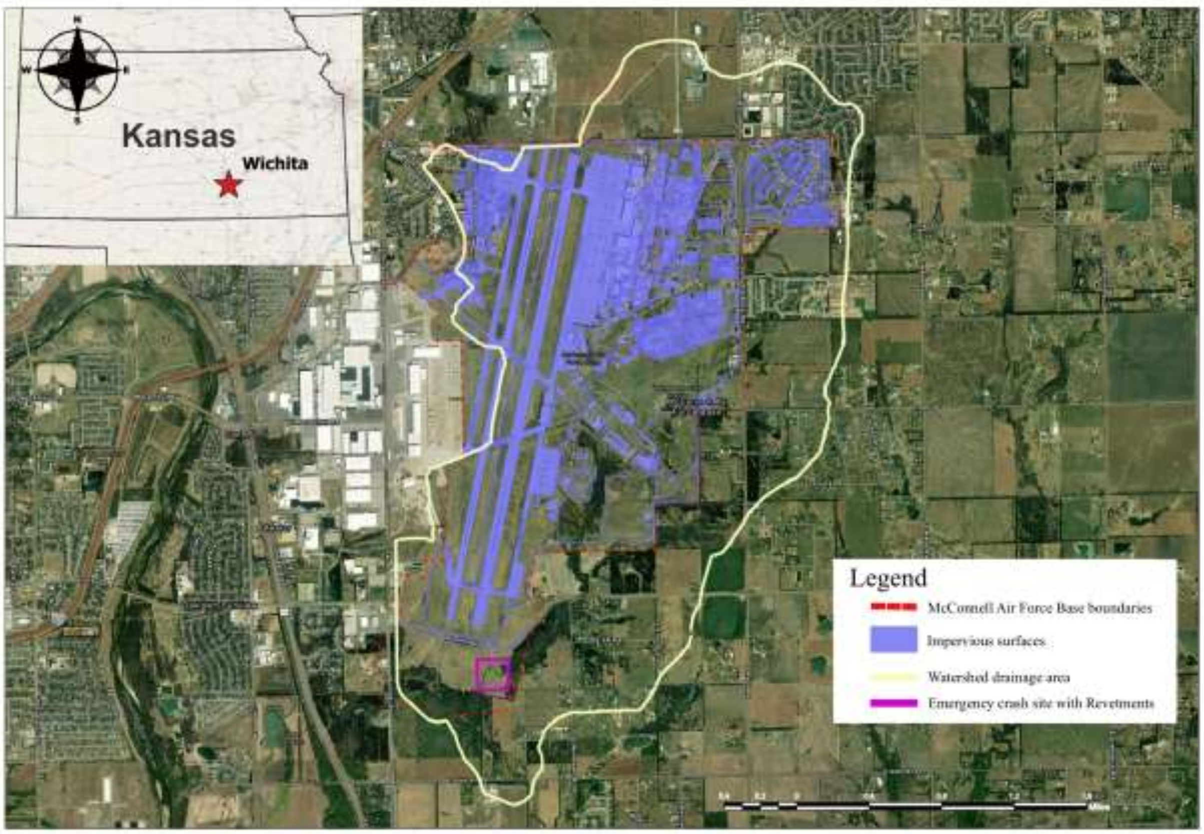

Figure 3.18 ArcGIS Pro map of McConnell AFB of impervious surfaces. And study site location

Possible Strategy

At the Air Force Base, expanding the use of permeable pavement and rain gardens may be a very efficient way to reduce significant runoff. Rainwater can seep into the ground through permeable pavement, such as porous asphalt or pervious concrete, limiting the quantity of runoff that flows off the surface. Landscaped spaces called rain gardens are made to collect and absorb rainfall runoff so that it can seep into the ground and be absorbed by plants.

The AFB stormwater management plan can be improved by including permeable pavement and rain gardens. By reducing the number of impervious surfaces, runoff and floods during rain events can be reduced. Additionally, by removing pollutants and other contaminants, these procedures can help to improve the quality of the water.

For permeable interlocking concrete pavement (PICP), the Interlocking Concrete Pavement Institute advises a minimum thickness of 2.5 inches to give enough structural support and avoid rutting in pedestrian walkways, patios, driveways, and other similar applications (Interlocking Concrete Pavement Institute, 2022.).

For permeable pavement systems, the U.S. Environmental Protection Agency suggests a minimum design infiltration rate of 1 inch per hour (U.S. Environmental Protection Agency, 2015).

With rain gardens its necessary to provide appropriate storage space and encourage infiltration, the U.S. Environmental Protection Agency advises a minimum size of 50 square feet of surface area (U.S. Environmental Protection Agency, 2020.).

For the creation of rain gardens, clayey soils require larger but shallow gardens. Sandy soils can be the opposite, the average depth is 4-6 inches. (Eyestone, 2009.). Table 3.4 shows a budget based on a previous rain garden project (Skabelund and Thomsen, 2008).

Table 3.4 Costs of different assets for Rain Gardens.

Expense Item	Cost ($)
Preliminary grading of rain-garden basins	$78.75
Delivered washed filter stone and topsoil	$447.46
Delivered flagstone and Dover shell limestone strips	$1,438.00
Work gloves and rental of tools	$85.08
Weed barrier and metal pins	$150.95
Rain-garden plants and mycorrhizal inoculum	$1,014.39
Prairie plants	$240.00
Plants, stone and mulch	$354.67
Supplemental prairie grasses	$98.17
Van rental transportation of plants	$123.48
Long-lasting bronze tone rain-garden sign	$800.00
Various purchases	$151.91
Total Expenses	$4,982.86
Tools and consultation time (Donation)	$407.50
Stone and consultation time (Donation)	$3,000.00
Loading and hauling stone from Bayer Stone Yard (Donation)	$450.00
Off-loading stone at the ISC (Donation)	$295.00
Donation of tools for multiple work-days (Donation)	$745.00
Prairie plants (Donation)	$50.00
5 cubic yards of mulch (Donation)	$200.00
Rain-garden sign (Donation)	$58.00
Use of skid-loader, in-kind time, consultation (Donation)	$1,250.40
Total Donations	$6,456.90
Cost per square foot (Total Expenses)	$29.31
Cost per square foot (Total Donations)	$37.98

Additionally, according to an article titled "How Much Does a Rain Garden Cost?" from CostHelper (2023), rain gardens can cost \$1-\$5 per square foot, or \$100-\$2,000 for a 100- to 400-square-foot rain garden, depending on various factors such as landscaping requirements and the need for new plants and supplies. Professional installation typically ranges from \$10-\$20 per square foot, or \$1,500-\$3,000 or more for 150 square feet, depending on complexity and landscaping. Installing a rain garden on a commercial, industrial, or institutional site can cost \$10-\$40 per square foot, or \$4,000-\$16,000 for 400 square CostHelper (2023)

According to Truegrid (2024) the cost of installing permeable pavement varies depending on the material used, Table 3.5 summarize the budget in range per square foot.

Table 3.5 Cost of different pavement types and additional items.

Permeable Pavement Type	**Cost Range per Square Foot (\$)**
Porous Asphalt	\$7 – \$13
Pervious Concrete	\$8 – \$16
Permeable Interlocking Concrete Pavers	\$4 – \$12
Permeable Concrete Block Paving	\$4 – \$12
Natural Stone Pavers	\$10 – \$30
Grass Pavers System	\$3 – \$9
Additional Cost Item	**Cost Range per Square Foot (\$)**
Gravel filler	\$1 – \$3
Sand fill	\$25 – \$45 per ton
Sod for grass pavers	\$0.30 – \$0.40

The choice of the best type of permeable pavement depends on personal preference and factors such as aesthetics and maintenance considerations. While porous asphalt and pervious concrete offer a sleek and clean-cut look, they may require more maintenance due to potential cracks. Grass pavers, on the other hand, provide a natural aesthetic appeal and may be preferred for their eco-friendly qualities.

Recommended Operation

Strategically positioning rain gardens in selected areas across the base, alongside a planned implementation of permeable pavement, may be a suitable approach to environmental sustainability. By gradually integrating permeable pavement in lieu of conventional surfaces each instance of damage to conventional pavement is replaced with permeable pavement, can mitigate runoff issues.

While ideal for most surfaces, exceptions must be made for high-traffic zones such as airport runways and highways, where heavy machinery transit regularly.

As highlighted by the article "Permeable Pavement: The Pros and Cons You Need to Know" (2017) from Green Blue Urban, permeable pavements, while environmentally beneficial, lack the structural integrity required for high-stress zones like highways and airport runways. This strategic application ensures that the benefits of permeable pavement are maximized while acknowledging its limitations.

The fact that permeable pavement is not ideal for the landing strip doesn’t discard the option to apply it for sidewalks, parking lots and streets inside the base where heavy machinery does not transit, this changes in the composition of the impervious surface in the base can positively reduce runoff percentage.

The combined approach of rain gardens and permeable pavement holds potential for significantly reducing runoff volumes across the Air Force Base. Once implemented, the maintenance of this eco-friendly infrastructure proves manageable, ensuring long-term sustainability.

Chapter 4 - Conclusion and Recommendations

The data provided by the erosion pins show that the redcedar revetments have effectively reduced the erosion rates and also capture sedimentation over the 2 years of the study. R1, that was the first installed, captured an average of 8.5 cm/year in the highest rate of the third year, compared with the first years of research that showed erosion of 4.9 cm/year, can demonstrate the improvement of the streambank integrity within the time span of the research. It’s important to clarify that mainly, deposition rates were held in lower data points of the stream due to the stream natural morphology, so other revetments will usually show more deposition rates in lower elements of the streambank. Another way to dimension all the sedimentation captured by R1 is by referencing Figure18 in which is demonstrated how it has captured 2.8 cubic meters of sediment, adding that to the 3.32 cubic meters documented by Molina (2021) in the previous case study, gives a total of 6.12 cubic meters.

The same way that the revetment mitigated erosion and captured deposition in R1, it did in the following revetments. R2 had high rates of sedimentation captured, being 6.5 cm its highest average per year in the third year of research, and the lower rebar captured unmeasured quantities of sediment because the pin was completely buried, which implies the efficacy of the revetment retaining sedimentation. The third revetment was installed for a shorter period compared with the previous revetments but successfully captured sediments, 3.95 cm/yr the highest rate. A similar case happens in R4, that even though is the most recent installation in the creek, it has captured sedimentation. More years of observation need to be conducted to fully picture the progress of the last two revetments installed, but with the data gathered, there is clear evidence that redcedar revetments can effectively reduce erosion and held deposition, keeping possible pollutants away from the creek.

The macroinvertebrate sampling gives a better perspective of the water quality and habitat quality. The revetments showed scores of biotic indices that on average were from fairly poor to poor in the pool areas, on the other hand, the cutbank area in the revetments had ratings from excellent to very good. The reason why they differ is due to the position in the creek, the cutbank area with revetment provided better conditions for sheltering macroinvertebrates, and the revetment not only captured sedimentation but also had suitable conditions to raise vegetation that improved the overall habitat quality. Diversity measured with Shannon-Wiener and Simpson scores implies that the revetments site had increase overall diversity of species compared with the previous research that had its highest Simpson score of 0.34 and it highest Wiener score of 0.8; those are low values compared to recent scores sampled, with Simpson scores around 0.8 and Shannon-Wiener scores around 2. A study comparing macroinvertebrates sampling in different sites can help to fully comprehend the impact of revetments as a factor of improvement in aquatic habitats.

The site photography can serve as graphical evidence of how the stream quality has improved, recent pictures show new vegetated areas and wildlife such as increase incidence of fish, turtles or frogs in the creek. The planted sandbar willows are successfully growing in the revetments sites and it is expected that they will strengthen the streambank area and improve habitat for hosting more and diverse species of animals and plants. Planting more native and flood resistant species can improve the revegetation of the bank and act as cover for enhancing erosion control and shear strength of the bank. This improved vegetation and the improvement of the riparian zone have been similar in previous research, Benitez (2019) had similar outcomes showing an improvement in the stream health and increased vegetation by implementing redcedar revetments.

Despite the fact that the AFB has a high percentage of impervious surface, implementing practices such as Rain Garden in combination with a permeable pavement transition plan can make a positive difference in the volume of water that runs to the creek, implementing a project that aims to install these two alternatives can work as another way to mitigate erosion and pollution entering to the water body through runoff.

Based on the results of this study, redcedar revetments are a good alternative to other common revetments such as riprap or rock-based revetments. This study shows cedar revetments demonstrated mitigation of erosion, and also captured sediment through the log, branches and fine twigs, this sediment can lead to vegetation growth and overall habitat improvement in levels that cannot be matched by solid and rigid structures like rock. Future research should be done to compare the efficacy of these two types of revetments on a long-term bias.

This methodology can be used in similar and higher streambanks using more chains of cedar in rows that can cover the streambank based in their unstable area. A thorough assessment of the stream's geomorphological characteristics should be done to fully determine if applying redcedar revetments could work the same way in widening or early successional streams sequence. Streambank erosion in widenings streams are most likely to stabilize eroding banks and prevent further widening after revetment installation, but a more specific research focus on that subject would have to be addressed.

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Appendix A - Raw Data

	family	Tolerance	Revetment 1 Pool	Cutbank	Family tolerance score pool	Family tolerance score cutbank	total Critters pool	total Family tolerance pool	total cutbank	total Family tolerance cutbank
Mayflies	Prong-gilled Mayfly	2	15	7	30	14				
	Small Square-gill Mayfly	7	8	9	56	63				
	Small Minnow Mayfly	4	0	0	0	0	23	86	16	77
Caddisflies	Micro Caddisfly	4	1	0	4	0	1	4	0	0
Coleoptera	Whirligig Beetle (larvae)	4	1	0	4	0				
	Water scavenger Beetle (Adult)	5	0	1	0	5				
	Long-toed Water Beetle	5	0	0	0	0				
	Crawling water beetle (adult)	7	0	0	0	0	1	4	1	5
Diptera	Non-biting [illegible] (larvae)	8	3	0	24	0				
	Non-biting [illegible] (larvae)	6	31	23	186	138				
	Biting Midge	4	2	1	8	4				
	Phantom midge	8	0	0	0	0	36	218	24	142
Odonata	Broad winged damselfly	5	0	1	0	5	0	0	1	5
Hemiptera	Water Treader	0	0	1	0	0				
	Broad-shouldered water strider	6	0	1	0	6				
	Water Scorpion	8	0	0	0	0				
	Shore Bug	0	0	0	0	0	0	0	0	6
					grand total of critters	Grand total of family tolerance	61	312	42	235
							biotic index pool	5.114754098	biotic index cutbank	5.595238095

Appendix Figure A 1 Revetment 1 first sample data.

			Reventment 2							
	family.	Tolerance	Pool	Cutbank	Family tolerance score pool	Family tolerance score cutbank	total Critters pool	total Family tolerance pool	total cutbank	total Family tolerance cutbank
Mayflies	Prong-gilled Mayfly	2	3	1	6	2				
	Small Square-gill Mayfly	7	2	0	14	0				
	Small Minnow Mayfly	4	0	0	0	0	5	20	1	2
Caddisflies	Micro Caddisfly	4	0	0	0	0	0	0	0	0
Coleoptera	Whirligig Beetle (larvae)	4	0	0	0	0				
	Water scavenger Beetle (Adult)	5	0	1	0	5				
	Long-toed Water Beetle	5	0	1	0	5				
	Crawling water beetle (adult)	7	0	0	0	0	0	0	2	10
Diptera	Non-biting Midge(red forms)	8	0	0	0	0				
	Non-biting Midge(pale forms)	6	0	0	0	0				
	Biting Midge	4	1	0	4	0				
	Phantom midge	8	6	6	48	48	7	52	6	48
Odonata	Broad winged damselfly	5	0	0	0	0	0	0	0	0
Hemiptera	Water Treader	0	0	0	0	0				
	Broad-shouldered water strider	6	0	0	0	0				
	Water Scorpion	8	0	0	0	0				
	Shore Bug	0	0	0	0	0	0	0	0	0
					grand total of critters	Grand total of family tolerance	12	72	9	60
							biotic index	6	biotic index cutbank	6.666666667

Appendix Figure A 2 Revetment 2 first sample data.

			Reventment 1							
	family	Tolerance	Pool	Cutbank	Family tolerance score pool	Family tolerance score cutbank	total Critters pool	total Family tolerance pool	total cutbank	total Family tolerance cutbank
Mayflies	Prong-gilled Mayfly	2	0	1	0	2				
	Small Square-gill Mayfly	7	65	4	455	28				
	Small Minnow Mayfly	4	0	0	0	0	65	455	5	30
Caddisflies	Micro Caddisfly	4	0	0	0	0	0	0	0	0
Coleoptera	Whirligig Beetle (larvae)	4	0	0	0	0				
	Water scavenger Beetle (Adult)	5	0	0	0	0				
	Long-toed Water Beetle	5	0	0	0	0				
	Water Scavenger Beetle (larvae)	5			0	0				
	Riffle Beetle (Adult)	5			0	0				
	Predaceous Diving Beetle (Adult)	5			0	0				
	Crawling water beetle (adult)	7	0	1	0	7	0	0	1	7
Diptera	Non-biting Midge(red forms)	8	0	0	0	0				
	Non-biting Midge(pale forms)	6	2	4	12	24				
	Biting Midge	4	0	1	0	4				
	Moth fly	10		2	0	20				
	Marsh fly	6		1	0	6				
	Aquatic dance fly	6			0	0				
	Phantom midge	8	0	0	0	0	2	12	8	54
Odonata	Narrow winged damselfly	9	1		9	0				
	Darner	3			0	0				
	Common Skimmer	7			0	0				
	Broad winged damselfly	5	1	1	5	5	2	5	1	5
Hemiptera	Water Treader	0	0	0	0	0				
	Broad-shouldered water strider	6	0	0	0	0				
	Water Scorpion	8	0	0	0	0				
	Shore Bug	0	0	0	0	0				
	Backswimmer	0			0	0				
	Water Strider	0			0	0				
	Water measurer	0			0	0				
	Water Boatman	9	36	13	324	0	36	324	13	0
					grand total of critters	Grand total of family tolerance	105	796	28	96
							biotic index pool	7.580952381	biotic index cutbank	3.428571429

Appendix Figure A 3 Revetment 1 second sample data.

			Reventment 2							
	family.	Tolerance	Pool	Cutbank	Family tolerance score pool	Family tolerance score cutbank	total Critters pool	total Family tolerance pool	total cutbank	total Family tolerance cutbank
Mayflies	Prong-gilled Mayfly	2	0	0	0	0				
	Small Square-gill Mayfly	7	15	4	105	28				
	Small Minnow Mayfly	4	0	0	0	0	15	105	4	28
Caddisflies	Micro Caddisfly	4	0	0	0	0	0	0	0	0
Coleoptera	Whirligig Beetle (larvae)	4	0	0	0	0				
	Water scavenger Beetle (Adult)	5	2	0	10	0				
	Long-toed Water Beetle	5	0	0	0	0				
	Water Scavenger Beetle (larvae)	5	2		10	0				
	Riffle Beetle (Adult)	5			0	0				
	Predaceous Diving Beetle (Adult)	5			0	0				
	Crawling water beetle (adult)	7	0	0	0	0	4	20	0	0
Diptera	Non-biting Midge(red forms)	8	0	0	0	0				
	Non-biting Midge(pale forms)	6	1	1	6	6				
	Biting Midge	4	1	0	4	0				
	Moth fly	10			0	0				
	Marsh fly	6		1	0	6				
	Aquatic dance fly	6			0	0				
	Phantom midge	8	0	0	0	0	2	10	2	12
Odonata	Narrow winged damselfly	9			0	0				
	Darner	3		1	0	3				
	Common Skimmer	7		1	0	7				
	Broad winged damselfly	5	0	0	0	0	0	0	2	10
Hemiptera	Water Treader	0	0	0	0	0				
	Broad-shouldered water strider	6	0	1	0	6				
	Water Scorpion	8	0	0	0	0				
	Shore Bug	0	0	0	0	0				
	Backswimmer	0			0	0				
	Water Strider	0	1	7	0	0				
	Water measurer	0			0	0				
	Water Boatman	9	15	8	135	0	16	135	16	6
					grand total of critters	Grand total of family tolerance	37	270	24	56
							biotic index pool	7.297297297	biotic index cutbank	2.333333333

Appendix Figure A 4 Revetment 2 second sample data.

			Reventment 3							
	family.	Tolerance	Pool	Cutbank	Family tolerance score pool	Family tolerance score cutbank	total Critters pool	total Family tolerance pool	total cutbank	total Family tolerance cutbank
Mayflies	Prong-gilled Mayfly	2	0	0	0	0				
	Small Square-gill Mayfly	7	13	4	91	28				
	Small Minnow Mayfly	4	0	0	0	0	13	91	4	28
Caddisflies	Micro Caddisfly	4	0	0	0	0	0	0	0	0
Coleoptera	Whirligig Beetle (larvae)	4	0	0	0	0				
	Water scavenger Beetle (Adult)	5	0	2	0	10				
	Long-toed Water Beetle	5	0	0	0	0				
	Water Scavenger Beetle (larvae)	5	2		10	0				
	Riffle Beetle (Adult)	5	3		15	0				
	Predaceous Diving Beetle (Adult)	5	4		20	0				
	Crawling water beetle (adult)	7	2	0	14	0	11	59	2	10
Diptera	Non-biting Midge(red forms)	8	0	0	0	0				
	Non-biting Midge(pale forms)	6	1	3	6	18				
	Biting Midge	4	2	2	8	8				
	Moth fly	10			0	0				
	Marsh fly	6		1	0	6				
	Aquatic dance fly	6		1	0	6				
	Phantom midge	8	0	0	0	0	3	14	7	38
Odonata	Narrow winged damselfly	9		1	0	9				
	Darner	3			0	0				
	Common Skimmer	7			0	0				
	Broad winged damselfly	5	0	3	0	15	0	0	4	24
Hemiptera	Water Treader	0	0	0	0	0				
	Broad-shouldered water strider	6	0	3	0	18				
	Water Scorpion	8	0	0	0	0				
	Shore Bug	0	0	0	0	0				
	Backswimmer	0			0	0				
	Water Strider	0		3	0	0				
	Water measurer	0		1	0	0				
	Water Boatman	9	21	8	189	0	21	189	15	18
					grand total of critters	Grand total of family tolerance	48	353	32	118
							biotic index pool	7.354166667	biotic index cutbank	3.6875

Appendix Figure A 5 Revetment 3 second sample data.

			Revetment 4							
	family.	Tolerance	Pool	Cutbank	Family tolerance score pool	Family tolerance score cutbank	total Critters pool	total Family tolerance pool	total cutbank	total Family tolerance cutbank
Mayflies	Prong-gilled Mayfly	2	0	0	0	0				
	Small Square-gill Mayfly	7	7	2	49	14				
	Small Minnow Mayfly	4	0	2	0	8	7	49	4	22
Caddisflies	Micro Caddisfly	4	0	0	0	0	0	0	0	0
Coleoptera	Whirligig Beetle (larvae)	4	0	0	0	0				
	Water scavenger Beetle (Adult)	5	0	0	0	0				
	Long-toed Water Beetle	5	0	0	0	0				
	Water Scavenger Beetle (larvae)	5		1	0	5				
	Riffle Beetle (Adult)	5			0	0				
	Predaceous Diving Beetle (Adult)	5	1		5	0				
	Crawling water beetle (adult)	7	1	1	7	7	2	12	2	12
Diptera	Non-biting Midge(red forms)	8	0	0	0	0				
	Non-biting Midge(pale forms)	6	5	2	30	12				
	Biting Midge	4	0	0	0	0				
	Moth fly	10			0	0				
	Marsh fly	6		2	0	12				
	Aquatic dance fly	6			0	0				
	Phantom midge	8	0	0	0	0	5	30	4	24
Odonata	Narrow winged damselfly	9	1		9	0				
	Darner	3		1	0	3				
	Common Skimmer	7			0	0				
	Broad winged damselfly	5	0	0	0	0	1	0	1	3
Hemiptera	Water Treader	0	0	3	0	0				
	Broad-shouldered water strider	6	0	0	0	0				
	Water Scorpion	8	0	0	0	0				
	Shore Bug	0	0	0	0	0				
	Backswimmer	0	1	6	0	0				
	Water Strider	0		2	0	0				
	Water measurer	0			0	0				
	Water Boatman	9		5	0	0	1	0	16	0
					grand total of critters	Grand total of family tolerance	16	91	27	61
							biotic index pool	5.6875	biotic index cutbank	2.259259259

Appendix Figure A 6 Revetment 4 second sample data.

			Control							
	family.	Tolerance	Pool	Cutbank	Family tolerance score pool	Family tolerance score cutbank	total Critters pool	total Family tolerance pool	total cutbank	total Family tolerance cutbank
Mayflies	Prong-gilled Mayfly	2	0	0	0	0				
	Small Square-gill Mayfly	7	5	3	35	21				
	Small Minnow Mayfly	4	0	0	0	0	5	35	3	21
Caddisflies	Micro Caddisfly	4	0	0	0	0	0	0	0	0
Coleoptera	Whirligig Beetle (larvae)	4	0	0	0	0				
	Water scavenger Beetle (Adult)	5	5	2	25	10				
	Long-toed Water Beetle	5	0	0	0	0				
	Water Scavenger Beetle (larvae)	5	1		5	0				
	Riffle Beetle (Adult)	5			0	0				
	Predaceous Diving Beetle (Adult)	5			0	0				
	Crawling water beetle (adult)	7	0	0	0	0	6	30	2	10
Diptera	Non-biting Midge(red forms)	8	0	0	0	0				
	Non-biting Midge(pale forms)	6	0	0	0	0				
	Biting Midge	4	0	0	0	0				
	Moth fly	10			0	0				
	Marsh fly	6			0	0				
	Aquatic dance fly	6			0	0				
	Phantom midge	8	0	0	0	0	0	0	0	0
Odonata	Narrow winged damselfly	9			0	0				
	Darner	3			0	0				
	Common Skimmer	7			0	0				
	Broad winged damselfly	5	1	0	5	0	1	5	0	0
Hemiptera	Water Treader	0	0	0	0	0				
	Broad-shouldered water strider	6	0	0	0	0				
	Water Scorpion	8	0	0	0	0				
	Shore Bug	0	0	0	0	0				
	Backswimmer	0	1	6	0	0				
	Water Strider	0		2	0	0				
	Water measurer	0			0	0				
	Water Boatman	9	16	12	144	0	17	144	20	0
					grand total of critters	Grand total of family tolerance	29	214	25	31
							biotic index pool	7.379310345	biotic index cutbank	1.24

Appendix Figure A 7 Control sample data.