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FINAL DELIVERABLE

Title	Keokuk County River Channel Mitigation
Completed By	Quinn Conroy, Charles Nash, Corey O'Brien
Date Completed	December 2019
UI Department	Department of Civil & Environmental Engineering
Course Name	CEE:4850:0001 Project Design & Management
Instructor	Paul Hanley
Community Partners	Keokuk County, Pathfinders RC&D

This project was supported by the Iowa Initiative for Sustainable Communities (IISC), a community engagement program at the University of Iowa. IISC partners with rural and urban communities across the state to develop projects that university students and IISC pursues a dual mission of enhancing quality of life in Iowa while transforming teaching and learning at the University of Iowa.

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River Channel Mitigation for Keokuk County

Report Prepared By:

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Report Submitted To:

Andrew McGuire, P.E.
Keokuk County Engineer

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Section I Executive Summary

This design report is for a river channel mitigation project on the Skunk River located in Keokuk County, Iowa. The purpose of this project is to protect both a county road and bridge from migration of the Skunk River. The area of concern is located on the Southeast side of Keokuk County. The path of river migration has been headed towards County Route W15, which is currently the highest traffic volume secondary road in Keokuk County. As the river migrates towards the road it will eventually compromise the integrity of the roadbed, which would severely impact this important route for the county. Furthermore, the river migration would minimize the positive benefits of county bridge 619', which was replaced in 2004. QCC also performed a forecast of the river migration pattern. Our model shows that future river migration would not only impact County infrastructure, but private property of residents that live near the Skunk River. We also provided a model showing how future migration trends can be changed based on the implementation of our riprap design.

QCC Engineering, is a team of three senior civil and environmental engineering students at the University of Iowa. The project is being conducted as part of the student's senior design course. QCC Engineering consists of project manager, Quinn Conroy, technology service representative, Charles Nash, and editor Corey O'Brien. The team has both educational and professional experience that qualifies them for the river channel mitigation project. The main contact for Keokuk County is the Keokuk County Engineer Andrew McGuire, P.E.

The design process required multiple methods of analysis that employed data acquisition as well as software and analytical techniques. The river channel and bank analysis required the use of USGS stream statistical data and USDA web soil survey data. USGS stream statistics provided the team with data on the stream including flow rates and USDA web soil survey provided data on the soil composition in the area. Both of these data acquisition services were important for the hydrologic analysis. The project has environmental impacts which required the team to closely follow local, state and federal guidelines and regulations. QCC closely followed guidelines outlined by the Iowa Department of Natural Resources (DNR) and the Army Corps Engineers. The final designs and models were completed through the River extension of Civil 3D 2020, the International River Interface Cooperative (iRIC) software and QGIS.

After evaluating possible alternatives, it was decided that the eroding banks will be reshaped and then held in place with the use of rock riprap. The banks will be reshaped to a slope of 3:1 and then rock riprap with size ranging from 8-12 inches will be placed over the top of the reshaped banks. There were two main methods evaluated for the placement of riprap along the bank. Riprap may be placed along both sides of the riverbanks or placed only on the outside of the three bends in the scope of the project. Placing riprap along both sides of the bank will result in a high cost, that our team determined would not be necessary for this project.

As with any design there will be constraints, challenges and societal impacts. The constraints of this project will include environmental regulations, construction boundaries, cost and time. Current regulations dictate that river straightening is not a viable option and designs that utilize this method will not be acceptable. There is a state wildlife area nearby and any changes to that area must be cleared through the DNR, Army Corps of Engineers and any other governing agency. The challenges of this project include accurately modeling river channel cross sections, using a “soft” armor engineering approach to the channel mitigation and accurately modeling the river migration pattern. The societal impacts of this project will be mostly positive. This project will protect the integrity County Route W15 and maximize the benefits of replacing County Bridge 619’ for the residents. Negative impacts will be minimal and happen during the construction phase of the project. Negative impacts include disrupting local wildlife and traffic delays while a temporary access road is built to the construction site.

The total project cost is estimated to be roughly $318,500. Table 1 and Table 2 found in Section VII provides a breakdown of how this cost was determined. This cost includes a preliminary estimate of all construction costs, a ten percent contingency, and a twenty percent cost for engineering and administration services.

Section II Organization Qualifications and Experience

1. Name or Organization

QCC Engineering

2. Organization Location and Contact Information

QCC Engineering is located at the Seamans Center in Iowa City, Iowa. The main point of contact will be the project manager Quinn Conroy. Quinn can be reached through email at quinn-conroy@uiowa.edu or through phone at 630-258-2485.

3. Organization and Design Team Description

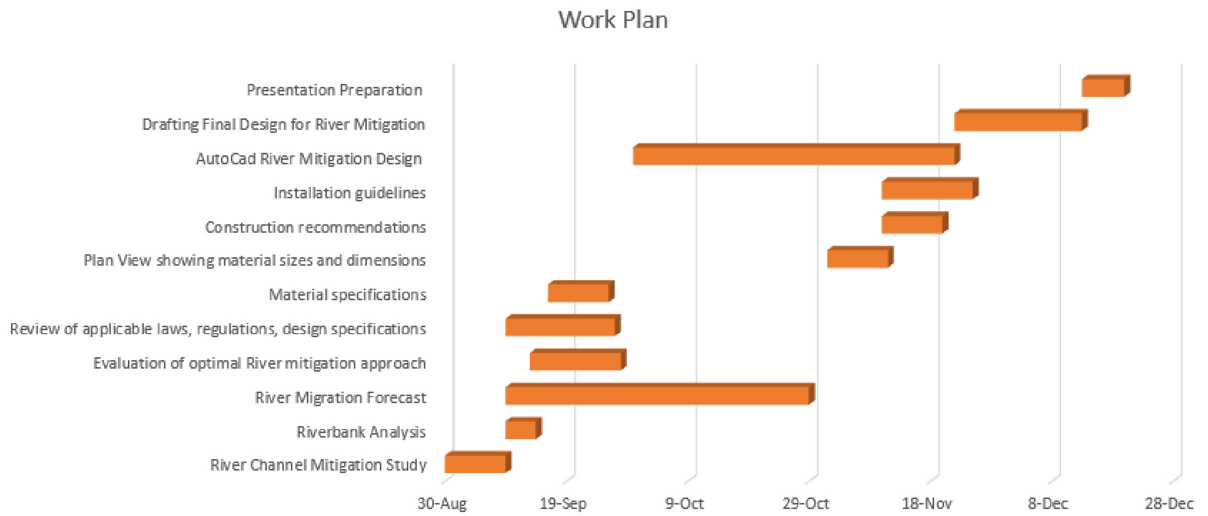
QCC Engineering is comprised of a team of senior University of Iowa students in the capstone Civil and Environmental Engineering Design class. Quinn Conroy is the project manager of this group. Quinn is majoring in Civil Engineering with focus area in Civil and Environmental practice. Quinn has expertise with AutoCAD software and will facilitate in the production of the design plan sheets that will be submitted for review. Charles Nash will operate as the team's technology services representative. Charles majors in Civil Engineering with a focus area in transportation. He specializes with road and culvert design. He will be leading with the hydraulic analysis on the river channel along with research into different alternative solutions for the project. Corey O'Brien serves as the team's editor. Corey majors specifically in environmental engineering with a focus on water resources. He specializes in environmental regulations and has a background in modeling hydrological events. He will be taking the lead on researching methods related to river channel migration modeling.

Section III Proposed Services

1. Project Scope

The scope of this project consists of designing alternative solutions for a river channel mitigation in Keokuk County. The proposed mitigation plans will protect the county road W15 and county bridge 619' from the increased meandering of the Skunk River in Keokuk County, Iowa. The Skunk River channel is developing a classic oxbow and increased meandering has started to form a side channel which is leading to a pinching of the main channel. This could potentially lead to the connection of two different channels in the Skunk River if channel mitigation is not used. The Senior Design engineering team, QCC Engineering, provided services for conducting a thorough evaluation of the main channel of the South Skunk River as well as the overflow side channel that is continually eroding away over time. As requested by the Keokuk county engineer, Andrew J. McGuire, P.E, QCC has conducted a riverbank analysis which includes a geomorphic analysis, a river profile and a forecasted river meander migration pattern with and without riprap. After completing the riverbank analysis, QCC analyzed the data and identified the most efficient river mitigation practice that would be utilized in the final design. The final design will protect the integrity of county road W15, maximize the benefits of County Bridge 619' and minimize the river meander migration. The final drawings include plan views, cross section views, and maps forecasting the river meander migration with and without riprap. The design addresses site location, construction boundaries, existing and final grading, design requirements, procedures, material specifications, construction recommendations, and installation guidelines.

2. Project Work Plan



	River Channel Mitigation Study	Riverbank Analysis	River Migration Forecast	Evaluation of optimal River mitigation approach	Review of applicable laws, regulations, design specifications	Material specifications	Plan View showing material sizes and dimensions	Construction recommendations	Installation guidelines	AutoCad River Mitigation Design	Drafting Final Design for River Mitigation	Presentation Preparation
Start Date	30-Aug	9-Sep	9-Sep	13-Sep	9-Sep	16-Sep	1-Nov	10-Nov	10-Nov	30-Sep	22-Nov	13-Dec
Days to Complete	10	5	50	15	18	10	10	10	15	53	21	7

3. Methods and Design Guides

Riverbank analysis Methods

USGS Stream Stats provided the peak flow for the hydrologic analysis and the velocity of the river for the hydraulic analysis. By entering a specified location, USDA web soil survey generated a report of the types of soil and the quantity of the different soil that surrounded the project site. Lastly, forecasting river migration was evaluated using the Johannesson-Parker River Meander Migration Model (JP Model). This program can be executed using a software package called the International River Interface Cooperative (iRIC). The JP Model calculates channel migration using a simplified form of equation for fluid flow and sediment transport. The software gave us the ability to predict current migration patterns of the river as well as a prediction of what happens to the migration patterns when mitigation measures are taken (Larsen et. al, 2017).

River Mitigation Methods

As requested, QCC examined soft armor/bioengineering approaches opposed to the hard-engineering approaches. Soft, bioengineering approaches tend to have better environmental outcomes and are less costly to construct. While this approach provides multiple benefits there was also a number of disadvantages to using this approach. An important aspect of bioengineering streambanks is having consistent flow and river elevations that can facilitate growth for vegetation. Vegetative roots hold the streambank in place preventing erosion. The riverbank must have areas that allow vegetation to receive water but are not constantly inundated as well. We evaluated the historical flow data of the Skunk River and found that it had a very high variability of both flow and water elevation levels. This would impede the growth and development necessary for a bioengineering approach (Cross, 2016). Another factor is the overall strength compared to hard armor such as rock riprap. Bioengineering has a very low resistance to erosion compared to all other streambank mitigation techniques. Furthermore, it is only effective at base level flows, meaning that it does not provide any protection for river toe erosion. It also does not work well for streambanks that have sandy soil, which is the case for the Skunk River (U.S. Department of Interior, 2015). Historical data on the Skunk River has shown a rapid erosion rate and our modeling techniques predict that this will continue into the future. We believe that the mitigation strategy for this river will require a high resistance to both erosion and varying flow rates. It is for these reasons we believe that using a bioengineering approach for Skunk River would not be an appropriate solution.

After eliminating bioengineering approaches the design team examined rock riprap as an alternative. This method is more expensive than bioengineering and does not provide the same environmental benefits of bioengineering but has a high resistance to erosion and flow variability. This method has also been widely tested and used for river channel mitigation and has been proven to work for larger rivers similar to the Skunk River. It is also easier to install and maintain relative to bioengineering, and provides some water quality benefits by increasing roughness and decreasing water velocity (Massachusetts Clean Water Toolkit, 2010) . For this reason, QCC chose to go with rock riprap as a final design solution.

River Mitigation design guides

Due to the fact that river channel mitigation has environmental impacts, it is important to follow all local, state and federal environmental regulations. The Iowa Department of Natural Resources carries out state and federal laws that protect air, land, and water through technical assistance, permitting and compliance programs. Since this project is in Iowa, the Iowa DNR will be critical for the evaluation of the design. The Army Corps of Engineers will also provide guidance and regulation on river channel mitigation methods. In addition, the Virginia Stream Manual and FEMA will provide valuable and further guidance on how the design will be carried out based on documented specifications and design criteria.

River mitigation design software

The site design was completed in AutoCAD Civil 3D. This software facilitates in the creation of the plan drawings that will be used to generate the final plan set that will be submitted to the client. Forecasting the river migration will be done using the iRIC software. Specifically, this software will utilize the JP Meander Migration Program, which implements the Johannesson-Parker Meander Migration model. This program will be used to create a 50-year forecast of the Skunk River migration. This program outputs shapefiles that will be placed into QGIS. QGIS will then be used to provide visual maps of the river migration pattern over a 50-year period.

Section IV Constraints, Challenges and Impacts

1. Constraints

This projects' constraints include environmental regulations, construction boundaries, cost of material and time. This project will cause changes to the river channel, which requires adherence to regulations from both the Iowa Department of Natural Resources and the Army Corps Engineers. Information given to us from our client indicated that river straightening would not be an acceptable design according to Army Corps Engineers. There are parcels of private land as well as a wildlife area near the Skunk River. Designs must take into consideration how this land will be affected by the river channel mitigation techniques. Changes to private land should be limited, and any changes to the wildlife require permission from the DNR. Reshaping banks requires the acquisition of permits from the Army Corps Engineers. As with any project cost of materials will be an important constraint. Designs must be able to fit within the budget of Keokuk County. Time will also be a constraint and all final designs must be submitted by December 13, 2019.

2. Challenges

Keokuk County asked that we develop a forecast of how the river will migrate in the coming years. The challenge in this task is developing a way to model the river. During our research we found and used a software package that uses the Johannesson-Parker Meander Migration Model as a solution to this problem (Larsen et. al, 2017). Another challenge was developing an accurate cross section sketch of the river channel. Using the data obtained at the site visit along with stream statistics from the USGS, we were able to accurately sketch the cross section of the river. For this project the county asked that we look specifically into bioengineering techniques, which uses natural materials to protect the riverbank. A bioengineering technique provides a more sustainable and cost-effective solution, but techniques have shown to be less reliable than hard engineering techniques such as rock riprap (Cross, 2016). Furthermore, after evaluating flow conditions it was determined that conditions in the Skunk River do not facilitate the necessary conditions for a bioengineering approach. Another challenge was planning for the future construction necessary for the design. One of the construction sites is located on private property, and access to this site will require a temporary easement, requiring negotiation with the property owners. Construction sites also have dense vegetation that will require grub work to remove trees and other dense vegetation.

3. Societal Impact within the Community and/or State of Iowa

The project has positive benefits for the residents of Keokuk County and the state of Iowa. Residents near this site now have a forecast of how far reaching the river migration will be in the upcoming years. This allows both residents, county engineers and county officials to plan and develop solutions for future issues regarding migration of the Skunk River. River mitigation techniques will also benefit both state and county residents. Keokuk County Route W15 is the highest volume secondary road in Keokuk County and is an important road for trucking produce through the state. Future river migration would likely compromise the roadbed of W15. This project will save Keokuk County residents money on road repairs, while keeping a valuable route open to the residents of Iowa. Lastly, this project will protect County Bridge 619’. The bridge was replaced in 2004 and future river migration would minimize the benefit that replacing the bridge has had for the residents of Keokuk County. Negative impacts will be minimal. The project will take place in a rural area, and noise from construction is unlikely to impact residents of Keokuk County. Residents near the third river bend will have to allow heavy construction equipment on their property. The area appears to be cropland and construction could have negative impacts on crop yields for farmers in that area.

Section V Alternative Solutions That Were Considered

We reviewed and considered multiple alternative design concepts before reaching a consensus on the design solution that we believed to be the best. The alternatives that the team explored incorporated mitigation practices such as bank protection, bank stabilization, grade control, and flow deflection. It was concluded that design alternatives that involved redirecting the river and dredging the river to an ideal channel shape were eliminated from consideration due to the fact that the Army Corps of Engineers would not permit such changes made on the South Skunk River. The first steps in all of our considered design alternatives required reworking and reshaping the banks. The current shape of the banks is either flat, elongated, or very steep. In order to effectively deploy a mitigation approach, grade control on the banks was determined to be critically needed in order to create a consistent trapezoidal shape that could be worked with and that would maintain an equal and consistent flow throughout the channel.

After a model of the proposed riverbank grading was created in AutoCAD Civil 3D, the team evaluated the pros and cons of the considered alternate design solutions aimed to combat the erosion that the riverbanks were experiencing. The first option our company considered were several variations of bank protection along the banks of the river. This approach deals with preventing loss or damage to the land that is adjacent to the stream because they work as a barrier. The team reviewed “hard armor” rock rip rap and bioengineering consisting of tree revetments. The bioengineering tree revetments were originally an attractive solution because it was a natural alternative and provided a more sustainable approach. Spruce trees are the common species of tree that is used for tree revetments. Figure 1 in the Appendix G is a concept drawing from The Virginia Department of Conservation and Recreation and illustrates that the trees would be placed horizontally along the bank with the tops facing downstream so that the tops of upstream trees cover the base of the downstream trees. Although this design alternative was highly sought after, the team did have some significant concerns with the limitations that came with using trees as an erosion control solution. Considering the very poor state of the current banks, high flow variability with minimum flows of 201 cfs and maximum flows of 1430 cfs, and the excessive meandering that was forecasted to move toward the county route W15, it was decided that this solution would not be practical in this case. Unlike a rock revetment which can adjust to changing bank contour geometry, tree revetments are completely dependent upon the strength of the soils in the bank. Furthermore, once the foundation soils are compromised, the trees may dislodge and float away which may lead to complications downstream (IDNR, 2006). Lastly, assuming predictable conditions, the trees and cables naturally decay over time and the Army Corps of Engineers declares that maintenance is required every 1 to 3 years. This led to the conclusion that the tree revetment solution would not serve as an effective alternative for protecting the county route from the eroding banks along the river (Army Corps Engineers, 2016).

Another environmental approach that was considered was to put in fascines and planting brush patches along the stream. According to the Army Corps of Engineers, the point of these measures would be to strengthen the bank and by having the roots dig into the undersoil. Live fascines are bundles of roots and sticks that are anchored down by stakes. The bundles are typically 6-8 inches thick on the ground. Planting brush along the banks would be a quick option to getting stabilization on the channel. Although this is a quick option it does not provide as strong of protection as riprap rocks (Army Corps Engineers, 2016). Similarly, to the tree revenant, this alternative had to be quickly dismissed due to the fact that this alternative does not effectively provide protection to the toe of the bank and would need further toe reinforcement such as a tree revenant regardless. This alternative is also easily damaged from ice scour and maintenance would be a never-ending requirement throughout the Iowa seasons.

Some alternatives were investigated that weren't necessarily bioengineering designs. Initially the team considered focusing on the stream itself and not the banks. The concept was to use either V or W shapes weirs as a flow deflection approach that would form a barrier for the water to flow over, causing flow to slow and energy to dissipate making the energy for erosion weaker along the banks. This option would be good to use if we determine that the erosion problem is caused by the velocity of the water and not the weakness of the soil. Although the soil analysis from the soil survey indicated that the banks consisted of nodaway silt loam, the hydrologic and hydraulic analysis overruled the soil analysis indication of the possibility of installing an effective weir design. This section of the channel experiences excessive flooding and the weirs would not act as a viable barrier. Due to the fact that the banks are in such bad shape and are dangerously encroaching closer to the county route W15, it was more important to address directly protecting the banks with armor rather than attempting to slow down a river of this size that inevitably will flood.

The last alternative that was eliminated from further consideration was applying rock riprap on both sides of the channel and throughout the entirety of the project site. Although this alternative could effectively work, it was ruled out for a few obvious reasons. The first reason is that it would require twice as much rip rap rock and inevitably would at least double the price of the project. The second reason is that there would be complications with installing the rip rap on the state park's side of the river. In our opinion, negotiating with the Iowa DNR about further disrupting the state park during the construction process would be an avoidable complication.

Section VI Final Design Details

1. JP Meander Migration Forecast

The JP meander migration model is a tool used to forecast the future migration pattern of the river meanders. The program was created by Dr. Eric Lasen, Ph.D, an expert on geomorphology and meander migration dynamics. The program is run through a software package called iRIC, a platform for numerical simulation of flow and morpho dynamics in rivers. The model operation utilizes the Johannesson-Parker Meander Migration model. This model has been used extensively for modeling and predicting river channel migration patterns. The model calculates channel migration using simplified forms of equations for fluid flow and sediment transportation. The model inputs require bank full discharge, width, height and slope (Larsen et. al, 2017). Using a 2-year recurrence interval for discharge starting from 1930 we calculated the bank full discharge to be 3050 cubic feet per second. Table B.1 shows the data collected from USGS Stream Statistics and Equation B.1 shows the 2-year recurrence interval calculation. The characteristic depth and width were obtained using a River extension in Civil 3D and were 2.14 ft and 159 ft respectively. The slope was also obtained using the River extension in Civil 3D and came out to 0.00054.

The JP Meander Migration pattern makes calculations based off a river centerline that can was created using QGIS. Using a map showing historical locations of the river centerline provided to us by the Keokuk County Engineers, we were able to build a centerline from the year 1970 and a centerline for the year 2016. We first ran the program from the 1970 centerline to 2016 to calibrate the model. The results of this calibration are shown in figure B.1 in appendix B.

After calibration we then ran our model from the years 2016 to 2066. As expected, our model shows continue migration on all three bends within the scope of the project. The results of this model are shown in Figure B.2 of appendix B. Two main areas of concern are on the Southeast side of bend 1 and on the southernmost end of bend 3. Bend 1 will continue to migrate towards county road W15 threatening the integrity of the road. Bend 3 shows the most dramatic migration and there is a very high chance that the property owners in that area will experience loss of land due to river erosion.

2. Gaining Access

This project will require access temporary access for heavy construction equipment. The design team has identified multiple access roads for bend 1 and bend 2. Access to the construction sites will also require grubbing work which has been included into the cost estimate. Figure C.1 identifies the access road for bend 1. It also shows that there is an overflow channel located in the area. We recommend that a section of the overflow channel be filled to allow access for heavy construction equipment. Bend 2 also has a road that will allow easy access that has been identified in Figure C.2. Construction on bend 2 will partially take place on the Skunk River State Wildlife Area. Due to this, it will require permission from the DNR for grubbing work. The use of these roads that are already in place will limit the project cost and need for easements for construction on bend 1 and 2. Bend 3 does not have an access road and will require one to be temporarily build for access of heavy construction equipment. Our team recommends that a temporary easement be negotiated with the landowners around the area for bend 3.

3. Reshaping the Banks

Regulations state that before installing riprap the bank should be reshaped to a maximum slope of slope 2 feet horizontal to 1 foot vertical (2H:1V) or flatter (IDNR, 2006). Our team evaluated different slopes through the river extension of Civil 3D. We found through our analysis that a slope of 3 feet horizontal to 1 foot vertical (3H:1V) would provide excellent bank stability, while remaining cost effective.

4. Sizing Riprap

Once the team concluded on selecting a rock riprap design solution as the optimal alternative, the process of designing the proposed cross sections of the rip rap armored riverbanks were carried out. The type of rock itself was decided on based upon the guidelines set forth by the Iowa DNR in the stream bank manual. According to the Iowa DNR, Class D or E revetment stone is the specific type of rock that is to be used for riverbank protection. The rough, angular surfaces and the variety of sizes allow the rock to fit together tightly to form a dense protective barrier. Class D revetment has the same weight gradation as Class E, but the Iowa DOT suggests that Class D is intended to be a temporary erosion control and only lasts several years before failure. As a result, the team then determined to use Class E over Class D revetment based on the fact that the aggressive nature of the erosion that the banks are undergoing are in need of a long-term solution. The gradation specifics for Class E revetment can be referred to in table 1 of Appendix E.

Similarly, the Iowa DNR guidelines were utilized to evaluate the size range of the rock that was needed for the design. The river model that was created in AutoCad Civil 3D used river flow data from USGS located in table E.5 that can be seen in Appendix E. After running an analysis with the USGS inputs, the outputs indicated that the stream's velocity in feet per second reached up to 5.83 feet per second. A summary of the river analysis outputs is visualized in Table 1 of Appendix E. Table 2 in Appendix E illustrates guidelines provided by the Iowa DNR streambank manual and suggests that the velocity of the stream during high flow would be classified as "Moderate". Thus, the size range of rock that was to be used to protect the bank had to be between 4" and 12" in diameter across the longest part of the rock. Additionally, the chart concluded that the average size of rock that would be used was on average 8" in diameter across the longest part of the rock. This information provided by the Iowa DNR facilitated the design team to create the cross section that is illustrated in the plan sheets.

5. Riprap Installation

Most of the riprap construction installation guidelines can be visualized using the cross section from figure F.2 in Appendix F. After the slopes of the banks where installation will occur have been reshaped to a slope of 3 feet horizontal to 1 foot vertical (3H: 1V), a six-inch layer of gravel is to be placed along the slopes. This six-inch layer stabilizes the soil and acts as a membrane that further protects the banks from the water that will penetrate through the crevices of the rip rap rock layer. Following the six-inch layer of gravel, the Class E revetment rock is to be implemented. The heaviest rock, which should be roughly 12'' in diameter, should be placed along the bottom of the bank and fill the streambed. Refer to figure F.2 in Appendix F for verification of the location of the streambed. The rest of the rock is to be placed along the slope up to an elevation of 625.5 feet and form a 12 to 18-inch layer. The DNR stream bank manual declares that the layer's minimum thickness must equal the maximum rock size. Due to the fact the maximum rock size our team is recommending is 12 inches, the minimum thickness of the riprap layer must be 12 inches. The calculations approximating the quantity of rock needed for the design are referenced in Appendix F.

Once the rip rap installation is completed along the banks, it is advised that any affected vegetation that underwent clearing and grubbing during the construction process, is restored to its original state. Additionally, the access roads may be damaged by the equipment during the construction process and therefore, should be restored if needed. The cost estimates provided for the project include the assumption of these damages.

6. Conclusion/Results

Using the iRIC software the design team was able to successfully assess the magnitude of the erosion problem on the Skunk River. Due to the rapid erosion rate of the river based on both historical data and our models, we recommend the rock riprap to be installed on the outside of the bends within the scope of the project. Furthermore, using the iRIC software we were able to evaluate the design and determine how the alternative would change the predicted migration pattern of the river. Figure B.3 shows the forecasted river migration after the installation of riprap on the outside of the three bends. The model shows significant reduction of erosion on all three bends. We believe that installing riprap in this manner will protect the integrity of the county road W15 and retain the benefits of the county bridge 619'. There will still be impacts and loss of property near the southern tip of bend 3, but these impacts will be greatly reduced. We also recommend that the riprap along bend 3 be inspected yearly and maintenance be performed as determined by the inspecting agency. We believe that with proper inspection and maintenance it is possible to eliminate the loss of property near bend 3 entirely.

Section VII Engineering Cost Estimate

Table 1: Preliminary Cost Estimate of Construction

Preliminary Estimate of Cost Mainline

Item No.	Bid Item	Qty.	Unit	Unit Price(US Dollar)	Cost
1	Clearing and Grubbing	1	L.S	16,000	16000
2	Crushed gravel	78727	SF	1.33	104,707
3	Seeding, Fertilizing & Mulching	2.65	Acres	2400	6,360
4	Excavation, Streambank	111	C.Y.	7	777
5	Revetment, Class "E" Riprap	2624	Tons	41	107,584
6	Access Road Repair/ Resurfacing	1	L.S	5500	5500
7	Traffic Control	1	L.S	4000	4000
	TOTAL				244,585

Table 2: Total Project Cost Breakdown

Construction Subtotal	245,000.00
10% Contingencies	24,500.00
20% Engineering and Administration	49,000.00
Total Project Cost	318,500.00

Section VIII Appendix

Appendix A: Site Characteristics

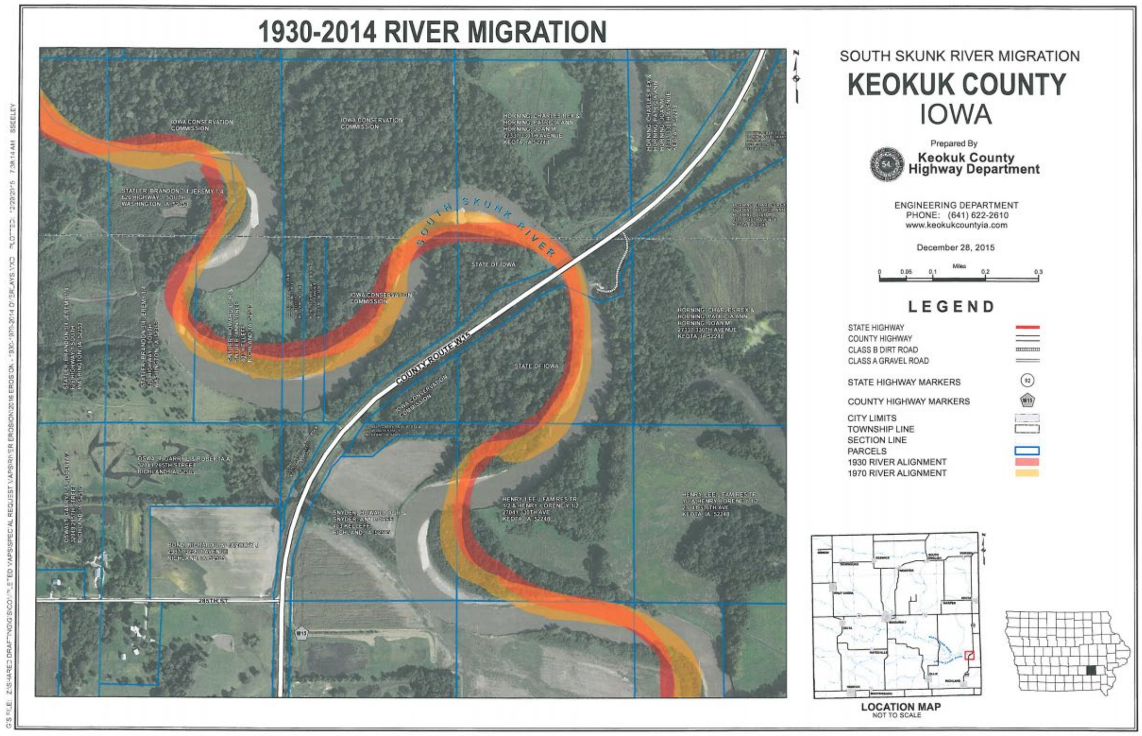


Figure A.1: Historical Data of South Skunk River Migration

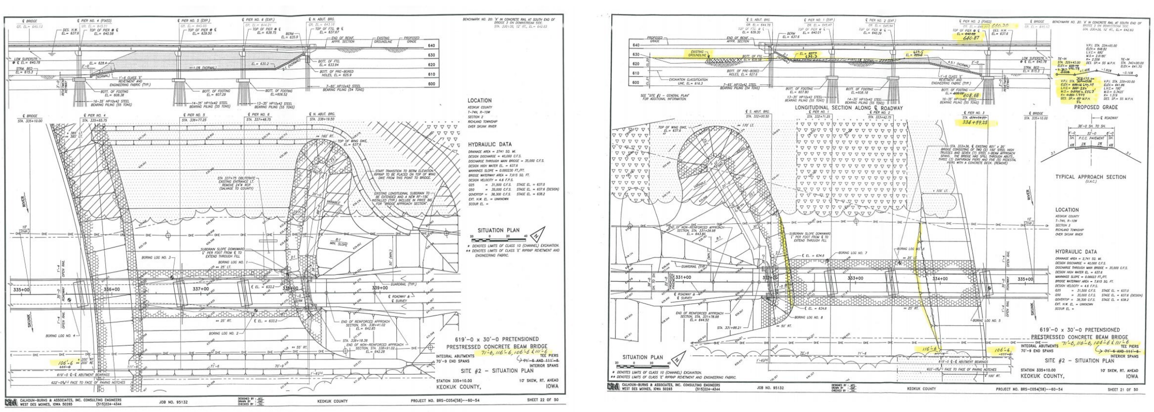


Figure A.2: Keokuk County Situation Plan Sheets

Appendix B: Forecasted Meander Migration Maps

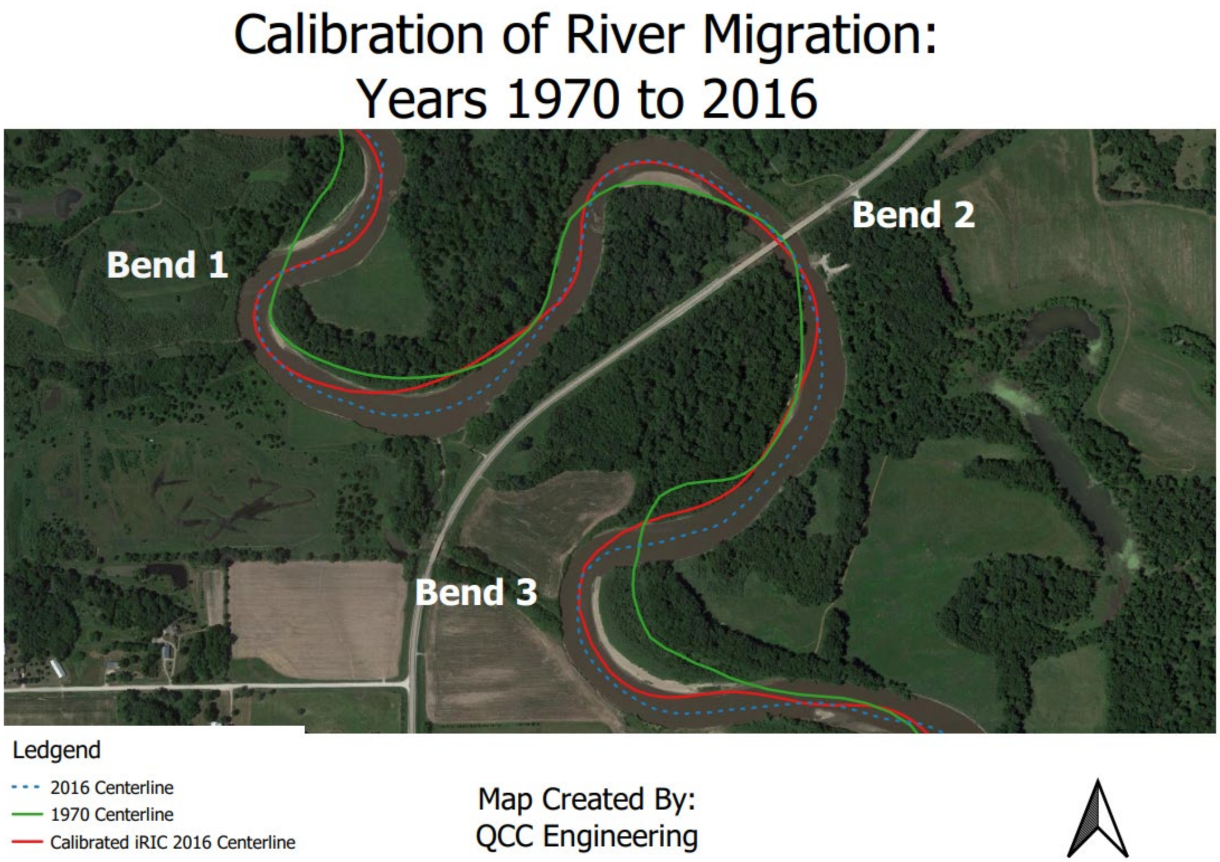


Figure B.1: This Map shows the end results of calibration from 1970 to 2016.

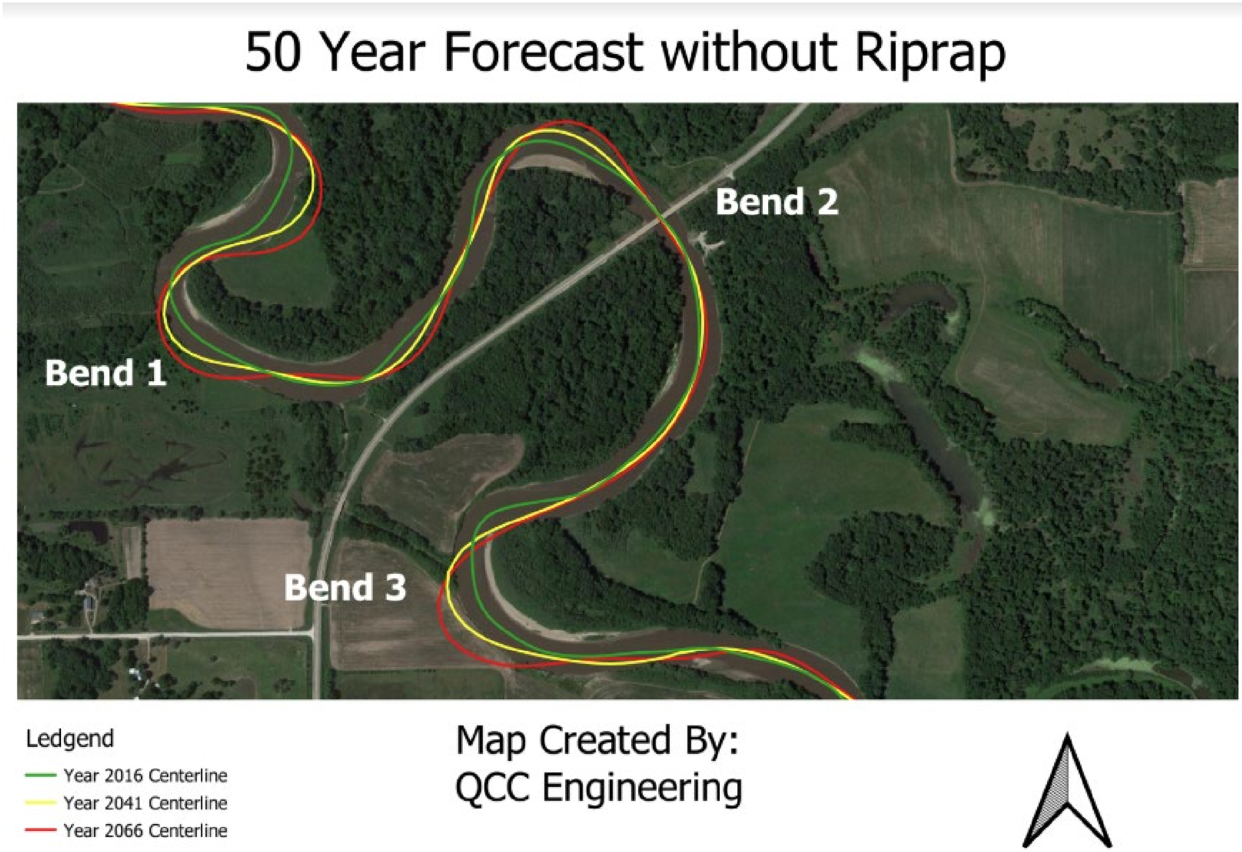


Figure B.2: This map shows a 50-year forecast before riprap is installed.

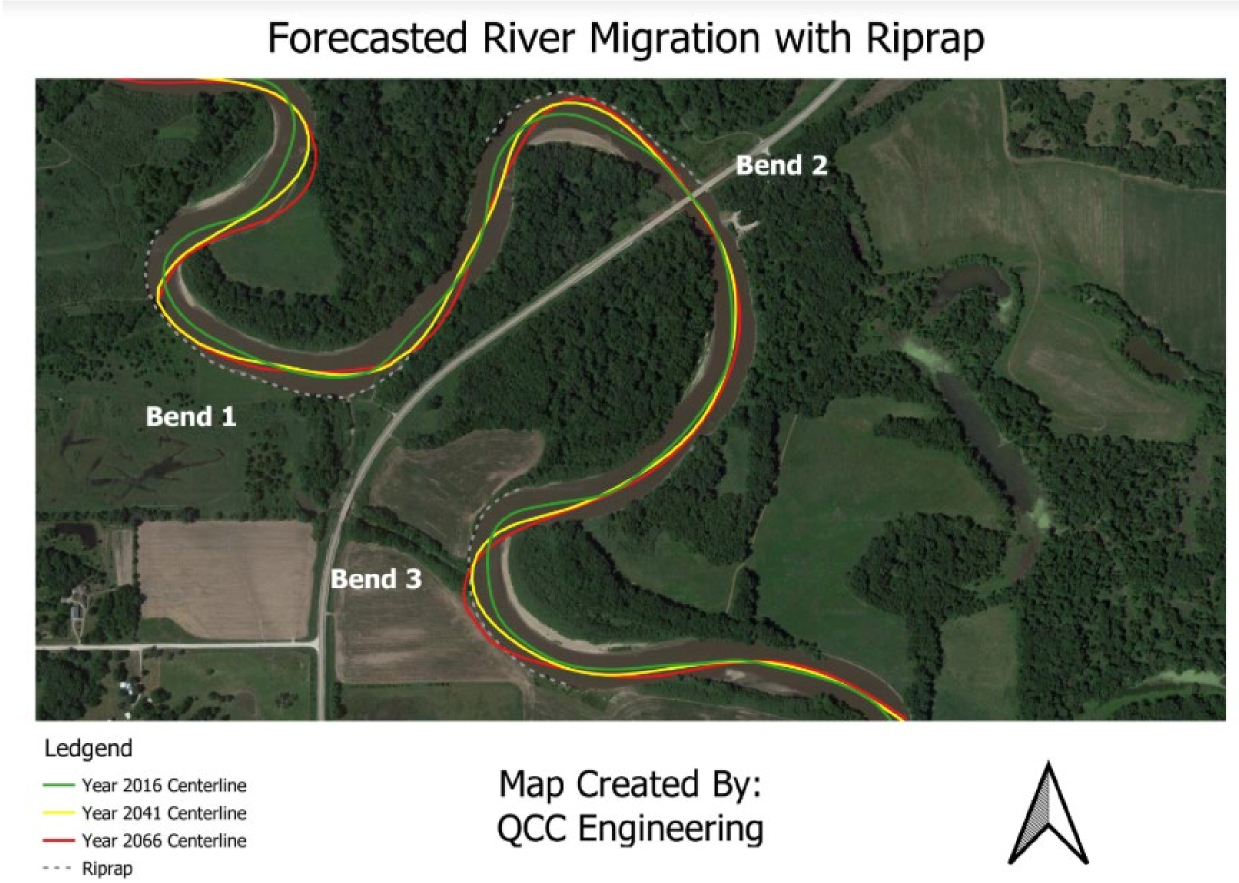


Figure B.3: This map shows a 50-year forecast of the river migration with riprap installed on the outside of the banks.

Table B.1: Data Collected for 2-Year Recurrence Interval. Data Collected from 1921 to 2016

Year	Flow (Cfs)	Rank	Reccurance Interval	Year	Flow (Cfs)	Rank	Reccurance Interval	Year	Flow (Cfs)	Rank	Reccurance Interval
2010	14800	1	94.00	1922	3370	41	2.29	1952	1630	81	1.16
1996	14000	2	47.00	1973	3340	42	2.24	2011	1620	82	1.15
1993	11200	3	31.33	2006	3330	43	2.19	1955	1340	83	1.13
2015	11200	4	23.50	1939	32302	44	2.14	1970	1330	84	1.12
2008	11000	5	18.80	1958	3150	45	2.09	2002	1070	85	1.11
2014	9250	6	15.67	1926	3120	46	2.04	1953	980	86	1.09
1954	8630	7	13.43	1941	3050	47	2.00	2000	906	87	1.08
1944	8060	8	11.75	1987	3040	48	1.96	1925	905	88	1.07
2013	6740	9	10.44	1972	3030	49	1.92	2012	730	89	1.06
1990	6600	10	9.40	1924	3010	50	1.88	1934	6002	90	1.04
1947	6550	11	8.55	1937	30002	51	1.84	1988	565	91	1.03
2007	6510	12	7.83	1949	30002	52	1.81	1956	376	92	1.02
2016	6420	13	7.23	1966	29002	53	1.77	1989	3702	93	1.01
1960	6210	14	6.71	1938	2890	54	1.74				
1974	5780	15	6.27	1967	2790	55	1.71				
1951	5320	16	5.88	1980	2720	56	1.68				
1977	5300	17	5.53	1948	2620	57	1.65				
1965	5260	18	5.22	1936	2580	58	1.62				
1930	5230	19	4.95	1942	2530	59	1.59				
1975	5230	20	4.70	2004	2520	60	1.57				
1983	5150	21	4.48	1927	2460	61	1.54				
1984	5020	22	4.27	1992	2350	62	1.52				
1979	4980	23	4.09	1994	2340	63	1.49				
1968	4890	24	3.92	1940	2320	64	1.47				
1998	4760	25	3.76	2005	2310	65	1.45				
1991	4700	26	3.62	1946	2270	66	1.42				
2009	4560	27	3.48	1978	2240	67	1.40				
1943	4500	28	3.36	1964	2170	68	1.38				
1969	4380	29	3.24	1997	20802	69	1.36				
1962	4300	30	3.13	2003	2030	70	1.34				
1986	4040	31	3.03	1933	1990	71	1.32				
1945	4010	32	2.94	1961	1990	72	1.31				
1950	3820	33	2.85	2001	1990	73	1.29				
1971	3660	34	2.76	1985	1980	74	1.27				
1999	3630	35	2.69	2017	1890	75	1.25				
1976	3580	36	2.61	1981	1880	76	1.24				
1921	3540	37	2.54	1963	1820	77	1.22				
1957	3540	38	2.47	1959	1720	78	1.21				
1935	3490	39	2.41	1923	1670	79	1.19				
1982	3490	40	2.35	1995	1640	80	1.18				

Equation B.1: 2-Year Recurrence Interval Calculation

$$Reccurance\ Interval = \frac{(1 + Number\ of\ Data\ Points)}{Rank}$$

$$Reccurance\ Interval = \frac{(1 + 93)}{47} = 2 - Corresponds\ to\ 3{,}050\ cfs$$

Appendix C: Gaining Access

Figure C.1: Access road for riprap construction along bend 1.

Figure C.2: Access road for riprap construction along bend 2.

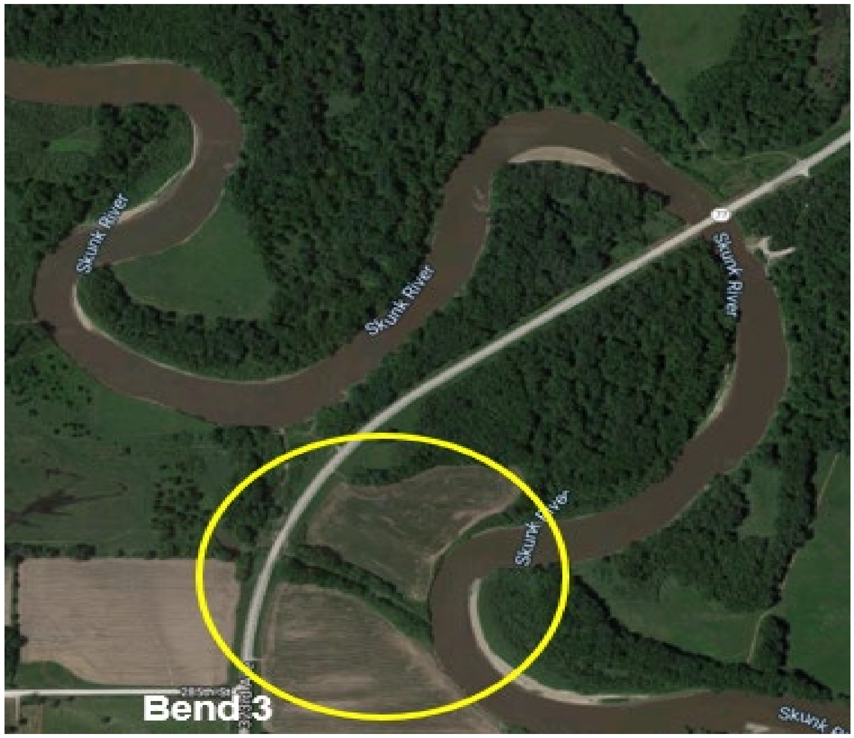


Figure C.3: Shows lack of access to bend 3. This bend will require temporary easement negotiated with landowners.

Appendix D: Reshaping the Bank / Cut and Fill

Table D.1: Cut and Fill Summary Table of Entire Channel

Summary Table Full Channel		
Net C/F LB	20.22	CY
Net C/F RB	89.49	CY
Total	109.71	CY
156.98 CY Fill		

Table D.2: Cut and Fill Summary Table of Implemented Design

Summary Table Turns		
Net C/F LB	-43.05	CY
Net C/F RB	-68.77	CY
Total	-111.82	CY
Total Cut/Fill = 111.82 Cut		

Table D.3: Cut and Fill Calculation at Each Cross Section

Cross Section	Left Bank			Right Bank		
Number	Cut	Fill	Total	Cut	Fill	Total
1						
2	13.65	18.75	5.10	31.00	7.75	-23.25
3	25.50	3.80	-21.70	30.75	15.60	-15.15
4	25.80	9.15	-16.65	0.70	64.50	63.80
5	44.20	8.45	-35.75	0.10	161.40	161.30
6	60.15	0.00	-60.15	0.00	249.60	249.60
7	59.30	0.00	-59.30	0.00	285.70	285.70
8	64.80	0.00	-64.80	0.00	307.65	307.65
9	44.10	4.70	-39.40	0.00	321.35	321.35
10	49.60	4.70	-44.90	0.00	333.40	333.40
11	70.30	0.00	-70.30	0.00	312.55	312.55
12	64.05	0.00	-64.05	0.00	274.40	274.40
13	44.25	0.00	-44.25	0.00	210.60	210.60
14	17.40	6.65	-10.75	0.00	102.35	102.35
15	17.90	12.00	-5.90	0.00	49.95	49.95
16	45.15	5.35	-39.80	6.10	35.15	29.05
17	50.80	0.00	-50.80	7.00	13.35	6.35
18	36.75	0.30	-36.45	0.90	14.95	14.05
19	25.70	6.80	-18.90	0.00	41.65	41.65
20	16.25	6.50	-9.75	0.00	77.25	77.25
21	41.40	0.00	-41.40	0.00	86.80	86.80
22	54.60	0.00	-54.60	0.00	79.95	79.95
23	55.00	0.00	-55.00	0.00	81.05	81.05
24	37.85	0.00	-37.85	0.00	80.05	80.05
25	21.35	0.00	-21.35	0.00	73.65	73.65
26	26.85	0.00	-26.85	0.00	68.65	68.65
27	22.85	0.00	-22.85	0.00	129.40	129.40
28	20.85	2.15	-18.70	0.00	163.75	163.75
29	14.80	2.15	-12.65	0.00	84.00	84.00
30	28.95	0.00	-28.95	28.30	15.40	-12.90
31	42.65	0.00	-42.65	57.35	0.00	-57.35
32	43.35	0.00	-43.35	29.05	0.00	-29.05
33	50.50	0.00	-50.50	0.55	27.80	27.25
34	60.25	0.00	-60.25	0.95	103.75	102.80
35	70.90	0.00	-70.90	0.85	166.20	165.35
36	75.65	0.00	-75.65	0.85	208.05	207.20
37	89.70	0.00	-89.70	0.80	251.80	251.00
38	92.75	0.00	-92.75	0.75	244.40	243.65
39	85.95	0.00	-85.95	0.75	177.50	176.75
40	70.45	0.00	-70.45	0.95	95.50	94.55

41	53.35	0.00	-53.35	28.70	28.40	-0.30
42	43.45	0.00	-43.45	50.50	0.00	-50.50
43	28.25	0.00	-28.25	32.95	2.30	-30.65
44	18.95	0.00	-18.95	31.05	2.30	-28.75
45	9.55	8.95	-0.60	33.05	0.00	-33.05
46	1.75	34.65	32.90	39.65	0.00	-39.65
47	1.15	64.35	63.20	56.55	0.00	-56.55
48	0.90	71.05	70.15	67.75	0.00	-67.75
49	1.00	59.15	58.15	60.40	0.00	-60.40
50	1.05	46.00	44.95	36.60	0.00	-36.60
51	0.95	57.35	56.40	46.65	0.00	-46.65
52	1.05	76.80	75.75	72.30	0.00	-72.30
53	1.05	90.35	89.30	61.35	0.00	-61.35
54	0.85	124.85	124.00	52.30	0.00	-52.30
55	0.75	177.60	176.85	64.70	0.00	-64.70
56	0.70	213.85	213.15	77.10	0.00	-77.10
57	0.75	203.35	202.60	79.55	0.00	-79.55
58	0.75	223.85	223.10	82.65	0.00	-82.65
59	0.65	272.50	271.85	85.55	0.00	-85.55
60	0.60	277.50	276.90	74.25	0.00	-74.25
61	0.65	247.40	246.75	78.65	0.00	-78.65
62	0.70	199.00	198.30	88.70	0.00	-88.70
63	0.70	156.65	155.95	88.60	0.00	-88.60
64	0.75	112.05	111.30	78.45	0.00	-78.45
65	0.95	75.50	74.55	76.25	0.00	-76.25

Appendix E: Sizing Rip Rap

Table E.1 : River analysis summary table output from Civil3D model

	Average					
	Min Ch El (ft)	W.S. Elev (ft)	Depth (ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)
Low	616.73	618.06	1.33	1.16	195.64	153.59
Mean	616.73	618.87	2.14	1.84	322.50	159.00
High	607.25	610.76	3.51	2.78	550.30	167.80

Table E.2: Gradation of Class E Revetment, Iowa DOT, Section 4130.02

Percent Lighter by Weight	Stone Weight in Pounds
100	250
50	90
10	5

Table E.3: Recommended sized for riprap, Iowa DNR, Streambank manual

Velocity of stream during high flow	**Size range (diameter across longest part of rock)**
Slow (2-4 ft/sec)	3" - 6"; average 4"
Moderate (4-6 ft/sec)	4" - 12"; average 8"
* Fast (6-12 ft/sec)	5" - 18"; average 14"

*This velocity is the most common cause of streambank erosion in Iowa.

Table E.4: Summary table, USGS station 05472500 North Skunk River

Type	Flow	Units
Low	201.00	ft^3/s
Mean	533.40	ft^3/s
High	1430.00	ft^3/s

Table E.5: StreamStats , USGS station 05472500 North Skunk River

Day of month	Mean of daily mean values for each day for water year of record in, ft3/s (Calculation 1945-2019											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	239	225	617	990	958	1,010	762	324	319	242	314	325
2	246	233	580	853	916	974	781	288	377	221	437	324
3	259	243	598	799	878	892	817	288	320	238	426	262
4	252	324	715	760	796	780	787	283	265	230	350	237
5	271	311	809	739	754	757	797	372	244	250	348	255
6	296	279	782	716	703	763	855	484	333	300	290	256
7	388	269	776	638	814	821	892	425	368	300	248	252
8	377	299	814	615	887	821	730	345	338	262	224	255
9	312	306	774	575	898	806	647	388	342	293	214	226
10	253	319	847	571	917	787	651	461	392	342	256	209
11	215	320	883	662	948	779	657	436	349	357	251	203
12	209	297	953	730	925	915	616	446	283	384	250	208
13	220	268	1,140	729	989	1,060	604	406	310	374	275	223
14	245	276	1,140	727	935	1,210	524	446	335	348	299	280
15	304	310	1,160	714	820	1,430	456	444	354	306	271	317
16	262	328	1,130	735	832	1,280	439	400	319	272	304	358
17	289	362	1,020	744	920	1,110	445	367	296	268	323	335
18	295	444	994	843	948	1,050	473	329	283	315	320	291
19	283	510	1,050	921	1,030	1,010	541	304	338	313	315	260
20	289	632	1,070	1,010	979	1,130	572	289	399	293	299	221
21	301	718	1,010	1,070	905	1,100	573	274	436	247	312	220
22	287	767	1,020	990	747	1,010	493	230	365	225	286	222
23	312	699	948	868	752	1,020	415	201	348	276	282	225
24	286	682	947	892	813	964	423	236	377	294	254	252
25	264	686	822	888	831	890	432	268	400	297	233	276
26	246	645	707	837	956	841	467	279	365	292	250	266
27	255	597	681	895	1,110	817	455	295	360	256	292	296
28	238	590	669	905	1,310	796	499	347	345	227	306	341
29	237	728	705	860	1,350	777	458	354	301	232	304	330
30	244		728	940	1,240	801	442	381	265	273	328	306
31	229		1,030		1,100		403	358		261		263

Appendix F: Installation of Rip Rap

Equation F.1: Riprap Quantity

$$\text{Rip Rap Quantity (Tons)} = \frac{Area * \text{Number of Cross Sections}}{30\ sf} = \frac{3030 * 26}{30\ sf} = \mathbf{2624\ tons}$$

Coverage Charts

Use this coverage chart to estimate the amount of material you need for your next landscape job.

PRODUCT	COVERAGE RATE PER TON OF MATERIAL
8”-18” Rip Rap	20 Square Feet
4”-10” Rip Rap	30 Square Feet
2″-4″ Rip Rap	70 Square Feet
1”-3” Rip Rap	90 Square Feet
3/4”, 7/8,” 1” Screened Gravel	100 Square Feet @ 2” depth
5/8”, 1/2” Screened Gravel	120 Square Feet @ 2” depth
1/4″, 3/8” Screened Gravel	140 Square Feet @ 2” depth
Minus Materials	100-120 Square Feet @ 2” depth

Figure F.1: Kalamazoo Materials Rip Rap Coverage Chart

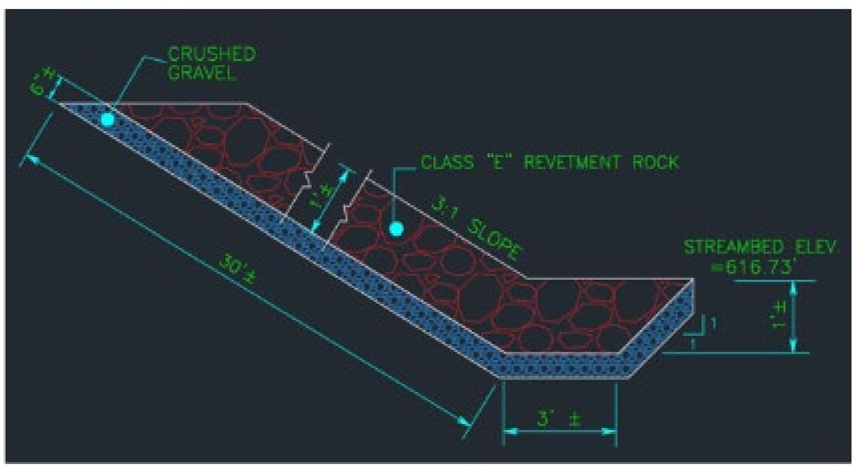


Figure F.2: Proposed Design Cross Section

Appendix G: Design Cross Sections

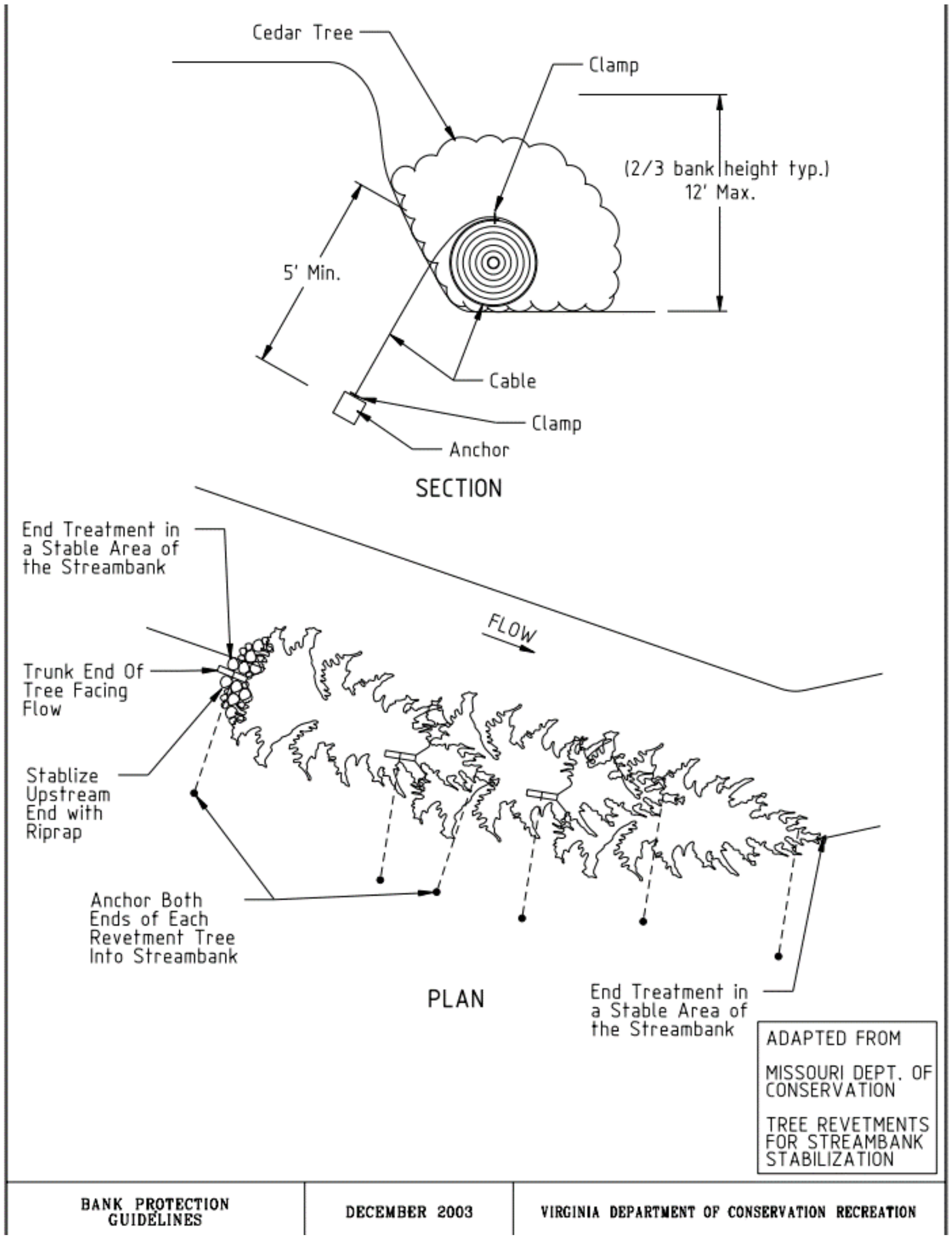


Figure G.1: Virginia Department of Conservation Recreation Tree Revetment Concept Drawing

Appendix H: References

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