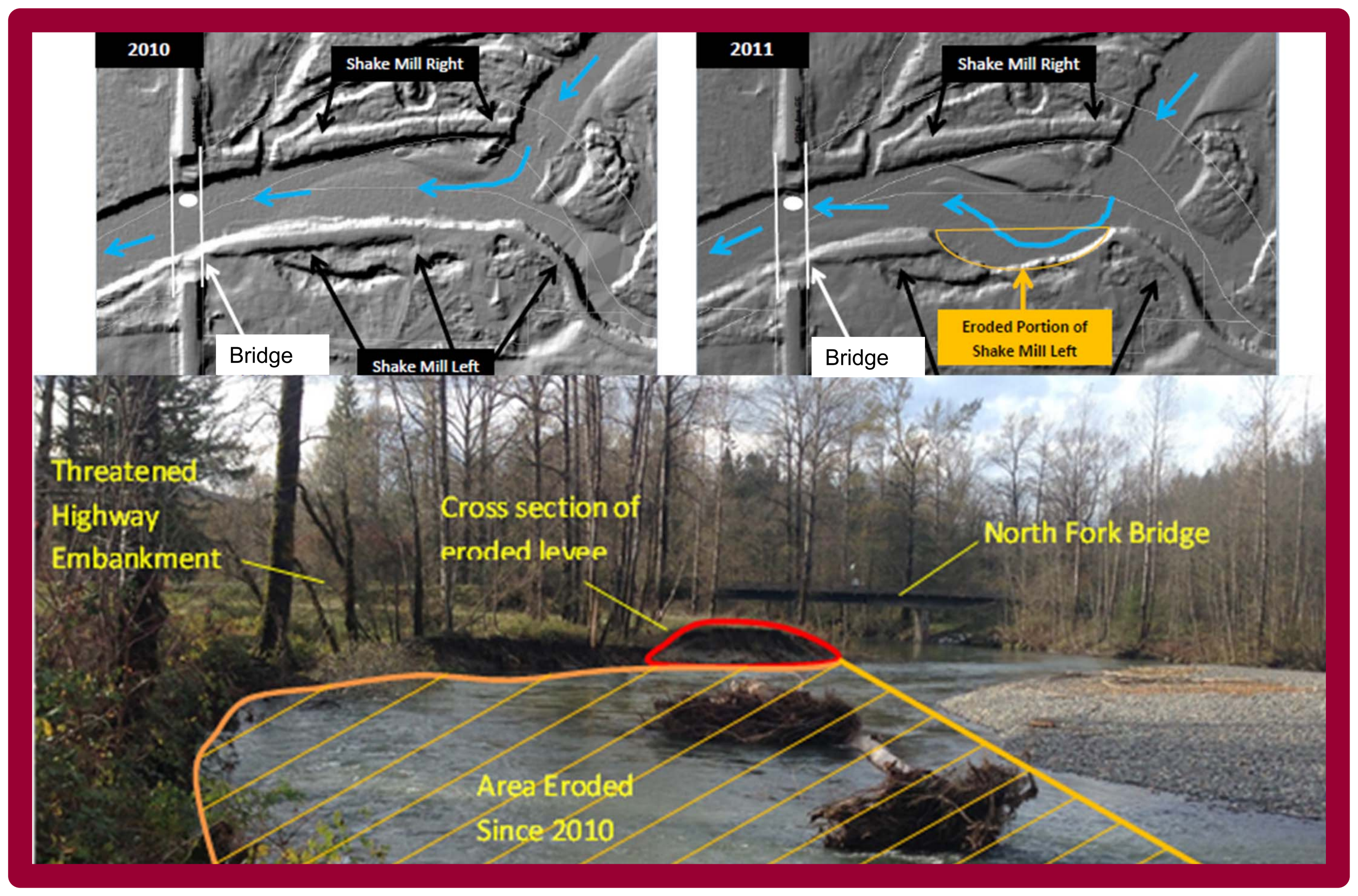
Design of Habitat-Sensitive Erosion Hazard Mitigation near a Bridge

Introduction

Large floods in 2011 caused bank erosion to threaten a bridge in a rural part of our county. Designing a solution to this problem that addressed erosion hazards, ecological needs, and community safety was the focus of a multi-year student project. Work involved two civil engineering senior capstone teams, two non-engineering students (biology and environmental studies), regular supervision by three engineers and several ecologists and planners at the county, input from engineers and drafters at a local consulting firm with experience in the regional river management, and a faculty advisor.

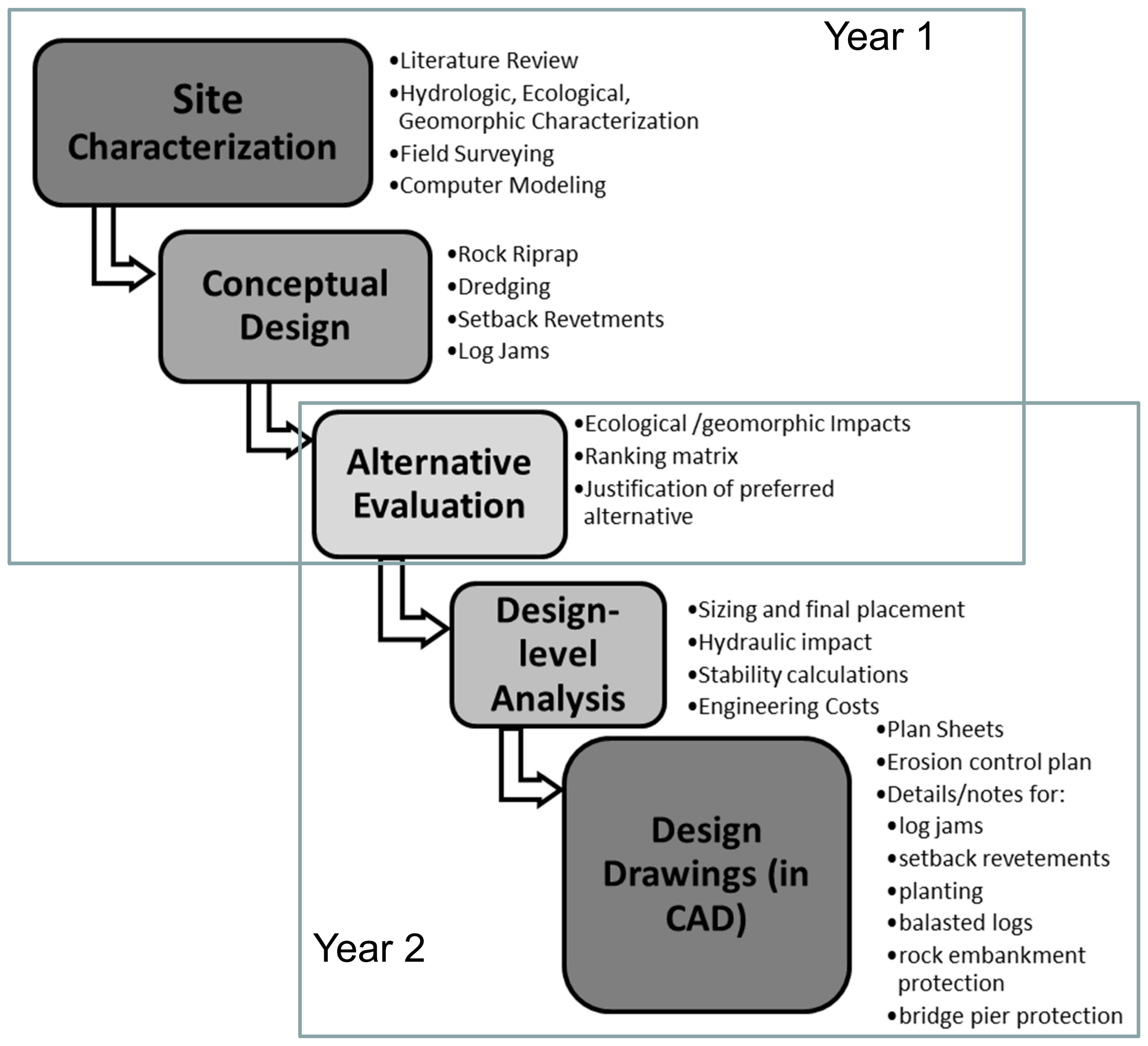


Background

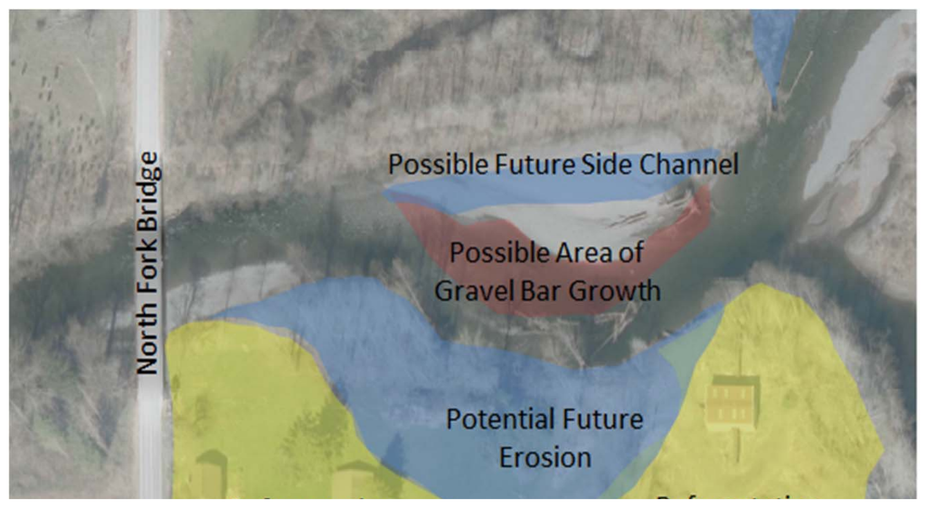
Erosion in 2010/2011 led to scour on the north abutment of the bridge. Further erosion of the bend would likely lead to change in flow direction through the bridge, potentially causing damaging scour near the bridge piers and could threaten the entire roadway embankment along the south bridge approach. Long-term sustainability and ecological impact are heavily-weighted considerations for the county flood management division and were emphasized on this project.

Scope of Work and Deliverables

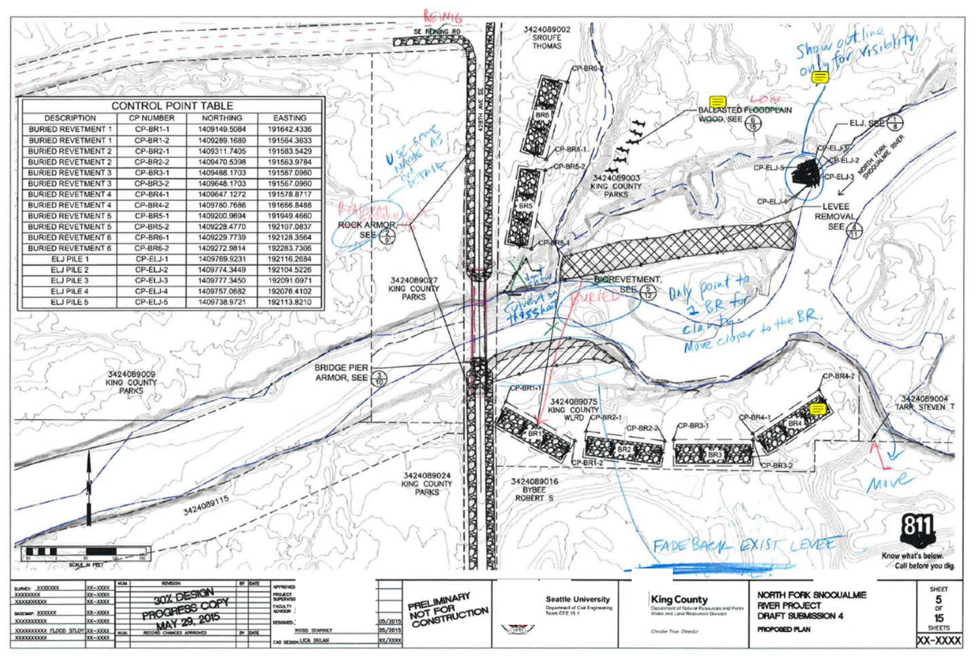
- Written Proposals (submitted in Dec '13 and Dec '14)
- Final Design Reports (submitted in June '14 and June '15). Year 1 and 2 tasks and deliverables were:



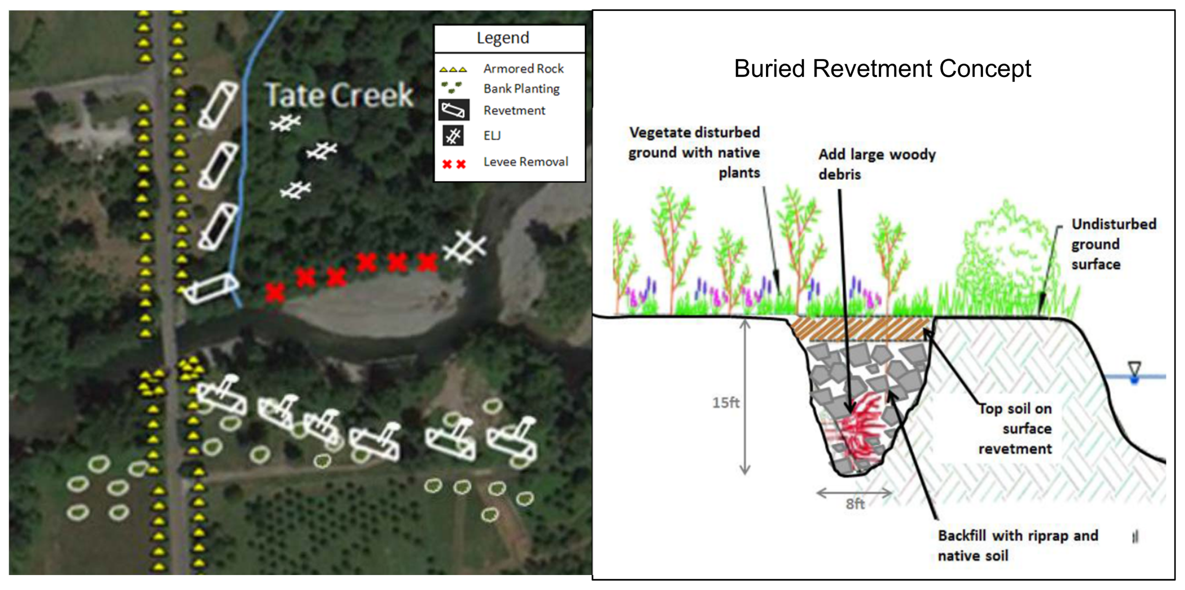
Key Elements of Project



Site Characterization included bathymetric mapping, hydraulic modeling, air photo analysis and ecological assessment. Flood and erosion hazards were used to map overall risk to infrastructure.



Design Review: Draft drawings were reviewed by three licensed engineers at the county who also provided training on review protocol.

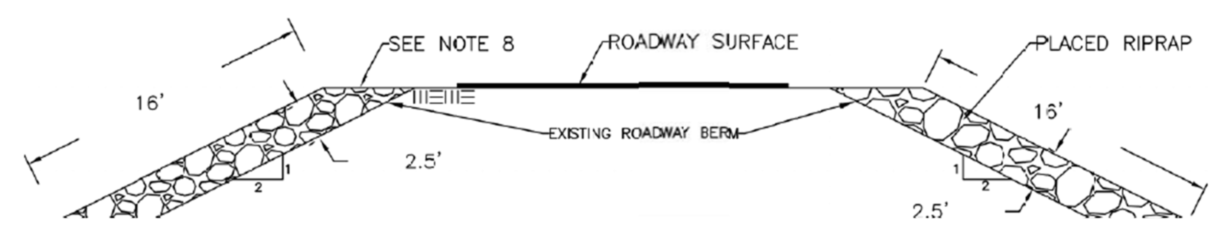


Conceptual Designs/Alternatives Evaluation: Teams developed a range of plans to minimize erosion using setback revetments, engineered log jams, rock embankment protection, and excavation, and evaluated with respect to effectiveness, cost, and ecological appropriateness.

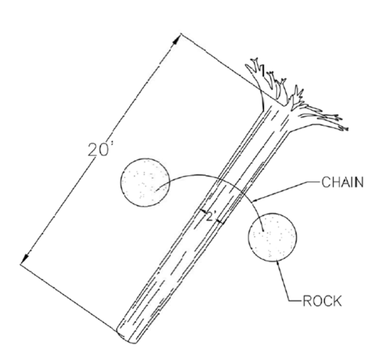
Engineered Log Jam						
Calculation	**Result Value**	**Units**	**Design Use**	**Equation**	**Source**	**Calc. Reference**
Scour	11.8	Ft		Landers & Mueller (1996)	USGS (2004)	A56
Drag Force (Horizontal)	99.7	Kips	Pile Stability		Large Wood Manual	A61
Passive Force (Horizontal)	475	Kips	Pile Stability		Foundation Engr. Handbook	A64
Active Soil Pressure (Horizontal)	35	Kips	Pile Stability		Foundation Engr. Handbook	A64

Design-level Analysis: Teams worked with county engineering liaisons to identify design standards and perform stability calculations. The chart illustrates some computations performed on a single project element.

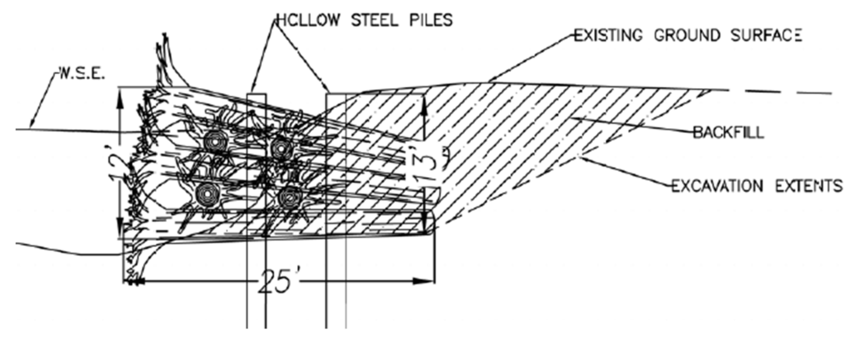
Embankment Protection



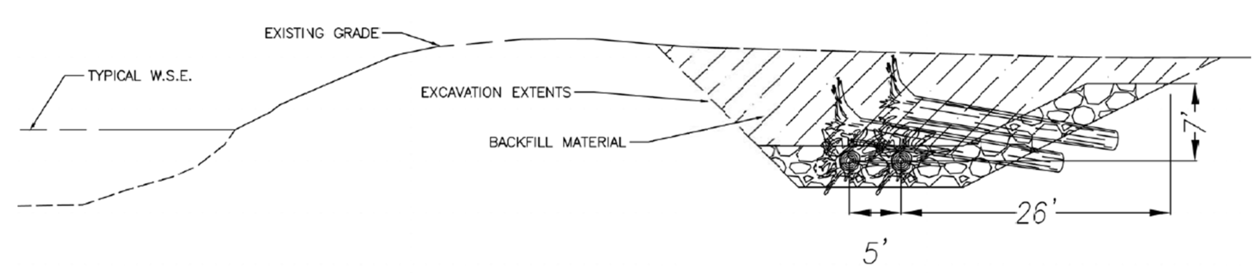
Ballasted Wood



Engineered Log Jam



Setback Revetment



Drawings: Both teams developed CAD drawings. In year 1, these focused on conceptual design. In year 2, drawings were taken to a typical 30% design level that can be used for initial review by regulatory agencies.

Major Design Challenges

- Developing hydraulic model for simulating velocities and shear stresses for use in design
- Designing for ecological appropriateness, which emphasized allowing for geomorphic change and required input from non-engineering team members.
- Developing system for evaluating the wide range of conceptual alternatives. This required the input from county planners and ecologists.
- Evaluating continued change that occurred at the site between year 1 and year 2.
- Identifying design standards for the relatively new low-impact technologies employed on the project.

Student Skills Developed

- **Technical skills**
  - Developing working knowledge of HEC-RAS, design manuals, AutoCAD, and GIS.
- **Communication skills**
  - Oral presentation and technical writing skills, developing client interaction
- **Project management and leadership skills**
  - Learning team dynamics, duties and responsibilities of a Project Manager; Setting up and running team meetings, preparing meeting agenda, following up with action items, keeping track of schedules, value of file organization and project archiving.
- **Collaboration with allied professions**
  - Ability to incorporate multidisciplinary criteria regarding ecology, transportation, hazard management in decision making

Design of Habitat-Sensitive Erosion Hazard Mitigation near a Bridge

Abstract

Our university regularly supports teams of 3-5 students on year-long capstone design projects. Recently, we supported two teams of civil engineering students who worked in collaboration with a local county flood management division to design erosion mitigation for a bridge. In addition to a host of traditional engineering analyses related to river hydraulics, slope stability, erosion protection, grading, and cost, the project required detailed assessment of geomorphic and ecological conditions. This would not have been possible in a single year, so the project was organized in two phases. The first occurred during the 2013-2014 academic year and focused on background analysis and conceptual design. The second occurred during 2014-2015 and focused detailed design analysis and design drawings. Continuity between project phases was maintained by a) working with the same team of engineers and scientists at the county both years; b) having a single faculty advisor supervise the project for its duration; and c) including a single biology/environmental studies student as a biological consultant during both years.

The project was motived by progressive erosion of a river bend that threatened an important bridge in a rural part of the county. The site is located in in a natural area, much of which is designated county parkland. Simply rebuilding the failing banks and lining with rock rip-rap was not a preferred alternative due to potentially significant impact on habitat and ongoing maintenance costs. Maintaining habitat quality for resident populations of trout and for terrestrial mammals such as elk was a priority for the County. The county was also interested in developing projects for which acquisition of environmental permits would be straightforward.

The project required regular (i.e. at least monthly) interaction between multiple departments at the County as well as input from a consulting firm with experience in the area. Several members of the sponsoring team are licensed as Professional Engineers, and others have advanced training in ecology and environmental planning. Because of the rather specialized nature of the work, students from both teams (as well as a non-engineering student) attended regional and national conferences on river restoration or water management where they interacted with professional engineers and restoration scientists. The team developing the design drawings regularly met with design engineers and drafters at county and at the consulting firm that had studied the reach.

The main tasks performed in 2013-2014 included background analyses related to hydrology, geomorphology, habitat, and hazards; hydraulic modeling; and conceptual design. The design alternatives included traditional rock-riprap based bank protection, construction of engineered log structures to divert flow away from the eroding bank, and buried rock/log structures that would be set back from the existing bank but that would stop erosion once it progressed into these structures. The 2014-2015 team performed additional hydraulic modeling necessary for developing design velocities and depths and detailed development of the preferred alternative, which included buried rock/log structures, construction of an engineered log structure in the channel, and rock armoring of the roadway embankment. Calculations were performed to assess performance of these project elements in range of failure modes. Design drawings were produced in AutoCAD representing project plan, cross-section, and profile; project details; and a full temporary erosion and sediment control plan for use during project construction.

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I. Project Description

Introduction

Progressive erosion of river banks is a significant threat to roads and bridges in much of the country. Mitigating erosion risk often requires designs that are compatible with multiple uses of the riparian corridor. Large floods in 2011 caused bank erosion to threaten an important bridge in a rural part of our county. Designing a solution to this problem that addressed erosion hazards, ecological needs, and community safety was the focus of a multi-year student project at our university. The project involved two civil engineering senior capstone teams, two non-engineering students (biology and environmental studies majors), regular supervision by three engineers and several ecologists and planners at the county, input from engineers and drafters at a local consulting firm with experience in the regional river management, and a faculty advisor.

Background

The North Fork of a local river is located approximately 30 miles from our University campus in a rural part of our county. A bridge across this river (the North Fork Bridge) provides the primary access to a community of several hundred people. The bridge is located in a flood-prone area near the confluence of two other forks of the river. The area near the bridge is designated as parkland and used for hiking, fishing, and other outdoor recreation.

In 1959, extreme flooding led the county to build training levees in several locations on this river system. Training levees redirect flow to discourage the river from meandering, but they do not prevent major floods. By locally increasing flow velocities, training levees upstream from the North Fork Bridge were effective for many years at preventing sediment accumulation and minimizing channel change near the bridge.

Beginning in 2010, large floods on the North Fork caused eroded portion of the left (south) training levee immediately upstream from the North Fork Bridge. Figure 1 illustrates the progressive erosion of this river bend between 2010 and 2011. Additional erosion occurred after 2011 and led to the formation of a large gravel bar on the north bank (Figure 2). The change in approach angle to the bridge led to scour on the north abutment of the bridge that was mitigated by rock placed by a county roads crew. However, further erosion of the bend would likely lead to further change in flow direction through the bridge, potentially causing damaging scour near the bridge piers. Furthermore, if erosion continues at the rates experienced between 2010 and 2011, the entire roadway embankment along the south bridge approach will be threatened by erosion within a few years. Finally, loss of the levee also led to additional flooding on the floodplain which caused scour where flow reentered the river immediately upstream from the bridge.

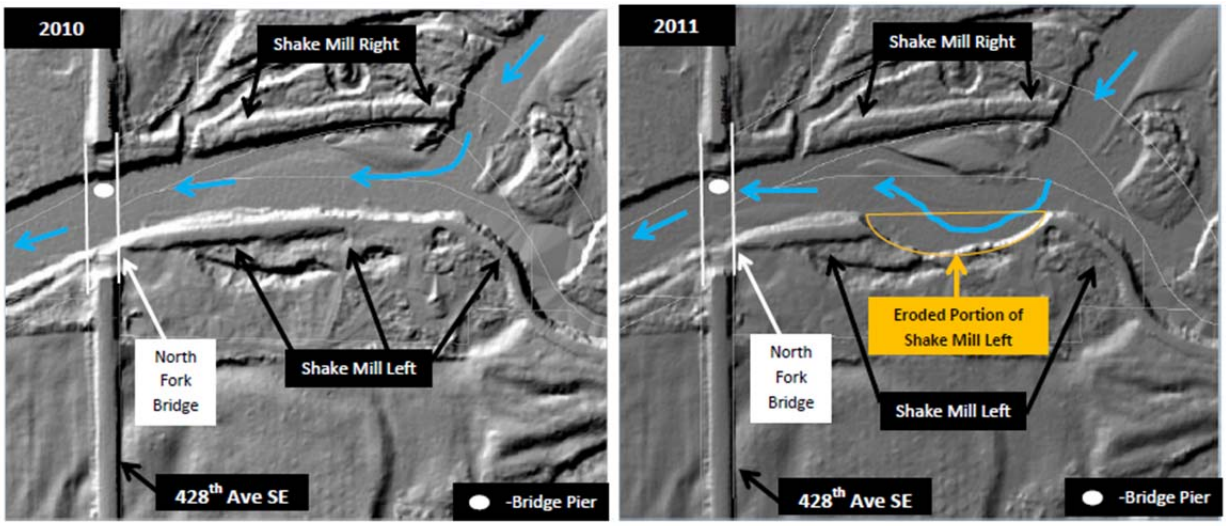

Figure 1. Erosion of the Shake Mill training levee upstream from the North Fork Bridge between 2010 and 2011.

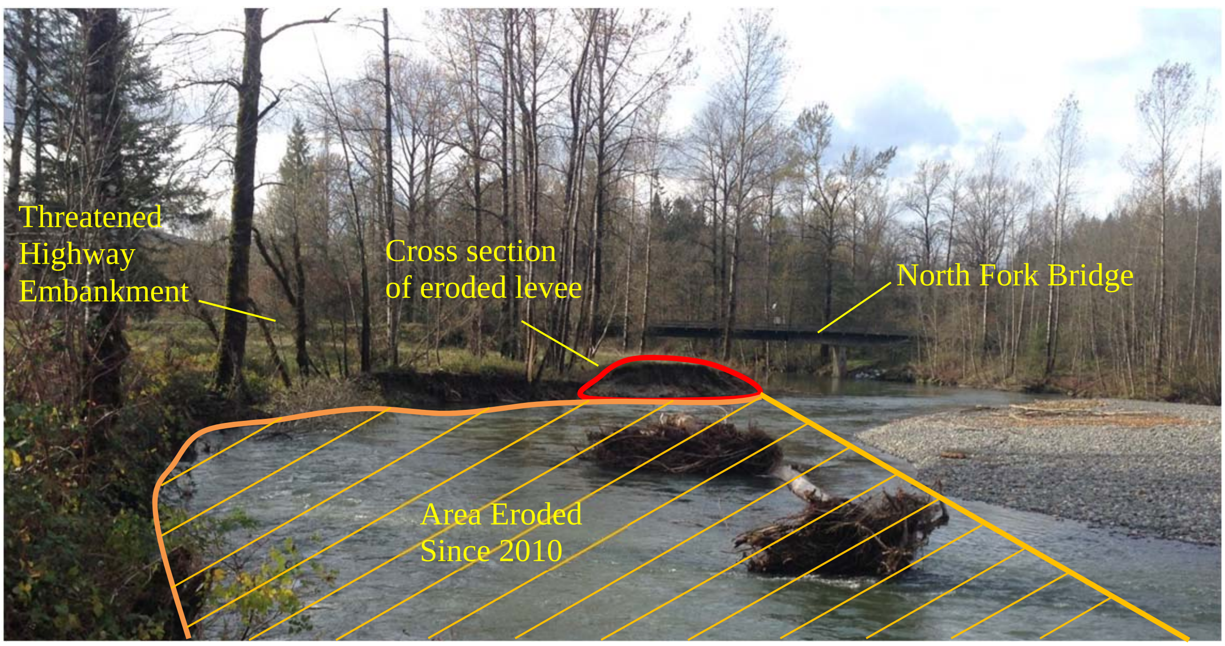

Figure 2. Bank erosion upstream from North Fork Bridge. The bend is migrating at a rate of 10-20 feet per year toward the highway embankment in the background of the photograph.

In the time since the construction of the training levees in the 1950s, our county has incorporated broader environmental considerations into river management. Long-term sustainability and ecological impact are now heavily-weighted considerations and must be incorporated into projects that address erosion and flood hazards. While the county will sometimes perform emergency repairs on eroding river banks to protect infrastructure, it prefers to proactively address erosion problems in advance of flooding because this allows broader impacts of the mitigation projects to be addressed. The county requested that [redacted] University develop an erosion mitigation plan that a) fully characterized and addressed flood and erosion hazards at the site and, b) was compatible with recreational and habitat values of the corridor. Recent flood and erosion mitigation projects built by the county incorporate features such as engineered log jams, floodplain planting, and large wood placement that are intended to m imic natural geomorphic stabilization processes.

Work Accomplished

The complex nature of the problem prevented a single design team from taking the project from initial problem characterization through drawing developing. Instead, tasks were split across two years, as illustrated in Figure 3. Both teams participated in design development and alternatives analysis, but the first team focused on feasibility level design and the second focused on development of design drawings. Continuity between project phases was maintained by a) working with the same team of engineers and scientists at the county both years; b) having a single faculty advisor supervise the project for its duration; and c) including a biology/environmental studies student as a biological consultant during both years.

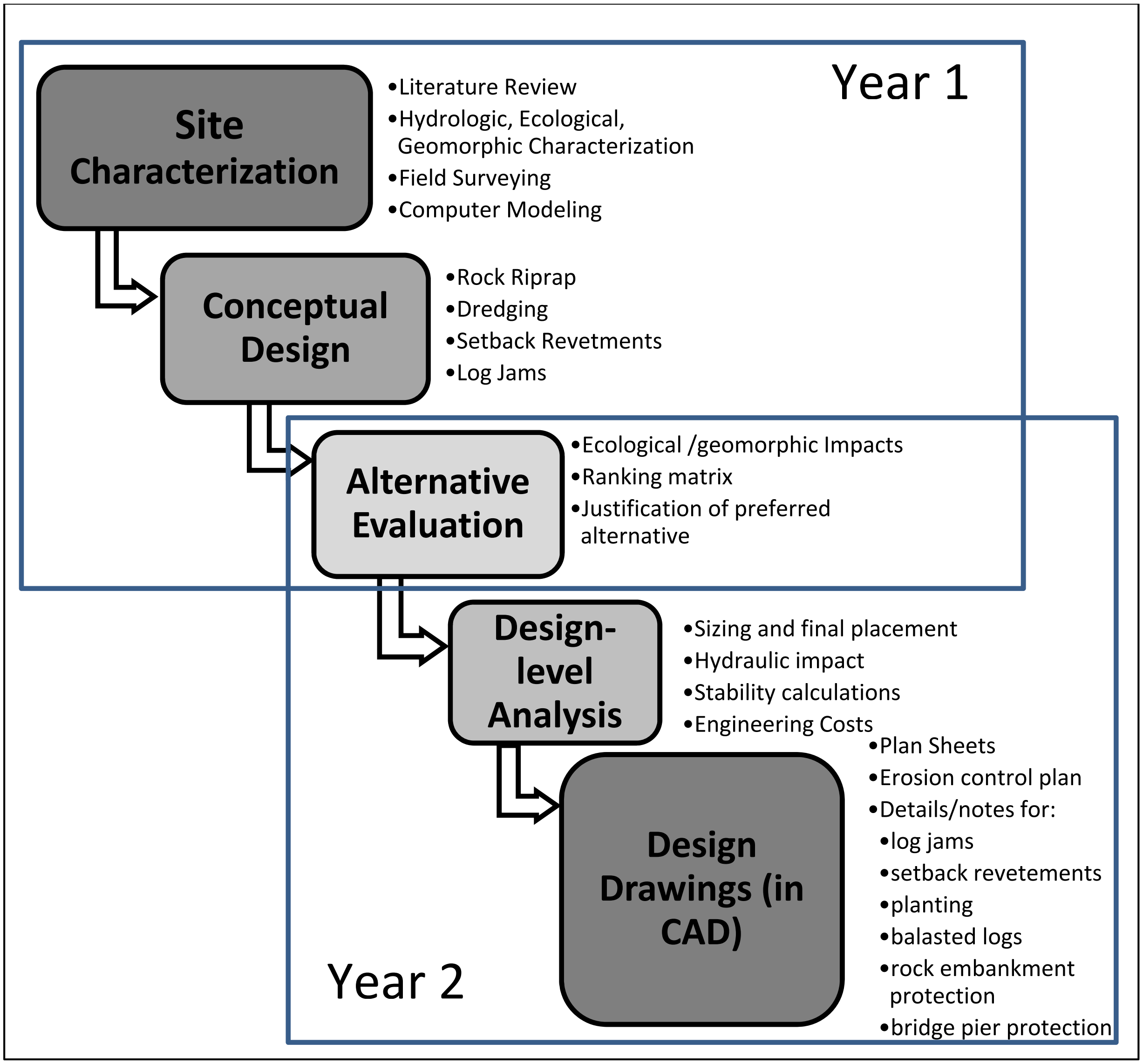

Figure 3. Main work elements completed by each team.

Year 1

During the first year, a 3-person civil engineering senior design team worked with a biology major and a biology/environmental studies double major to develop conceptual design options and a recommended design for the site. During the first quarter of the academic year, the team developed a proposal that characterized the basic problem and outlined a scope of work, schedule, and list of deliverables. This guided their work during the remainder of the year. A licensed engineer at the county and several engineering faculty members reviewed and provided comments on their scope of work as they were developing it.

Students performed the main body of technical work during winter and spring quarters. The work required extensive characterization of site and watershed-scale hydrology, topography, geomorphology, and ecology. It was supported by the development of a 2-D hydraulic model for the site that was used to evaluate flood hazard and to characterize the interaction between flooding on each of the forks of the river (all of which converge with the mainstem over a ~1/2 mile reach). The geomorphic characterization included field visits and air photo analysis to describe the bank erosion trends at the site and upstream. A major conclusion from this work was that movement of an upstream bend had reoriented flow at the site, and that simply stabilizing the left bank immediately upstream from the bridge might not fully address the erosion problem. Another major conclusion of the numerical modeling and field visits was that during high flow events, the channel also occupies a trench north of the presently-intact north-bank levee. If this channel were to enlarge during a flood, it could capture the main river flow and would refocus erosion on the south abutment of the bridge, which presently does not experience significant erosion.

The ecological characterization focused on both terrestrial habitat at the site (which is used by a herd of elk during parts of the year) and on fish habitat (the North Fork is a popular river for trout fishing). The ecological analysis concluded that channel migration is a natural process that recruits large wood into the river and creates gravel bars serve as a substrate for new forest. This caused the team to put significant weight in their alternatives analysis on solutions that are compatible with natural channel change processes and do not completely stop channel migration.

The year-1 team then developed a set of three design alternatives for addressing the erosion problem and used the background analysis and cost estimates for each alternative to justify a preferred alternative. The preferred design incorporated a set of engineered log structures in the channel and several buried rock and log revetments set back from the streambank to provide protection from bank erosion. Conceptual design drawings were produced detailing each of these features. The biology/environmental studies students then critiqued the design elements for ecological appropriateness. All of this information was incorporated into a final project report.

Year 2

The year-2 team included four civil engineering seniors and the biology/environmental studies major who had participated in the project during year 1. Once again, the team developed a proposal for their work that characterized the problem (drawing significantly from the year-1 report) and developed a detailed scope, schedule, and list of deliverables for second year technical activities. The main tasks in the scope were outlined in advance for the team by the county liaison, but negotiation on the details occurred over much of the first quarter of the second year.

While the year-1 team had performed an extensive alternatives analysis and had developed feasibility-level conceptual design drawings, the county desired additional detail before selecting a preferred alternative. The need for additional alternatives analysis provided a good entry point for the year-2 team, ensuring that they understood the issues involved in alternatives evaluation and selection. The main goals for the second year included development of a more complete alternatives analysis and project evaluation matrix, detailed design calculations for project elements, and development of 30% design drawings for the preferred project alternative. The final plan incorporated several elements not included in the year-1 feasibility-level analysis such as rock slope protection along the highway embankment, rock protection to be placed at one of the two bridge abutments, and modifications to the number and locations of the in-channel and buried log/rock structures. Analysis work included developing a hydraulic model for developing design flow velocities and depths and evaluating hydraulic impacts of the preferred project alternative. The team found standards in the literature for most of these design calculations and developed design criteria in collaboration with the liaison engineer when standards were not available. The structural analysis of the rock/log structures required analysis of buoyancy, bending, active and passive soil pressures, pile analysis, and river bed scour. The team presented its work in a final project report that justified the selection of the each element of the preferred design alternative, included all design calculations, and presented 30% design drawings including project plan, typical cross sections, details, notes, and a temporary erosion and sediment control plan.

II. Collaboration of Faculty, Students and Licensed Professional Engineers

During their senior year, students at our program are divided into teams of four or five students and assigned a project that is supported by an external organization such as an engineering consulting firm or municipal engineering agency. Teams prepare a written proposal during fall and a final report at the end of the academic year for the client. Teams are advised by a faculty member and are supervised by a faculty instructor who organizes capstone project milestones and provides day-to-day continuity for the entire capstone class. In this project, both faculty members were licensed professional engineers. The design team was supported by two liaison organizations--the county flood management division and by an engineering consulting firm that had developed management plans near the study reach. Three of the county liaisons who met regularly with team are licensed engineers, and others on the county team have advanced degrees in ecology and land use planning, bringing a unique interdisciplinary element to the project. Meetings with the county occurred regularly during both years (i.e., at least once/month).

III. Benefit to Public Health, Safety and Welfare

The North Fork Bridge provides the primary access from a nearby interstate highway to a community of several hundred people. While there is another transportation corridor into the community, it is blocked by flooding every year or two. During those periods, the North Fork Bridge is the sole emergency access and evacuation corridor for the community. A large flood (approximately a 10-year event) occurred at the site during the second year of the project. The flood was sufficiently large that a portion of the embankment was overtopped and began to experience scour several hundred feet north of the bridge. Students were able to calibrate a hydraulic mode that correctly simulated overtopping in this area and used it to design scour protection for the roadway embankment. By addressing both embankment overtopping and providing erosion protection for the bridge itself, the project will ensure that this important transportation corridor is available for residents to use even after large flood events.

The project is located in a popular recreation corridor that draws from throughout the metropolitan area. Students collaborated with county planners to identify properties adjacent to the project site that could be acquired and restored to natural vegetation. A significant portion of the ecological characterization work focused on restoration of this parcel. They also planned the project to ensure that work within the river itself would be compatible with natural geomorphic process that maintain riparian habitat. The site is sometimes used for navigation by canoes and kayaks. Students evaluated potential impacts to navigability associated with the proposed engineered log jam and designed the structure to minimize hazards to boaters.

IV. Multidiscipline or Allied Professional Participation

Students in both years collaborated with multiple departments at the county. These included county roads crews, who installed emergency rock protection at one of the bridge abutments during the first year; county transportation engineers, who attended student presentations and clarified transportation department priorities; county surveying crews, who the teams directed regarding locations for cross-section surveys and identification of benchmarks; county drafters, who provided the teams with site topography and helped set up AutoCAD templates in standard County format; and with county ecologists and planners who worked closely with the non-engineering team members on their site assessment work.

Students also benefitted from input from periodic input from a range of professionals outside the county. In the fall quarter of both years, several practicing engineers from multiple engineering disciplines provided lectures and workshops to the class on project planning, project scheduling, project management, team work and making effective presentations. In the spring quarter, project reports were reviewed by several external engineering reviewers. A local consulting firm that had developed reach-scale management plans for the river system also met with team members and provided advice regarding drawings and engineered log jam design.

We encourage our students to enter their projects in regional and national student design competitions. Consequently, the year-2 team entered their project in a national undergraduate design competition sponsored by a water resources engineering organization and was selected to attend the associated conference to present their project. They won the competition and, by competing, benefitted from feedback from nationally-recognized engineers. The biology/environmental studies student who served the role of “consulting” ecologist presented her work at a regional professional meeting on river restoration. Three of the year-2 team members also attended this conference where they received specialized training on river morphology. The regional conference draws professionals with engineering and ecological backgrounds and thus also supported the interdisciplinary nature of the project.

V. Knowledge and Skills Gained

The capstone experience provided the students an opportunity to apply their technical knowledge to a real life situation and develop soft skills much needed by employers.

a) Technical skills

The students learned how to develop and assess river management projects. They also became proficient in using several industry-standard tools for addressing river hydraulics:

- Design and Analysis Software: US Army Corps of Engineers HEC-RAS model; US Army Corps of Engineers HEC-SSP flood statistics program; CAESAR and BAGS sediment transport models
- Mapping and Computer aided drafting (ArcGIS, AutoCAD)
- Research: a host of reports on guidelines for engineered log jam design, rock revetment design, bridge scour analysis, and multiple studies on fish and terrestrial habitat in the North Fork.

b) Oral and Written Communication skills

Each year, the students submitted a written proposal to the county sponsor at the end of fall quarter, outlining their understanding of the project, scope of work, plan of implementation, and schedule. At the end of spring quarter, they submitted a final report describing the work done, engineering calculations, drawings and other deliverables requested by the client. Incorporating ecological and planning-level assessment work into the final reports required engineering students to serve as editors in an area outside their own expertise.

The students were required to make oral presentations to their peers twice a quarter. Each student had to make at least one presentation each quarter. In addition, students presented their proposed work to the county at the end of fall quarter and their final design at the end of spring quarter. Each academic year concluded with a conference style event, where the team presented its work to the entire university community, sponsors of all the senior capstone projects, prospective sponsors, friends, family and alumni.

c) Leadership, Management and Soft skills

Students took turns serving as project managers. The project manager arranged and ran the team meetings, prepared meeting agendas, delegated tasks to the team members and followed up on action items. He/She was also responsible for contacting the liaisons and the faculty advisor in between team meetings, when needed. Managing the two non-engineering students on the project required extensive coordination regarding meeting times and scheduling.

A licensed engineer met with the team in early winter quarter each year with no faculty member present to assess the team's understanding of project management; they discussed project goals, constraints, and deliverables, the process of solution development, and issues related to team dynamics. At the beginning of spring quarter, each team had a formal major project review meeting with the faculty advisor and the course instructor in a conference room to assess the technical merit of the work; they went over the project scope, work accomplished and the remaining work to successfully complete the project by the academic year.