Analysis of river restoration and stabilization practitioners, their design tools and limits

by

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Abstract

One of the many consequences of anthropogenic influence on streams is accelerated stream erosion. The industry of stream restoration and/or stabilization has grown to meet the needs of this consequence. Despite its magnitude there are many issues regarding the vagueness of objectives and guidelines that have impacted the success of stream restoration and/or stabilization projections. The objectives of this study were to create a detailed understanding of the tools and design guidelines practitioners use in the field, describe the constraints that affect practitioners' ability to perform in the field and develop a HEC-RAS model that reflects its use in the practice through application to a planned bank stabilization project in Kansas. A survey was created to examine aspects of the design process (guidelines, data, and models) employed by stream practitioners as well as determine the relative influence of factors such as funding, time, location, on their ability to design projects. In addition, a HEC-RAS model was created for a case study streambank stabilization project on the Cottonwood River in east-central Kansas to determine its ability as a design tool to assist in predicting hydraulic conditions and erosion for a future stream restoration projects. The practitioner survey provides a benchmark for current practices and constraints for practitioners in the stream restoration/stabilization industry, with the primary results being: (1) HEC-RAS is the predominant computational model used by practitioners, (2) many other potential models are not utilized due to lack of training and time, (3) respondents who did not use models did so due to their ineffectiveness and difficulty of use, (4) guidelines used were highly varied but were mostly based off of Rosgen's Natural Channel Design methods (with few exceptions by region), (5) practitioners within governmental organization use guidelines primarily due to regulations and not their effectiveness, (6) the waiting time on permits can be damaging to the success of the project, and (7) more long term

data is needed to support project design, including suspended sediment, sediment bedload and subsurface flow. The results from the HEC-RAS model demonstrated that while possible locations for erosion can be found using the model, erosion rates are unreliable to determine using just shear stress as an indicator. This study recommends the following items. The first is to educate practitioners to use models like HEC-RAS and to use that education system in part to collect long term data that would improve the field. The second is to continue studying the Cottonwood River and implementation of streambank stabilization structures over time using HEC-RAS to determine its long-term accuracy.

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Thank you to Dr.Moore for helping me along my educational journey and Kari Bigham for helping me discover my love of river work and helping me with HEC-RAS.

Dedication

I would like to dedicate this to my loved ones who have my back win or tie.

Chapter 1 - Introduction

Humans have impacted the ecological health of the planet. One of the many ecosystems impacts has been rivers. As reviewed by Arthington (2012), rivers and other aquatic ecosystems are the world's most damaged ecosystems; globally, over 80% of land surrounding aquatic systems has been impacted by human activities. Chief among human impacts is the increase of agriculture and urban development throughout the watersheds that feed rivers, which has led to an increase in high flow events which cause stream instability and accelerated erosion from bed and bank materials (Wu, et al., 2018). While erosion is a natural geomorphic process that is necessary to maintain the health of stream ecosystems (Florsheim, Mount, & Chin, 2008), a high rate of erosion can become a threat to landowners and the important infrastructure near them (Bigham, 2020). To lessen the impacts stream restoration and stabilization methods have evolved to reduce erosion and place the river in a semi-stable state. In the United States alone, the stream restoration practice has grown into a multi-billion-dollar industry to meet the need of addressing degraded riverine systems (Bernhardt, et al., 2005).

However, despite the massive amount of funding that goes into channel stabilization and/or restoration projects, project success is inconsistent. Most of this inconsistency can be attributed to the lack of adequate training, education, and standards available to design dynamic, natural-based systems such as stream restoration projects relative to other scientific or engineering fields (Lave, 2012). Understanding how the people practicing in this field have contributed to the growth of stream restoration and/or stabilization is critical to understanding the current circumstances of the practice as well as the steps being taken to improve and advance the practice.

The current practice relies heavily on Rosgen methods, which has had controversy in the scientific community in the past, but this controversy has subsided in recent years (Wohl, Lane, & Wilcox, 2015). Additionally, there are many challenges regarding the practice. The first is the need for post-construction monitoring to improve the practice is high, there is still insufficient monitoring (Bigham, 2020). The second is the ambiguity of objectives and the vagueness of success (Lightbody, Radspinner, Diplas, & Sotiropoulos, 2010). The third is while project success does involve design, certain factors such as experience of the location of the project may have more impact on a project's success rather that a reliable design guideline (Lightbody, Radspinner, Diplas, & Sotiropoulos, 2010; Bigham, 2020; Thompson, et al., 2021). There is a need to establish further communication between scientists and practitioners to understand the limitations of the practice and what the needs are (Rhoads, Urban, & Herricks, 1999). With these challenges in mind, the research questions were posed to be answered in this thesis:

1. What models and literature do stream restoration and stabilization practitioners use to inform their design?
2. What are the factors that constrain practitioners' design?
3. How does shear stress vary spatially across a range in flow events along a reach in the Cottonwood River in southeast Kansas prior to the construction of streambank stabilization structures?

The first two questions go into unknowns about the practice. The third question establishes a case study which will provide insight into future projects. To address these research questions, the following objectives for the thesis were set:

1. Create a detailed understanding of the guidelines and models practitioners used.

2. Describe the factors that constrain practitioners' ability to perform in the field of stream restoration.
3. Develop a case study to assess hydraulic conditions and potential bank erosion hotspots for the Cottonwood River prior to implementation of a streambank stabilization project.

These research questions and objectives are presented in the next five chapters of this thesis. Chapter 2 provides a background into the history of the stream restoration and bank stabilization practice, the current problems facing the practice, previous surveys done regarding the practice and finally the need for a new survey to address research questions 1 and 2. This new survey is discussed in Chapters 3 and 4. Chapter 3 details the methods of creating, collecting, and analyzing the survey, while Chapter 4 provides the results of the survey. Chapter 5 addresses research question 3, and provides information regarding the background, creation, calibration, analysis, and conclusions of a HEC-RAS model created for the Cottonwood River case study site. Finally, Chapter 6 provides a summary of the results and conclusions of the thesis.

Chapter 2 - Literature Review

Humans have impacted the ecological health of the planet. One of the many impacts has been on rivers. One of the many consequences of anthropogenic influence on streams have been stream erosion (Wu, et al., 2018). The increase of agriculture and urban development has led to an increase of high flow events which cause stream instability. While it is a natural geomorphic process that is necessary for a healthy stream, a high rate of erosion can become a threat to landowners and the important infrastructure near them (Bigham, 2020). To lessen the impacts an industry has developed methods such as stream restoration to reduce erosion and place the river in a semi-stable state.

Stream restoration can be defined as, "… the design and construction of a vertically and laterally stable, floodplain-connected channel that is capable of carrying the bankfull or effective discharge, which typically occurs within a one-year to two-year return interval, and its produced sediment load (Bigham, 2020, p. 352)." The purpose of this is to construct a channel that is supposed to carry the expected sediment load and discharge so that it remains relatively stable. Alternatively, there is streambank stabilization which is, "single technique or system of techniques that maximize localized streambank shear strength and/or minimize the forces acting on a streambank with the intent of halting or minimizing lateral retreat (Bigham, 2020, p. 352)." The techniques involved to stabilize a bank include instream structures, which reduce the shear stress acting on the streambank, and streambank management, which increases the strength of the bank via organic or non-organic means.

2.1 Relationship between practitioners, scientists, regulations, clients

Stream channel stabilization and restoration has become a formidable industry in recent years with it becoming a billion-dollar industry more than a decade ago (Bernhardt, et al., 2005).

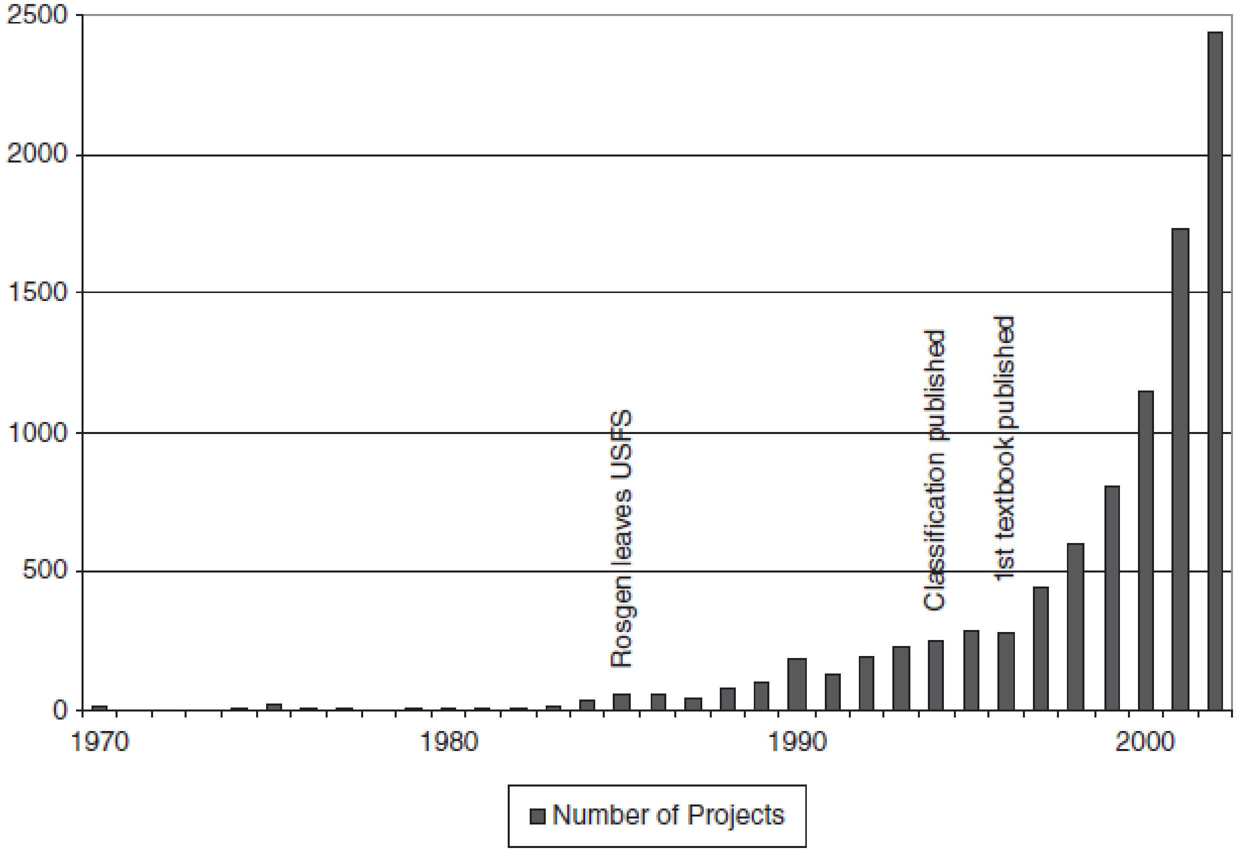
This growth is a result of the growing need to protect economic and environmental interests (Bigham, 2020). As shown later, this industry covers a vast variety of different projects with each kind having different objectives. These can include environmental objectives such as establishing better fish habitats to more hydraulic purposes such as reducing streambank erosion to projecting farmland. One of the large needs that has attributed to part of this industries growth has been the drive to reverse the previous negative anthropogenic effects of the past (Wohl, Lane, & Wilcox, 2015).

However, despite the massive amount of funding that goes into channel stabilization and/or restoration projects, project success is inconsistent. Most of this inconsistency can be attributed to the lack of adequate training, education, and standards available to design dynamic, natural-based systems such as stream restoration projects relative to other scientific or engineering fields (Lave, 2012). Understanding how the people surrounding this field have contributed to this growth is critical to understanding the current circumstances of the practice as well as the steps being taken to improve and advance the practice.

2.1.1 Development of current design criteria, certification, and government regulations

While the practice of stream channel stabilization and restoration has been around since the late 1800's, general sets of objectives that have shaped the practice have evolved from primarily aesthetic, to maintaining navigation and mitigating flood hazards in the 20th century, to more recent recognition of the need to restore ecological function of riverine systems (Wohl, Lane, & Wilcox, 2015). The practice continues to evolve – particularly to achieve ecological-based objectives – and requires a diverse knowledge of various hard sciences. Like any other developing field, especially regarding ecological engineering, the practice of channel stabilization and restoration has been led by observation and empirical testing in the field as opposed to theory (Dale, et al., 2021). The practice has been expanded to what it is today in large part due to legislation and the rise of natural channel design concepts (NCD) put forth by Dave Rosgen. (Lave 2012; Thompson, 2005) (Fig 2.1).

Figure 2.1 The number of stream restoration projects per year within the United States compared to Rosgen's works. Original figure credit: (Lave, 2010) But original data **(Bernhardt, et al., 2005)**.



Despite the boom of activity behind the practice and its evolution of focus from aesthetics to controlling certain objectives, the designs and standards developed during this time do rely on the basic blueprints of the original design (Thompson D. M., 2005). They also remain unable to produce consistent results over a long period of time (Jones & Johnson, 2015). Now while any new emerging field requires trial and error to improve design and mitigate consequences, the learning process to do this has been hampered by lack of monitoring and vague objectives. Therefore, the industry has developed its training, certification, and regulation around these designs without full knowledge of their success and failure (which will be discussed later in section 2.1.4). Unlike most scientific fields, the development of the practice's training and guidelines were not developed by universities and public research agencies (Lave, 2012). To meet the growing industry and its need for guidelines, Rosgen developed both a classification system for stream channels as well approaches for restoring them to a stable pattern, profile and dimension (Natural Resources Conservation Service, 2007). In addition, Rosgen developed a series of training and education workshops targeted to teach stream practitioners in his methods. This design guidance provided step-by-step instructions for the process of designing different types of structures and the training was the only education that was largely available within the United States (Lave, 2012). This step-by-step process could be used universally in any location or region. Additionally, the designs were developed by using natural structures such as trees and rather than the usual concrete structure. In the early, 2000s the NCD approach was appealing for regulatory agencies (Lave 2012). The combination of structured universal guidelines, training and certification was immensely valuable to a field that was otherwise lacking for practitioners. Besides practitioners, of whom thousands have been trained by this method, it also had the backing of several prominent experts in the field (Malakoff, 2004). One such expert was geomorphologist and Professor Luna Leopold. Luna Leopold was the head of the USGS Water Division, a member of the National Academy of Sciences, and is a holder of the National Medal of Science (Lave, Doryle, & Robertson, 2010). The support of this influential expert allowed these methods to be used in the field despite pushback from other designers within the US Army Corps of Engineers (Lave, Doryle, & Robertson, 2010).

As the industry was developing in the early 2000s, federal regulatory agencies looked to provide stronger guidance for the practice. Rosgen’s NCD method was adopted by federal agencies such as the Environmental Protection Agency (EPA), the National Resources Conservation Service (NRCS), the U.S. Forest Service (USFS), and the U.S. Fish and Wildlife Service (USFWS). This was due to a combination of Rosgen’s method providing a specific step-by-step design compared to the more arbitrary criteria provided by universities and the regulatory bureaucrats not being experts in the field (Lave, Doryle, & Robertson, 2010). Now backed by expert scientists, federal agencies, and the practitioners, Rosgen’s NCD method has become a recognized standard for the practice.

2.1.2 Clients and Projects

As stated beforehand the industry of stream restoration and stabilization has grown into a billion-dollar industry. Each stream stabilization and restoration project can vary wildly depending on the location, the client, project objectives (Tullos, Baker, Curran, Schwar, & Schwartz, 2021). One client may be a local community who has an eroding bank that threatens their property, while another client may be state organization who is looking to improve the water quality of a watershed (Princeton Hydro, 2012; Jacobs Creek Watershed Association, 2009).

Each project comes with its own requirements and permits depending on the location within the United States. While federal regulations can apply broadly, local designers still have certain control over how they can design a project (Lightbody, Radspinner, Diplas, & Sotiropoulos, 2010; Tullos, Baker, Curran, Schwar, & Schwartz, 2021). Despite this relative freedom, clients still influence how practitioners design projects. The first major cause of this is funding. Stream restoration and stabilization projects can cost upwards of millions of dollars

(Bernhardt, et al., 2005). This expense provides significant financial risk on the client. Therefore, to mitigate this risk, typical design projects for these jobs require some level of certification or proof of concept from the designer to implement. Being that one of the few, established certifications available is Rosgen's NCD method, many clients will require designs to follow his method (Lave 2012). Such requirements are not just limited to local clients as many permitting agencies will require Rosgen methods in the design to implement the projects at all (Tullos, Baker, Curran, Schwar, & Schwartz, 2021). Innovative projects have a problem with "buy-in" with clients and regulators as new techniques have less trust than simpler methods with historical precedent (Tullos, Baker, Curran, Schwar, & Schwartz, 2021).

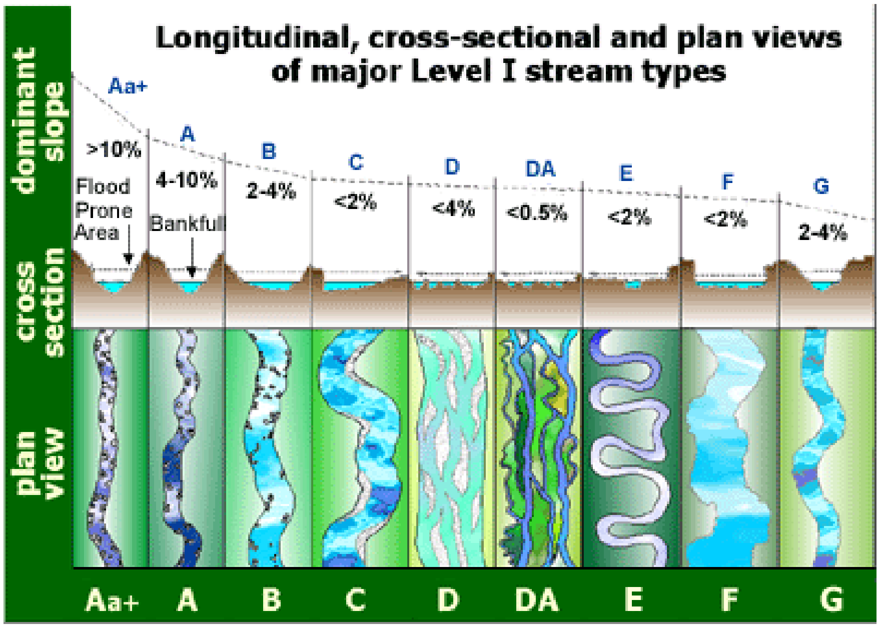
Besides regulations, the needs of the client can also affect the project itself. Stream restoration projects can be designed to address a diversity of different problems such as channelization, to floodplain reconstruction to dam removal (Wohl, Lane, & Wilcox, 2015). The type of structure or design depends heavily on the ultimate objective of the project. This change in objectives also influences the definition of success. These objectives in stream restoration and stabilization are often vague and therefore the success and failure are often subjective (Jones & Johnson, 2015). If a project's objective is to increase the stability of a stream so that it does not migrate into important property, then success will be determined simply on whether the river migrates and if any more valuable property is lost. However, if a project focuses on habitat restoration of a stream, then the goal of the project might be to assist in developing a healthy migrating stream. The results of these two projects are completely different and yet can both be considered successes due to their differing objectives (Thompson, et al., 2021). However, if these projects were evaluated based on the criteria of the other, they would be seen as failures. Additionally, while there can be many benefits to developing a successful restoration project such as improving the ecological health of the site, the societal viewpoint of a restoration project is often asthetics (Wohl, Lane, & Wilcox, 2015). This can lead to a scenario in which a client is ill-informed of the overall purpose of a project therefore the determination of its success (to the client) may not be based on function, but appearance.

Finally, clients influence the design through the budget available to complete the project. Due to the extreme costs, some clients may not want to pay for tasks they deem as not necessary for the completion of the project. An example is pre- and post-construction monitoring. While scientific literature and agencies do encourage post-construction monitoring, some clients are not willing to provide the amount of funding required for long-term monitoring (Wohl, Lane, & Wilcox, 2015). This becomes a problem as a large part of improving current designs and methods requires post-construction monitoring (Moerke & Lamberti, 2004; Jones & Johnson, 2015; Wohl, Lane, & Wilcox, 2015; Rubin, Kondolf, & Rios-Touma, 2017; Smith, 2021).

2.1.3 Current Approaches to Stream Channel Stabilization and Restoration

While the Rosgen design is currently seen as the default method in river restoration and stabilization design, it has been seen controversially amongst informed scientists for multiple reasons (Lave 2012). While there was a gap formed in the 1990s and early 2000s between scientists and practitioners, it has narrowed in some respects (Wohl, Lane, & Wilcox, 2015). However, the controversy between the two will still be discussed here. Rosgen's methods are based upon three major ideas that he has developed (Lave 2010). The first is the Rosgen classification system. This system categorizes types of rivers alphabetically (Aa+, A, B, C, D, DA, E, F, and G) based upon the plan view, the cross section, and the slope. Figure 2.2 illustrates the process (U.S. Environmental Protection Agency, 2022).

Figure 2.2 Rosgen Stream Classification System



The classification system has been criticized for several reasons. The data gathering process to determine a type of river can result in incorrect classification, or two different rivers could be classified as the same type but behave differently (Simon, et al., 2007). Thus, while they are treated similarly in design the results may be completely different. The second is the source of the information. In the history of geomorphology two systems of describing fluvial landscapers were formed. One was from a scientist name Davis and the other from Grove Karl Gilbert (Simon, et al., 2007). While Davis' method was popular at the time it has since been considered obsolete by scientists due to its simplicity. Rosgen's method of classification is reminiscent of Davis' method due to its simplicity. The second Rosgen method is a set of reach-level techniques for implementing restoration designs. The third method is a step-by-step design guideline that can be used anywhere in the United States. The problem with these two methods is that the approaches simplify the complexity of a river system (Simon, et al., 2007; Lave, 2012). These applications are made with the assumption that this can be done anywhere and succeed with minor changes without regarding several important factors of the watershed and the conditions upstream and downstream of the reach and how the river has been changing over time. By not regarding certain factors upstream, such as land use, or possible structures, such a bridge, this could impact the overall success of a project. Another criticism of traditional methods is how they encourage practitioners to alter a naturally migrating stream and attempt to prevent its natural movement across a landscape (Florsheim, Mount, & Chin, 2008). This is determinantal to the ecosystem of the river. However, the main challenge to Rosgen's methods is how little of it draws upon existing scientific and engineering literature (Simon, et al., 2007). The data used to develop his methods remains unavailable and his writings have not been peer-reviewed (Lave 2012). In short, Rosgen's methods are a primary source in a scientific field for practitioners despite lacking proper scientific deliberation.

Despite this pushback on Rosgen's methods, they were still widely used as universities did not provide education on training and did not provide alternative design methods (Lave 2012). By the time methods were developed, Rosgen's methods had already been ingrained into the industry. Much of this can be attributed to the clients requiring Rosgen's NCD. If the client requires Rosgen's methods, then newer less used methods will not be developed or explored (Wohl, Lane, & Wilcox, 2015). This has caused a disconnect between the scientists and the practitioners (for analysis of practitioner's reference section 2.1.4). This develops a need for scientists to communicate to non-scientists. Effective communication from scientists who understand the subject to non-scientists like practitioners, clients, and regulatory agencies is critical to improving design and implementation (Rhoads, Urban, & Herricks, 1999). This communication also benefits scientists as well, understanding challenges of non-scientists such as constraints of implementation (funding, data availability, training, etc.) allows for compromise. Scientists and engineers can then develop methods that both is honest to the science but provides enough structure to practitioners.

In recent years, communication between scientists and the practitioners has improved (Wohl, Lane, & Wilcox, 2015). Criticism over Rosgen's NCD and his other methods has steadily decreased. Additionally, practitioners have also bridged the gap between the two by implementing monitoring (Wohl, Lane, & Wilcox, 2015). This was a very popular criticism from scientists and practitioners have begun to implement it more over time (although it is still lacking). To improve current design guidelines, scientists and engineers worked with practitioners and developed a stream restoration body of knowledge and accompanying recommended educational curriculum, to effectively train practitioners (Niezgoda, et al., 2014). To develop these guidelines, the authors (scientists and engineers) identified current education trainings, determined disciplinary knowledge and skills that would be necessary for practitioners to adequately participate in the field, and developed a basic body of knowledge practitioners require. The body of knowledge encompasses several areas of competence from the sciences such as fluvial geomorphology and ecology, to engineering design practices such as analytical techniques and restoration design to more social skills such as ethics and communication (Niezgoda, et al., 2014). While this is an improvement and step in the right direction, there are still hurtles that affect the practices' ability to evolve. One of which is monitoring. While scientists are quick to encourage an increase of monitoring, there is still little participation amongst researchers to do the monitoring themselves due to lower publication potential of long-term monitoring case studies and minimal funding for such research (Wohl, Lane, & Wilcox, 2015). There has been some increase in monitoring but not enough to meet the need to inform design approaches from the success and/or failure of previous projects (Wohl, Lane, & Wilcox, 2015; Bigham, 2020; Smith, 2021).

2.1.4 Practitioners

The previous three sections detailed how the practice of stream channel stabilization and restoration has been impacted by regulation, clients, and scientists. This following section illustrates the impacts of these on practitioners as well as what the current state of the practice is. In the previous sections it was explained that regulations clients and scientists all play a role on the guidelines and standards used in the industry. Currently, the most common design guidance used is based upon Rosgen’s NCD method (Wohl, Lane, & Wilcox, 2015). However, specific design guidance for structures used as part of NCD or other restoration approaches is lacking. For example, a survey of practitioner experiences with in-stream flow control structures found that the lack of clear design guidelines, as well as the lack of comprehensive theory upon which to base such guidelines, hindered successful implementation (Lightbody, Radspinner, Diplas, & Sotiropoulos, 2010). This results in each practitioner developing habits based on their own experience (Lightbody, Radspinner, Diplas, & Sotiropoulos, 2010; Tullos, Baker, Curran, Schwar, & Schwartz, 2021). If a practitioner had success in the past with a particular design, they are more inclined to use it later despite the possibility that it may be unsuited for the new location (Tullos, Baker, Curran, Schwar, & Schwartz, 2021). Practitioners developing their own habits toward design over time can create tension between them and scientists. Practitioners are unlikely to change their process if a scientist proposes a different method that goes against their current process (Rhoads, Urban, & Herricks, 1999; Tullos, Baker, Curran, Schwar, & Schwartz, 2021). Therefore, it is important to establish more effective communication between scientists and the practitioners to convince practitioners to utilize more effective design processes.

In addition to the variability and ambiguity of current project channel design guidance, determining success is a major problem within the field. Determining success is difficult as the criteria for success depends on the objective of the project, and if the project can be properly surveyed after its construction (Moerke & Lamberti, 2004; Lightbody, Radspinner, Diplas, & Sotiropoulos, 2010; Jones & Johnson, 2015; Wohl, Lane, & Wilcox, 2015). Finally, even if the first two conditions are met, some criteria for success is so vague that it is difficult to determine. In some cases, clients have attempted to file lawsuits against contractors due to the unsatisfactory results of a project but have failed due to inconsistent language used to define failure (Jones & Johnson, 2015). This also reflects a possible reason as to why it remains unclear if the current practice of stream channel stabilization and restoration is improving the structure and function of riverine systems over extended time scales. If failure is unreported, then knowledge from that failure is not gained and progress from that experience is lost.

Also important to a project's success is the surrounding land use. Certain land practices that increase runoff, such as agriculture and urban development, can heavily impact the success of a project (Bigham, 2020; Thompson, et al., 2021). With all of these problems, project success is dependent on the following five factors. The first factor is the land use of the watershed. The conditions of the watershed can impact the success of the project. The second factor was utilizing several structures in the project that address the various physical processes causing channel degradation (Lightbody, Radspinner, Diplas, & Sotiropoulos, 2010). The third factor is the river channel has a width-to-depth ratio. Structures designed and installed as part of the channel restoration and/or stabilization projects in shallower rivers generally have a higher success rate than projects in highly entrenched rivers (Lightbody, Radspinner, Diplas, & Sotiropoulos, 2010; Thompson, et al., 2021). The fourth factor is the riverbed is composed of large particle sizes (although this is when the objective is stability) (Thompson, et al., 2021). The fifth and final factor is the experience of the practitioner (Bigham, 2020). Therefore, while the overall success of the project does have to do with the success of design, the circumstances of the project and the experience of the practitioner make more of a difference. Understanding what a practitioner learns from experience to be successful in design is important to developing better guidelines for the practice.

2.2 Understanding needs of Practitioners

Surveys in the past regarding the practice of channel restoration and stabilization have focused on different goals. In this section, previous surveys will be examined for both their purpose as well as what was determined from them. The goal is to establish a base understanding of what information has been historically collected and what is understood about practitioners and what effects their practice.

2.2.1 Previous Surveys

The first survey analyzed was the paper written in 2005 titled, “Synthesizing U.S. River Restoration Efforts” (Bernhardt, et al., 2005). This paper did not directly solicit practitioners experience, but it did examine historical documentation regarding the practice. They did this by compiling data from 18 federal national coverage databases regarding restoration projects. These databases then removed duplicates and gathered a list of recording restoration projects in the United States. This study was focused primarily on three different factors of the practice. The first was organizing projects into 13 categories based upon the type of restoration effort (example includes water quality and bank stabilization). The second was determining the costs of each project. Finally, the third factor was determining whether monitoring had been conducted. However, it should be noted that not all sources contained monitoring information and the amount of monitoring was also not recorded. These factors were then compared regionally to determine differences in cost and objectives across different regions. The final dataset represented stream restoration projects from seven regions containing 23 states in total. The results of the survey reported the number of projects per 1000km per state, the total cost/1000km per state, the percentage of projects that indicated monitoring was conducted for each state, and the proportion of each type of project for each region.

The second survey analyzed was a paper written in 2010 titled, "River Training and Ecological Enhancement Potential Using In-Stream Structures" (Lightbody, Radspinner, Diplas, & Sotiropoulos, 2010). This survey examined the use of in-stream structure types and hydraulic design criteria. This survey collected responses from 64 practitioners with professional affiliations including both public and private sectors. They determined the location of these practitioners by physiographic provinces. Overall, the paper did make note of differences of structures used based upon the location of the region, how different types of structures were used, and if there were successful trends. This study concluded that rates of project success were higher for projects that used multiple in-stream structures and for projects implemented in channels with high width-to-depth ratios.

The third survey analyzed came from a paper titled, "Defining a Stream Restoration Body of Knowledge as a Basis for National Certification" (Niezgoda, et al., 2014). This paper developed a survey for the explicit purposes of establishing what education and training would be necessary to become a general practitioner. It contained 17 questions in total, with six involving demographics, eight involving education, and three involving certifications. A total of 152 responses were collected through a national conference and two national symposiums. The survey concluded with four major findings. The first was that the backgrounds of practitioners are diverse, and they had acquired their education through several avenues including a traditional college background along with outside training. The second was that multidisciplinary curriculum will be necessary for education. The third was education in topics should include, at minimum, application-based learning. This was defined as, “Use in new situations; apply tools, laws, concepts, and principles.” The fourth and final conclusion was that universities are the most appropriate for teaching the processes and their application to design whereas professional practitioners are best for teaching design, monitoring, and management.

The fourth and final survey examined was from a paper named, “Enhancing Resilience of River Restoration Design in Systems Undergoing Change” (Tullos, Baker, Curran, Schwar, & Schwartz, 2021). This paper used a survey to determine the different types of projects (practices like floodplain reconnection, and stream stabilization), their amount of use, their resiliency (both overall and resistance to climate change), and what concepts (habitat, regulations etc.) affect the “vision” of restoration design. The survey was conducted online though Qualtrics and distributed by listservs to both professional scientists and practitioners. A major finding from the survey was that the main challenge to resilient river restoration was funding. Lack of funding affected modeling during design, post-project monitoring, maintenance, species-specific funding, and the scope of the project. The second challenge was a “lack of focus on geomorphic processes and landscape-scale dynamics” which was how projects are affected by the surrounding landscape and they may be insufficient to combat changing climate or land use. The third challenge was the need for innovation particularly focused on design and regulation. It was stated that the current approaches dictated by regulation, “limit[ed] the use of more advanced and innovative design tools.” Other notable conclusions were that most designs are based on historical flows and that they are required to do some based off permitting agencies (or they do not have better tools).

“The most common practices … were streambank stabilization, analog/reference reach design, and floodplain reconnection (Tullos, Baker, Curran, Schwar, & Schwartz, 2021, p. 3).”

2.2.2 Understanding Limitations of the Practice

As previously demonstrated, communication between practitioners and scientists needs to be improved to improve design guidelines (Rhoads, Urban, & Herricks, 1999). As part of this communication, understanding limitations practitioners face is important to developing improved guidelines. While surveys have been conducted in the past that have covered multiple topics such as educational needs, costs, types of projects used and limitations (Bernhardt, 2005; Lightbody, Radspinner, Diplas, & Sotiropoulos, 2010; Niezgoda, et al., 2014; Tullos, Baker, Curran, Schwar, & Schwartz, 2021), there are still some factors that are worthy of investigation that could impact the field and design.

The first factor is the constraints that practitioners in the field face. While there has been a study that examined major limitations such as funding, this survey included both practitioners and scientists (Tullos, Baker, Curran, Schwar, & Schwartz, 2021). Additionally, there is a need to understand the factors behind those limitations. Using the funding example, in the previous study, funding was determined to be the major roadblock in the field (Tullos, Baker, Curran, Schwar, & Schwartz, 2021). While this is a notable result, understanding where practitioners receive that funding could be an important factor. Other notable factors could be demographics such a location of the practice, as well as type of organization.

The second factor is tools and guidelines. While guidelines have been repeatedly been reported as inadequate, there is a need to understand what practitioners are using and why they are using it. While clients may affect this decision, it could be informative to understand how much influence comes from clients and how much comes from practitioners. Additionally, what models are being used and is there a combination of models being used to inform design? If they are not using models, why not? Finally, what data are practitioners collecting, what do they want to collect, what is stopping them from collecting it, and why? Answering these questions may inform what is missing from the current practice that can be focused on and improved in design criteria. Understanding the data gathered and the different types of tools used in the field as well as their limitations are important in educating future practitioners.

Overall, the goal in developing the survey is to establish a baseline understanding of practitioners. Developing a sense of the how and why of a limitation is just as important as the what. Additionally, understanding the tools utilized in current design as well as their limits can help train future practitioners as well as establish certification for the practice.

Chapter 3 - Methods

This chapter provides on overview of how the survey was created, distributed, collected, and analyzed. The first section will discuss the process of creating the survey, and details how it was designed. The second section discusses how the survey was distributed and collected. Finally, the third section discusses how the survey questions were analyzed statistically.

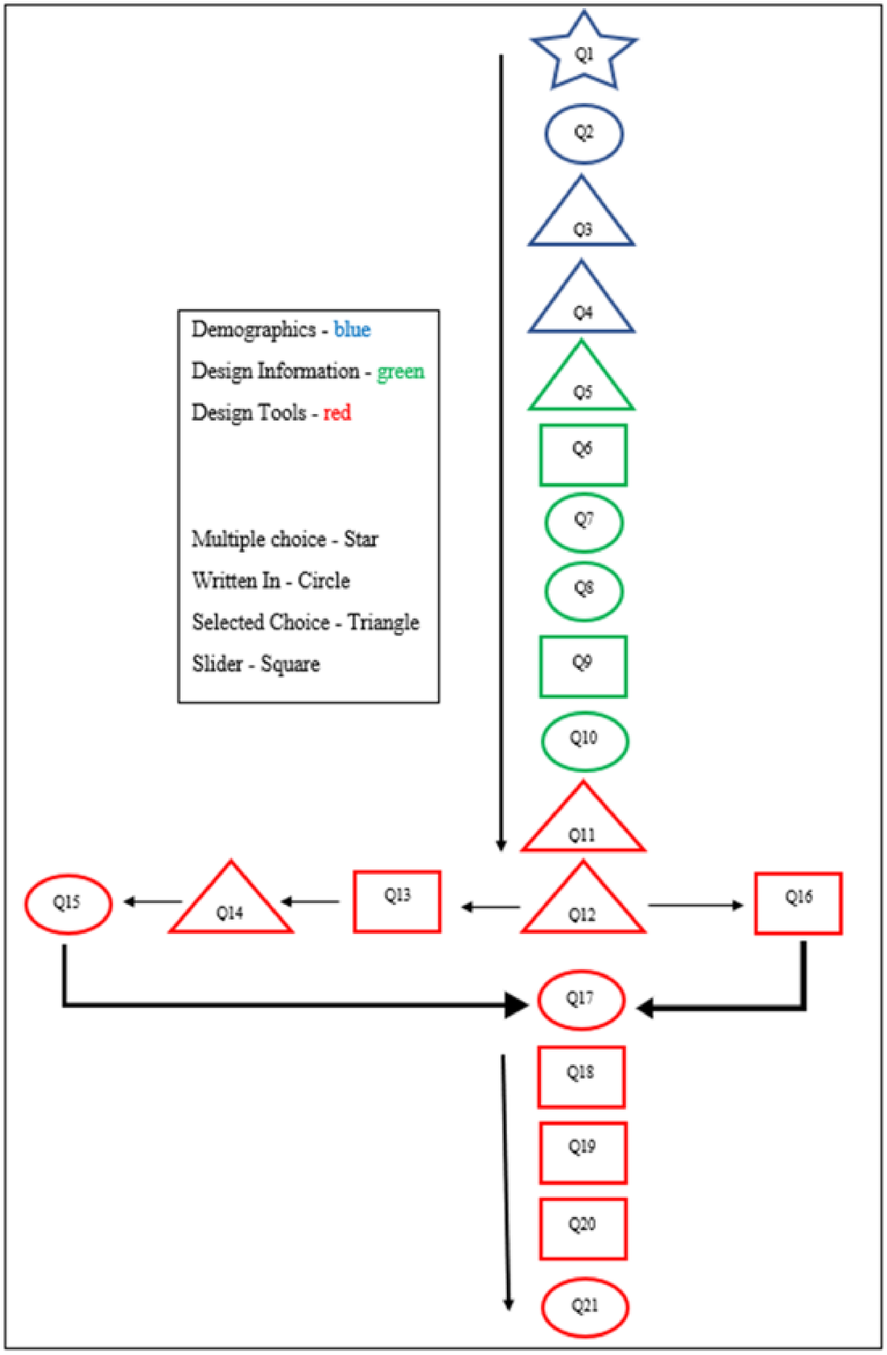
3.1 Survey Creation

The survey, "Streambank Stabilization/Restoration Design Tools & Approaches," was developed in Qualtrics and had 23 total questions. After IRB approval from Kansas State University (in Appendix A), the survey was distributed to 5,000 people on March 4, 2022, through the Resource Institute's listserv. The Resource Institute is a non-profit whose goal is to, "protect and enhance water resources through restoration, education, and project management (Resource Institute, 2022)." The purpose of the study is to examine how regional, economic, and other factors influence approaches to stream channel restoration and/or stabilization design. The intended benefits of this study include improving the understanding of tools and approaches in use by the river restoration and stabilization design community. The survey was intended for experienced designers in streambank stabilization/restoration. Participants could at any time stop the survey and they had the ability to skip questions. It was designed to take anywhere from 15 to 25 minutes. All the above facts were communicated to the potential participants before the start of the survey. If they did not fully complete the survey, the question they did answer were still considered. The survey was closed on March 28th, 2022 but allowed those who were currently conducting it to finish (with April 4th being the last entry for the survey). The actual questions as well as the format of the survey can be found in Appendix B. Overall the survey can be characterized into two different labels, the question topic and the question type. The first is the topic of the question. This can be broken down into demographics, design information, design tools, and follow-up contact preferences. The second label is the question structure. The questions in the survey were structured as multiple choice, written in, selected choice (this is multiple choice, but the respondents could select multiple answers, whereas multiple choice question could only select one), and slider questions (i.e., on a scale of 0 to 100). Selected questions are important to understand on how they function. Several questions use this method and therefore could not be analyzed via a pie chart because respondents could choose several answers and therefore the percent of each option chosen would not be 100%. This overall survey characterization scheme is illustrated in Figure 3.1 and are discussed further in Sections 3.1.1 and 3.1.2.

Branch logic tools in Qualtrics were employed to link some of the questions to previous questions, so that if the participants answered a certain way, they would be given a set of related questions and not receive other survey questions. As an example of branch logic used in this survey, respondents were asked if they use computer models in the design process. If they responded: “I do not use computer models,” they would be directed to a set of questions regarding why they do not use models, but they would then not be given questions about why they use a particular model. A diagram of the survey demonstrating branching question pathways as well as the type of questions is shown in Figure 3.1. The arrows at Question 12 indicate a branching structure created with Qualtrics branch logic tools.

At the conclusion of the survey, participants were given the option to provide contact information if they would be willing to be contacted for with follow up questions. After the survey was collected and analyzed, a second follow up questionnaire was given to those individuals that had given permission to be contacted. These follow up questions were tailored to each individual participant to either expand or clarify their responses in the original survey.

Figure 3.1 Outline of survey with types of questions.



3.1.1 Topic Breakdown

The topics of demographics, design information, design tools, and follow-up contact preferences are all follow in the order presented (Figure 3.1). This organizational structure was chosen for two reasons. The first reason was to present the simpler questions first. Demographics are generally easier questions to deal with such as location of practice, and what organization one works for. If a complex question was presented first, it may prevent respondents from continuing the survey. The second reason was to present the more spatial questions first. Demographics questions, such as location, was important to determine if there were regional differences. These two reasons where why demographics was presented first.

3.1.1.1 Demographics

Demographics played a major role in writing the survey as it was of interest to understand the extent to which such demographic features influenced channel restoration and stabilization design approaches. The primary demographic factors solicited through this survey were experience, organization type (private, government agency, or non-profit), and location. With respect to the latter, there was concern over how spatial patterns should be determined. Such as, do state borders or natural borders determine factors in design? Is it both either or neither? As a result, two different maps were utilized as questions for the survey. One was state borders and the second was physiographic provinces. The reason why physiographic provinces were selected was due to other surveys utilizing it in the past (Lightbody, Radspinner, Diplas, & Sotiropoulos, 2010) and that channel assessment and associated design criteria often follow physiographic regions.

3.1.1.2 Design Information

The design information category was focused on several factors including objectives of projects, cost of projects, funding of projects, size of projects, how time is distributed, and guidelines used. The project objectives question was structured as a selected choice question and presented respondents with a list of 12 potential objectives including both physical (e.g., bank stabilization) and ecological (e.g., fish passage, in-stream species management) outcomes. The list of project objectives was based on a previous review of design objectives in channel restoration projects done by (Bernhardt, et al., 2005). The "how time is distributed" (see Fig 3.1) question refers to how much time a practitioner is given to certain aspects of the project such as data collection or post-construction monitoring. The cost of project refers to how much each project cost for its given size. The funding for projects is the source of funding for the project including how often it come from a certain source such as state funding and how much is provided from that source. The "guidelines used" question refers to what specific guideline literature practitioners use for their design.

3.1.1.3 Design Tools

Design tools section focused on two items: Models and data. In this case, the specific models examined were hydraulic models. Now while other models, such as hydrology, can be used in the field, the primary concern was if several models were being utilized for one subject and if so, why. As for data, the focus was what data is used for models, as well as what can they gather and what they can't and why. This was to determine possible limits of data gathering.

3.1.1.4 Follow-up Contact Preferences

The final question was strictly focused on whether the respondent wanted a follow-up. If they agreed, they would provide contact information that would best suit them.

3.1.2 Type of Questions

The different types of questions were multiple choice, short answer, selected choice, and slider scale. Multiple choice provided respondents with a list of choices from which only one could be selected. Short answer questions prompted the respondent to write in their answers with the only limit being the amount of text, they could put in. Generally, these questions were given with the allowance for “multiple lines” to an “essay box”. Selected choice was where the respondents were given several options to select, and they could pick any number of them. Finally, the slider scale questions\ asked respondents to rate their responses on a scale of 0 to 100. For example, a slide scale question could be framed as, “how is ______ divided amongst the following factors?” Then each factor had to be rated on a scale from 0-100 that indicated percentage. The sum of all the factors should be 100. An example question is “What percentage of your funding comes from the following sources?” Then the options given were private, donations, federal, state, and other, the latter of which allowed the respondent to write in a factor that was not included in the list. The respondent was expected to indicate how much of their funding came from each source. Thus, one person could indicate 25% federal and 75% private. This question was designed to quantify certain questions and relate factors to each other instead of providing vague values from 1-10 as in a Lickert Scale.

3.2 Survey Analysis

After collection of the data from Qualtrics, it was downloaded into Excel and examined in three different ways. The first was a general examination where questions were read thoroughly. The second was using general statistics on the slider questions to calculate descriptive statistics. The third was a more in-depth correlation analysis. This correlation analysis was used to examine spatial relationships between certain factors such as what type of source practitioners were using or if certain organizations differed depending on location.

3.2.1 General Gathering

Once it was gathered into Excel the data were examined to determine if participants had correctly filled out the survey. Certain conflicting details would be noted and then investigated. For example, the states selected to indicate where an individual practitioners' company worked did not always align with the physiographic region that they had said they had personally worked in. An example of this discrepancy was a practitioner who indicated their company only practiced in Wyoming and Colorado, but who also marked a physiographic region located in Oklahoma. Another example includes a respondent who, while not actively participating in the practice, did currently work for a company that did and was able to describe in detail what tools and guidelines the company used. This participants' answers were marked and checked to see if answers were complete enough to be used. For some questions, certain answers were removed from the examination due to its inability to be used. This was only apparent in write in questions where the respondent did not clarify their answer enough to be used. Examples included not providing enough information on what source they used for designs or not providing descriptive units to indication how their budget scaled to a typical project. Besides this general search for possible errors, the other purpose of the general gathering was used for reading the written in answers and examining repeated phrases or thoughts. If there were instances where several respondents gave the same answer, then the message was simplified to the same theme. For example, if several respondents mentioned that they were lacking data on the water table for a project, and others mentioned lacking subsurface flow data, they would be filed under the same category. After this general gathering and examination of the results, statistical methods were used as described in the following sections.

3.2.2 Descriptive Statistics

After initial survey data review as described in Section 3.2.1, simple statistics were used to characterize distributions of numerical data. Numerical data included survey responses such as cost, and year of experience. For some questions, like how much a project cost per linear foot, the written in answers did not provide effective answers because they were either labeled incorrectly, or the range provided could have described whole projects rather than a unit of $ per linear foot. As a result, deeper analysis could not be done for the question. However basic analysis was done. If the respondent provided a range, then the minimum and maximum of that range was counted then the average and median values for the minimum and maximum values could be found.

Slider questions were also analyzed; however, there were additional steps employed prior to analysis. First, these questions had to have some answers edited. These questions required respondents to input how much each option was valued and the sum of the values had to equal 100. For example, in the funding question, various options for funding sources were state, federal, donations, private, and other. Regardless of an individual' funding allocation, the important part is that it ends up adding to 100%. As a result, each answer was evaluated to see if the answers totaled 100. If not, the answer would then be marked and then their answer would be edited so that the total would be 100 but the relative weight between their answers would be the same. This weighting was accomplished by dividing by the respondent's entry for each option by the sum of the total and then multiplying by 100. This ensured each option maintained its weight, but it would be out of 100. After this analysis the mean and median were determined for each option of the slider questions.

3.2.3 Spatial Analysis

Prior to conducting spatial analysis, it was of interest to understand if the collected survey data provided a representative sample of stream restoration and stabilization practitioners. While the actual spatial distribution of stream practitioners was unknown, we used results of prior surveys to get a general sense of spatial representation. Firstly, the survey was compared to previous surveys based upon the two questions related to location. The first was, “What state(s) does your organization design projects for? Select all that apply.” The second was, “What Physiographic Region(s) of the United States do you do work in?” To compare the respondents based upon physiographic region the survey was compared to the results from a practitioner opinion survey related to flow training structures common to streambank stabilization and channel restoration designs (Lightbody, Radspinner, Diplas, & Sotiropoulos, 2010). The authors had used the same set of 24 physiographic provinces utilized in this survey and so the relative number of responses from each physiographic region between the two surveys were compared using the Spearman's Rank Correlation Coefficient (Higgins, 2004). This test was conducted in Microsoft Excel. The test compares two lists by rank and then determines the possibility that the twos correlation is by chance. To do the test the counts for each survey were ranked from 1 to 24 (with 1 denoting the highest number of counts) based upon how many respondents were from each region. If certain counts tied, then the rank for the tied data was averaged. For example, if there were two regions with five respondents each located there, and the next rank in line was 5, then the rank given to both would be 5.5. This is due to rank 5 and 6 having to be averaged. The next rank after this would then be 7 (unless it tied as well). After it is ranked, equation 1 below is used to determine the coefficient, R.

Equation 3.1 Spearman’s Rank Correlation Coefficient

$$R = 1 - \left(\frac{6\sum d^2}{n^3 - n}\right)$$

Here, *n* represents the number of total ranks (in this case 24 for each physiographic region) and *d* represents the difference between the ranks. The result of *R* on a scale from -1 to 1, with -1 representing a negative relationship and 1 representing a positive relationship. The closer *R* is to 1 or -1, the stronger the correlation. Finally, the number of degrees of freedom, or the number of ranks minus 2, does have a determining factor on whether the correlation is strong or not. Once *R* is calculated and the degrees of freedom are found, a graph can be used to determine the significance level of correlation coefficient (Barcelona Field Studies Centre, 2022). If the significance level is below the 5% line, then the hypothesis must be rejected as the correlation is less than 95% reliable and therefore, if the two are correlated, then it cannot be said with above 95% confidence.

Besides physiographic regions, states rank was also compared using the Spearman’s Rank Correlation Coefficient. This was done with the only other stream practitioner survey identified in which practitioner responses were differentiated on a state (Bernhardt, et al., 2005). This survey had 23 states and reported responses as a number of projects per 1000 feet of stream length. Due to this difference in reporting, a direct comparison was not possible; however, the relative ranking of states based on number of stream projects was compared to ranking of number of responses per state from this study for the same 23 states counts.

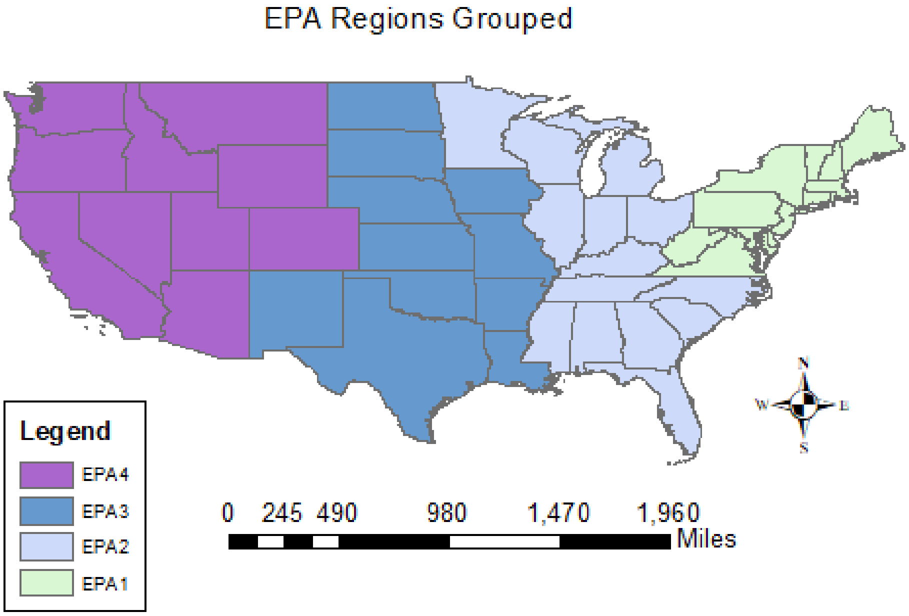
Finally, the states, regions and their corresponding counts were compared to the other surveys via linear regression. By graphing the relationship between the two surveys, finding the line of best fit, and by finding the R^2, the strength of the relationship between the two can be found (Agresti, 2007). If the R^2 is not close to 1 or approaching, it then the relationship between them is not strong. Linear regression was also conducted via Microsoft Excel.

In addition to comparing the data to previous surveys, both states and regions were compared to their shared population. The data was taken from ESRI online population data regarding the population for each individual county, then the state population was derived from the total sum of its counties. The physiographic population was derived from the same source. By using ArcMap (10.7.1), the counties that intersected with the physiographic regions had their population density averaged and then multiplied by the total area of the region. This gave an estimated population for each physiographic region. Once their populations were determined, the populations for the regions were compared to the responses from the survey. The comparisons were done using Spearman’s Rank Correlation Coefficient and linear regression.

After the comparisons with the previous two surveys, the spatial information of the state and physiographic regions was compared to different design factors. There were many states for which the number of survey responses were small and not adequate for analysis; therefore, states were combined into two different types of regions. The first was based upon EPA regions and were grouped into west, central, middle east, and eastern coast regions (United States Environmental Protection Agency, 2022). These regions are demonstrated in Figure 3.2. They were grouped this way to account for a higher level of counts to conduct a chi-squared test (which will be discussed later). Additionally, the EPA regions were selected due to how practitioners may be influenced by governmental organizations. The second was based upon the

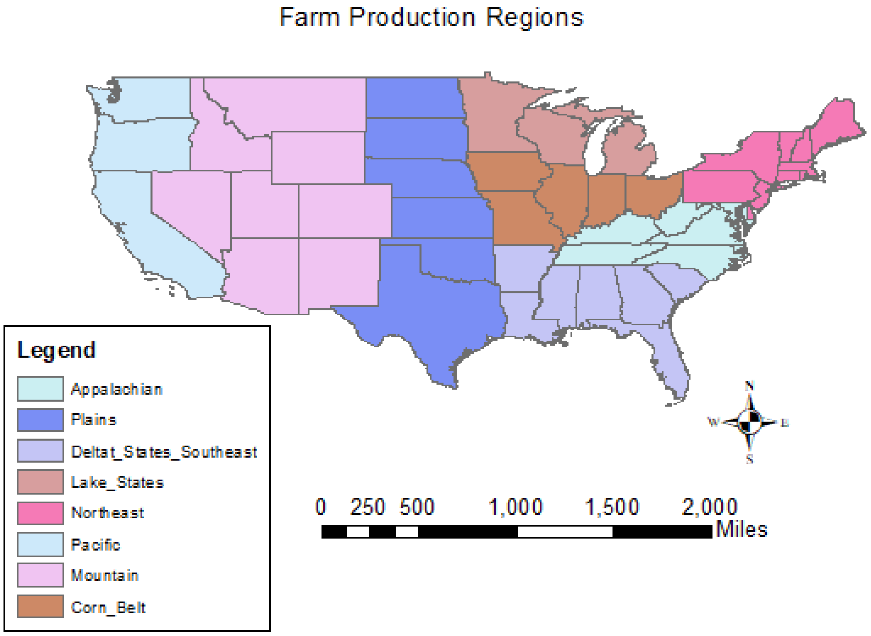
USDA farm production regions (Heimlich, 2000). This was to separate the practice to determine if there was any correlation between land use and other factors. This was chosen as land use is a major factor of success in stream restoration projects (Smith, 2021). This map is also shown below in Figure 3.2.

Figure 3.2 EPA regions grouped



After these groups were created, they were used to determine potential correlation between location of practitioners and the design guidance sources. For this question each induvial source was noted and placed into different categories. Initially they were placed in categories of “Rosgen”, “Internal Company Documentation”, “Federal”, “State”, “Local”, “Literature”, and “Unknown”. Due to Rosgen’s influence in the industry (see section 2.1.3) these categories were then lumped into “Rosgen” and “Not Rosgen” to examine if his influence changed spatially throughout the United States. “Rosgen” sources were if the respondent had used any source that had Rosgen influence and “Not Rosgen” sources were if the respondent did not have a source that had Rosgen influence. “Rosgen” influence includes both direct Rosgen sources such as Wildland Hydrology, and NCD, or non-direct such as the source itself includes Rosgen as a source for their documentation. Everyone was then placed into categories of whether they did or did not use Rosgen.

Figure 3.3 USDA Farm Production Regions grouped



Finally, the Fisher’s Exact Test was applied to test for association between region and type of design source. Fishers exact test is a statistical test used to determine if there are nonrandom associations between two categorical variables (Agresti, 2007). To do the test each individual person in the test can only be counted twice. Additionally, this test can be conducted despite low counts, therefore it could be used for regions with less counts than others test like the Chi-Squared Test (Agresti, 2007). An example of the Fisher’s Exact Test is shown below:

Figure 3.4 Fisher's Exact Test for Corn Belt Region

		Rosgen?	
	Corn Belt	Yes	No
Are they in the region	Yes	9	4
	No	33	7

This illustrated table is an example of a 2x2 contingency table developed for one region in the USDA farm production map. The columns represent whether individuals use Rosgen, and the rows are whether the individual is within the region. The test then compares these two options to determine if there is an association between the two variables. If the null hypothesis is not rejected then the variables are independent, if the test is rejected the variables are not independent. Therefore, overall, the test is evaluating whether there is association between the location and if Rosgen's methods are being used. This test was conducted through MATLAB (version R2022a) and the code can be found in Appendix D.

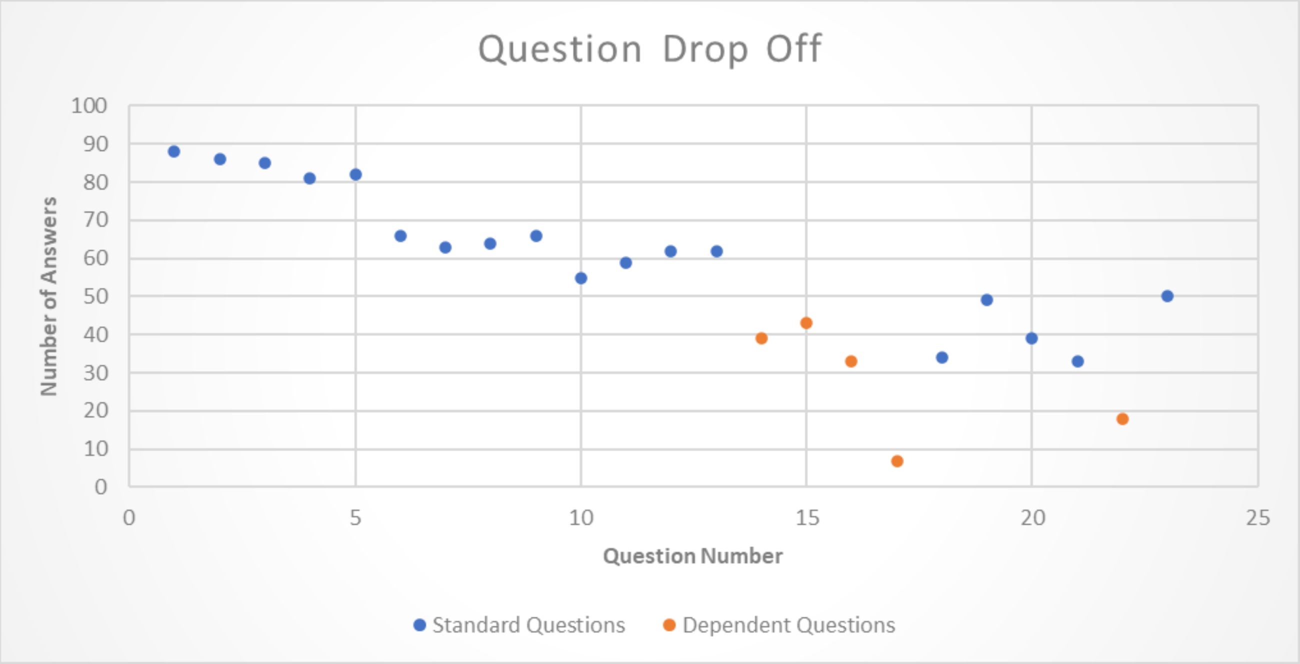
Chapter 4 - Results and Discussions

The survey, “Streambank Stabilization/Restoration Design Tools & Approaches" was closed by March 28th but allowed participants to finish their surveys by April 4th, 2022. After this date, the results were downloaded and analyzed with the following results.

4.1 Initial Evaluation and Summary Statistics

In total, there were 98 respondents who participated in the survey. However, not all the participants completed the survey. Out of the 98 total respondents, 50 completed the survey with 48 partially completing. Participation dropped most significantly after Question 13 in which respondents were asked, “Do you use computer models for your Pre-design/Design process? And if so, what kind do you use?” However, this is partially a result of questions 14, 15, 16, 17, and 22 requiring certain answers beforehand to answer. If they had answered question 13 with, “I do not use computer models.” As a result, many participants did not receive certain questions. The number of responses for each question is shown in Figure 4.1 with the orange dots representing the questions that required previous questions to be answered in a certain way.

Figure 4.1 The number of people who answered each question.

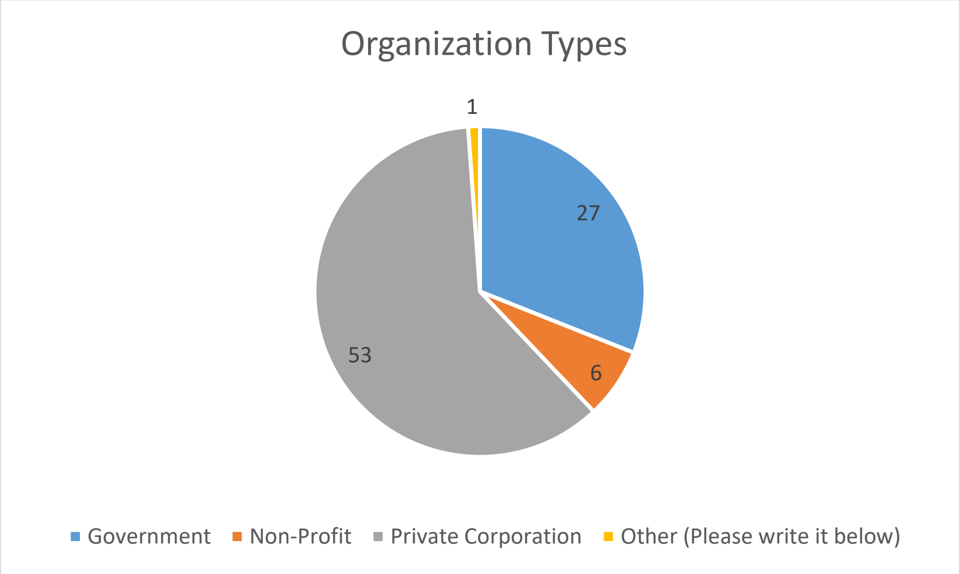


It can be noted that certain questions had a higher count than others despite being later in the survey. Respondents were allowed to skip questions in the survey and were not reminded to come back and complete the questions. Additionally, the time it took to take the survey was recorded, but it did include times in which the window for the survey was open but not necessarily viewed. This resulted in the highest recorded survey time being 79 hours. The median time recorded to take the full survey (people who completed the survey) was 17 minutes and 33 seconds.

4.1.1 Organization Types

The organization types provided in Question 1 to ascertain the types of organizations for which stream practitioners worked were "Private corporation", "Non-Profit", "Governmental", and "Other". Figure 4.2 shows the distribution of the respondents by organization type.

Figure 4.2 Number of respondents for each organization type.



The overwhelming majority of the respondents came from private corporations (61.63%) with this option being chosen almost twice more compared to the second most chosen option (Government 31.40%). The “Other” category was self-employed.

4.1.2 Experience of Practitioners

The range of experience for the practitioners was wide with the longest experience being 50 years and the shortest being less than one. The distribution of the experience is shown in Figure 4.3.

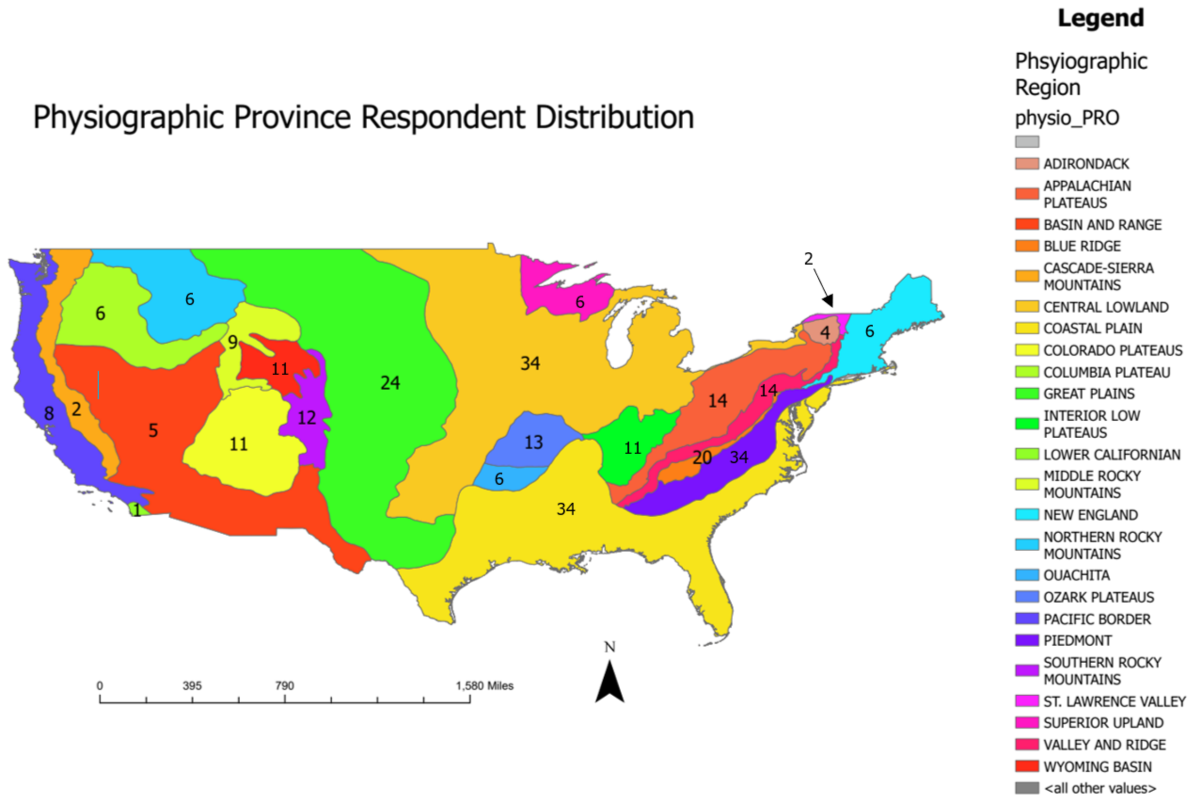
Figure 4.3 Number of respondents for each organization type.

This distribution is non-normal and skewed left, with the average experience of practitioners being 15 years and the median being 14 years. The largest two groups are those with less than 5 years and those who have 19 to 21 years of experience. Therefore, most of the practitioners surveyed had relatively less experience in the practice.

4.1.3 Spatial Distribution

The range of locations for the respondents was vast. All states were represented except for Pennsylvania and every physiographic region was also represented. The physiographic regions are shown below in Figure 4.4. The numbers within each region represent the number of respondents for that given region. The table in Appendix C is notes the overall counts for the regions as well as the possible (-) and (+) for respondents that had listed regions that appeared contradictory to the other answers, as was detailed in Section 3.2.1 of the Methods to reflect suspected erroneous entries

Figure 4.4 Map of Physiographic Regions with number of respondents per region.

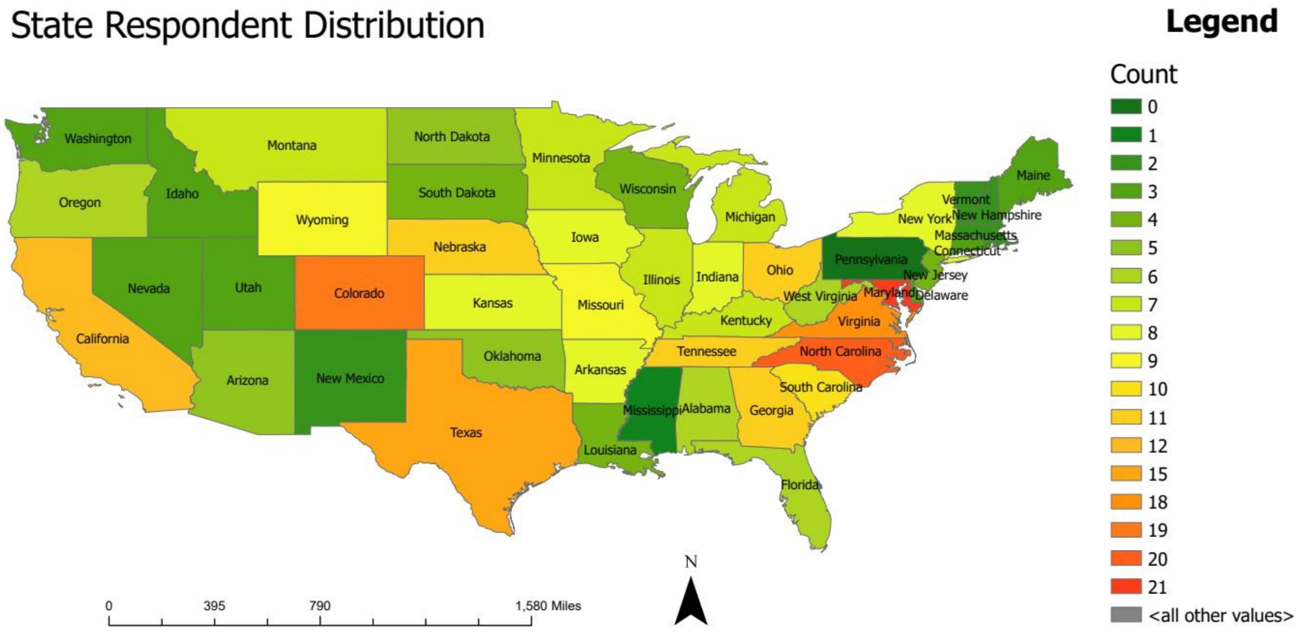


The highest number of respondents for the regions was a three-way tie between the regions of Piedmont, Central Lowland, and the Coastal Plain. The lowest represented region was the Lower Californian region followed closely by the St. Lawrence Valley and Cascade-Sierra Mountains. However, these results may change do to the possible (+) and (-). One of these could be the Columbia Plateaus region. If it had four answers subtracted from its total, it would drop into the lower section of represented regions. Comparing the results between the physiographic region and past surveys using Spearman's Correlation Coefficient revealed that the relationship between the two had some correlation but not at a confidence of 95%. While there were some shared characteristics such as high representation from the Central Lowland, Coastal plain, Piedmont, and Appalachian Plateaus region, there were discrepancies in representation from the

Cascade-Sierra Mountains, the Columbia Plateau, Colorado Plateaus, Interior Low Plateaus, and Wyoming Basin regions this survey and previous surveys. The Cascade-Sierra Mountains, and the Columbia Plateau had more cases in the survey conducted by, "Development of Design Guidelines for In-stream Flow Control Structures." (Radspinner R. R., 2009). Which is later referenced in the paper, "River Training and Ecological Enhancement Potential Using In-Stream Structures" (Lightbody, Radspinner, Diplas, & Sotiropoulos, 2010). While the other three regions had much less relative to this survey. Geographically, the Cascade-Sierra Mountains and the Columbia Plateau are in the western U.S. near or in California while the Colorado Plateaus and Wyoming Basin fall within Colorado and the Interior Low Plateau are in the east near Tennessee. Therefore, this survey has a lower representation of stream professionals practicing within physiographic regions of California than previous surveys but represents practitioners within Colorado and the eastern U.S. to a greater extent. The linear regression test also proved a weak correlation. Using the raw counts of both surveys resulted in a R^2 of 0.3521 which indicates a poor relationship between Radspinner's 2009 survey and the results gathered in the survey.

The total population of each region was also examined as a potential explanatory variable for the number of survey responses obtained from a given region. In other words, it was hypothesized that more populous regions would have a higher number of survey respondents. Using both Spearman's Coefficient as well as linear regression demonstrated a very weak relationship between population and the location of practitioners. The test was conducted between results of the survey rank and the ranks of the population and the population density. All Spearman's coefficients were 0.51 or less, indicating the correlation was positive and insignificant. Linear regression between the same factors as well as comparing the respondents per area of the region vs the population density showed similar results. Linear regression between population density and the survey count had a R^2 of 0.004 and the respondents per area of the region vs the population density had a R^2 of 0.0282. Both low R^2 values indicate population metrics have poor explanatory power. The strongest relationship demonstrated was between the total population for each region and the number of respondents for the region, which had a R^2 of 0.52. This result also indicates that the number of survey respondents from a given region was positively correlated with the population, but that there was still a substantial portion of unexplained variability (nearly 50%) in the regional distribution of survey respondents. As for state distribution, the overall results of the survey distribution are shown in Figure 4.5.

Figure 4.5 Survey State Distribution



Overall, the greatest number of responses came from Maryland, North Carolina, Colorado, and Virginia, which the highest, Maryland, was represented by 21 respondents out of the 85 who answered the question (24.7%). The fewest responses came from Pennsylvania, Mississippi, Massachusetts, Rhode Island, Hawaii, New Hampshire, New Mexico, and Vermont which each accounted for fewer than 3 counts. Comparison of this survey to the previous survey by (Bernhardt, et al., 2005) was limited as the Bernhardt survey only listed responses from 13 total states. In addition, results from this study were reported as the number of projects per 1,000 km of stream rather than actual number of projects of practitioners. Nevertheless, these 13 states were compared. The results of the Spearman's Correlation Coefficient test and the linear regression test were similar. The coefficient values for each of the following relationships are shown in Table 4.3. Overall, the correlation between all factors is small except for the representatives and the population. So, while there is little correlation between the number of projects and population/population density or between practitioners and the number of projects, there is correlation between the general population of the state and the number of representatives from the survey who practice in the state.

Table 4.1 Results of State Correlation Tests

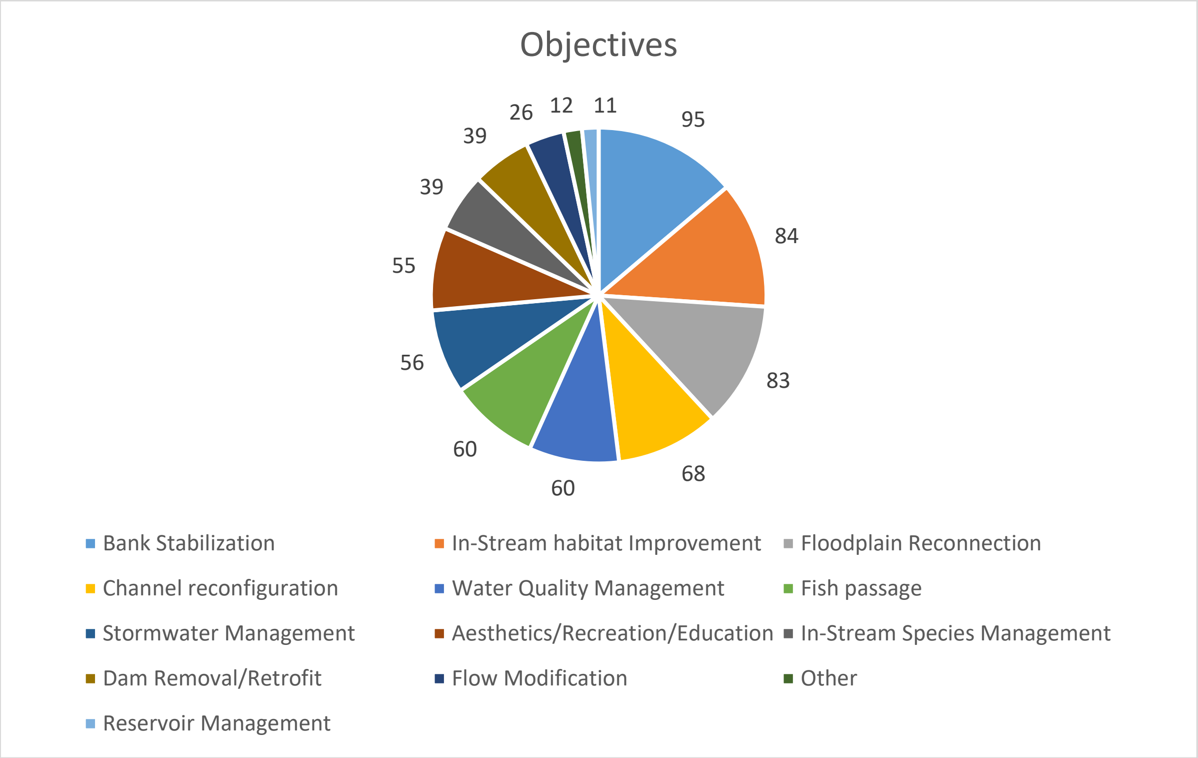
Test	Correlation Coefficient	p-value
# Of projects and representatives	-0.005	0.108
representatives and population per square mile	0.026	0.739
representatives and population	0.324	0.008
# Of projects and population per square mile	0.341	0.413
# Of projects and population	0.230	0.822

Both the state and physiographic regional analysis determined that population is not a direct method for explaining the spatial distribution of practitioners who responded to the survey. While previous surveys do not necessarily correlate with this one in terms of exact numbers, this could have resulted for several reasons. The first is the time gap between the surveys. The state focused group has a gap in years from 2005 to 2022 and only has 13 states listed. The physiographic study has less of a year time gap the survey was conducted in 2009 (Radspinner R. R., 2009), though this is still a gap of roughly 13 years. Additionally, this survey focused on researchers and practitioners while this survey was explicitly targeted to practitioners. Finally, the main reason could be the collection itself. While the surveys may have been released without bias, there could have been factors that affected the spread of the survey or the response for both surveys. These differences may explain why the differences between the surveys had occurred.

4.1.4 Objectives

There were 82 responses for the question targeted typical objectives practitioners aimed to address when designing a stream project. This question allowed for multiple responses and the results are shown in the pie chart below (Figure 4.6). It should be noted that the figure refers to the percent of respondents who chose a particular objective. Since each respondent could choose multiple objectives, the percentages do not sum to 100.

Figure 4.6 Percent of Respondents who selected type of Objective.



The most selected objective was “Bank Stabilization” followed by “In-Stream habitat Improvement” and “Floodplain Reconnection”. The least selected options were “Reservoir Management”, “Other”, and “Flow Modification”. The “Other” section had a total of 10 responses. The “Other” section had one repeated answer which was nutrient reduction. The other section did include answers such as, ecological restoration, mitigation credits, stream grade control, riparian function improvement, water supply, flood mitigation, and grade control. The average number of objectives selected was 6.963 and the median number of objectives selected was 7. Table 4.4 shows the distribution of how many objectives were selected. With the distribution being normal and it contains three major peaks of 4, 6, and 8.

Table 4.2 Distribution of objectives selected.

Number of objectives selected	Number of Respondents
1	1
2	0
3	4
4	12
5	7
6	13
7	9
8	12
9	8
10	9
11	4
12	1
13	1

The distribution of the number of objectives selected and the types of objectives selected illustrates a position where practitioners will have many different projects that they initiate in but there are some practices such as bank stabilization, in-stream habitat improvement, and floodplain reconnection that emerge as the most widely used.

4.1.5 Funding

Out of the 67 respondents for the question, “What is your organization's funding source(s)?” 17 were adjusted to sum to 100 percent. Of the 26 respondents who indicated funding came from “Other” sources, 16 indicated local government, tax, or funds. Table 4.5 shows the summary of statistics for funding sources for stream restoration and stabilization projects.

Table 4.3 Descriptive Statistics of % Funding by Source.

Summary of Statistics	State	Federal	Donations	Private	Other
Average	38	22	1	16	23
Median	33	18	0	10	0
% Of people who selected	85	74	14	62	47

As indicated in Table 4.5, most respondents had a combination of funding from several different sources. While most respondents had some funding from “State” and/or “Federal” sources, rarely did such sources serve as the sole source of funding. This means that their funding is derived from multiple sources and not one is usually primary.

Figure 4.7 Funding Sources Distribution. The following graph depicts the number of times a respondent placed a funding source in one of the following groups of percentages.

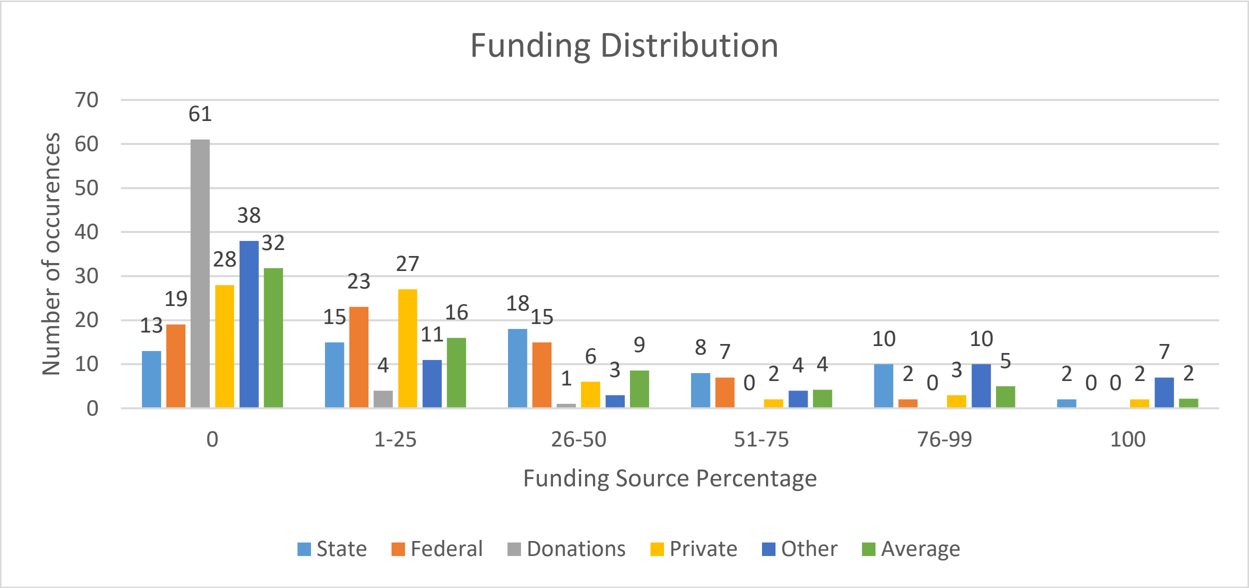


Figure 4.7 demonstrates how each funding source is distributed amongst practitioners. If a respondent had placed “State” funding to be around 30% of their funding, then one count would be placed in the 26-50 category. Therefore the 27 number of occurrences in the 1-25 bin refers to the number of respondents who stated that 1-25% of their budget comes from private

sources. This type of chart appears often, and it can be read similarly. Thus, it can observe that the highest category (besides zero), was the 1-25 group, meaning that when people did select a funding source it would most likely represent a relatively small portion of their total project funding. In other words, most respondents do receive funding from several different sources. It should be noted responses do not reflect a specific project but provide a general indication where their funding comes from. The lowest funding division, 0%, was assigned to responses in which it was indicated that no funding was received from a particular source. The highest of these was "Donations" whereas the second highest was "Other" and then "Private." Of these, donations were the least typical source of funding for stream projects. If "Donations" are given, they do not represent a large portion of the funding provided. The largest source of funding in the second section, 1-25, was private funding. This means that if private funding is received, it represents a low portion of their overall funding. The largest source of funding in the 26-50 region was State funding. This means that, while state funding was selected as the most often used funding source, it most often only accounts for equal to or less than half of practitioners total funding. The fourth section, 51-75, had the least number of counts, with the average being 4. If practitioners do receive most of their funding from one source, then it will likely cover more than three-quarters of their funding. Finally, the fifth section, 76-99, has the most counts from "State" and "Other" sources (most other sources were local). Both the "State" and "Other" sources had less than average percentages in the lower 1-25 section and scored much higher than other categories in the 76-99 category. This indicates that while having a diverse amount of funding is more likely, those who do receive most of their funding from one source are most likely to receive that from "State" or "Other" (i.e., local) sources.

4.1.6 Cost

As mentioned in Chapter 3, section 3.2.2, written-in responses to the question regarding project cost were difficult to analyze. One of the main challenges that arose was ambiguity in units when respondents did not include units with the cost range. For example, the magnitude of some responses suggested total project costs were being reported whereas others were likely given in cost per unit length, but when units were not included with the written-in response it was difficult to deduce. Thus, only general descriptive statistics were used to analyze the ranges in cost reported by survey respondents (Table 4.6).

Table 4.4 Maximum and Minimum Project Budget Statistics

	Minimum Budget for Project $/linear foot	Maximum Budget for Project $/linear foot
Average	2756.574	3370.704
Median	225	475
Minimum	5	7
Maximum	130000	150000

These ranges in Table 4.6 represent all the given values. As can be seen, the ranges on the data can vary widely using the measurement of $/linear foot. Despite the wide variation across the ranges reported, the central tendency of the minimum and maximum costs fell within a relatively narrow range of $2,757 to $3,371 per linear foot and $225 to $475 per linear foot for the average and median, respectively. It is likely that further analysis of project costs in relation to project size would help explain the variability in reported costs, as using the unit of cost per linear foot for the restoration or stabilization project may change depending on the size of the river itself in its other dimensions.

4.1.7 Time

Analyzing the slider question, “How much time do you typically spend on each of the following stages of a project?” was similar to that of the funding question. There were 14 responses that had to be adjusted to sum up to 100%. The “Other” section had a total of 21 answers. Of these there were a few notable repeated answers. Permitting was noted 10 times of the 21 “other” responses, followed by fundraising (mentioned 6 times), and public outreach (mentioned twice). The general descriptive statistics are presented in Table 4.7 below.

Table 4.5 Descriptive Statistics of Allocation of Time spent on Projects (%)

	Data Collection	Design	Construction Oversight	Post-Construction Monitoring	Other
Average %	19	38	24	14	6
Median %	20	35	20	10	0
% Of people who selected	97	95	97	94	32

As shown in Table 4.7, most respondents selected each of the activities identified in the question, meaning that most of the practitioners spent time to participate in all the above activities. This time also appears to have been evenly divided with the “design” portion taking at least a third of the time. “Construction oversight” took the second most amount of time with it taking at least a fifth of the time for a project. “Data collection” took the third amount of time, and “post-construction monitoring” taking the fourth. The distribution of the responses by frequency of selection is shown in Figure 4.8.

Figure 4.8 Distribution of Time Spent on Certain Aspects of Design Process

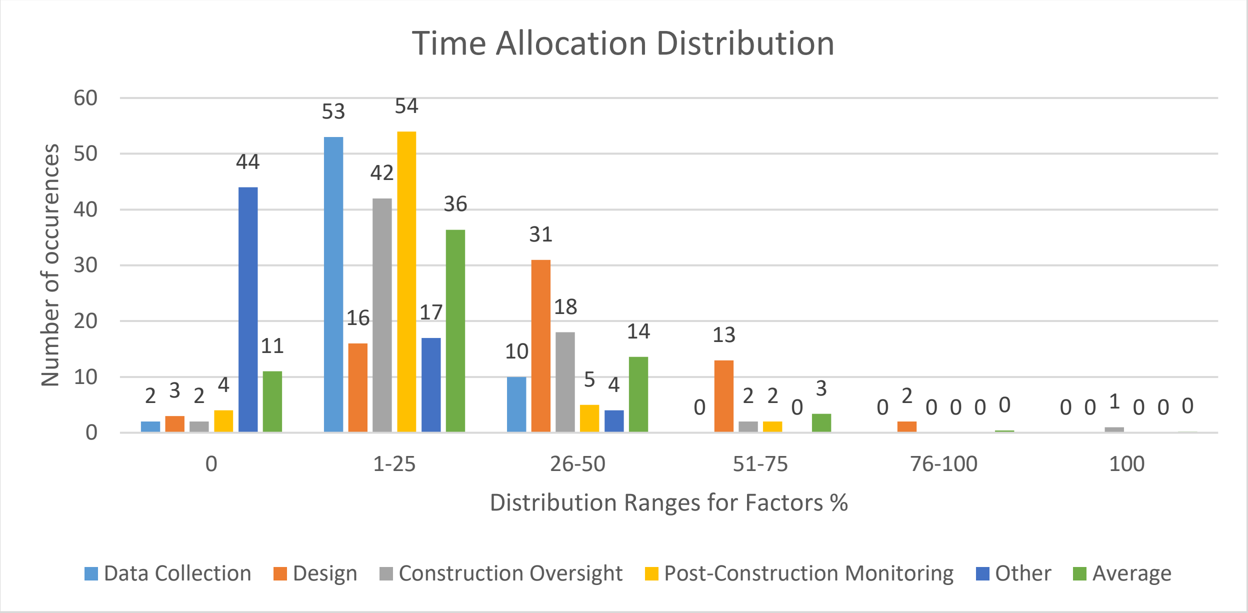
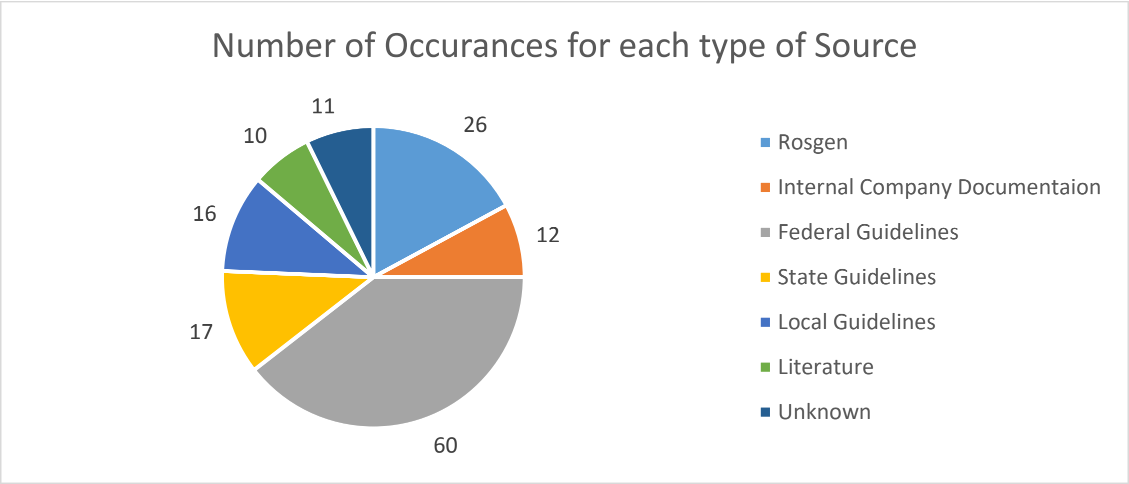


Figure 4.6 also shows how often each of the activities are selected and what percentage group they were placed in. Most responses fell into the 1-24 group. This indicates that many respondents allocate their time relatively evenly across all activities. In the higher range groups such as the 26-50 group and the 51-75 group the "Design" activity had a noticeably higher count than the other activities. This indicates that the out of all the categories, "Design" is the activity on which practitioners tend to will spend the most time on. Other notable observations include that both "Post-Construction Monitoring", and "Data Collection" have more responses in the first group, 1-25, than the other categories but then have little to none later. While this trend was noted on most other categories, (other than "Design") this trend is stronger for the "post-Construction Monitoring" and "Data Collection" activities. In the 0 group, there were four who did not do "Post-Construction Monitoring", three who did not do "Design", two who did not do "Data Collection" and two who did not do "Construction Oversight".

4.1.8 Sources of Design Guidance

For the initial analysis of the survey, sources were read and then tagged with more generalized categorical terms. The following tags were used: Rosgen, Internal Company Documentation, Federal, State, Local, Literature, and Unknown. Rosgen is a tag that refers to documentation created by Dave Rosgen (Ph.D.). The internal company documentation tag refers to when the respondent had written that they use their companies own design guidance. The federal, state, and local tags refer to documents published by governmental institutions. Unknown is a tag that was if the respondent had put down a reference that could not be found or be placed in the other tags. An example of this would be if they stated a person's name that could not be researched down to a particular guidance or article. Each respondent could respond with any number of documents and so despite there only being 55 respondents to this question, the number of sources listed were 152 in total. Figure 4.9 illustrates the number of occurrences for each tag.

Figure 4.9 Pie chart for Type of Sources Used by Practitioners



Out of these 152 occurrences, an estimated 92 of them are considered unique. This can vary however depending on what the respondent meant. Some answers given were quite vague only giving some one-word answers that could refer to different documents. An example is the US Corps of Engineers (USACE), that has several documents which respondents provided exact titles and others simply mentioned USACE. Thus, the actual number of 'unique' documents is relative. The average amount of sources that each person used was 2.76 sources. A notable noticeable pattern was that each respondent generally utilized a federal source and then one to two sources from a different source.

In addition to the source type, the reason why sources were used was analyzed as a selected choice question. Table 4.8 illustrates both the options for the question as well as how the answers were distributed.

Table 4.6 Why Certain Sources were Used

	Count	Added[1]	Total % chosen
Effectiveness / Success Rate	46	(+)2	84.21
Regulations	30	(+)3	57.89
Cost efficient	21		36.84
Other	10	(-)5	8.77
Total	107		

The added counts in the third column of Table 4.8 indicates the number of additional counts from responses written in under the "Other" option but which were very similar to one of the other three options. An example includes a written answer that simply stated "permitting", as a write-in response under the "Other" category, which can be interpreted a part of regulations and was therefore placed in the "Regulations" section instead. This was noted and the total percentage in the far-right column includes those corrections. The highest category chosen was "Effectiveness" with the second being "Regulations". More than 80% of respondents chose the "Effectiveness" category, meaning that even if there are other influences that affect design, the actual success is the highest reason why a source is used. Despite this high percentage there were still 11 respondents who did not list "Effectiveness" as a reason for why they use a source. This indicates that while it is a minority of practitioners, over 10% do not use a source for implementing design for the purpose of its effectiveness.

4.1.9 Design Tools

In the selected choice question, "What types of design tools do you use in the design process of streambank stabilization and restoration projects?" the analysis was mostly descriptive after initial examination. Table 4.9 below describes the results of the question.

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[1] The added category refers to how certain responses from the "Other" category, could be reflected in different categories. Thus the modifications are noted in this column.

Table 4.7 Design Tools used in design process

Tool	Counts	Percentage of Respondents who selected (%)
Empirical-based tools (regional hydraulic geometry)	48	80
Analog-based tools (reference reach approach)	48	80
Analytical tools (hydraulic models)	49	81.67
Other	10	16.67
All three	34	56.67

The overall results demonstrate that empirically based, analog-based and analytical tools had almost equal representation. More than half of the respondents had selected all three options. The “Other” category had written in answers that included historical data, professional judgement, or went into further detail about what they specifically did.

4.1.10 Models Used

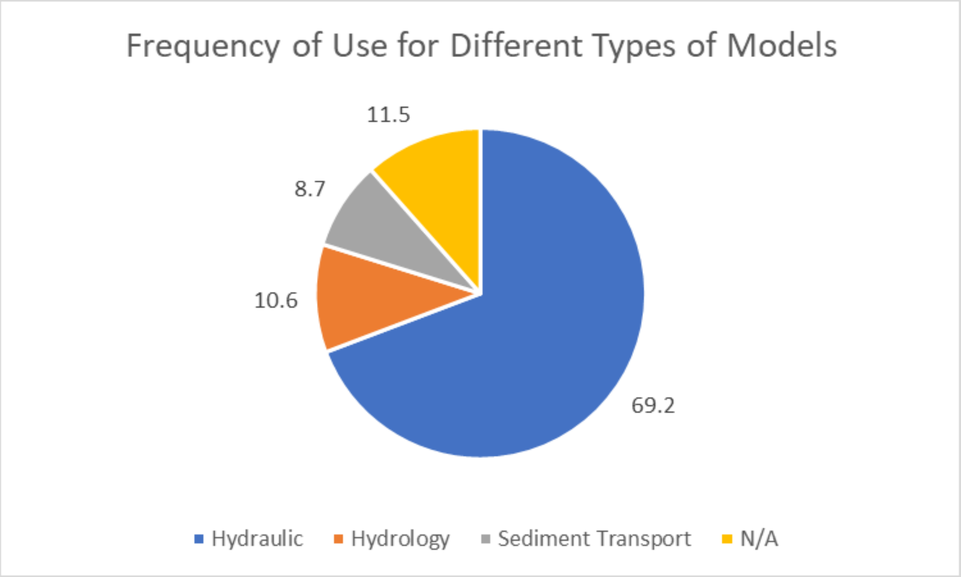
Respondents were asked about what type of models they used in a selected choice question. Table 4.10 presents the list of models and their overall use. The respondents could select multiple choices. Out of the 60 respondents for the question there were 96 answers resulting in an average of 1.6 models per person.

Table 4.8 Models and their use

Model	Count	Percentage of Respondents who selected (%)
HEC-RAS	50	83.33
Others	11	18.33
I do not use computer models	9	15.00
BSTEM	5	8.33
HEC-6	4	6.67
RiverMorph	4	6.67
HEC-HMS	4	6.67
AutoCAD Civil 3D	2	3.33
SRH-2D	2	3.33
FASTER	1	1.67
FLUVIAL-12	1	1.67
MIKE 11	1	1.67
Flowsed/Powersed	2	3.33
Respondents	60	

The overwhelming majority of people used HEC-RAS. Apart from one individual, those who did not use HEC-RAS, did not use any computer models at all. Further analysis of the types of models revealed that the most predominately type of model used was hydraulic followed by hydrologic and only a couple used water quality models or models related to sediment transport or bank erosion. The distribution of the types of models are shown in Figure 4.10.

Figure 4.10 Types of Models and their use



The N/A category indicates responses of “I do not use computer models” or if in the “Other” category, they did not provide a specific model. Due to the overwhelming use of HEC-RAS, the predominant use of hydraulic models was expected. The most popular hydrologic model was HEC-HMS. What this analysis proved is that despite there being a vast amount of model software available, HEC-RAS is still the most popular one used and that other types of models such as hydrological, sediment transport, and water quality models are much less used (Brewer, et al., 2018).

Examining the dimensions represented in models used by practitioners use for models was also analyzed in a slider question. For this question, six answers needed to be modified to add up to 100. The descriptive statistics are shown in Table 4.12.

Table 4.9 Relative use of 1D, 2D, and 3D models by stream practitioners (%).

	One-dimensional	Two-dimensional	Three-dimensional
Average (%)	51	46	3
Median (%)	50	50	0
% Of people who selected	90	90	10

The same number of respondents (include # of respondents in parentheses) selected one-dimensional and two-dimensional models, but responses indicated one-dimensional models were used a higher percentage of the time. Additionally, while three-dimensional models were used, those who did use the model only used it a quarter of the time. Meaning practitioners only sparingly use 3-dimensional modeling tools.

Finally, a written response question was also given to participants to ask how organizations use hydraulic models in their design process. The overwhelming majority discussed how they used hydraulic models to predict shear stress as well as velocity for their designs as well as predict future shear stress. Others use models to compare to a reference location or physical model and then use it to calibrate and validate designs. Others use models to determine how water will move across a floodplain in the event of a serious flood. Finally, other notable model uses include determining the size and location of structures and assessing fish passage depth and velocities.

4.1.11 Models Not Used and Why

Those who responded that they do not use models (Section 4.1.10) were asked why using a slider question. Out of the nine who did not use computer models, two mentioned they had others use models (outsourcing) and were able to describe in detail what they did with them. As a result, only seven had specific reasons why they did not use computer models in design that were not outsourcing. Out of these seven responses, two had to be adjusted to get an answer to sum to

100%. Table 4.14 presents the descriptive statistics of the reasons why practitioners do not use computer models.

Table 4.10 Reasons why Practitioners do not use Computer Models Descriptive Statistics

	Time	Money	Regulations	Availability	Effectiveness / Credibility	Ease of Use / Usability	Other
Average (%)	29	7	0	18	14	14	17
Median (%)	20	0	0	19	0	0	0
% Of people who selected	86	29	0	71	43	43	29

Those who selected other had three major reasons. The first was that it was not their focus and others did modeling (i.e., someone else in their company but not specifically them). The second was they used outsourced consultants from other companies to run HEC-RAS. These answers were removed the question as their company did use models for the design. The third was that it was difficult to find time and adequate training to use models. The most selected reasons why practitioners did not use models was “Time” and “Availability.” “Money” scored the lowest with “Effectiveness” and “Ease of Use” scoring similarly with “Ease of Use” edging out. There was no overwhelming reason why and so most had reported multiple reasons for not using models, with any individual reason being equal to or under 50%. Thus, it is a combination of these factors that is preventing practitioners from using models.

In addition to those who don’t use models, practitioners were also asked about models they had wanted to use but were constrained. This was a slider question and Table 4.15 presents the descriptive statistics of the question. The “Other” reasons were that models often were too expensive and time consuming both in training and in running the model that the time would be better spent understanding the system itself.

Table 4.11 Reasons Why Practitioners Wanted to Use Certain Models but Were Constrained Descriptive Statistics

	None	Time	Money	Regulation	Training	Other
Average	41.89	14.42	12.31	1.35	25.16	4.86
% Of people who selected	45.71	45.71	34.29	5.71	51.43	5.71
# Of people who selected	16	16	12	2	18	2

The most frequently cited constraint for working with desired hydraulic models was due to “Training.” In addition to being the highest chosen reason, it also had the second highest average answer amongst practitioners. It should be noted that both “Time” and “Training” had either the same number of answers or more than the “None” category. Out of the 37 respondents for this question, 21 selected a response other than “None”, meaning there were models available that they had wanted to use but were unable to, due to some combination of training, time, and/or money. When people did have training as a factor, it was the most significant factor. The overall distribution of answers resulted in most people having several reasons for why they choose their models but not a predominant one. The exception to this was training which did have the highest percentage chosen. Additionally, “Time” was cited more frequently, whereas “Money” was a more substantial constraint when selected as a limiting factor.

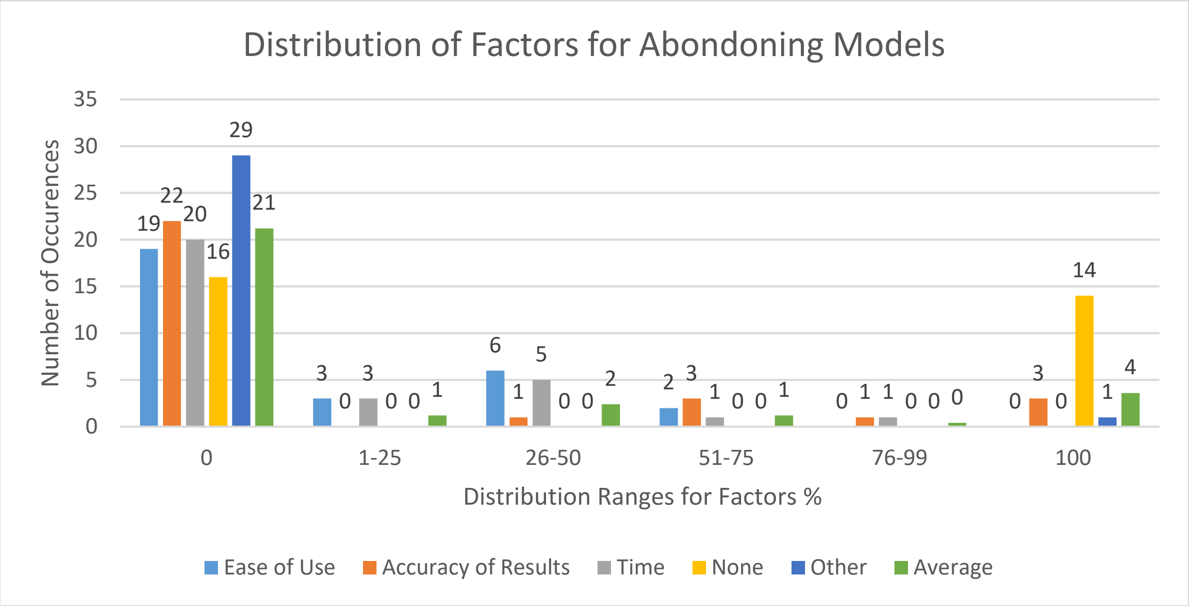
Abandoned models were also analyzed. The abandoned models mentioned were SRH-2D, RiverFlow 2D, HEC-RAS 2d, HEC-RAS sediment modeling, FLOWSED, PCSWMM, Hydromagic, EPDRiv1, and Flowsed/Powersed. Non-specific models were also mentioned such as abandoning sediment models for their reach-scale inaccuracies. Out of these abandoned models, a slider question was provided for detailing the reasons for abandoning these models. The descriptive statistics for the results are shown in Table 4.16.

Table 4.12 Descriptive Statistics on Reasons Why Practitioners Abandoned Computer Models

	Ease of Use	Accuracy of Results	Time	None	Other
Average (%)	16	20	13	47	3
% Of people who selected	37	27	33	47	3
# Of people who selected	11	8	10	14	1

There were 30 responses for this question and almost half selected none, indicating about half of survey respondents have abandoned a model at some point. The greatest factor was "Ease of Use". Despite being the highest chosen, the "Accuracy of Results" factor was still the highest of in terms of average by a large margin, indicating that when "Accuracy of Results" was selected, it was the most important factor. While "Time" did not score as high as the other factors in terms of its average, it did occur more than "Accuracy of Results" and it still was a significant factor that affected dropping the use of the model. In addition to Table 4.16, the distribution of the factors chosen can also be examined in Figure 4.11.

Figure 4.11 Distribution of Factors for Abandoning Models Distribution



Examining the graph above gives insight into why models are abandoned. The first note is that the “Accuracy of Results” has the highest count in the 100 group. This indicates that while “Time”, and “Ease of use” may have some influence on decisions to discontinue the use of a particular model they are never the only reason for abandoning a model. Even in the higher categories (e.g., 51-75% and 76-99%), these factors rarely appear as a predominant reason for abandoning a model. Whereas if the accuracy of results is a factor, it is the predominant reason for abandoning a model.

4.1.12 Gathered Data

The selected choice question examining the data used to calibrate hydraulic models was analyzed as shown in Table 4.17.

Table 4.13 Descriptive Statistics on the Data Collected for Hydraulic Models

Data Type	Count	%
Stratigraphy / Soil texture	21	50.00
River Network	13	30.95
Bankfull flow indicators	35	83.33
Cross Section Geometry	42	100.00
Bed elevation / bathymetry	28	66.67
Erodibility	19	45.24
Erosion Rates	24	57.14
Bed Stability / Scour Chains	16	38.10
Velocity	24	57.14
Momentum	5	11.90
Bed sediment Size / Particle Size Distribution	34	80.95
Shear Strength	22	52.38
Dissolved Oxygen	7	16.67
Nutrients	9	21.43
Water temperature	9	21.43
Primary Productivity	1	2.38
Vegetation	26	61.90
Biota	9	21.43
Other	4	9.52
Total	42	

The “Other” section was mostly other terms for previously mentioned items. The confusion on terminology affected this question as some referred the bed elevation as profile data. One respondent noted that “sediment load” data were collected under the “Other” category. The most frequently cited types of field data collected as part of the design process were Cross Section data, which everyone gathered, followed by Bankfull flow indicators, bed sediment size and particle size distribution.

4.1.13 Data Needed

Practitioners were asked what data that they would like to collect but were unable to. This was a write-in question to which 32 participants provided a response. The type of data most discussed was sediment data. Practitioners discussed the need to collect sediment transport data, especially long-term suspended sediment, and bedload data. They wanted data so they could fully develop reliable sediment rating curves. Often projects are not funded for multiple visits to collect multiple sets of suspended sediment data and so either developing methods to collect long term or economical ways to develop better curves or complete detailed bathymetric surveys is greatly needed. Having more historical data is difficult to acquire for the short length of a project. In addition to sediment data, the second most cited data need was the need for monitoring data collection. Practitioners wanted to gather data to validate their project or hydraulic models but often funding wasn't available to do so. Therefore, there was a call for more economical methods to collect and evaluate post-construction monitoring data. This post construction monitoring also extended to habitat data such as fish community data or water quality, which clients often did not want to pay for the extra time needed and so the before and aftereffects of a project were unknown. The third most discussed topic was more flow data, specifically site-specific data in areas that do not have flow gages or are in headwaters. Stage height for specific storm and flooding events is often needed at specific sites to determine what it could possibly affect and if there isn't a gage nearby it might be hard to determine. Flow records are also useful as a line of evidence for determining Bankfull flow. Practitioners often do not have the time or money to conduct flow data on their own. The fourth main topic discussed was the need for better subsurface flow or groundwater data. This extends to understanding the water table more as well as salinity data. One practitioner explained that groundwater is an extremely important component to stream ecology design and obtaining the information is difficult as it requires several surveys (archeological surveys, biological botanical surveys, and separate T&E species survey) to be conducted to get clearance from agencies before the subsurface data can be acquired. This process is expensive and time consuming to conduct. Finally, the fifth and final general data need discussed by practitioners was the need for more precise elevation data, like LiDAR, to get proper geomorphic evaluation of streambanks and floodplain areas.

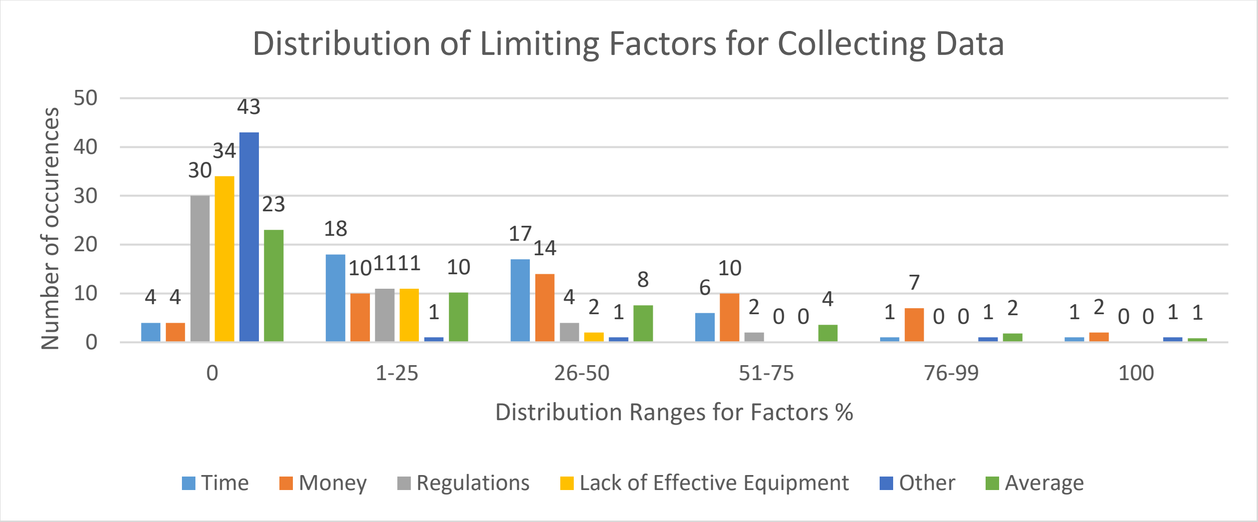
After discussing data needs, practitioners were given a slider question about the factors that limited them from collecting data. Out of the 47 respondents 9 were adjusted so that their responses summed to 100%. Table 4.18 provides the general descriptive statistics of the results.

Table 4.14 Factors that limit Practitioners from Collecting Data

	Time	Money	Regulations	Lack of Effective Equipment	Other
Average	34	48	8	5	5
Median	30	50	0	0	0
% Of people who selected	91	91	36	28	9
# Of people who selected	43	43	17	13	4

The “Other” category had responses that included, “none”, “experience”, and “client priorities”. “Client priorities” referred to the willingness of the client to pay to collect the data. The results show that the largest two factors that limit gathering data is “Time” and “Money”. These two were overwhelmingly chosen with “Regulations” and “Lack of Equipment” being relatively infrequently by comparison. Despite both “Time” and “Money” being chosen the same number of times (43 out of 47 respondents), the average shows that money was chosen as the larger hurdle between the two. Figure 4.12 provides a more in-depth examination of the distribution of answers.

Figure 4.12 Factors for Limited Data Collection Distribution



The distribution of data collection constraints noted by practitioners in Figure 4.10 demonstrates how large of a factor “Money” is compared to the other factors. While other categories fell in the larger bins such as 51-75 and 76-99, “Money” represents of 50% of the responses in these bins. While “Regulations” and “Lack of Effective Equipment” are present in the 26-50 range they are more prevalent within the 1-25 range meaning they are factors but are almost never the priority reason.

4.2 Follow-Up Analysis

After the initial analysis, a follow up questionnaire was given to practitioners who provided their email. Out of the 22 practitioners who were contacted for follow-up questions, there were 6 who responded to the follow-up questionnaire. As different respondents received specific questionnaires tailored to them, only the questions that were addressed to all of them are discussed in this section. The other tailored questions were primarily clarification on their past answers to the survey.

4.2.1 Permitting Time

The first shared question given to practitioners was, “How much time is usually taken up for project permitting and how long do you wait for the permitting to be processed?” The ranges given for how long permitting takes was highly variable. The shortest time given was 13 hours to complete a form followed by an approximately 3-week wait. This was short compared to the permit applications to national and regional agencies with waiting times for permits could take over a year. Additionally, this waiting time was mentioned several times to be getting worse, with the waiting time extending as well as the permitting review becoming stricter. The types of permits mentioned were all different, and depending on the type of permit, it can change the waiting time.

4.2.2 Design Process Guidance/Training Improvement

The second shared question given to practitioners was, “Are there components of the stream restoration/stabilization design process for which additional guidance or training would likely improve outcomes of channel design projects? If so, which ones? (e.g., hydraulics, sediment transport, field data collection methods, analytical/modeling techniques, watershed hydrology and assessment, etc.). Feel free to elaborate as desired.” Respondents tended to answer this question differently, with only a couple of similar responses. The first was that some new to the field do not have the training or experience enough to be rigorous enough in their methodology. This creates issues when they haven’t developed detailed notes about the site and haven’t developed enough knowledge of the site. The second was the lack of knowledge around geomorphology. The designer did not have enough knowledge about the driving forces of the river and how that has resulted in the channels’ current form. The third was sediment transport. Not having enough background data in most parts of the US leads to problems where models do not have enough understanding of how sediment moves within a reach to predict it. The fourth was utilizing more methods for redundancy on projects. As this has a history of success, it needs to be used more in practice (Lightbody, Radspinner, Diplas, & Sotiropoulos, 2010). The fifth was how guidance standards need to match the growing knowledge of the practice. The respondent referred to a workshop on May10-11th 2022, titled, “Workshop on Benefits, Applications, and Opportunities of Natural Infrastructure.” This workshop contained a presentation by Edward Brauer, a Professional Engineer form the U.S. Army Corps of Engineers that highlights the needs for developing a community to support new practices, use the case studies to inform design, use pilot projects to inform guidance and develop technical documentation, and finally develop a willingness to take risks and try new approaches.

4.3 Regional and Organizational Influences on the Design Process

After conducting the initial and follow up analysis, there was a more in-depth examination of possible regional differences amongst practitioners and examination of how different organization might affect certain factors of the practice.

4.3.1 Spatial Analysis

The first spatial analysis done was examining the regional distribution of channel restoration/stabilization design guidance sources across the United States. Following the initial analysis of design guidance sources (Section 4.1.8), design guidance source documents were categorized as following Rosgen’s methods (e.g., NCD) or some other, non-Rosgen design approach. Respondents were then characterized according to whether they had listed a source that had used Rosgen’s methods and then compared spatially over different geographic regional groupings. Analysis was done using both the USDA regions and the EPA regions mentioned in Section 3.2.3. The results of the Fisher’s Exact test for the EPA regions are shown in Table 4.19.

Table 4.15 Fishers' Exact Test Results for EPA regions

Region	Fishers Exact Test Results[2]
Northeast	0
Central East	1
Central	0
West	0

The results of the tests show that while the Northeast, Central, and West regions do not pass the test, the Central East does. This means that the variables of whether Rosgen's methods are used, and the location are not independently related. What this means is that practicing in the "Central East" region, will impact whether Rosgen's methods are used or not. This test indicates that Rosgen's methods are equally likely to be used across most of the U.S. regardless of location, likely reflecting the prevalence of Rosgen's training programs and associated uptake by several state and federal agencies. This test also highlights regions that are less likely to use Rosgen's methods. In this case, practitioners in the Central East region are less likely to use Rosgen-based methods relative to other regions. Examining this through the USDA regions, we get the following result shown in Table 4.20.

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[2] A zero indicates that the null hypothesis in not rejected and 1 indicates that the null hypothesis is rejected. The null hypothesis is that the variables of location and whether or not Rosgen's methods are used, are independent.

Table 4.16 Fishers' Exact Test Results for USDA regions

USDA Region	Fisher's Exact Test Results
Appalachian	0
Plains	0
Northeast	0
Delta States + Southeast	1
Corn Belt	0
Pacific	0
Lake States	1
Mountain	0

From this test, practitioners in the Delta States/Southeast region and the Lake States region are less likely to use Rosgen's methods compared to the other regions. Both are less likely to use Rosgen's methods compared to the other regions. There is overlap between the USDA region and the EPA regions. The "Central East" region does contain both of the "Delta States + Southeast" and the "Lake States" regions.

4.3.2 Organizational Analysis

In addition to examining spatial differences, how the type of organization affected certain factors was also analyzed. As noted in Section 4.1.1most practitioners were affiliated with either governmental or private organizations; therefore, groupings of "Governmental" and "Private" were used to examine potential organizational influences on other design process factors. Other organizational affiliations (e.g., nonprofit) were not explored herein due to insufficient representation in the dataset. The first factor analyzed for differences was project funding sources, which, as described in Section 4.1.5 included a mix of public and private funds. The results of the descriptive analysis are shown in Tables 4.21 and 4.22.

Table 4.17 Descriptive Statistics for Stream Project Funding Sources for Practitioners in Governmental Organizations

	State	Federal	Donations	Private	Other
Average (%)	34	30	0	9	26
Median (%)	22	25	0	0	0
% Of people who selected	77	77	5	41	50

Table 4.18 Descriptive Statistics for Stream Project Funding Sources for Practitioners in Private Corporations

	State	Federal	Donations	Private	Other
Average	44	16	1	20	19
Median	40	10	0	10	0
% Of people who selected	90	72	13	72	44

Design guidance sources was examined by how organization may impact the choice of design guidance. Again, Private and Governmental were just compared as the counts from other sources were not high enough. Tables 4.23 and 4.24 provide a comparison of why practitioners within both governmental and private organizations, respectively, use the design guidance(s) that they use.

Table 4.19 Rationale for using selected design guidance(s) cited by stream practitioners in Governmental organizations

Governmental	Count	Added	% With corrections
Effectiveness / Success Rate	16	0	30
Regulations	21	0	40
Cost efficient	11	0	21
Other	5	0	9
Total	53		

Table 4.20 Rationale for using selected design guidance(s) cited by stream practitioners in Private Corporations

Private Corporation	Count	Added	% With corrections
Effectiveness / Success Rate	28	(+)1	45
Regulations	21	(+)2	35
Cost efficient	11		17
Other	5	-3	3
Total	65		

Practitioners within governmental institutions selected “Regulations” as the highest reason why they use a particular design guidance source, while Private Corporations selected “Effectiveness/ Success rate” as the highest reason why they choose their sources. Notice the reason “Cost Efficient” was selected the same amount of times (although percentage wise it represents a different value). This indicates that main reason why private corporations choose their design guidance sources was due to its success whereas governmental organizations chose design guidance sources not due to its effectiveness but because they were required to.

The third analysis was based upon the type of sources each organization used and if there was a significant difference. Table 4.25 shows the difference in percent usage of different design guidance source types by the different organization types.

Table 4.21 Percent Usage of Different Sources Separated by Organization Type

	Federal	Local	Literature	Rosgen	State	Internal Company Documentation	Unknown
All	37.86	11.43	9.29	19.29	10.00	7.86	3.57
Government	39.02	9.76	7.32	19.51	9.76	4.88	9.76
Private Corporation	38.37	13.95	8.14	20.93	8.14	9.30	1.16

There is little difference of the sources private corporations use and what government organizations use. The only noticeable difference between the two is the use of "Internal Company Documentation." However, this can become negligible if the "Unknown" category is in reference to sources that are internal documentation. Additionally, a federal source could be technically, internal documentation, but since the respondents were not asked about the name of their organization, this cannot be determined.

4.4 Survey Conclusion

Stream channel restoration and stabilization is a major industry, with annual expenditures estimated to exceed $1 billion (Bernhardt et al., 2005). Despite this large investment in the industry, we lack a clear picture of design approaches employed by practitioners in the industry as needed to benchmark current design processes and tools used across the practice. To fill this gap, a survey was administered to practitioners in the stream channel restoration and/or stabilization industry. The purpose of this survey was to develop an understanding of the stream restoration and stabilization practice, particularly throughout the design process. The results of this survey, combined with previous knowledge discussed in Chapter 2 Literature Review, provide useful insights to the state of the practice of stream restoration/stabilization design in the United States.

Among the key takeaways from this study is that most practitioners have several objectives that guide the design of projects, including physical stability, habitat, and functional connectivity. The most frequently cited design objectives were bank stabilization, in-stream habitat improvement, and floodplain reconnection. While these are the highest three ranked, the survey practitioners indicated, on average, seven different design objectives, although not necessarily in the same project. Therefore, when determining success projects need to specifically clarify what the objective of the project is to validate success later as one project, even done by the same practitioner, is not guaranteed to have the same objective as the other.

A second conclusion is the widespread adoption of Rosgen's NCD methods across the United States. The geospatial analysis conducted in this study, however, demonstrated that some there are some regions in the United States – most notably in the Lake States and the Southeast and Delta States where his methods are less likely to be used.

The third conclusion was the use of design tools. While there was use of multiple design tools, those who do use computational models, use HEC-RAS (section 4.1.10). Additionally, while sediment transport, hydrologic, and water quality models are available, the overwhelming majority use hydraulic models.

The fourth conclusion that affects practitioners is how certain factors affect the design process. The results of the survey show that permitting, money, and time are significant factors for data collection, determining what models to use, and why practitioners abandon certain models. Time was the primary reason why models are abandoned, and money was the primary reason field data was not gathered. Due to these factors, more than half of practitioners have abandoned a model. Also, the wants of the client as well as permitting affects what the practitioners can afford and what they have time for.

The fifth conclusion is that regulation impacts how practitioners choose their models. Those who work for governmental organizations have their design guidance chosen mostly due to regulation and not the sources' effectiveness. This will be difficult to correct as regulations are behind the practices' evolution and do not update quickly. Therefore, regulations should be investigated to resolve time constraints that limit the practice while still ensuring safety.

Chapter 5 - HEC-RAS Model of Cottonwood

In Chapter 2, the literature review detailed how emerging ecological industries, such as river restoration and stabilization, need post-construction monitoring to learn from implemented projects to improve the practice. Later, as per the conclusion of Chapter 4, HEC-RAS is a widely used hydraulic modeling tool used to support the design stream restoration and stabilization practices regardless of a practitioner's location or organizational affiliation. In this chapter, a HEC-RAS model was developed for a study reach along the Cottonwood River, where a streambank stabilization project is soon to be implemented. This will provide both a case study to examine and to demonstrate HEC-RAS as a tool. The model presented here was developed for the year 2018, which was the first-year pre-construction geomorphic data were collected for this site. Creation of this model is a first step in a longer-term monitoring and modeling study which will include development of models for the remainder of the pre-construction period and then the period after construction. The long-term work of this research chapter will examine HEC-RAS's ability to predict projects success after implementation. For now, the 2018 model was created, calibrated, and used to analyze shear stress at points of interest and will be presented in this chapter.

5.1 Review on HEC-RAS Projects and Shear Stress

Utilizing HEC-RAS for hydraulic and, more recently, sediment transport analysis is not a new concept as it has been done before on a variety of different projects. Sediment analysis has been conducted on large reservoirs and detailing bridge scour (Shelley, Gibson, & Williams, 2015; Garcia-Santiago & Calderon, 2021). Additionally, as demonstrated in Chapter 4, practitioners use HEC-RAS as a means for measuring shear stress and velocity for a stream design project. Others have examined the effectiveness of HEC-RAS as a design tool for various river restoration approaches, including the design of compound channels (MacWilliams Jr., Thompkins, Street, Kondolf, & Kitanidis, 2010). Results of these studies have found that HEC-RAS's 1D models for simulating shear stress can have a higher chance of errors in certain conditions and are not accurate for compound streams (Shelley, Gibson, & Williams, 2015) (MacWilliams Jr., Thompkins, Street, Kondolf, & Kitanidis, 2010). However, they also concluded that the 2D version could handle these shortcomings.

As stated in Chapter 4, shear stress was the frequently cited output of hydraulic models (all of those who did use models, used HEC-RAS) used to support stream designs. This leads to the examination of how shear stress ties into erosion. Equation 5.1 (shear stress equation) is how shear stress is determined. Equation 5.2 (excess shear stress equation) demonstrates how shear stress and erosion are related (Clark & Wynn, 2007). Finally, Equation 5.3 (erodibility coefficient equation) uses the critical shear stress to determine the erodibility coefficient.

Equation 5.1 Shear Stress Equation

$$\tau = \gamma R s$$

Equation 5.2 Excess Shear Stress Equation

$$\varepsilon_r = k_d(\tau_a - \tau_c)^a$$

Equation 5.3 Erodibility coefficient equation

$$k_d = 0.2 * {\tau_c}^{-0.5}$$

Here, τ is shear stress (Pa), γ, is the specific gravity of water (kg/m3), R is the hydraulic radius of the channel (m), s is the slope of the channel ε_r is the erosion rate (cm/s), k_d is the erodibility coefficient (cm^3/Ns), τ_a is the average applied shear stress on the soil boundary (Pa), τ_c is the critical shear stress (Pa), and a is the empirical exponent often assumed to be 1. In this case, examining a location’s shear stress and comparing it to the soil’s critical shear stress can reveal locations of erosion susceptibility. As described mathematically in Equation 5.1, the higher the shear stress, the higher the erosion will be. However, shear stress is only a part of how total erosion occurs on a bank. Bank failure can occur on two different ways, rotational and planar failure (Layzell, Peterson, Moore, & Bigham, 2022, pg. 4). “Rotational failures typically occur where bank angles are less steep and result from the generation of positive pore-water pressure and the loss of confining pressure during the recessional period of the flood hydrograph. In contrast, planar failures commonly occur where bank angles are steep and coincide with the formation of tension cracks (Layzell, Peterson, Moore, & Bigham, 2022).” Other factors such as pore-water pressure and the angle of the bank also play a role in determining the actual erosion rate.

The objective of this chapter was to create a HEC-RAS model for a planned streambank stabilization project to assess the effectiveness of HEC-RAS for predicting future changes to a site and as a design tool. The model presented in this chapter represents pre-construction conditions in a study reach of the Cottonwood River in south central Kansas and is a first step in a larger project in which subsequent models representing channel conditions through time – both before and after stabilization structures are implemented – will be created as part of a long-term study. In this chapter, a HEC-RAS model was created for the year 2018, which was the first year in which pre-construction data were collected. The following section provides a description of the study reach as well as methods for creating the HEC-RAS model.

5.2 Methods for HEC-RAS Model

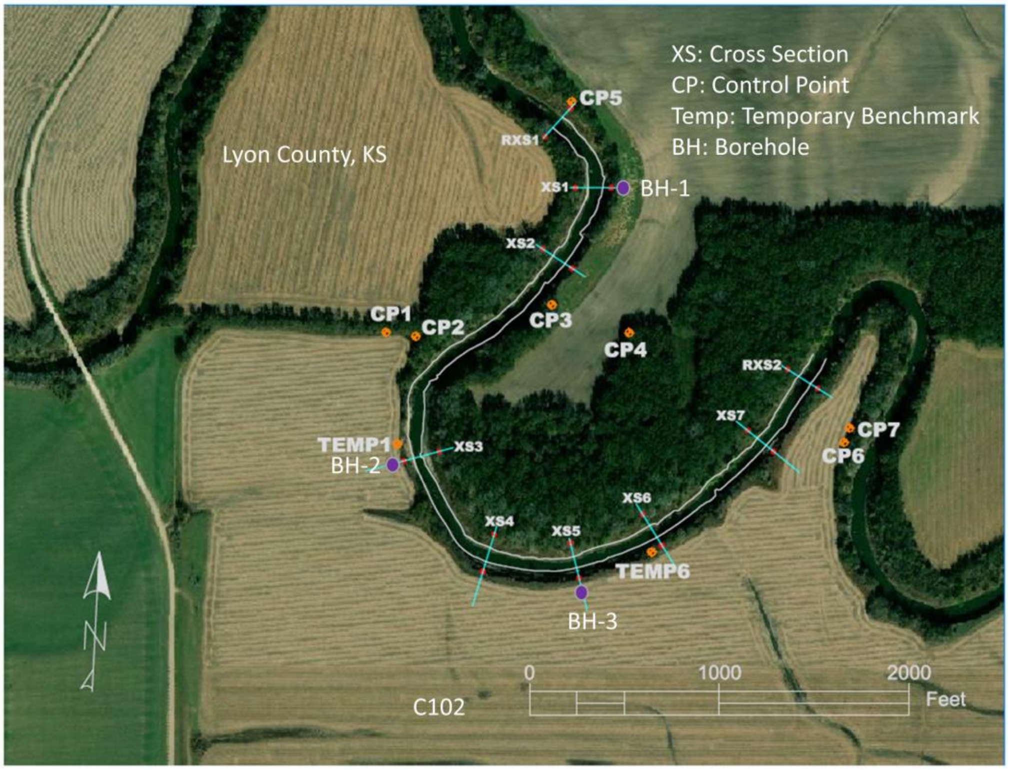
5.2.1 Site Location and Description

A study reach was selected on the Cottonwood River, located in Lyon County, Kansas. The state of Kansas had selected the John Redmond watershed to prioritize stabilization on to remove additionally sediment that was being transported by the stream. The site used for the analysis was chosen due its location to a USGS gage site and it had a streambank stabilization project planned soon. The study reach was near Plymouth, Kansas and south of US-50 (see Figure 5.1 for site location). This location is in the Flint Hills with the drainage area at the USGS gauge near Plymouth is approximately 4,506 km^2 (1,740 mi^2). The land use is primarily agricultural with most of it being either cropland or grassland. The mean annual precipitation can range from 750 mm to 900 mm (Layzell, Peterson, Moore, & Bigham, 2022). The site is next to a railroad and a highway and was surrounded by a relatively narrow buffer of deciduous trees and agricultural land. The erosion at the site was eroding the farmland and the landowners were concerned about losing valuable farmland. Thus, one of the purposes of the streambank stabilization project was to prevent further damage to the farmland. The site's location on the Cottonwood River – which has been identified as a major source of sediment to a downstream flood control and water supply reservoir (John Redmond Reservoir) – was a primary motivator for the project. All pre- and post-construction geomorphic monitoring as well as most of the project design and construction are funded through the State of Kansas as part of the state's efforts to extend the life of its water supply reservoirs. All design work for the project was completed by The Watershed Institute.

5.2.2 Data Collection

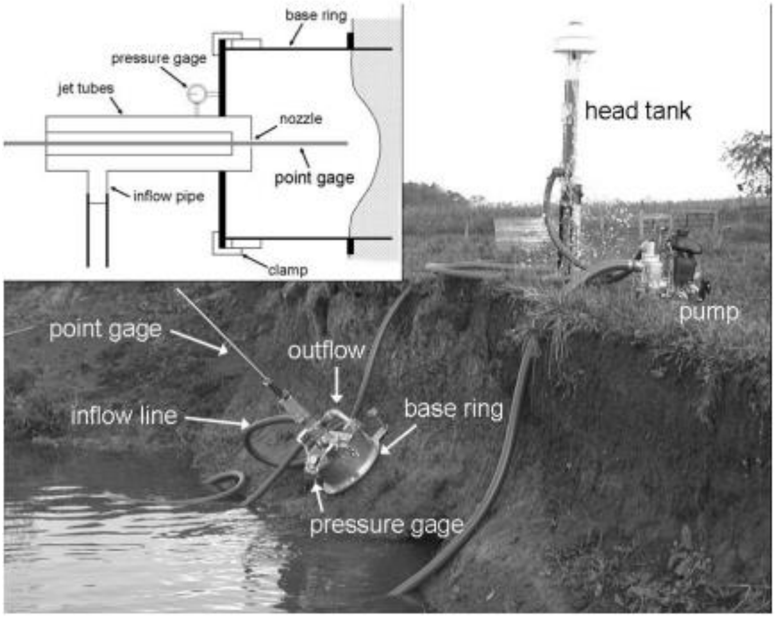
The first step in the process was to gather data on the site. Fortunately, this site has been studied extensively since 2018 to characterize channel geometry, profile, and soil properties. Figure 5.1 illustrates the studied site location with its analyzed cross sections and boreholes from which both soil texture and shear strength properties were determined.

Figure 5.1 Studied Site Location with cross sections (XS-prefix). Figure courtesy of K.A. Bigham.



On-site elevation data were collected using a total station to map out cross sectional dimensions at nine locations within the reach. Streambed elevation data were also measured along the length of the reach. Field surveys were conducted during days of low flow when it was safe to measure (flow generally less than 6.5 cubic meters per second). In 2018, geomorphic surveys of this reach were conducted in May 2018. In addition to geomorphic surveys, streambank soil materials were characterized by a mini jet test to determine the critical shear stress for regions of XS3 and XS2. A mini-jet test is performed by holding a jet at a certain pressure and spraying it into an angled bank (the angle of the bank is recorded) for a certain period of time. The jet is then sprayed for longer periods of time until it has stopped eroding the bank. After the jet stops eroding the bank three consecutive times, the jet test is over. The recorded depths with their times in accordance with the type of soil and angle of the bank determine the critical shear stress of the bank. For full details of how the jet test is conducted refer to Clark & Wynn (2007). A jet test (which is simply a larger form of the mini jet test) is shown in Figure 5.2.

Figure 5.2 Picture of equipment and schematic of interior parts of multi-angle jet test.



Additionally, LiDAR data (gathered in 2018) were used for to characterize elevation of the surrounding terrain and floodplain and was tied into total station geomorphic surveys of the channel. Land use and cover data were gathered from the National Land Cover Database (NLCD 2016). Hydrologic data was collected from USGS Gage 07182250 for use in creating the HEC-RAS model. The hydrograph measured over the period from September 5, 2018, to September 15, 2018, was selected for initial model calibration as it represented a period in which the flow of the river left the main channel and spilled onto the surrounding floodplain. This was selected to determine how the water flows once it has left the bank and to calibrate model roughness parameter (Manning's n) for out-of-bank flows. Two sets of data were taken from the USGS gage for these dates. The first was the flow hydrograph which was to be used for the boundary conditions. The second was the hourly stage height of the river, which was used for calibration purposes. After initial model calibration to this short-term flow event, USGS flow and stage data for the time between May 12, 2018, and November 10, 2019, were collected. Flows occurring during this time were of interest because these dates represent the site survey dates. The geomorphic data used for the model represents the time after the May 12th, 2018, survey.

5.2.3 Developing the HEC-RAS model

Using ArcMap (10.7.1), the site data presented in Section 5.2.2 (elevation, lidar, land use and cover) was placed in a GIS file to be imported into HEC-RAS 6.2. Next, HEC-RAS was loaded, and a new project was created. Then, a geometric data file is created under that project. Once that is completed, a spatial reference system was implemented into the model (Projection was "NAD83/Kansas South" "GCS North American 1983").

Next, a terrain layer was implemented into the project. Using the previous files developed in ArcMap, the RAS terrain was input into the geometry file allowing for the higher resolution layer created by the total station to have priority over the LiDAR layer. This created a terrain with a raster data, with each pixel having an associated elevation. Once the appropriate terrain layer was created from the input files, the layer was then “associated” with the terrain, meaning that any future geometry features created would refer to the correct terrain layer.

After developing the terrain, the next step was to import a land cover layer into the geometry data file. This was done by creating a new land cover layer and then importing the correct land cover layer previously gathered and associating the land cover values with the NLCD 2016 naming standard. The NLCD 2016 naming standard needs to be associated as when the files are initially imported, each land cover type is associated with a number. Thus, associating it with the naming convention utilized by NLCD 2016 makes each number refer to the appropriate land cover type to which impervious % and Manning’s n values can then be assigned. The Manning’s n values used for the base model were taken from the recommended values given from the HEC-RAS version 6.0 Mapper User’s Manual (US Army Corps of Engineers, 2020, page 43). After implementing the land cover layer and its associated Manning’s n values the computational mesh was the next step.

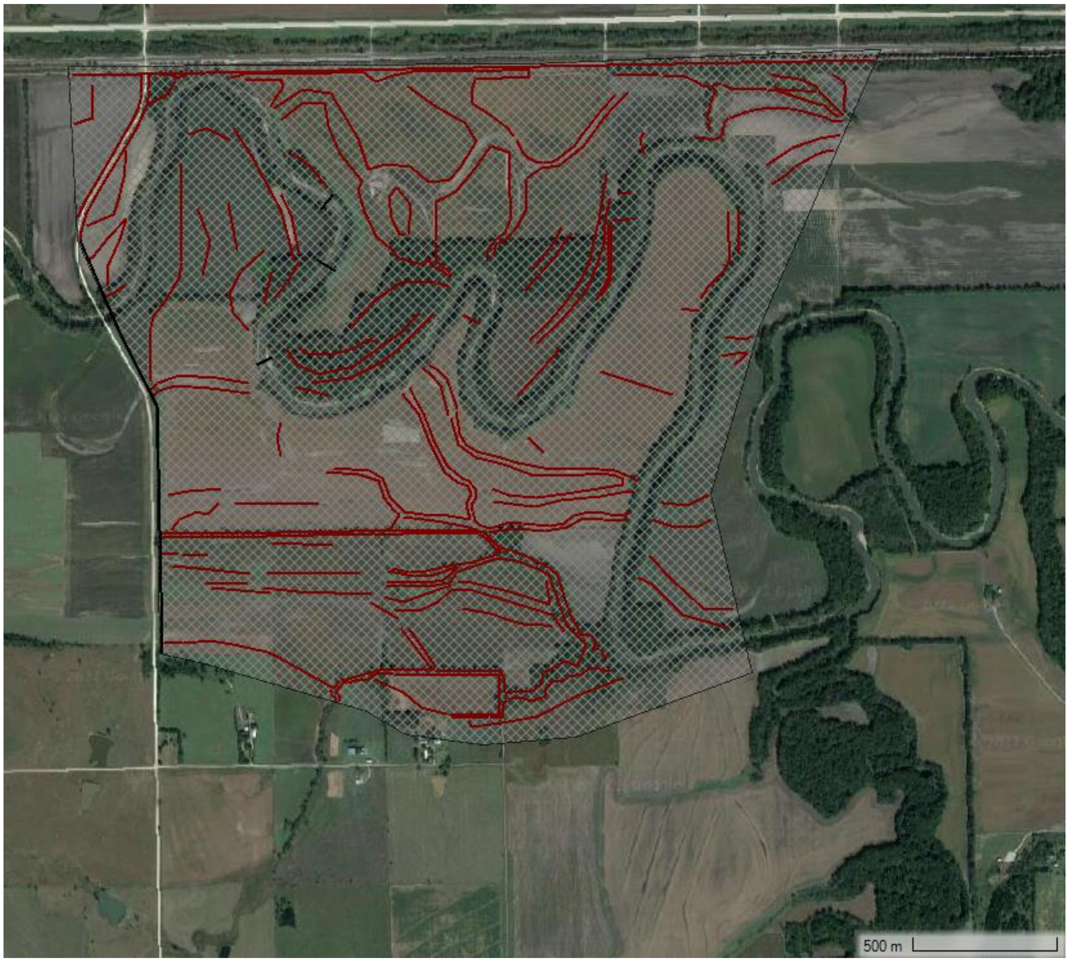
Developing a computational mesh required six steps. The first step is to develop a perimeter. This perimeter represents the boundary of the 2D flow area, which is where the simulation will occur. The simulation calculates the flow inside this perimeter using a diffusion wave equation that is derived from the continuity equation and the momentum equation. For full information about how this equation is derived, refer to the HEC-RAS Hydraulic Reference Manual (US Army Corps of Engineers, 2022). When developing the perimeter, the standard computational points must be set. In this model, the standard spacing for each cell was a 10m-by-10m cell. Each cell has a computation point for it that represents the calculation done for that cell. As the resolution gets smaller the more detailed the model will be. Drawing the perimeter requires deciding where to begin and end the simulation and/or to define the spatial extent of primary interest. For the perimeter shown in Figure 5.3, each boundary (North, East, South, and West) was selected for a specific reason (the black lines refer to the cross sections RXS1, XS1, and XS3 moving downstream.

Figure 5.3 HEC-RAS Perimeter for 2D Flow Area

The north section had the boundary placed by the uphill railroad, the eastern section was selected as it both was past the main area of interest (which is in the middle), and it is in a straight section of the river with a clear exiting route. The southern section was selected as it was at a higher elevation area compared to the surrounding area and therefore unlikely to have any water flow into it. The western section was chosen for two reasons. The first was that it was a straight section of the river, like the exiting route in the eastern section, and the second was that it was just slightly downriver (less than 5 meters) of the bridge and the USGS gauge. This made it a perfect starting point as the flow entering in could be set exactly to the real flow and compared to it.

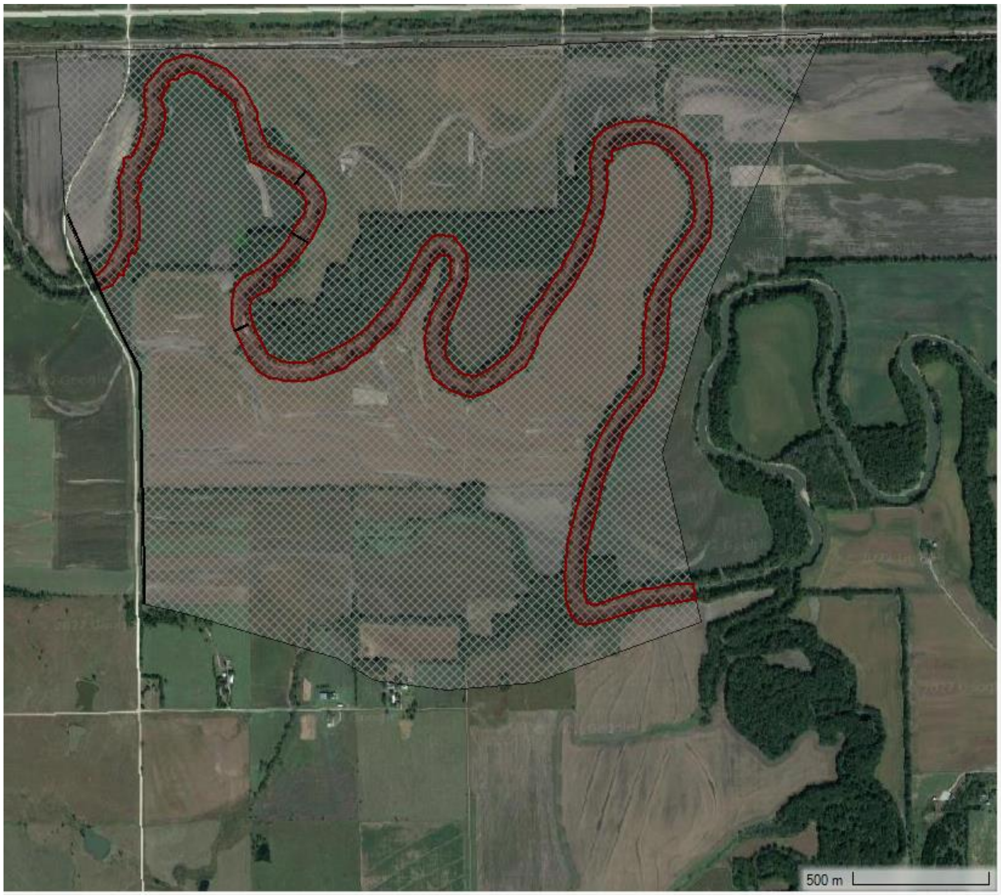
The second step after developing a perimeter was establishing breaklines. These breaklines have the property of "magnetizing" the cells to it. Additionally, the breaklines were set to have a resolution of a 5m-by-5m cell, making it a higher resolution that that of the normal cell. These were placed in areas of high interest such as areas of elevation change where flow would be more likely to change across the terrain. For this model there were a total of 103 breaklines created and they can be viewed in Figure 5.4.

Figure 5.4 HEC-RAS Breaklines for 2D Flow Area



After developing the breaklines, the third step was to create a refinement region. This region is effectively like breaklines but instead of just tracing a line it instead covers an entire area. Similar to the breaklines the region that is contained within the refinement region was created with a resolution of a 5m-by-5m cell. One singular refinement region was created, and it was placed in the river itself with its outside boundaries following an approximation of the vegetation line or edge of channel of where the elevation turned into the bank. This followed the entire river from the western edge to the eastern edge and is shown in Figure 5.5.

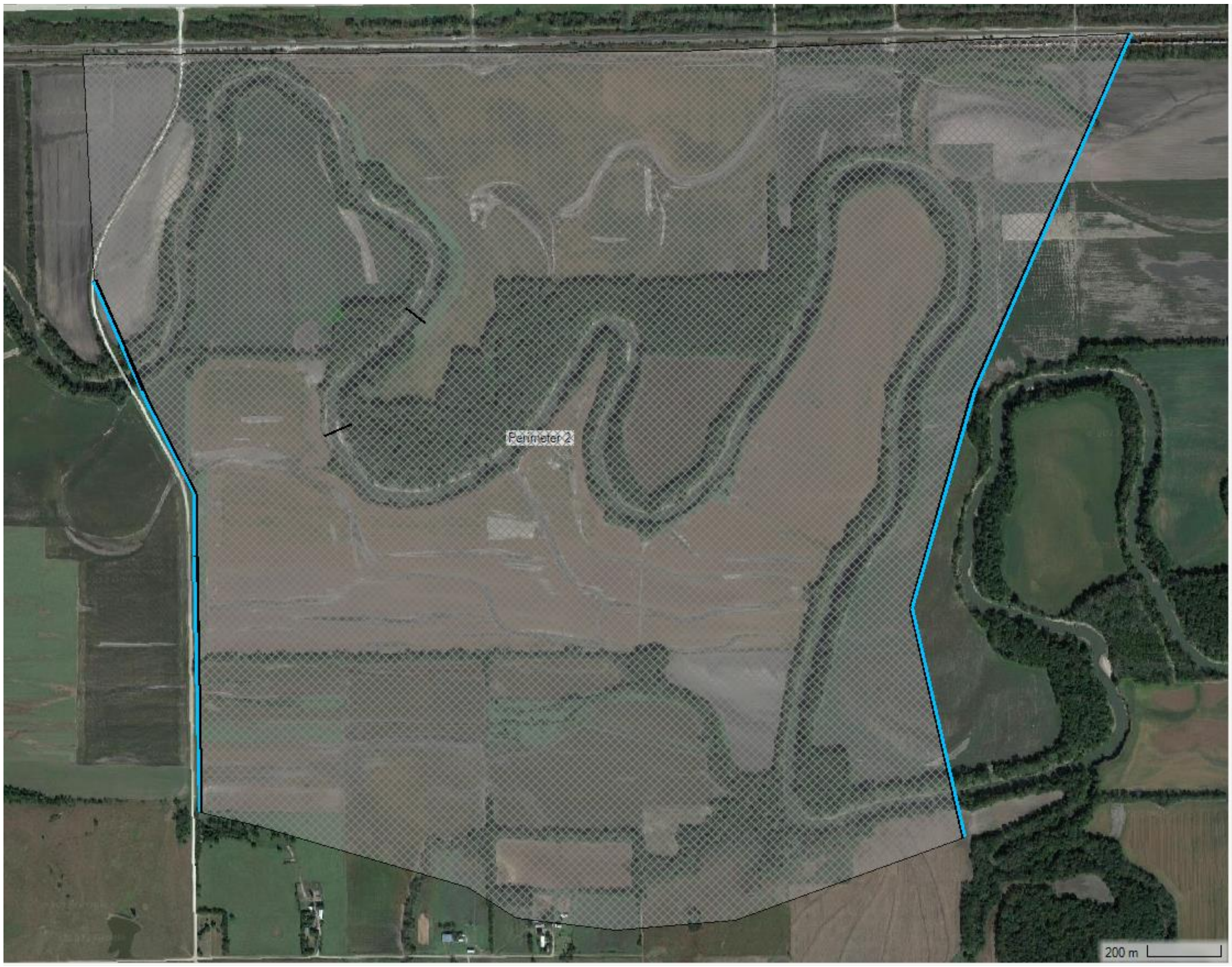
Figure 5.5 HEC-RAS Refinement Regions for 2D Flow Area



After developing the perimeter, breaklines, and refinement region, the fourth step was to have the model create the computational mesh. This is when HEC-RAS creates the cells and computational points within the perimeter area based upon the details of the perimeter, breaklines, and refinement region. Then after generating it, the computational points were edited so that there were no errored cells. Errored cells most commonly occur when there are too many sides to a cell which require too many calculations. When a cell has an error, it will show up as a red dot meaning it won’t properly run. After errored cells were removed, the fifth and final step was to have HEC-RAS was to compute the 2D flow area hydraulic tables.

After the 2d computational mesh was created, the fifth step was to create boundary conditions for the model. These were placed just outside the perimeter of the computational mesh and designated where the model would start the flow through the computational mesh and were it would end after it. Figure 5.6 illustrates the boundary conditions as they are placed on the western and eastern sides of the perimeter.

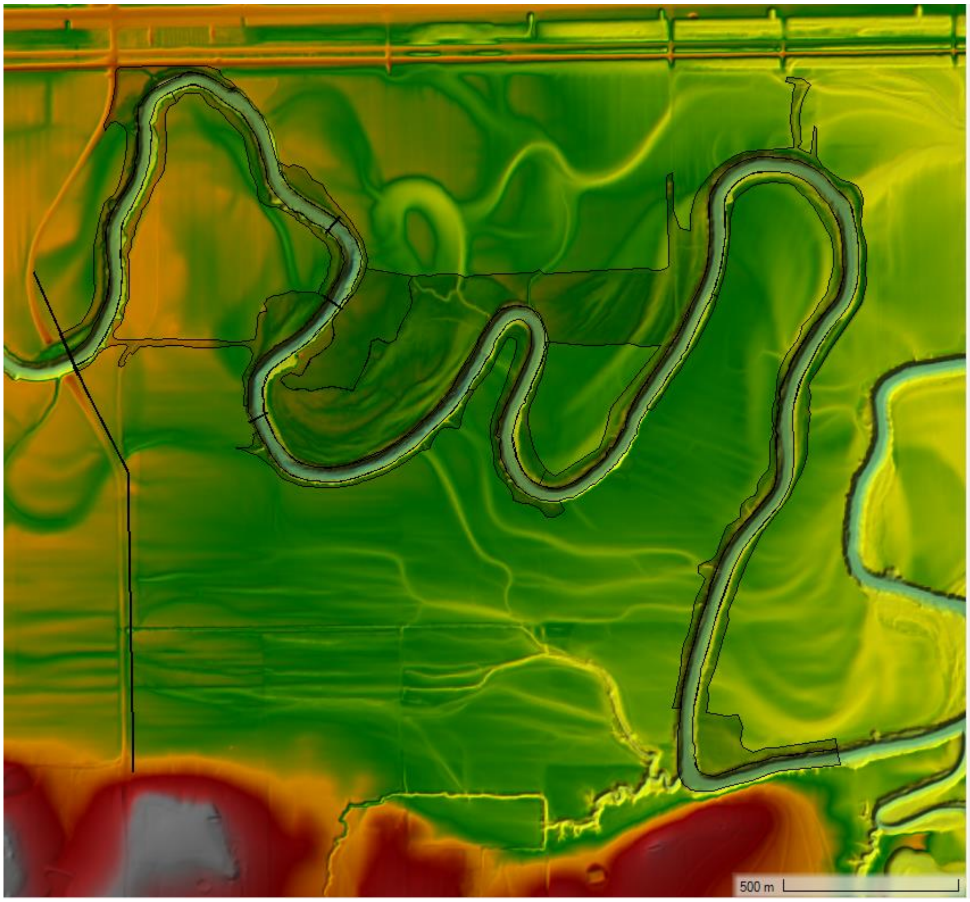
Figure 5.6 HEC-RAS Boundary Condition Lines for 2D Flow Area



The eastern boundary condition is implemented with the hydrograph of the flow event; thus, during the simulation the flow into the computational mesh with the western boundary condition was that of the flow conditions of the inputted hydrograph. There was no precipitation modeled in and the only flow into the system was through the eastern boundary. Thus, when simulated, the only flow is through the river channel that moves from west to east. The eastern boundary condition was the simulated normal depth of the model with a set slope of 0.0004 m/m.

After the boundary conditions were created, the sixth and last step was to establish Manning's n regions for the model. While the land cover layer has already been established and placed in as part of the terrain, it was a large 30mx30m raster and therefore certain areas of the land cover were not representative of the actual location. Therefore, polygons were created that surrounded certain regions and then were given Manning's n values. These certain regions were the deciduous forests around the river, the river itself and farm regions that were mislabeled by the land cover layer. These regions were given the same Manning's n values as the land cover layer. There was a total of 11 Manning's n regions, with most of them being counted as deciduous forest except for two. The Manning's n region that represented the river was considered open water and there was one region that was considered cultivated crops that was located between the river and deciduous forest. Figure 5.7 illustrates the Manning's n regions made for the model. After the geometries had been developed the analysis could then begin.

Figure 5.7 HEC-RAS Manning's n Regions on Elevation Terrain Map



5.2.4 Running the HEC-RAS model

The chosen test for analysis was the Unsteady Flow analysis. The first step was to develop a flow hydrograph that would be placed as the western boundary condition. This hydrograph was created from the flow events from September 5, 2018, to September 15, 2018. The flow data collected from the USGS for this time were placed into the flow hydrograph and saved. The western boundary condition was selected as where the flow hydrograph was started. A measured slope of 0.0004 (from stream profile data collected through geomorphic surveys) was used for the model. Next, the time step controls were changed so that the maximum courant (or residence time within a cell) was 2, the minimum courant was 0.9, the number of steps below the minimum before doubling was 5, the max number of doubling base time step was 1 (60 seconds), the max number of halving base time step was 5 (0.94 seconds) and the courant methodology was set to Velocity/Length. The output interval was set at 15 minutes. Finally, a description of the model was written detailing its base details and the flow plan was saved. Then, once saved the unsteady flow simulation was run for the dates of September 5, 2018, to September 15, 2018.

5.2.5 Calibrating the HEC-RAS model

After the model was successfully run, the model was calibrated. The model was calibrated for the stage height at the starting location at the bridge where the USGS gage is located (corresponding with the Western boundary condition). The simulated stage height was compared to the actual stage height and calibrated to it. This was done by changing the Manning's n within the calibration zones made (The polygons created for Manning's n regions). This can be explained by Manning's equation (Equation 5.3) shown below (Huffman, Fangmeier, Elliot, & Workman, 2013).

Equation 5.4 Manning's Equation

$$Q = VA = \frac{A * R^{\frac{2}{3}} * S^{\frac{1}{2}}}{n}$$

Here, Q represents the flow rate (m^3/s), V represents the velocity (m/s), A represents the flow area (m^2), S represents the channel slope (m/m), n represents Manning's roughness coefficient, and R represents the hydraulic radius (m). The hydraulic radius is the cross-sectional area divided by the wetted perimeter. USGS gages measure the depth of the water or its stage and then relate to discharge using a rating curve that associates water stage with periodic field measurements of channel velocity and flow area from which discharge is derived. Therefore, the flow rate in this equation was replaced for the equation used to determine flow rate using the stage height. Therefore, the equation was altered to solve for stage height. The relationship then between the stage height and Manning's n is a proportional relationship. If Manning's n increases, then stage height will increase and vice versa. The simplified relationship used for calibration is shown (Equation 5.5) below.

Equation 5.5 Simplified Manning's Equation

$$D = \frac{K}{n}$$

Here D represents the stage height (m), the K represents the combination of variables left unmodified in calibration (flow area, channel slope, and hydraulic radius), and n still represents Manning's n. This relationship was used in the calibration of the model to get the appropriate stage height measured using Manning's n. Manning's n was adjusted so that the corresponding stage height was as close to the actual elevation as possible. That original Manning's values were derived from the NLCD 2016 data. The stream channel Manning's n was originally set to 0.035 but then altered after the original run. Table 5.1 below shows the test results of each of the simulated runs used to get a calibrated model. Several goodness of fit statistics, including Nash-Sutcliffe Efficiency (NSE), percent bias (PBIAS), root mean square error (RMSE), and the ratio of RMSE and standard deviation of measured stream stage data (RSR) were utilized to evaluate how well simulated stream stages matched measured stream stage.

Table 5.1 Simulation and Calibration Tests

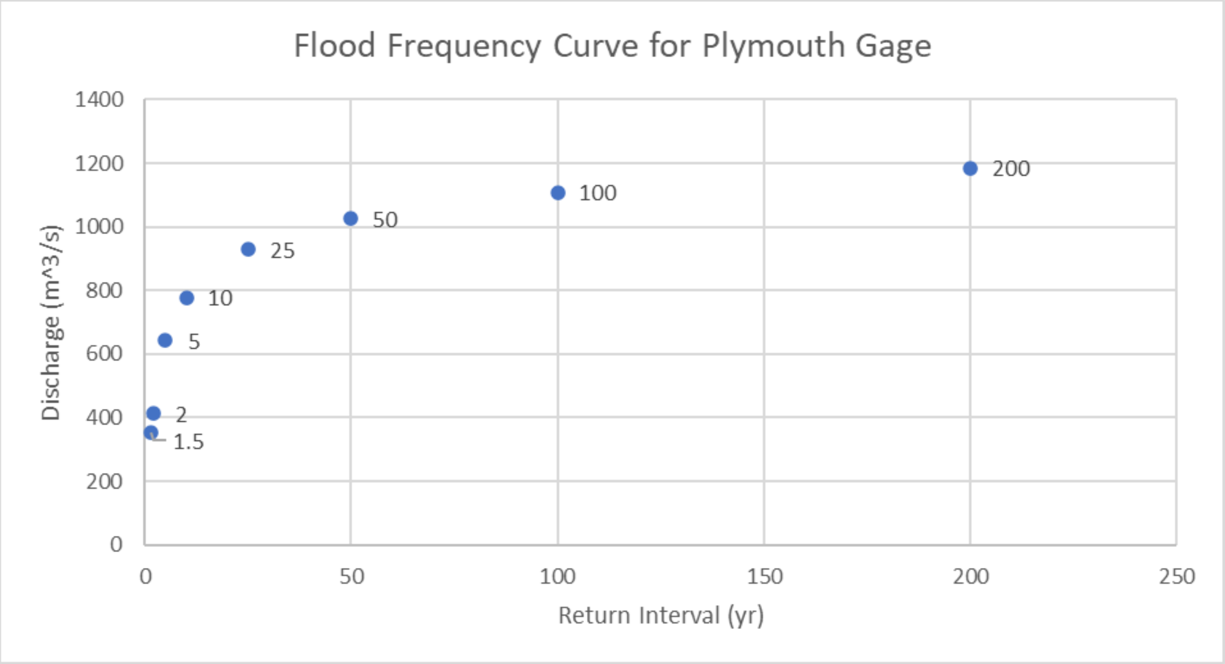
Simulation	Manning's N for Stream Channel	Manning's N for Deciduous Forest	NSE	PBIAS	RMSE	STDEV	RSR
1	0.04117	0.08	0.9949	-0.0377	5.1233	72.0621	0.0711
2	0.04117	0.1	0.9948	-0.0404	5.1750	71.7960	0.0721
3	0.04	0.08	0.9954	-0.0336	4.9374	72.4725	0.0681
4	0.02	0.08	0.9946	0.0858	6.3745	87.1323	0.0732
5	0.03437	0.08	0.9969	-0.0014	4.2512	75.9602	0.0560
6	0.03437	0.065	0.9969	-0.0013	4.2449	75.9736	0.0559

With the NSE approaching 1, the PBIAS approaching zero, and RSR approaching zero, the tests verify the relative accuracy of the model's ability to simulate stage height (Moriasi, et al., 2007).

5.2.6 Scenario Creation

Prior to setting model scenarios, a flood frequency analysis was conducted for the study reach to determine the 2, 5, 10, 25, 50, 100, 200-year flood events and their discharges. Using these discharges would be useful in scenarios in which a high flood event would occur. To determine the flood frequency curve, a Log-Pearson type III flood frequency analysis was conducted. This was done using the maximum annual discharge for every available year in the Plymouth USGS gage (1963-2022). For full details on the flood frequency analysis, refer to Barcelona Field Studies Centre (2022). While the 1.5-year event was not readily determined by this analysis, it was approximated by finding a line of best fit using the other discharges for the 2-, 5-, and 10-year events and using the equation for the line of best fit to find the peak discharge for the 1.5-year event. The Log Pearson Type-III analysis is shown in Figure 5.8 below.

Figure 5.8 Flood Frequency Curve for Plymouth Gage



The next step was to determine events that would be analyzed for their shear stress. Due to unresolved errors in model outputs that occurred when longer time periods were run (i.e., brief periods of high shear stress occurring in odd locations), shorter data periods representative of singular events were chosen. The events chosen where the 1.5-, 10-, 25-, and 100-year return interval storm events. The 1.5-year return would analyze the erosion rate of a relatively common flow event that is often associated with the so-called bankfull flow, or the flow that is generally believed to do, on average, most of the geomorphic work in the channel (Dunne & Leopold, 1978). The other interval flow events would determine how progressively higher discharges could affect the shear stress with the cross sections. Both the 100-year return event as well as the two scenarios had to be artificially created. For the 100-year return, the discharge for the return interval (1109 cubic meters per second) was set as the peak flow, so a similar flow event was taken in the time but then had its peak set to be the return interval discharge. This was done by taking the rate at which the discharge increased towards the peak and extending it until it reached the appropriate discharge. This artificial peak then replaced the old, with the old hydrographs rising and recessing limbs remaining. This type of change was also done for the two scenarios discussed later. However, for the 100-year event the peak and the rising slope had to be modified. When HEC-RAS starts analysis, one possible error to occur is if the flow does not start in the channel. If a high enough beginning flow is placed at the beginning of the simulation period, then the flow will be out of the banks and not be correct. In this case, the highest flow event had started with a high flow due to an older event occurring. This older event was removed but the rising limb still maintained a similar slope until it reached a discharge that matched the actual flow event and then the rest of the hydrograph remained the same. Essentially events with artificial rising limbs were edited so that they would start with a smaller flow for it to be in the channel. For the 1.5-, 10-, and 25-year events, a unit hydrograph was developed and was modified to match the peaks for each of the events based.

Next, two flood scenarios were selected. The first scenario chosen was the highest flow event of the studied period (from May 2018 to November 2019), this would show the possible erosion rate of a serious flood. This scenario was modified similarly to the 100-year flood with the rising limb edited so that no errors occurred. The peak flow for this event was 980 cubic meters per second, which corresponded to a flow between the 25-year and 50-year storm events. The second scenario chosen was a smaller discharge of 168 cubic meters per second. This was to simulate a flow that was below a bankfull depth to determine what shear stresses would occur below the most fluvially dynamic rate and compare it to the 1.5-year event.

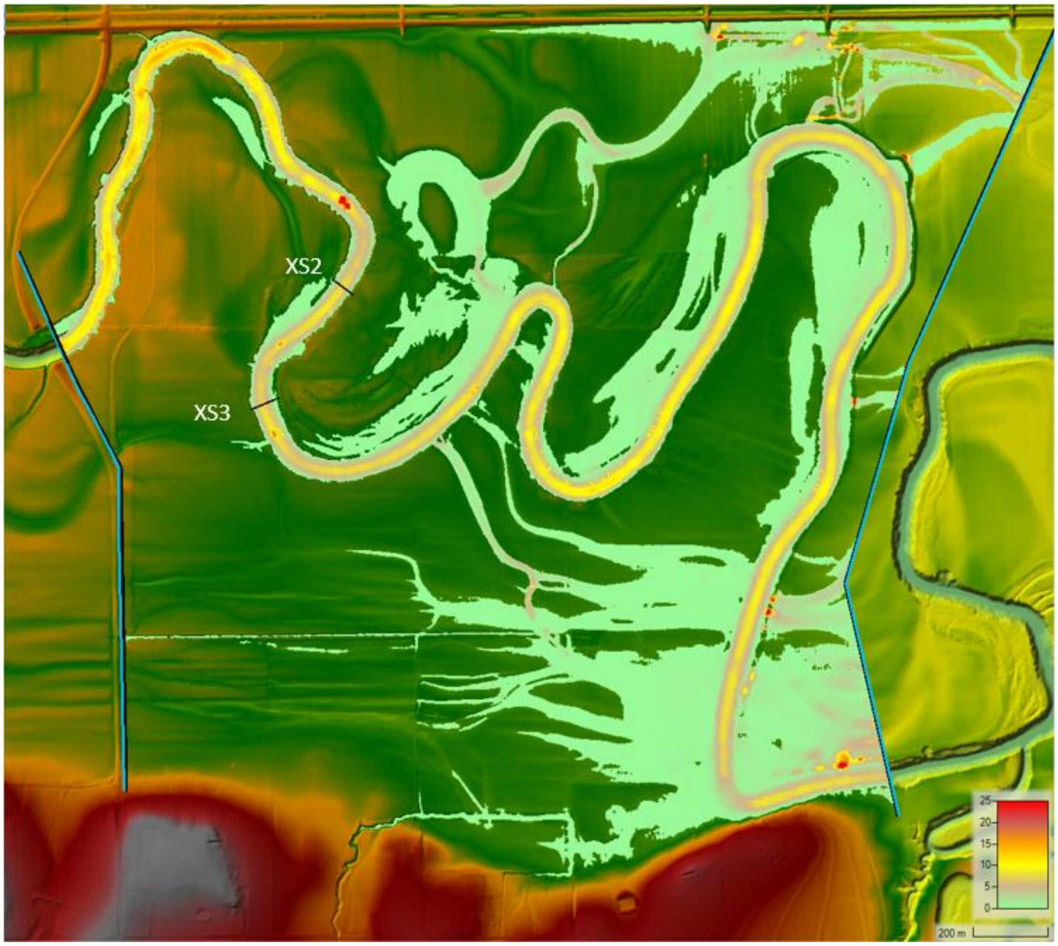
In addition to the events the locations for analysis also had to be decided. The chosen locations were the profiles XS2 and XS3 (see Figure 5.2). These were chosen as these cross sections were directly measured within the field and were points of interest that could be referred to later once further analysis was conducted.

Finally, the 1.5-, 10-, 25-, and 100-year events and the two scenarios were analyzed by comparing their shear stresses at both locations to each other as well as calculating an estimated erosion rate. The cross sections were analyzed during the highest occurring shear stress periods for the event. For this time, location, and event, the erosion rate (cm/s) was calculated.

5.3 Results of HEC-RAS Model

Once calibrated for the given time frame, the HEC-RAS model was then run for the four events and the two scenarios. Shear stress distributions across the study reach as well as the profiles for XS2 and XS3 are presented in Appendix E. An example of one of the successful HEC-RAS runs is shown in Figure 5.9.

Figure 5.9 Maximum Shear Stress (Pa) for the 1.5 Year Flow Event



The results are quite different depending on the location along the stream. The shear stress predicted upstream and downstream of the total station topographic data was much higher. This did not affect the analysis as the two sites for examination occurred in the total station data. The results of the analysis are summarized in Figures 5.10 and 5.11.

Figure 5.10 Shear Stress at XS2 at different events and scenarios

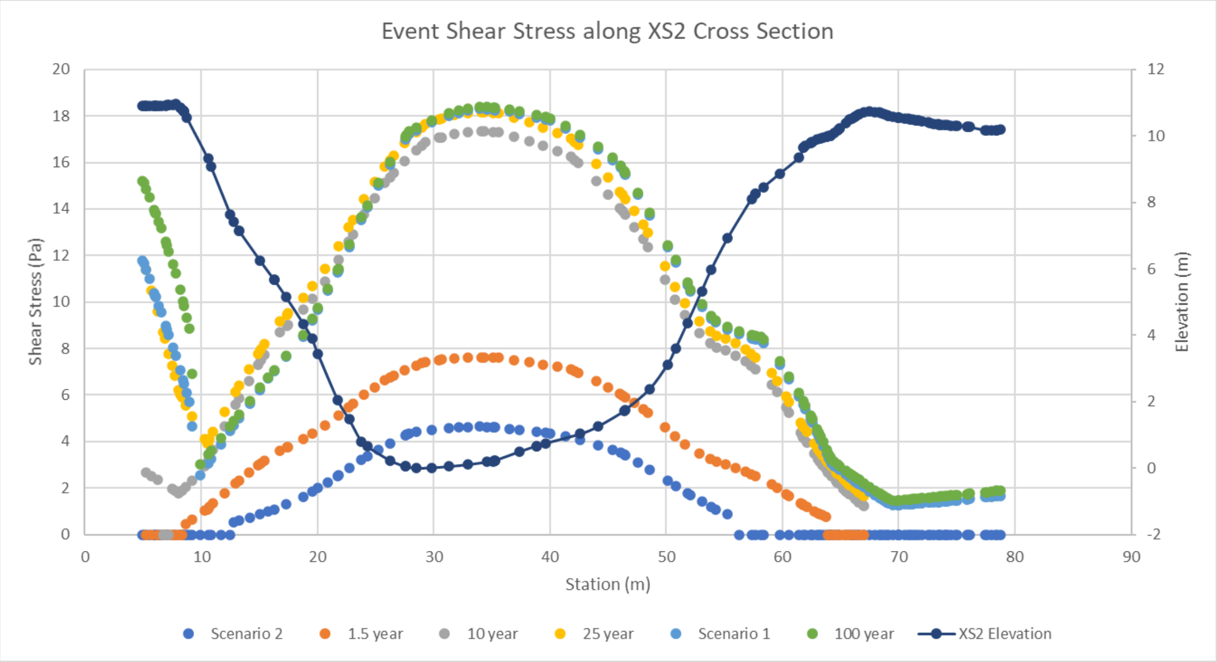
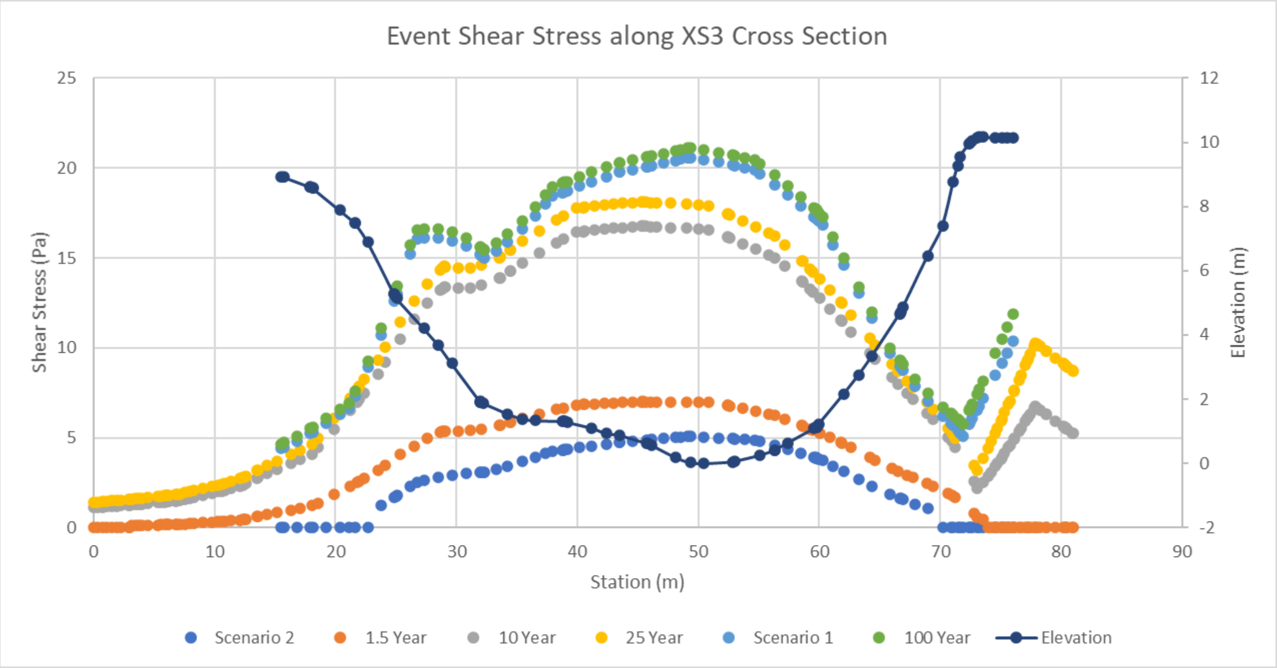
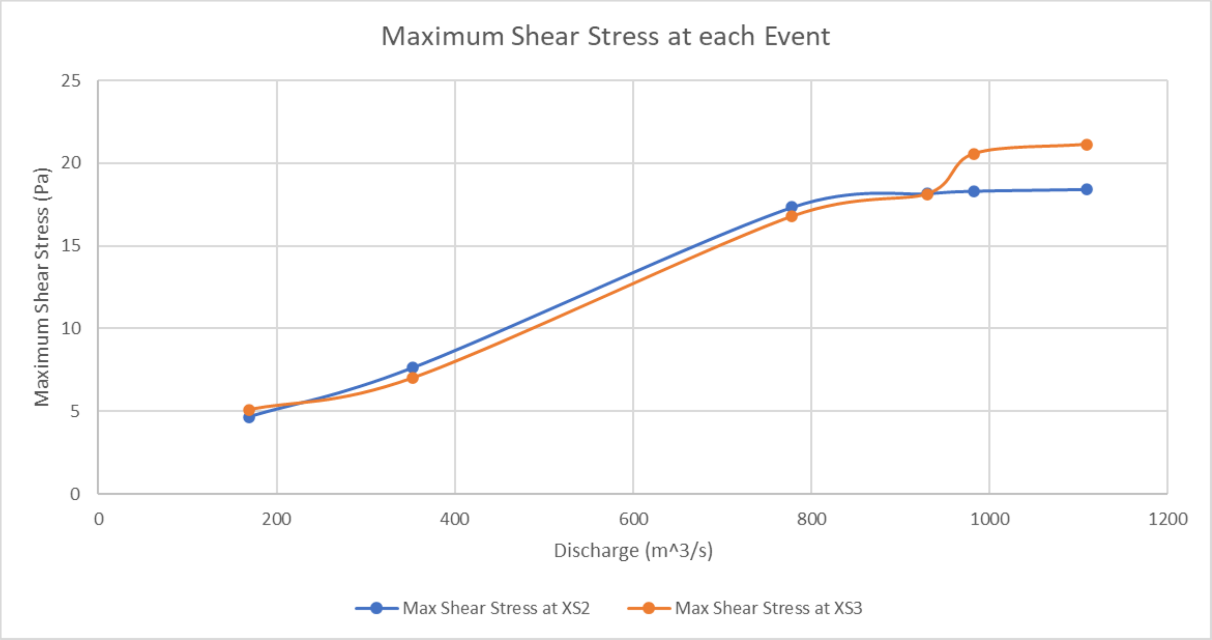


Figure 5.11 Shear Stress at XS3 at different events and scenarios



The shear stress along both cross sections indicates a higher shear stress along the center of the channel with a spike in shear stress along the concave banks for the higher discharge events. XS2 had a higher peak in shear stress compared to XS2 indicating a higher incision toward the center of the channel compared to XS3. In addition to the location of the shear stress in the channel the overall max shear stress was compared to the discharge of each event, illustrated in Figure 5.12 below.

Figure 5.12 Discharge to Shear Stress Graph



The shear stress at each event is similar for both XS2 and XS3. XS2 remains higher for the lower events while XS3 contains higher shear stress for the higher discharge events. Both end up smoothing out due to the flow leaving the channel for the high flow events. In addition to shear stress their calculated erosion rates can be found below in Table 5.2. The erosion was calculated using Equations 5.2 and 5.3 (Can be found in section 5.2.1) along with the critical shear stress determined from JET tests by (Layzell, Bigham, & Moore, 2021).

Table 5.2 XS2 Erosion Rates for each Event and Scenario

Event	Max Erosion Rate XS2 (cm/s)	Max Erosion Rate XS2 (cm/s)
1.5	15.23	13.994
10	34.648	33.526
25	36.282	36.228
100	36.808	42.226
Scenario 1	36.598	41.128
Scenario 2	9.274	10.15

The critical shear stress for XS2 was 0.01 Pa which was reflected in the higher estimated erosion rate. Even at a lower 1.5-yr and scenario 2 flow events, the max erosion is quite high. The XS3 critical shear stress was 0.43 Pa which was considerably higher. Overall, the erosion skyrockets with the higher discharge events until the flow starts to leave the bank.

According to these results the highest loss of bank should be from the XS2 site (up until massive flood events). However, these results do not match the recorded losses at these locations from geomorphic surveys. The west or right bank (looking downstream) of site XS3 has been recorded to have an erosion rate of more than 42 times compared to the east or left bank (looking downstream) of site XS2 (Layzell, Bigham, & Moore, 2021). The erosion that the model predicts is largely in the center of the channel and not the banks. However, it does indicate that storm events higher than a 10-year storm such as the first scenario will see erosion occur during on the banks of interest at a large rate. Which may explain the differences in erosion of the two banks at each site. Now while these amounts can be referenced generally, the results of erosion from other factors must be considered for erosion, such as the pore pressure and the slope of the bank. Additionally, it should be noted that the average critical shear stress at the XS2 site is remarkably low. This could be due to errors done in performing the JET test or it could be caused by a lack of clay in the soil. The USDA classification from the soil samples gathered, labeled it as a silt loam, which can have anywhere from 0-26% clay content (Natrual Resources Conservation Service, n.d.). Equation 5.6 demonstrates how a low clay percentage can be a predictor in low critical shear stress (Clark & Wynn, 2007).

Equation 5.6 Determining Critical Shear Stress with Percent Clay content

$$\tau_c = 0.493 * 10^{0.0182 * P_c}$$

The higher the clay content, the higher the critical shear stress. While this may explain the reason why the critical shear stress at site XS2 is so low, it cannot fully explain erosion situation of the sites. In this case, other factors including the relative pore pressure, the slope of the profile, and geotechnical failure of the bank could affect the simulated and real-life results. Shear stress is only a part of a larger puzzle regarding the erosion that can occur at a site, especially over a long examination period.

Chapter 6 - Conclusion

In Chapter 1, the topic of streambank stabilization and restoration was briefly introduced from its history, and it developed the key research questions posed for this thesis:

1. What models and literature do practitioners use when informing their design?
2. What are the factors that constrain practitioners' design?
3. How does shear stress vary spatially across a range in flow events along a reach in the Cottonwood River in southeast Kansas prior to the construction of streambank stabilization structures?

To address these research questions, the following objectives for the thesis were set:

1. Create a detailed understanding of the guidelines and models practitioners used.
2. Describe the factors that constrain practitioners' ability to perform in the field.
3. Develop a case study to assess hydraulic conditions and potential bank erosion hotspots for the Cottonwood River prior to implementation of a streambank stabilization project.

In Chapter 2, the literature review discussed the history of steam channel stream channel restoration and stabilization. This included the development as well as the current limits of the practice. This chapter concluded that there were still two major factors that could impact the field. The first was the need to understand factors that impacted the limitations. The second was understanding the tools and guidelines practitioners used and the reason why these were used.

After establishing a need to understand the factors that limit practitioners and the practice, Chapter 3 presented the development of the survey, the goal of which was to deepen understanding of the stream restoration and stabilization practice, particularly throughout the design process. This chapter established the development of this survey as well as its means of analysis.

Chapter 4 discussed the results of the study. There were five key takeaways from the survey. The first was how objectives differ amongst practitioners, the second was how Rosgen's methods are prevalent throughout all but two main regions, the third was that HEC-RAS is the predominant computational model used, the fourth was the lack of data for certain analysis such as sediment bedload, and the fifth was how practitioners differ by

Chapter 5 discussed the development and the main results of the HEC-RAS model. The chapter reflected on how the discharge affected the shear stress along the two main locations of the site and what can be expected for the erosion at the site.

The objectives were met in each of the following ways. The first objective, "Create a detailed understanding of the guidelines and models practitioners used" was addressed in Chapter 4, where the survey addressed the guidelines and standards typically used by practitioners as well as the predominant scholarly and proactive-based influences on those guidelines. This analysis showed that most practitioners used Rosgen-based methods (e.g., natural channel design) except for two USDA farming regions (Lake States and Southeast and Delta States). The second objective, "Describe the limits that constraint practitioners' ability to perform in the field" was also addressed in Chapter 4, where the limits of money, regulation and time were analyzed by how much they impacted certain factors such as the ability to choose what data to collect, and what models they use. Regulation and time impacted practitioners' ability to perform certain studies in the field such as post-construction monitoring, permitting time especially effected practitioners' abilities to perform efficient studies, with some taking upwards of a year to process. The lack of time to train or the lack of effectiveness impacted using new modeling tools. The third and final objective, "Develop a case study to assess hydraulic conditions and potential bank erosion hotspots for the Cottonwood River prior to implementation of a streambank stabilization project," was examined in the 5th chapter. Here, two cross sections of the Cottonwood River where field data had been previously collected were examined for shear stress that helped locate both the amount of shear stress and the locations of shear stress for the site. The results of the study showed that the location of likely erosion was quite accurate, with the higher discharge events reflecting higher erosion rates on the banks than the lower discharge events. While the erosion locations were accurate, the calculated erosion rates strictly from the simulated shear stress are not accurate as other factors such as JET test error, geotechnical failure, and pore pressure can affect the overall erosion at a site.

6.1. Future Work

This section will break down the potential future work related to the survey (6.1.2) and the HEC-RAS model (6.1.3) separately.

6.1.1 Site Location and Description

As noted previously, the purpose of this survey was to develop a general picture of the state of the practice. There are opportunities for future work to expand upon several questions and topics covered in this survey. An example would be the costs of stream projects, which. as demonstrated in this survey, can be highly variable. A follow-up cost analysis survey could be done regionally and could examine other design and site-specific factors that affect cost. It also should be compared to previous surveys, such as Bernhardt et al. (2005) and the one presented in this chapter, to both validate previous surveys as well as expand the knowledge of the practice. Previous comparisons to surveys to the one presented in this paper revealed that the spatial correlation of the participants to be similar although statistically uncorrelated. Therefore, validation through more surveys would add credit to both this survey, past surveys, and future work that builds upon these previous efforts. Additionally, future surveys should use population but not population density as a proxy to validate how well the survey was distributed amongst the actual stream designer population.

Future work to advance the state of the practice of stream channel restoration and stabilization design includes development of university-based programs such as specialization areas within bachelor's or master's degree programs, certification programs or other educational training pathway (perhaps training courses). While this isn't necessarily a new suggestion (Niezgoda, et al., 2014) two additions are recommended to the engineering side of the educational pathway based on this work. The first is to provide technical training in computer models. The survey demonstrated that most practitioners use HEC-RAS and/or other hydraulic software tools to inform design. While Niezgoda, et al., (2014) have discussed including technical training, this is a direct recommendation for educational training in the use of hydraulic models, such as HEC-RAS. The use of the model should be taught, but also its limits and weaknesses. While these tools are valuable and used, those who don't use them often refer to the fact that sometimes they are too inaccurate. The second is to provide in-the-field training. Students or participants enrolled in the educational platform should have the opportunity to gather data in the field. While certain data such as cross-section geometry, bankfull flow indicators, and bed sediment size would be good to teach (due to its widespread use and importance in the design process), using the platform as an opportunity to gather long-term data as part of pre- and post-construction monitoring efforts could be beneficial to both the students and the practice as these results could become available to the practitioners in the form of case studies. It might be difficult to start these programs since university professors are less likely to investigate these topics due to lower publishing ability or winning grants. There are two possible solutions to this. The first is that if this training were available to outside practitioners, then fees could be collected from the practitioner's workplace. With enough participants, this would be cheaper than the practitioners conducting monitoring and potentially other field data collection themselves, and it would provide funding for the university to do so. The second solution is that if the funding is placed as part of a degree program, rather than grant research, then the funding wouldn't be solely the professor's responsibility and it would be part of a larger program (of course this then places the financial burden on other places of the university). There are several benefits for this education platform. The first is that it would provide education to future practitioners and provide them experience which will improve success in the practice. The second is that it would create more communication between the practitioners and the universities. This would allow networking between the two, so that practitioners would be provided with training and necessary data, and the universities would have their students be able to network with future employers and develop problem-based research questions from deeper interactions with practitioners.

6.1.2 Conclusions for HEC-RAS Model

This HEC-RAS model remains a part of a larger study to examine HEC-RAS's ability to simulate and predict erosion across a channel and as a design tool to inform placement of streambank stabilization or other structures. Further research comparing models created for later time periods to actual measurements will be necessary to determine HEC-RAS's effectiveness in predicting erosion rates. After examining the results of the modeled scenarios, HEC-RAS performed acceptably for locating sections that are susceptible to erosion. However, utilizing it to determine exact rates of erosion should be done with caution. HEC-RAS does have the capability for simulating sediment transport, yet most practitioners use HEC-RAS to understand shear stress and velocity only. Understanding this, HEC-RAS should be used in conjunction with other methods to determine both location and rate of erosion along a channel. It may be that the current method for utilizing HEC-RAS in the field (i.e., only examining velocity and shear stress) is insufficient in predicting future changes in the river. While HEC-RAS may improve and create newer and more effective tools to predict changes in a stream, if practitioners have inadequate training, or time to use them, then these tools may not be used to their fullest extent.

Bibliography

Agresti, A. (2007). *An Introduction to Categorical Analysis.* Hoboken: John Wiley & Sons, Inc.

Arthington, A. H. (2012). *Environmental Flows: Saving Rivers in the Third Millennium.* University of California Press. Retrieved from https://www.jstor.org/stable/10.1525/j.ctt1ppw56

Barcelona Field Studies Centre. (2022, 06 05). *Spearman's Rank Correlation Coefficient*. Retrieved from GeographyFieldwork: https://geographyfieldwork.com/SpearmansRank.htm

Bernhardt, E. S., Palmer, M. A., Allan, J. D., Alexander, G., Barnas, K., Brooks, S., . . . Sudduth, E. (2005). Synthesizing U.S. River Restoration Efforts. *Science*, 636-637.

Bigham, K. (2020). Streambank Stabilization Design, Research, And Monitoring: The Current State And Future Needs. *American Society of Agricultural and Biological Engineers,* 351-387.

Brewer, S. K., Worthington, T. A., Mollenhauer, R., Stewart, D. R., McManamay, R. A., Guertault, L., & Moore, D. (2018). Synthesizing models useful for ecohydrology and ecohydraulic approaches: An emphasis on integrating models to address complex research questions. *Ecohydrology*, 1-26.

Clark, L., & Wynn, T. (2007). Methods For Determining Streambank Critical Shear Stress And Soil Erodibility: Implications For Erosion Rate Predictions. *ASABE*, 95-106.

Dale, G., Dotro, G., Srivastava, P., Austin, D., Hutchinson, S., Head, P., . . . Liu, H. (2021). Education in Ecological Engineering—a Need Whose Time Has Come . *Circular Economy and Sustainability*.

Dunne, T., & Leopold, L. B. (1978). Water in Envrionmental Planning. In T. Dunne, & L. B. Leopold, *Water in Envrionmental Planning* (p. 818). San Fancisco: Freeman.

Florsheim, J. L., Mount, J. F., & Chin, A. (2008). Bank Erosion as a Desirable Attribute of Rivers. *BioScience*, 519-529.

Garcia-Santiago, K., & Calderon, C. A. (2021). *1D and 2D Hydraulic Modeling to Estimate Bridge Scour: A Case Study.* San Juan: Civil & Environmental Engineering and Land Surveying Department Polytechnic University of Puerto Rico.

Heimlich, R. (2000, August 1). *Farm Resource Regions.* Retrieved from Economic Research Service U.S. Department Of Agriculture: https://www.ers.usda.gov/publications/pub-details/?pubid=42299

Higgins, J. J. (2004). *Introduction to Modern Nonparametric Statistics.* Pacific Grove: Thomson Learning, Inc.

Huffman, R. L., Fangmeier, D. D., Elliot, W. J., & Workman, S. R. (2013). *Soil and Water Conservation Engineering, 7th Edition.* St. Joseph: American Society of Agricultural and Biological Engineers.

Jacobs Creek Watershed Association. (2009). *Jacobs Creek Watershed Implementation And Restoration Plan.* Pittsburgh: A.D Marble & Company.

Jones, C. J., & Johnson, P. A. (2015). Describing Damage To Stream Modification Projects In Constrained Settings. *Journal of the American Water Resources Association*, 251-262.

Lave, R. (2012). Bridging Political Ecology and STS: A Field Analysis of the Rosgen Wars. *Annals of the Association of American Geographers*, 1467-8306.

Lave, R., Doryle, M., & Robertson, M. (2010). Privatizing stream restoration in the US. *Social Studies of Science*, 677-703.

Layzell, A. L., Peterson, A., Moore, T. L., & Bigham, K. A. (2022). UAS-based assessment of streambank stabilization effectiveness in an incised river system. *Geomorphology*, 2-14.

Layzell, T., Bigham, K., & Moore, T. (2021). *Streambank Evaluation of the Cottonwood and Neosho Rivers above John Redmond reservoir: FINAL REPORT.* Kansas Water Office.

Lightbody, A. F., Radspinner, R. R., Diplas, P., & Sotiropoulos, F. (2010). River Training and Ecological Enhancement Potential Using In-Stream Structures. *Journal Of Hydraulic Engineering*, 967-980.

MacWilliams Jr., M. L., Thompkins, M. R., Street, R. L., Kondolf, G. M., & Kitanidis, P. K. (2010). Assessment of the Effectiveness of a Constructed Compound Channel River Restoration Project on an Incised Stream. *Journal Of Hydraulic Engineering*, 1042-1052.

Malakoff, D. (2004). the River Doctor. *SCIENCE*, 937-939.

Moerke, A., & Lamberti, G. (2004). Restoring Stream Ecosystems: Lessons from a Midwestern State. *Society for Ecological Restoration International*, 327-334.

Moriasi, D., Arnold, J., Liew, M. V., Bingner, R., Harmel, R., & Veith, T. (2007). Model Evaluation Guidelines For Systematic Quantification Of Accuracy In Watershed Simulations. *American Society of Agricultural and Biological Engineers*, 886-900.

Natrual Resources Conservation Service. (n.d.). *Soil texture Calculator*. Retrieved from United States Department of Agriculture: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/soils/?cid=nrcs142p2_054167

Natural Resources Conservation Service. (2007). *Part 654 Stream Resoration Design National Engineering Handbook Chapter 11 Rosgen Geomorphic Channel Design.* United States Department of Agriculture.

Niezgoda, S. L., Wilcock, P. R., Baker, D. W., Price, J. M., Castro, J. M., Curran, J. C., . . . Shields Jr, F. D. (2014). Defining a Stream Restoration Body of Knowledge as a Basis for National Certification. *Journal of Hydraulic Engineering*, 123-126. doi:https://doi.org/10.1061/(ASCE)HY.1943-7900.0000814

Princeton Hydro. (2012). *Stream Bank Stabilization Design for Urbanized Segment of the Whippany River Between Lake Pocahontas and the Railroad Crossing* . Ringoes: Princeton Hydro.

Radspinner, R. R. (2009). *Development of Design Guidelines For In-stream Flow Control Structures.* Blacksburg: Virginia Polytechnic Institute and State University.

Radspinner, R. R., Diplas, P., Lightbody, A. F., & Sotiropoulos, F. (2010). River Training and Ecological Enhancement Potential Using In-Stream Structures. *JOURNAL OF HYDRAULIC ENGINEERING,* 967-980.

Resource Institute. (2022). *Resource Institute*. Retrieved from Resource Institute: https://www.resourceinstituteinc.org/

Rhoads, B. L., Urban, M., & Herricks, E. E. (1999). Interaction Between Scientists and Nonscientists in Community-Based Watershed Management: Emergence of the Concept of Stream Naturalization. *Environmental Management*, 297-308.

Rubin, Z., Kondolf, G. M., & Rios-Touma, B. (2017). Evaluating Stream Restoration Projects: What Do We Learn from Monitoring? *Water*. doi:DOI: 10.3390/w9030174

Shelley, J., Gibson, S., & Williams, A. (2015). *Unsteady Flow And Sediment Modeling In A Large Reservoir Using HEC-RAS 5.0.* Kansas City: U.S. Army Corps of Engineers.

Simon, A., Doyle, M., Kondolf, M., Shields Jr., F., Rhoads, B., & McPhillips, M. (2007). Critical Evaluation Of How The Rosgen Classification And Associated ‘‘Natural Channel Design’’ Methods Fail To Integrate And Quantify Fluvial Processes And Channel Response. *Journal of the American Water Resources Association*, 1117-1131.

Smith, B. S. (2021). *On the Design of Instream Structures in the Mid-Atlantic United States: An Investigation of the Design, Project, and Watershed Factors that Affect Structure Success.* Blacksburg: Virginia Polytechnic Institute and State University.

Thompson, D. M. (2005). The history of the use and effectiveness ofinstream structures in the United States. *Geological Society of America*, 35-50.

Thompson, T., Smith, E., Withers, S., Smith, B., Paraszczuk, W., Hendrix, C., . . . Akinola, A. (2021). *Improving the Success of Stream Restoration Practices – Revised and Expanded.* Blacksburg: Virginia Tech.

Tullos, D., Baker, D. W., Curran, J. C., Schwar, M., & Schwartz, J. (2021). Enhancing Resilience of River Restoration Design in Systems Undergoing Change. *American Society of Civil Engineers*. doi:10.1061/(ASCE)HY.1943-7900.0001853

U.S. Environmental Protection Agency. (2022, 10 24). *Fundamentals of Rosgen Stream Classification System*. Retrieved from Watershed Academy Web: https://cfpub.epa.gov/watertrain/moduleFrame.cfm?parent_object_id=1199

United States Environmental Protection Agency. (2022, February 7). *Regional and Geographic Offices*. Retrieved from EPA: https://www.epa.gov/aboutepa/regional-and-geographic-offices

US Army Corps of Engineers. (2020). *HEC-RAS River Analysis System HEC-RAS Mapper User's Manual.* US Army Corps of Engineers. Retrieved from https://www.hec.usace.army.mil/Software/hec-ras/documentation/HEC-RAS_Mapper_User's_Manual.pdf

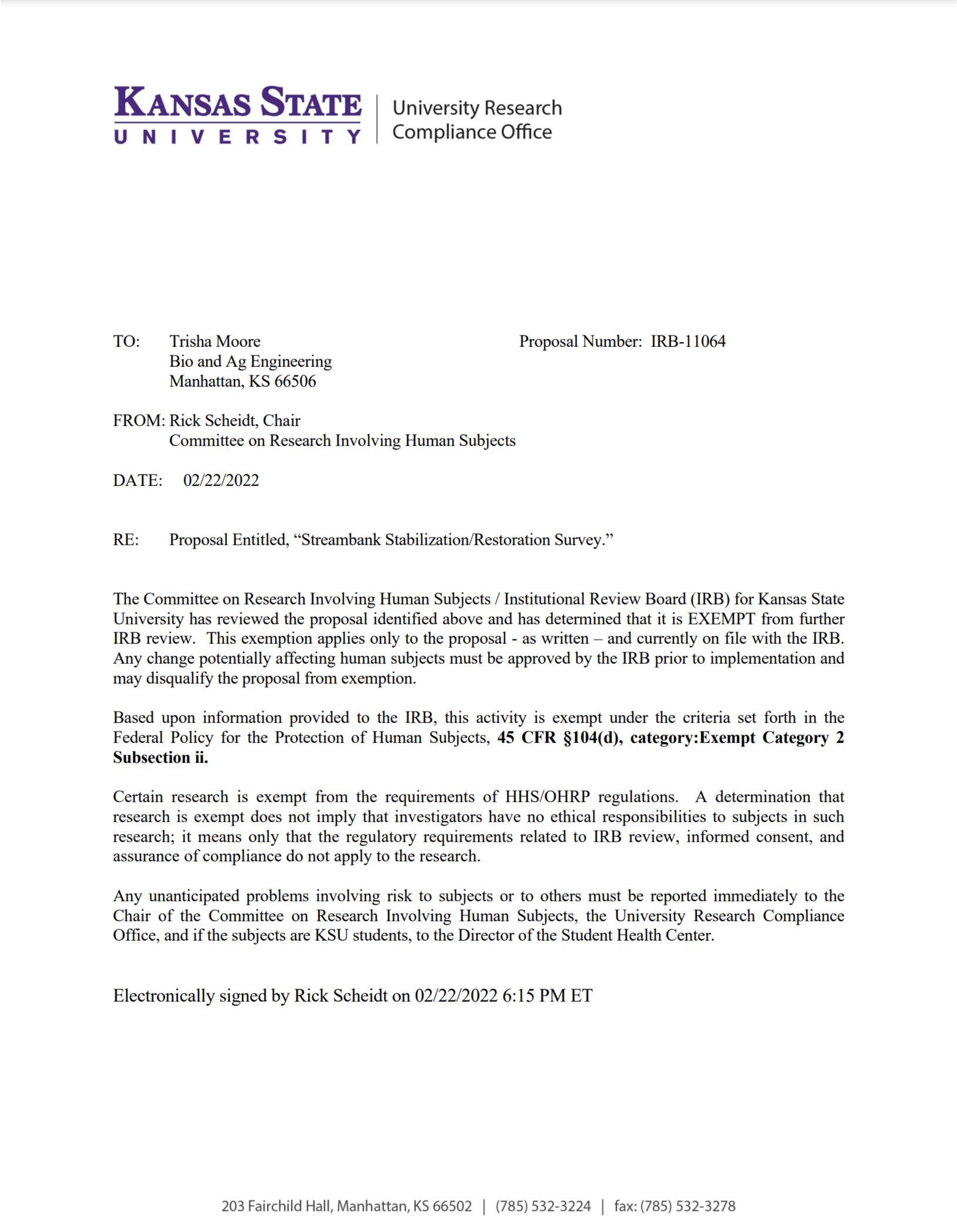
US Army Corps of Engineers. (2022). *Diffusion-Wave Equation Solver*. Retrieved from HEC-RAS Hydraulic Reference Manual: https://www.hec.usace.army.mil/confluence/rasdocs/ras1dtechref/latest/theoretical-basis-for-one-dimensional-and-two-dimensional-hydrodynamic-calculations/2d-unsteady-flow-hydrodynamics/numerical-methods/diffusion-wave-equation-solver

Wohl, E., Lane, S. N., & Wilcox, A. C. (2015). The science and practice of river restoration. *American Geophysical Union,* 5974-5997.

Wu, L., Xu, Y., Xu, Y., Wang, Q., Xu, X., & Wen, H. (2018). Impacts of Land Use Change on River Systems for a River Network Plain. *Water,* 609-623.

Yochum, S. E. (2018). *Guidance for Stream Restoration.* Forest Service, United States Department of Agriculture. Fort Collins: National Stream & Aquatic Ecology Center.

Appendix A - IRB Approval



KANSAS STATE UNIVERSITY | University Research Compliance Office

TO: Trisha Moore
Bio and Ag Engineering
Manhattan, KS 66506

Proposal Number: IRB-11064

FROM: Rick Scheidt, Chair
Committee on Research Involving Human Subjects

DATE: 02/22/2022

RE: Proposal Entitled, "Streambank Stabilization/Restoration Survey."

The Committee on Research Involving Human Subjects / Institutional Review Board (IRB) for Kansas State University has reviewed the proposal identified above and has determined that it is EXEMPT from further IRB review. This exemption applies only to the proposal - as written – and currently on file with the IRB. Any change potentially affecting human subjects must be approved by the IRB prior to implementation and may disqualify the proposal from exemption.

Based upon information provided to the IRB, this activity is exempt under the criteria set forth in the Federal Policy for the Protection of Human Subjects, **45 CFR §104(d), category:Exempt Category 2 Subsection ii.**

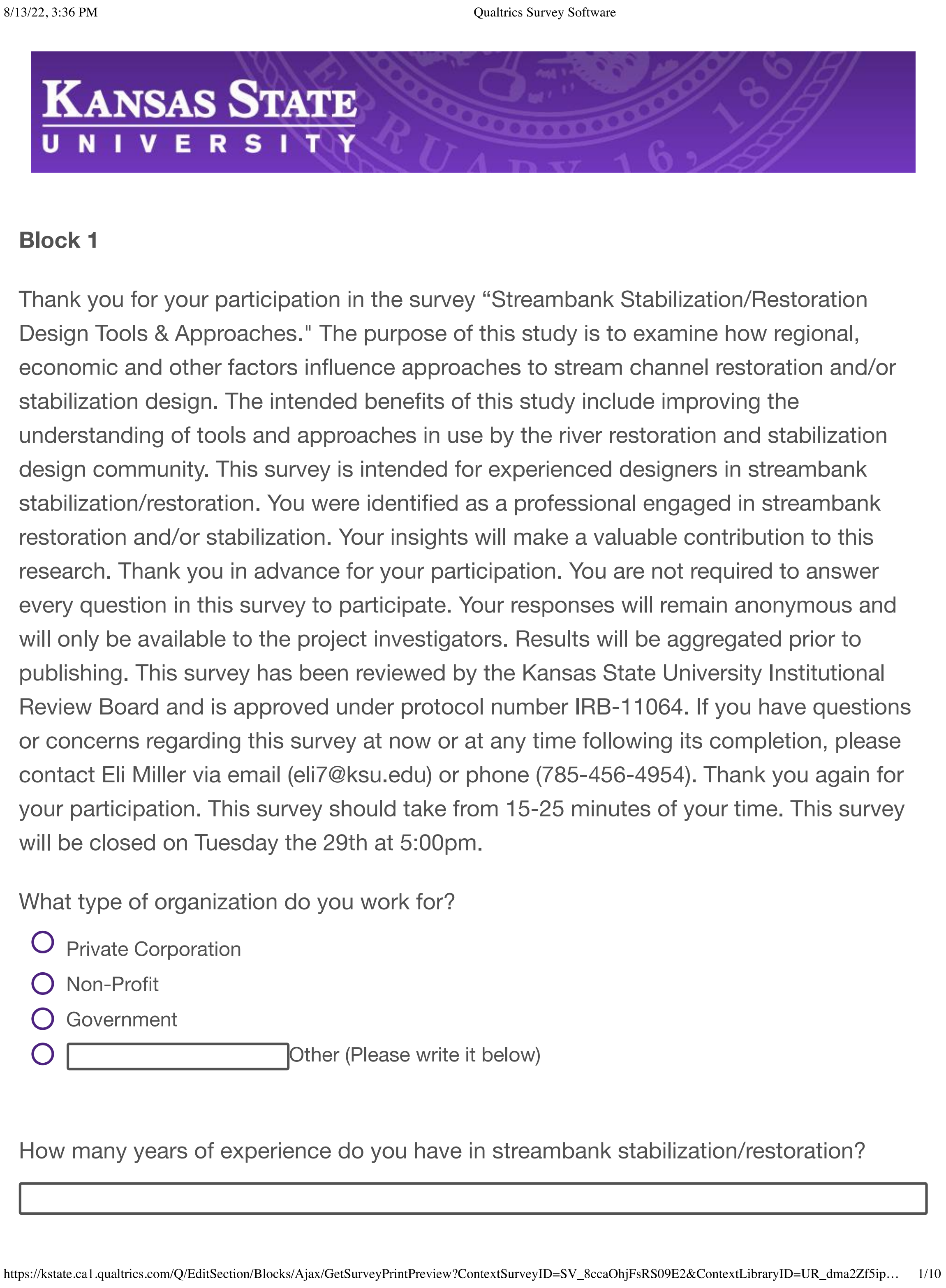
Certain research is exempt from the requirements of HHS/OHRP regulations. A determination that research is exempt does not imply that investigators have no ethical responsibilities to subjects in such research; it means only that the regulatory requirements related to IRB review, informed consent, and assurance of compliance do not apply to the research.

Any unanticipated problems involving risk to subjects or to others must be reported immediately to the Chair of the Committee on Research Involving Human Subjects, the University Research Compliance Office, and if the subjects are KSU students, to the Director of the Student Health Center.

Electronically signed by Rick Scheidt on 02/22/2022 6:15 PM ET

203 Fairchild Hall, Manhattan, KS 66502 | (785) 532-3224 | fax: (785) 532-3278

Appendix B - Survey Questions



Block 1

Thank you for your participation in the survey “Streambank Stabilization/Restoration Design Tools & Approaches." The purpose of this study is to examine how regional, economic and other factors influence approaches to stream channel restoration and/or stabilization design. The intended benefits of this study include improving the understanding of tools and approaches in use by the river restoration and stabilization design community. This survey is intended for experienced designers in streambank stabilization/restoration. You were identified as a professional engaged in streambank restoration and/or stabilization. Your insights will make a valuable contribution to this research. Thank you in advance for your participation. You are not required to answer every question in this survey to participate. Your responses will remain anonymous and will only be available to the project investigators. Results will be aggregated prior to publishing. This survey has been reviewed by the Kansas State University Institutional Review Board and is approved under protocol number IRB-11064. If you have questions or concerns regarding this survey at now or at any time following its completion, please contact Eli Miller via email (eli7@ksu.edu) or phone (785-456-4954). Thank you again for your participation. This survey should take from 15-25 minutes of your time. This survey will be closed on Tuesday the 29th at 5:00pm.

What type of organization do you work for?

- ○ Private Corporation
- ○ Non-Profit
- ○ Government
- ○ Other (Please write it below)

How many years of experience do you have in streambank stabilization/restoration?

3. What state(s) does your organization design projects for? Select all that apply.

☐ Alabama
☐ Alaska
☐ Arizona
☐ Arkansas
☐ California
☐ Colorado
☐ Connecticut
☐ Delaware
☐ Florida
☐ Georgia
☐ Hawaii
☐ Idaho
☐ Illinois
☐ Indiana
☐ Iowa
☐ Kansas
☐ Kentucky
☐ Louisiana
☐ Maine
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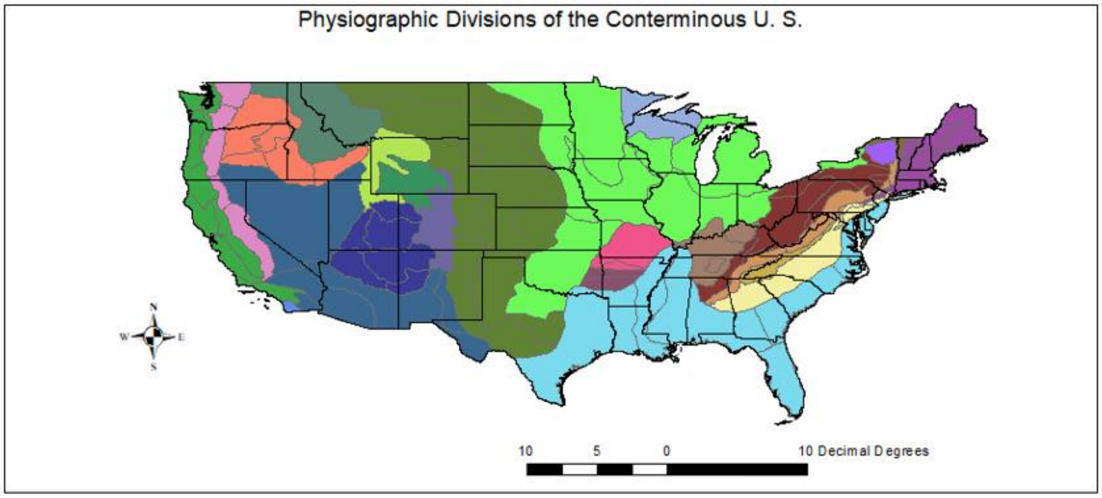
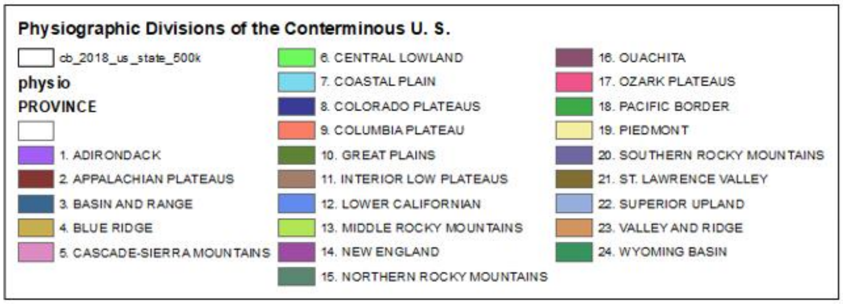
☐ Nebraska
☐ Nevada
☐ New Hampshire
☐ New Jersey
☐ New Mexico
☐ New York
☐ North Carolina
☐ North Dakota
☐ Ohio
☐ Oklahoma
☐ Oregon
☐ Pennslyvania
☐ Rhode Island
☐ South Carolina
☐ South Dakota
☐ Tennessee
☐ Texas
☐ Utah
☐ Vermont
☐ Virginia
☐ Washington
☐ West Virginia
☐ Wisconsin
☐ Wyoming
☐ International

The figure below depicts Physiographic Divisions of the United States of America. Please use it to answer the question that follows.



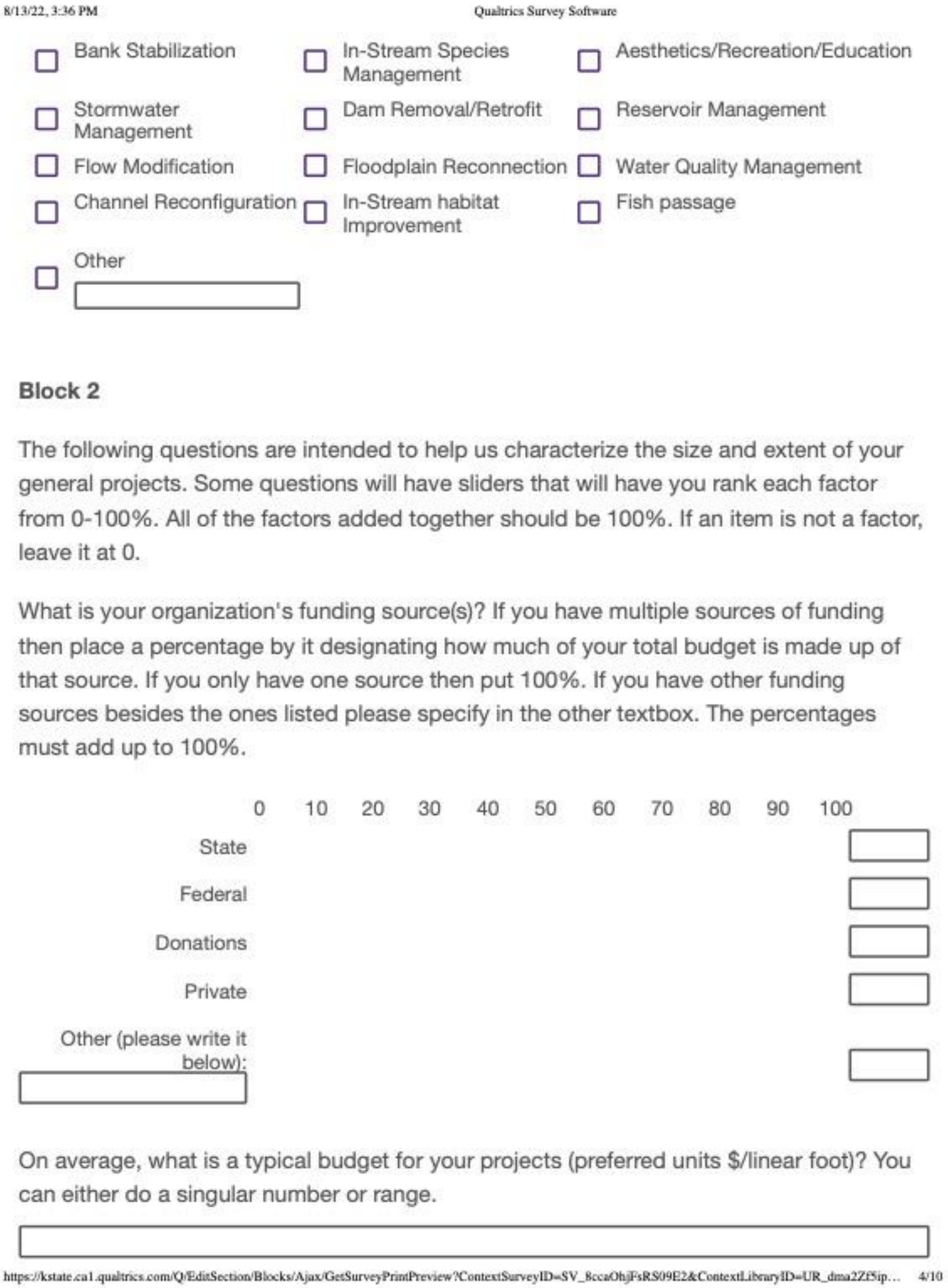
*USA state boundary lines shapefile provided by ESRI, USA physiographic shapefile information provided by USGS



What Physiographic Region(s) of the United States do you do work in? (Use the map above).

☐ 1
☐ 2
☐ 3
☐ 4
☐ 5
☐ 6
☐ 7
☐ 8
☐ 9
☐ 10
☐ 11
☐ 12
☐ 13
☐ 14
☐ 15
☐ 16
☐ 17
☐ 18
☐ 19
☐ 20
☐ 21
☐ 22
☐ 23
☐ 24
☐ 25
☐ Alaska
☐ Hawaii

What typical objective(s) do you have when designing stream restoration and/or stabilization projects (select all that apply)?



☐ Bank Stabilization
☐ Stormwater Management
☐ Flow Modification
☐ Channel Reconfiguration
☐ Other ▭

☐ In-Stream Species Management
☐ Dam Removal/Retrofit
☐ Floodplain Reconnection
☐ In-Stream habitat Improvement

☐ Aesthetics/Recreation/Education
☐ Reservoir Management
☐ Water Quality Management
☐ Fish passage

Block 2

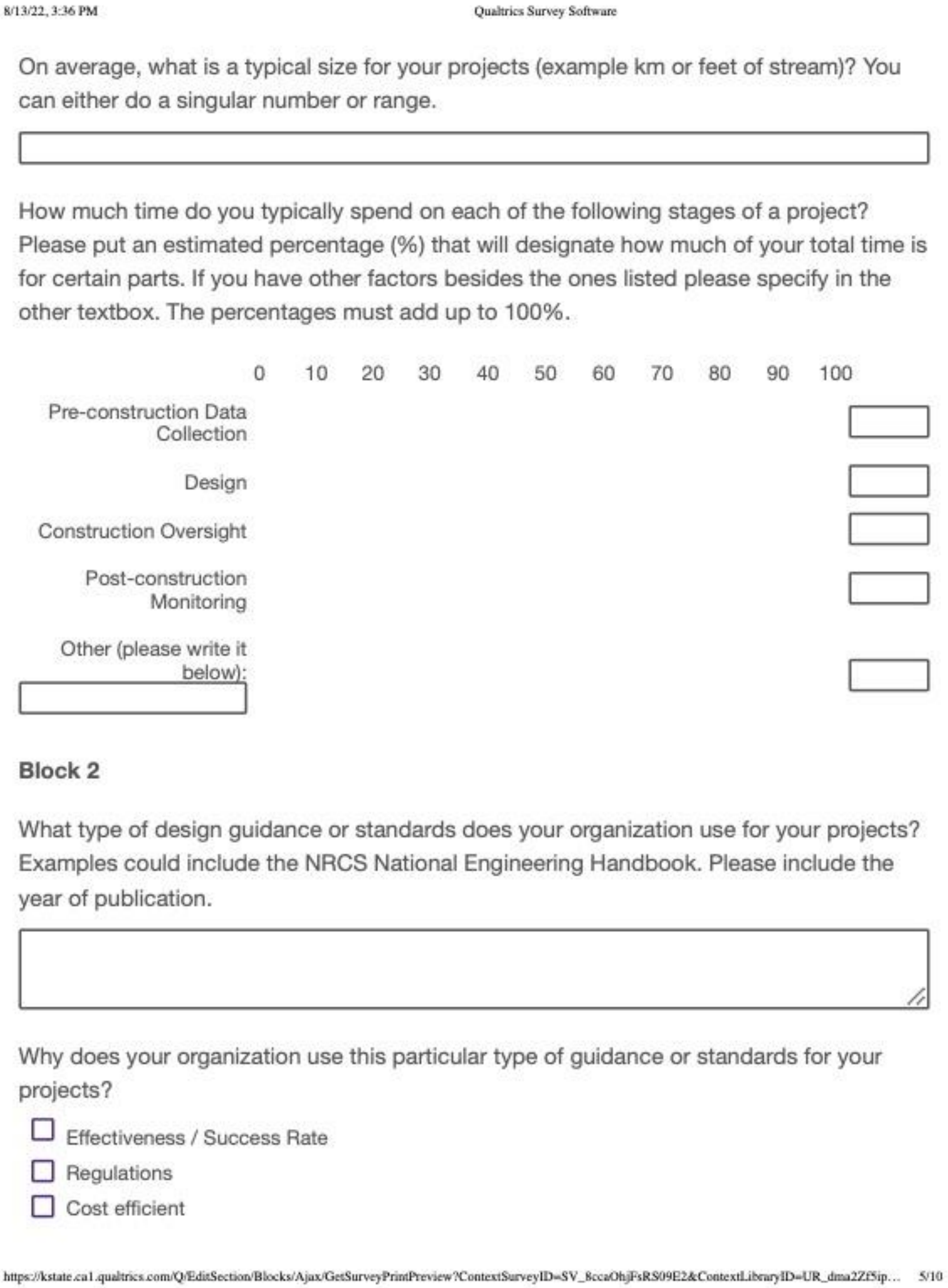
The following questions are intended to help us characterize the size and extent of your general projects. Some questions will have sliders that will have you rank each factor from 0-100%. All of the factors added together should be 100%. If an item is not a factor, leave it at 0.

What is your organization's funding source(s)? If you have multiple sources of funding then place a percentage by it designating how much of your total budget is made up of that source. If you only have one source then put 100%. If you have other funding sources besides the ones listed please specify in the other textbox. The percentages must add up to 100%.

	0 10 20 30 40 50 60 70 80 90 100	
State		▭
Federal		▭
Donations		▭
Private		▭
Other (please write it below): ▭		▭

On average, what is a typical budget for your projects (preferred units $/linear foot)? You can either do a singular number or range.

▭



On average, what is a typical size for your projects (example km or feet of stream)? You can either do a singular number or range.

How much time do you typically spend on each of the following stages of a project? Please put an estimated percentage (%) that will designate how much of your total time is for certain parts. If you have other factors besides the ones listed please specify in the other textbox. The percentages must add up to 100%.

	0	10	20	30	40	50	60	70	80	90	100	
Pre-construction Data Collection												
Design												
Construction Oversight												
Post-construction Monitoring												
Other (please write it below):												

Block 2

What type of design guidance or standards does your organization use for your projects? Examples could include the NRCS National Engineering Handbook. Please include the year of publication.

Why does your organization use this particular type of guidance or standards for your projects?

- ☐ Effectiveness / Success Rate
- ☐ Regulations
- ☐ Cost efficient

☐ ☐ Other

What types of design tools do you use in the design process of streambank stabilization and restoration projects? (Select all that apply)

☐ Empirical-based tools (e.g., regional hydraulic geometry)
☐ Analog-based tools (e.g., reference reach approach)
☐ Analytical tools (e.g., hydraulic models)
☐ ☐ Other

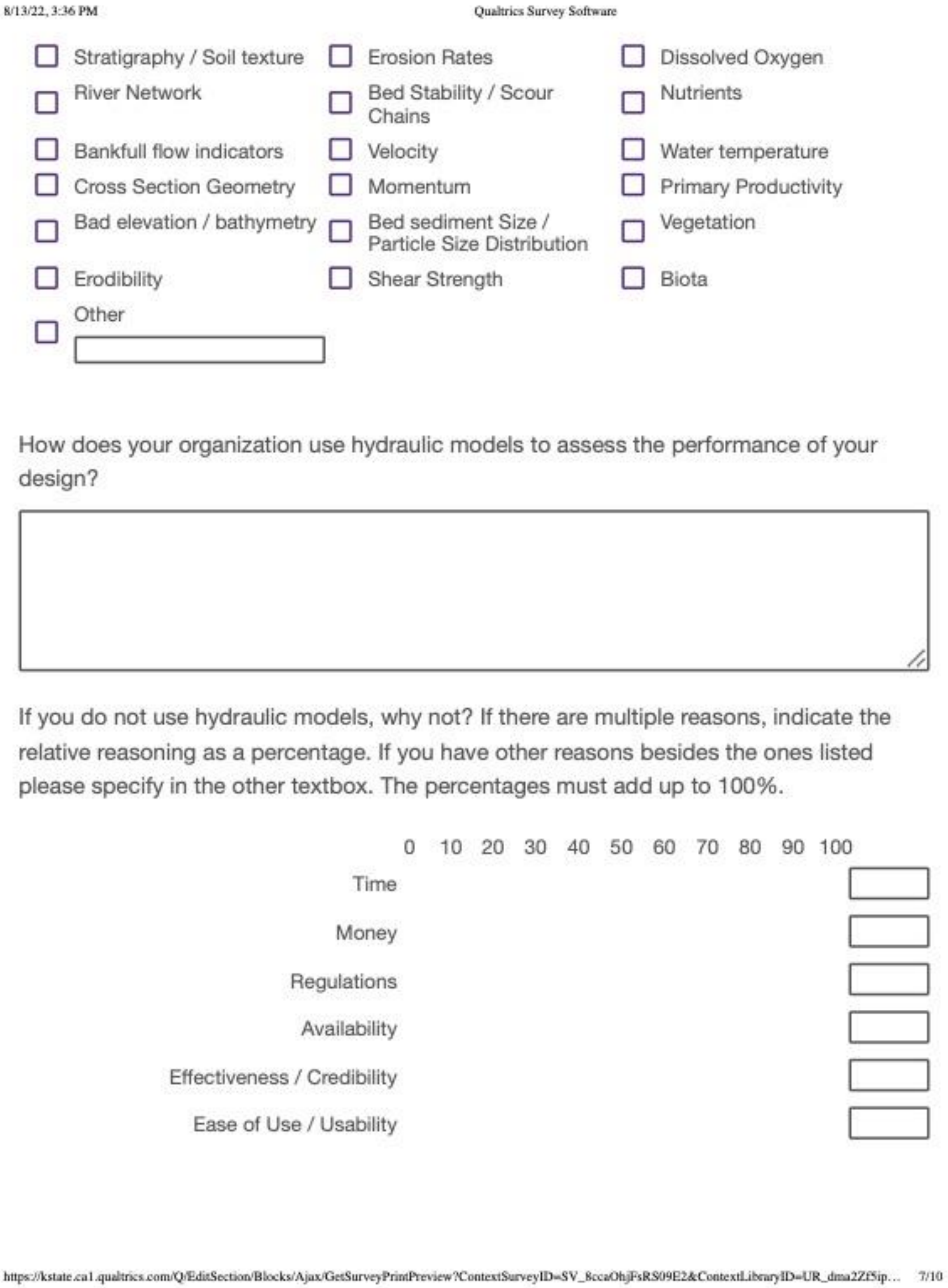
Do you use computer models for your Pre-design/Design process? And if so what kind do you use (select all that apply)?

☐ I do not use computer models
☐ BSTEM
☐ Delft-3D
☐ FASTER
☐ FLUVIAL-12
☐ Other ☐
☐ HEC-RAS
☐ LISFLOOD
☐ MIKE 11
☐ Rsim-3D
☐ HEC-6

If you use hydraulic models what type do you use? If you use multiple, indicate relative frequency of use as a percentage. The percentages must add up to 100%.

	0	10	20	30	40	50	60	70	80	90	100	
One-dimensional												☐
Two-dimensional												☐
Three-dimensional												☐

What field data do you to collect on-site to create and/or calibrate your hydraulic models (select all that apply)?

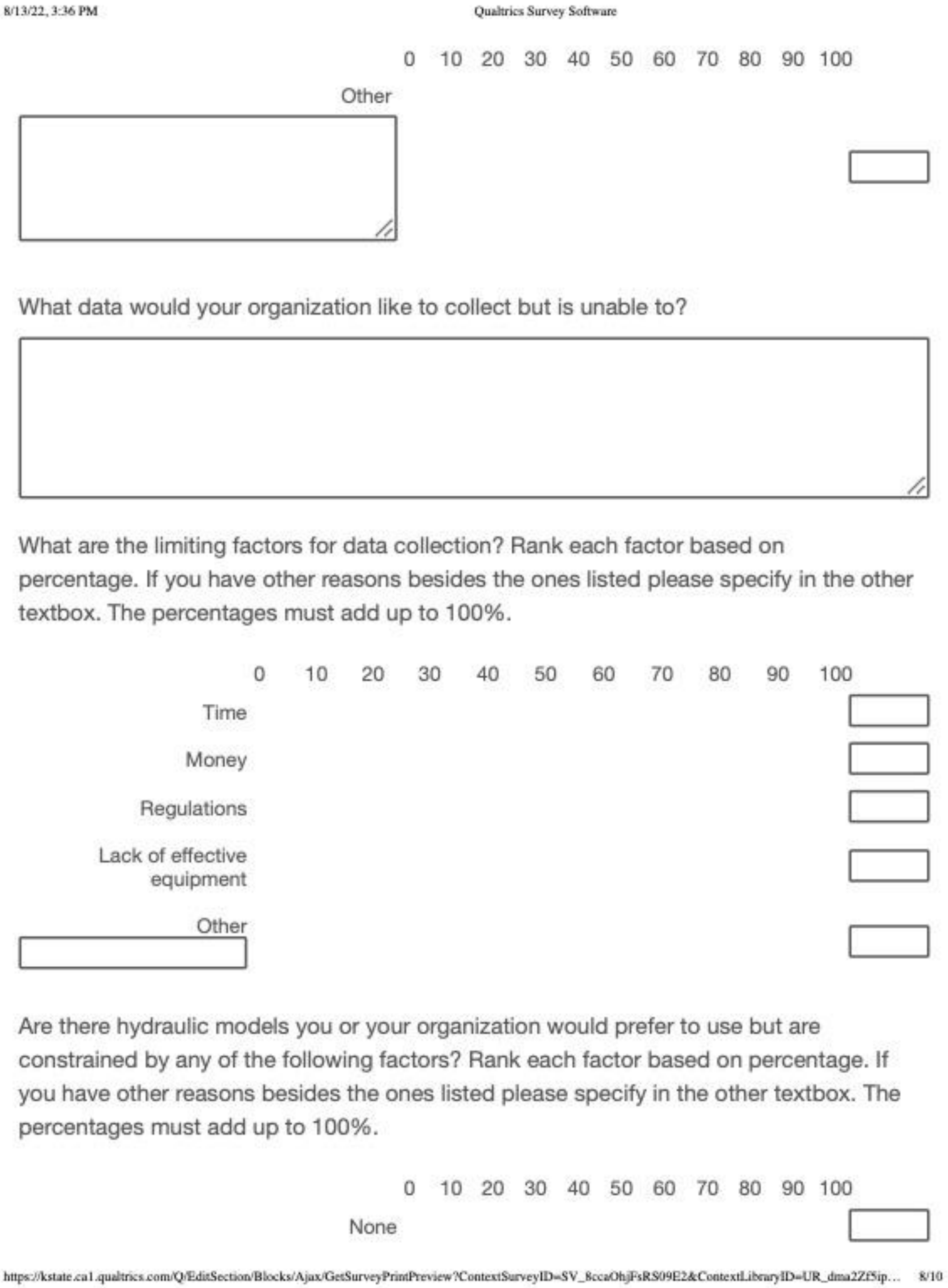


☐ Stratigraphy / Soil texture
☐ River Network
☐ Bankfull flow indicators
☐ Cross Section Geometry
☐ Bad elevation / bathymetry
☐ Erodibility
☐ Other ____
☐ Erosion Rates
☐ Bed Stability / Scour Chains
☐ Velocity
☐ Momentum
☐ Bed sediment Size / Particle Size Distribution
☐ Shear Strength
☐ Dissolved Oxygen
☐ Nutrients
☐ Water temperature
☐ Primary Productivity
☐ Vegetation
☐ Biota

How does your organization use hydraulic models to assess the performance of your design?

If you do not use hydraulic models, why not? If there are multiple reasons, indicate the relative reasoning as a percentage. If you have other reasons besides the ones listed please specify in the other textbox. The percentages must add up to 100%.

	0 10 20 30 40 50 60 70 80 90 100	
Time		☐
Money		☐
Regulations		☐
Availability		☐
Effectiveness / Credibility		☐
Ease of Use / Usability		☐



0 10 20 30 40 50 60 70 80 90 100

Other

What data would your organization like to collect but is unable to?

What are the limiting factors for data collection? Rank each factor based on percentage. If you have other reasons besides the ones listed please specify in the other textbox. The percentages must add up to 100%.

0 10 20 30 40 50 60 70 80 90 100

Time

Money

Regulations

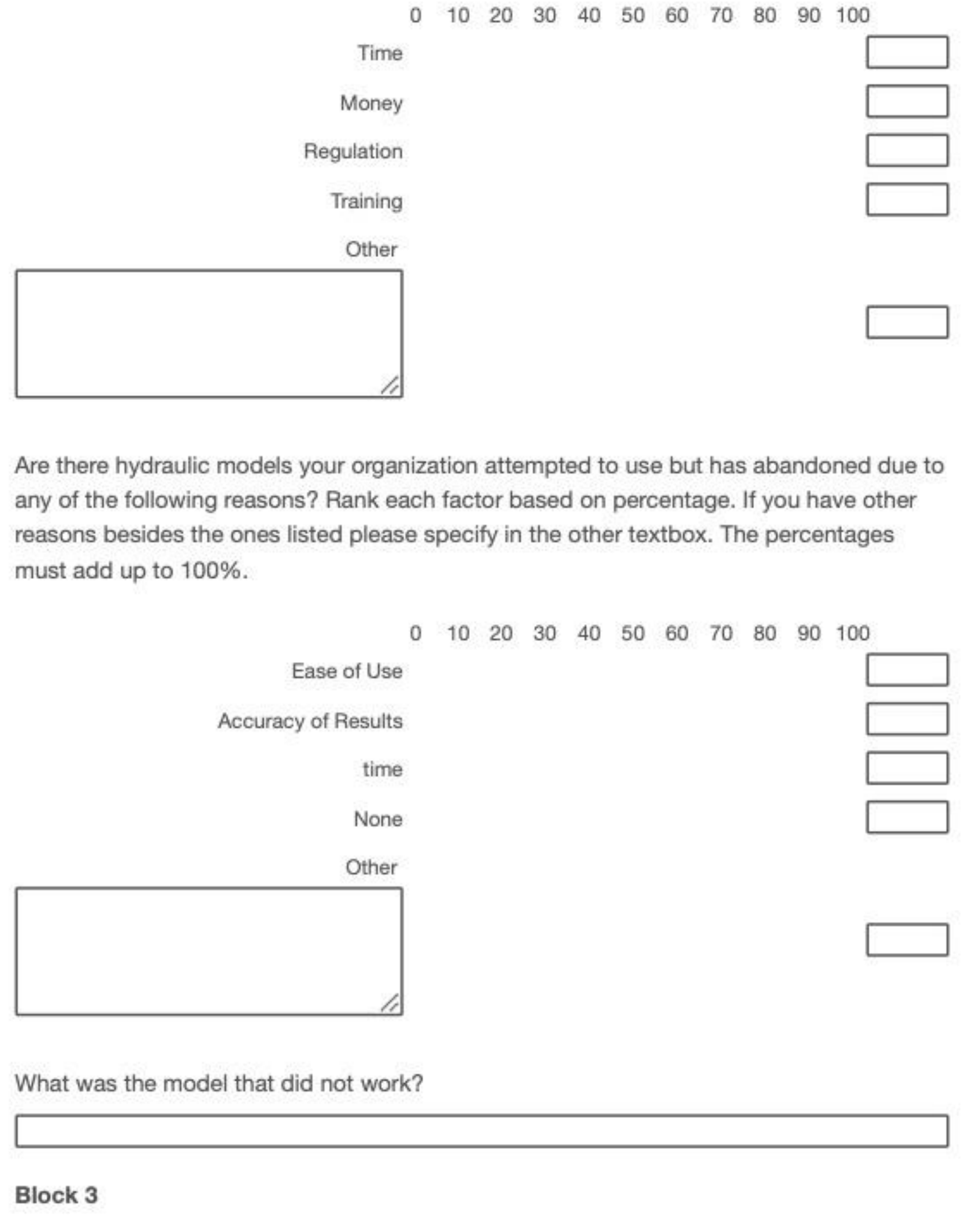
Lack of effective equipment

Other

Are there hydraulic models you or your organization would prefer to use but are constrained by any of the following factors? Rank each factor based on percentage. If you have other reasons besides the ones listed please specify in the other textbox. The percentages must add up to 100%.

0 10 20 30 40 50 60 70 80 90 100

None



0 10 20 30 40 50 60 70 80 90 100

Time

Money

Regulation

Training

Other

Are there hydraulic models your organization attempted to use but has abandoned due to any of the following reasons? Rank each factor based on percentage. If you have other reasons besides the ones listed please specify in the other textbox. The percentages must add up to 100%.

0 10 20 30 40 50 60 70 80 90 100

Ease of Use

Accuracy of Results

time

None

Other

What was the model that did not work?

Block 3

Are you willing to be contacted later for either clarification or further questions?

☐ No

☐ Yes (please put how you are willing to be contacted?)

If you have questions or concerns regarding this study now or at any time following its completion, or if you would like to request notification regarding publication or other formal presentations of study results, please contact Eli Miller via email (eli7@ksu.edu) or phone (785-456-4954). Thank you for your participation in the survey “Streambank Stabilization/Restoration Design Tools & Approaches." Your participation will help improve the understanding of tools and approaches in use by the river restoration and stabilization design community.

Appendix C - Survey Variability

Regions	Region Name	Count	Possible -	Possible +
1	ADIRONDACK	4	2	
2	APPALACHIAN PLATEAUS	14		
3	BASIN AND RANGE	5	1	
4	BLUE RIDGE	20		1
5	CASCADE-SIERRA MOUNTAINS	2		2
6	CENTRAL LOWLAND	34		1
7	COASTAL PLAIN	34		
8	COLORADO PLATEAUS	11		1
9	COLUMBIA PLATEAU	6	4	
10	GREAT PLAINS	24		1
11	INTERIOR LOW PLATEAUS	11		
12	LOWER CALIFORNIAN	1		
13	MIDDLE ROCKY MOUNTAINS	9	1	
14	NEW ENGLAND	6		1
15	NORTHERN ROCKY MOUNTAINS	6	1	
16	OUACHITA	6	2	
17	OZARK PLATEAUS	13		
18	PACIFIC BORDER	8		
19	PIEDMONT	34		
20	SOUTHERN ROCKY MOUNTAINS	12		2
21	ST. LAWRENCE VALLEY	2	1	
22	SUPERIOR UPLAND	6	1	
23	VALLEY AND RIDGE	14		
24	WYOMING BASIN	11	1	

Appendix D - MATLAB Code

EPA Region

```
clear
clc
%Creates tables for each of the regions.
NE = table([13;29],[5;6],'VariableNames',{'Ment Rosgen','Not
Rosgen'},'RowNames',{'In Region','Not In Region'})
CE = table([10;32],[8;3],'VariableNames',{'Ment Rosgen','Not
Rosgen'},'RowNames',{'In Region','Not In Region'})
C = table([16;26],[6;5],'VariableNames',{'Ment Rosgen','Not
Rosgen'},'RowNames',{'In Region','Not In Region'})
W = table([16;26],[2;9],'VariableNames',{'Ment Rosgen','Not
Rosgen'},'RowNames',{'In Region','Not In Region'})

%Conducts Fisher's exact test on each of the tables
NEtest = fishertest(NE)
CEtest = fishertest(CE)
Ctest = fishertest(C)
Wtest = fishertest(W)

% 00000000000
% The returned test decision "= 0" indicates that fishertest does
% not reject the null hypothesis of no nonrandom association between
% the categorical variables at the default 5% significance level. There
are
% no nonrandom associations between the two categorical variables.

% Therefore, based on the test results, individuals who
% are part of a region do not have different odds of using Rosgen
% than those who are not part of the region.

% 1111111111111
% The returned test decision "= 1" indicates that fishertest does
% reject the null hypothesis of no nonrandom association between
% the categorical variables at the default 5% significance level.

% Therefore, based on the test results, individuals who
% are part of a region do have different odds of using Rosgen
% than those who are not part of the region.
```

USDA Farm Regions

```
clear
clc
%Creates tables for each of the regions.
CB = table([9;33],[4;7],'VariableNames',{'Ment Rosgen','Not
Rosgen'},'RowNames',{'In Region','Not In Region'})
Mountain = table([15;27],[2;9],'VariableNames',{'Ment Rosgen','Not
Rosgen'},'RowNames',{'In Region','Not In Region'})
```

```
Pacific = table([6;36],[2;9],'VariableNames',{'Ment Rosgen','Not
Rosgen'},'RowNames',{'In Region','Not In Region'})
NE = table([11;31],[3;8],'VariableNames',{'Ment Rosgen','Not
Rosgen'},'RowNames',{'In Region','Not In Region'})
SP = table([6;36],[3;8],'VariableNames',{'Ment Rosgen','Not
Rosgen'},'RowNames',{'In Region','Not In Region'})
LS = table([1;41],[4;7],'VariableNames',{'Ment Rosgen','Not
Rosgen'},'RowNames',{'In Region','Not In Region'})
DS = table([4;38],[3;8],'VariableNames',{'Ment Rosgen','Not
Rosgen'},'RowNames',{'In Region','Not In Region'})
SE = table([3;39],[5;6],'VariableNames',{'Ment Rosgen','Not
Rosgen'},'RowNames',{'In Region','Not In Region'})
Appalachian = table([10;32],[6;5],'VariableNames',{'Ment Rosgen','Not
Rosgen'},'RowNames',{'In Region','Not In Region'})
NP = table([5;37],[3;8],'VariableNames',{'Ment Rosgen','Not
Rosgen'},'RowNames',{'In Region','Not In Region'})

%Conducts Fisher's exact test on each of the tables
CB_test = fishertest(CB)
Mountain_test = fishertest(Mountain)
Pacific_test = fishertest(Pacific)
NE_test = fishertest(NE)
SP_test = fishertest(SP)
LS_test = fishertest(LS)
DS_test = fishertest(DS)
SE_test = fishertest(SE)
Appalachian_test = fishertest(Appalachian)
NP_test = fishertest(NP)

clear CB Mountain Pacific NE SP LS DS SE Appalachian NP
%Null hypothesis is that the two variables are independent. The
alternative
%hypothesis is that the variables are not independent.

% 00000000000
% The returned test decision "= 0" indicates that fishertest does
% not reject the null hypothesis. i.e. the variables are independent.

% 1111111111111
% The returned test decision "= 1" indicates that fishertest does
% reject the null hypothesis. i.e. the variables are not independent.
```

USDA Farm Region with Updated Values

```
clear
clc
%Creates tables for each of the regions.
Plains = table([11;31],[4;7],'VariableNames',{'Ment Rosgen','Not
Rosgen'},'RowNames',{'In Region','Not In Region'})
Delta_States_edit = table([6;36],[5;6],'VariableNames',{'Ment Rosgen','Not
Rosgen'},'RowNames',{'In Region','Not In Region'})
Appalachian_edit = table([14;28],[7;4],'VariableNames',{'Ment Rosgen','Not
Rosgen'},'RowNames',{'In Region','Not In Region'})
```

```
NE_edited = table([5;37],[1;10],'VariableNames',{'Ment Rosgen','Not
Rosgen'},'RowNames',{'In Region','Not In Region'})

%Conducts Fisher's exact test on each of the tables
Plains_test = fishertest(Plains)
Delta_test = fishertest(Delta_States_edit)
Appa_test = fishertest(Appalachian_edit)
NE_edit_test = fishertest(NE_edited)

clear Plains Delta_States_edit Appalachian_edit NE_edited
%Null hypothesis is that the two variables are independent. The
alternative
%hypothesis is that the variables are not independent.

% 00000000000
% The returned test decision "= 0" indicates that fishertest does
% not reject the null hypothesis. i.e. the variables are independent.

% 1111111111111
% The returned test decision "= 1" indicates that fishertest does
% reject the null hypothesis. i.e. the variables are not independent.
```

Appendix E - HEC-RAS Results

Figure E.1 . Scenario 1 Flow Event at Maximum Shear Stress

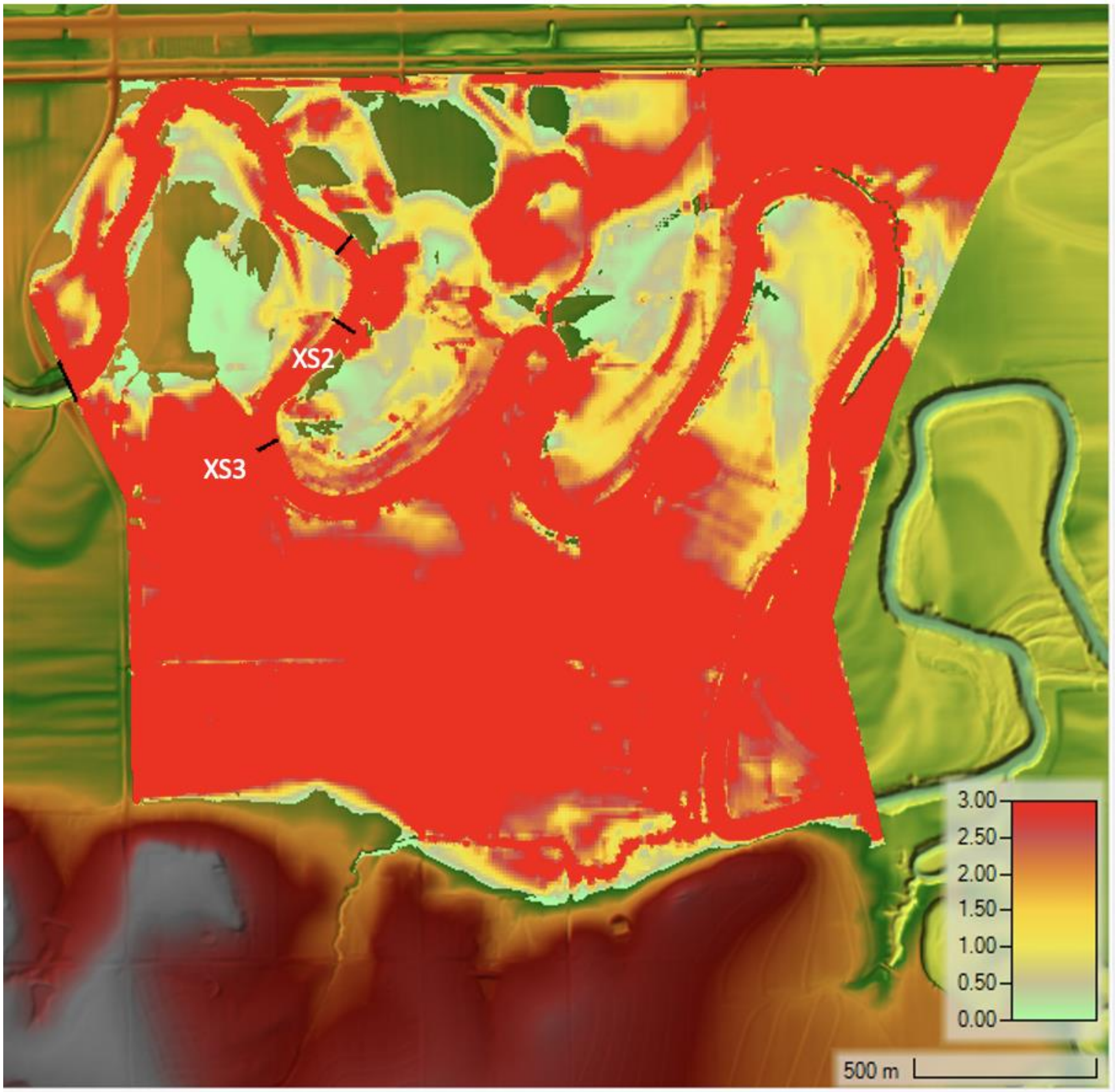


Figure E.2 Scenario 2 Flow Event at Maximum Shear Stress

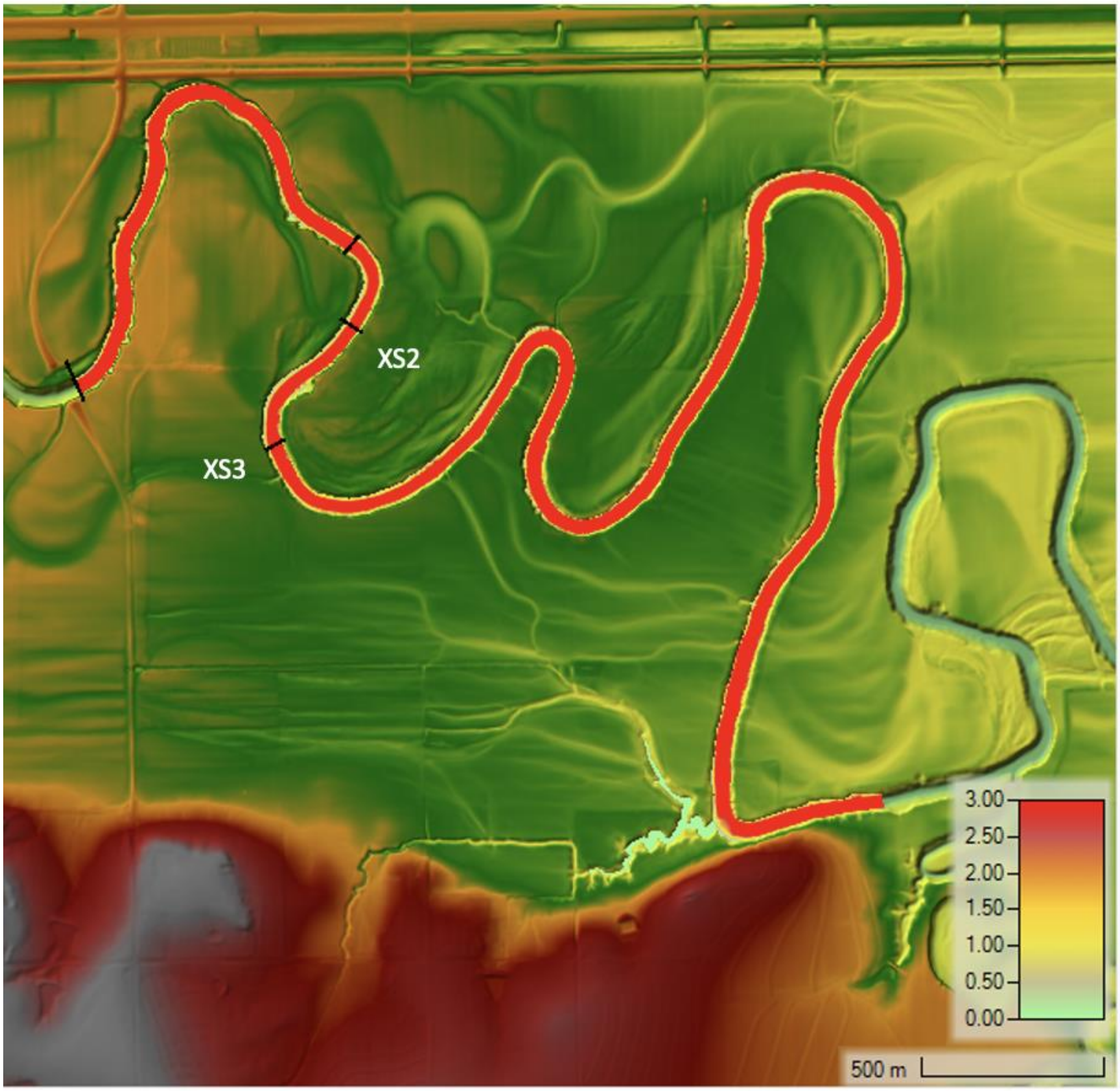


Figure E.3 100-Year Flow Event at Maximum Shear Stress

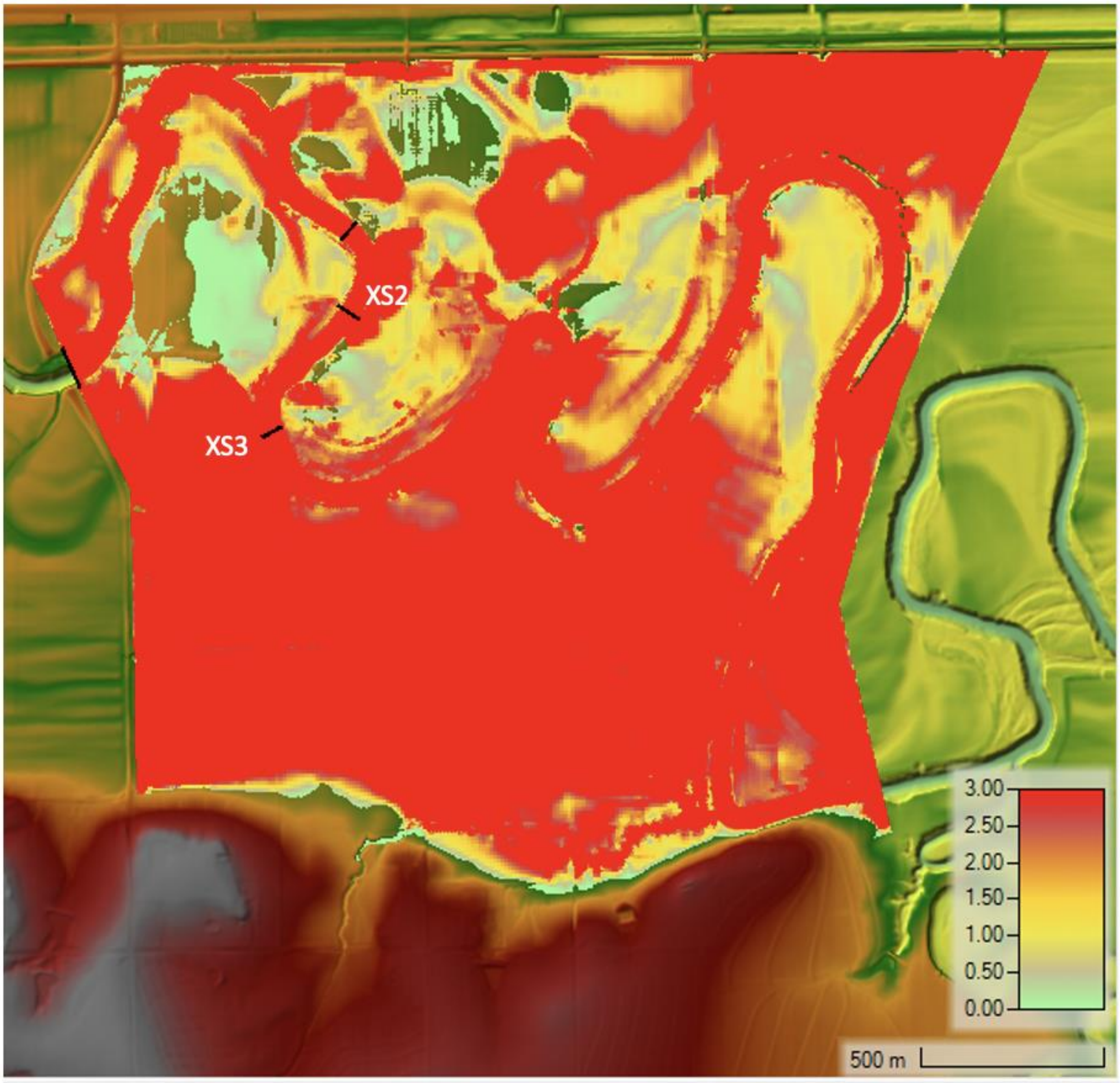


Figure E.4 25 Year Flow Event at Maximum Shear Stress

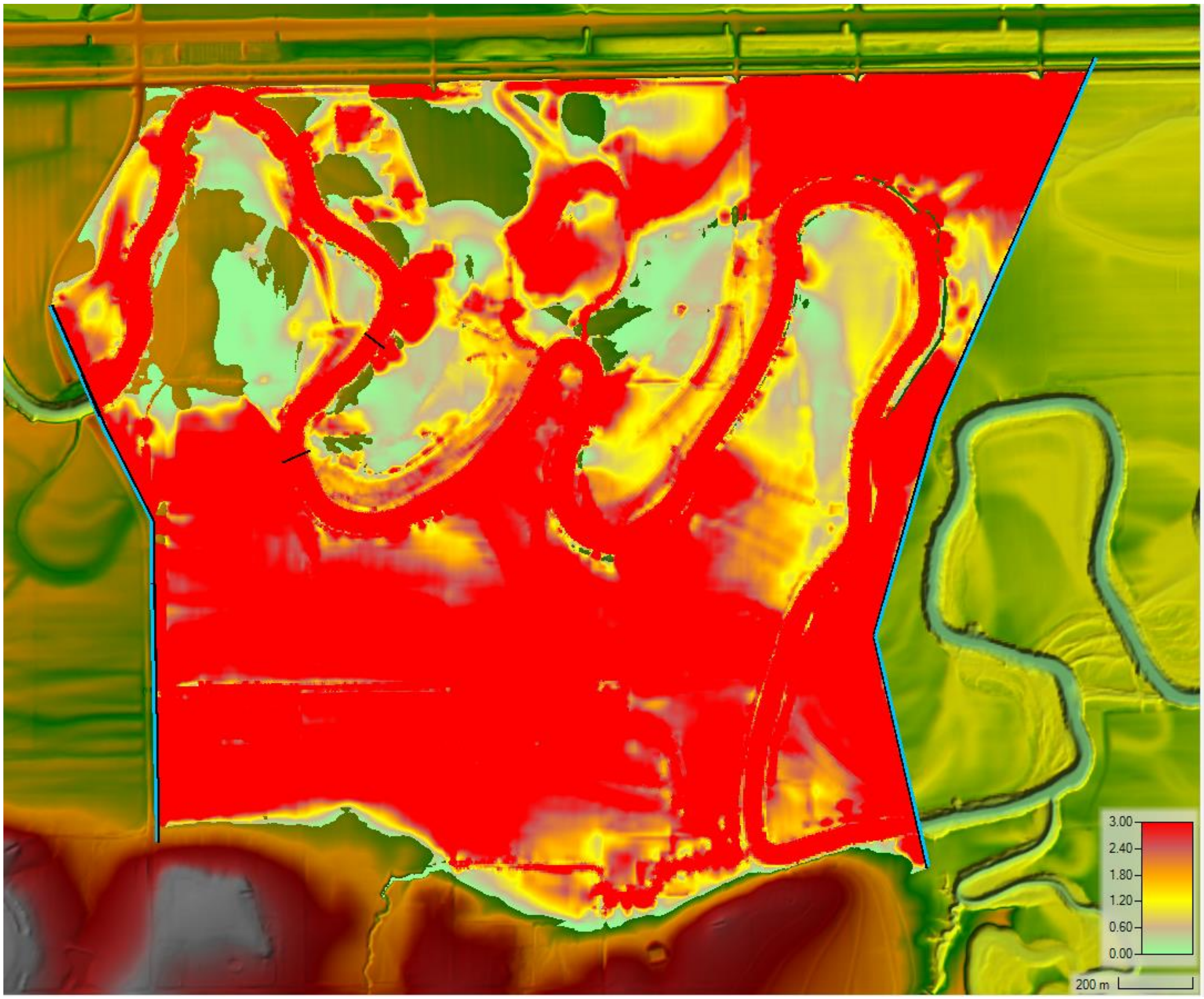


Figure E.5 10 Year Flow Event at Maximum Shear Stress

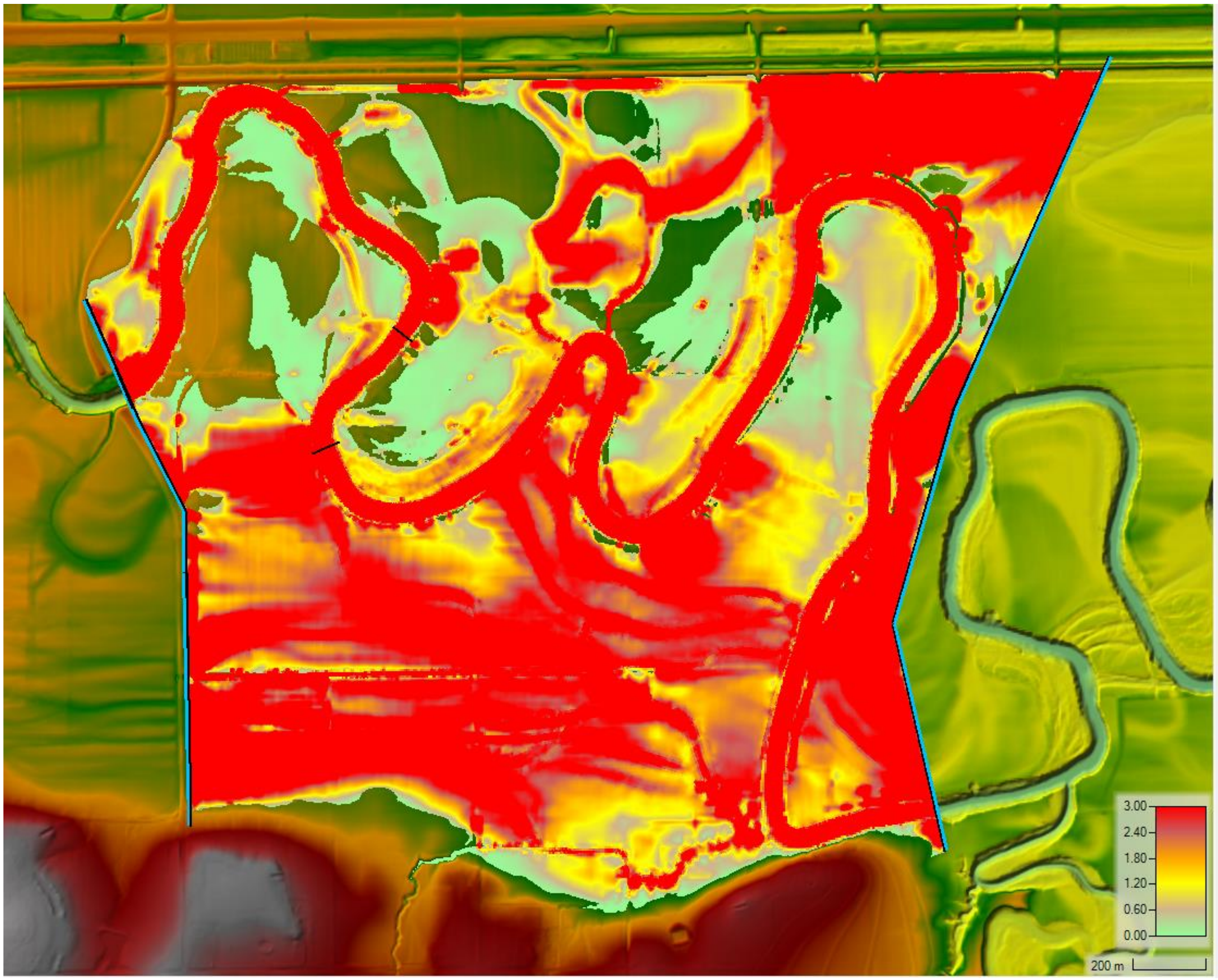


Figure E.6 1.5 Year Flow Event at Maximum Shear Stress