Alternative Stream Channel Maintenance at Bridge Crossings

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16. Abstract

Ohio Department of Transportation (ODOT) forces undertake routine and sometimes extensive maintenance of stream channels that impact the performance and safety of bridges. Unfortunately, county crews have limited options available to solve maintenance. This research project evaluates the potential and viability of natural channel design practices to provide sustainable solutions to maintenance problems.

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List of Acronyms

GIS – Geographic Information Systems
GPS – Global Positioning System
NCD – Natural Channel Design
NRCS – Natural Resources Conservation Service
ODOT – Ohio Department of Transportation
RGP – Regional General Permit
USACE – United States Army Corps of Engineers
USGS – United States Geological Survey

1.0 Executive Summary

Throughout the state, Ohio Department of Transportation (ODOT) county crews and district construction forces undertake routine and sometimes extensive maintenance of stream channels to improve the performance and safety of bridges. Unfortunately, county crews have limited options available to solve maintenance problems and current approaches often are not self-sustaining. Sites with recurring maintenance issues are a burden to county forces and leads to allowable, but repetitive and unnecessary impacts to the environment.

Over the past several decades, scientists and engineers in the field of stream restoration have developed numerous practices, called *natural channel designs* (e.g. vanes, cross vanes, w-weirs, etc.), to improve stream function and stability and enhance the environmental quality of the water resource. Many practices are fairly standardized in their design approach and have been widely applied. However, there has been little research and too few applications of these practices in the vicinity of bridges. Evidence suggests that natural channel design may be a preferable alternative to current maintenance practices, such as dredging and armoring, and lead to more sustainable and environmentally sensitive maintenance solutions.

ODOT county crews are typically unfamiliar with natural channel design practices and their abilities to implement these practices in the field are unknown. The proposed research sought to: 1) develop a baseline understanding of current maintenance practices and techniques used by ODOT forces, 2) assess ODOT resources (e.g. equipment, availability of skilled labor, ability to acquire construction materials, etc.) and capabilities to implement alternative approaches, 3) select and design practices suited to solving a range of typical maintenance problems suitable for the region, 4) demonstrate and test feasibility of the approach by implementing these practices through a series of pilot projects, and 5) assess and document project outcomes to facilitate adaptive management and promote workforce education and training.

The research findings revealed that natural channel design practices can be implemented reliably by ODOT county and district forces. Furthermore, collaborative research led to innovation as ODOT partners provided input and suggestions that simplified and improved the implementation process. In particular, the use of concrete blocks in the construction of vane structures led to cost and time efficiencies that greatly improved the return on investment for these types of projects. In fact, actual time and costs were reduced by ~75% over initial estimates.

While pilot projects were implemented successfully, there were aspects of the process that may need to be addressed before widespread adoption of natural channel design practices is a preferable alternative to traditional maintenance approaches for county forces. In particular, county forces may not be as likely to undertake natural channel design practices when traditional maintenance practices (i.e. armoring and dredging) are already covered in ODOT's Regional General Permit (RGP) and can be permitted quickly and more economically. We recommend that ODOT discuss this issue with the US Army Corps of Engineers to determine if the natural channel designs practices tested in this research project might meet the existing conditions of the RGP B when used for maintenance projects at bridge crossings.

2.0 Project Background

Historically, bridge design methods have not given adequate consideration to stream channel morphology and the natural processes of channel aggradation (i.e. sedimentation), degradation (i.e. channel incision), and lateral migration. Streams are dynamic systems. Flowing water erodes channel banks and beds and sediments are deposited within the channel and on floodplains to constantly shape and reshape stream pattern (planform), profile (longitudinal slope), and dimension (cross sectional geometry). Unfortunately, the natural movements and adjustments of stream systems are problematic for designers that must engineer bridge structures that remain in a fixed location.

Several problems typically arise when a bridge intersects a stream and are due to disruptions in the flow and sediment transport regimes that result as the stream channel is modified. Local scour of bridge structural components occurs when flood flows that would normally be conveyed downstream across a broad floodplain are constricted and forced to pass through a narrow bridge opening. Economics often dictate design of a narrow bridge opening that meets a specified design discharge rate, but may result in backwater effects, an elevated water surface, and increased flow velocities and shear stresses through the bridge opening that may cause scour of the bridge foundation. Similar conditions occur when debris accumulations at the bridge opening result in the blockage of flow.

Another problem, channel aggradation, occurs when a bridge opening is constructed too wide relative to the streams bankfull channel and cannot maintain effective sediment transport through the modified reach. The typical response in this scenario is aggradation at the bridge opening that leads to the formation of a sediment bar in the over-widened section. The development of a bar can then direct flow towards the opposing channel bank, which causes erosion at the bridge embankment. Another potential negative consequence of sediment deposition at the bridge opening is a reduction in the designed conveyance capacity and, therefore, increased risk of upstream flooding and further aggradation of the channel bed.

Another common issue occurs when lateral migration of stream channel meander bends causes erosion of the bridge embankment or misalignment of flow with the bridge opening. Stream channel migration is a natural process and migration rates span a wide range. Low migration rates typically occur in low-energy streams (i.e. low sloping channels with small drainage areas and low discharge rates) with highly erosion-resistant channel banks. High migration rates typically occur in high-energy streams (i.e. highly-sloped channels with high runoff rates) with banks that have low-resistance to erosion and failure. Channels with medium or high migration rates will often require stream channel maintenance during the typical design life of a bridge structure.

The approach used in the present research project was to assess and evaluate the utility of natural channel design practices to solve stream channel maintenance issues at bridges and test the approach at multiple sites. The practices provide a means to smoothly transition flow through the bridge opening, protect the channel boundary and bridge structural components, more effectively balance sediment transport through the reach, and route debris through the bridge opening without snagging and creating obstructions to flow.

3.0 Research Context

The goals of the research were to: 1) identify techniques and materials that are feasible alternatives to placement of rip-rap slope protection by hand or heavy equipment, 2) identify suitable and cost-effective natural channel design practices that are reasonably implementable by county maintenance forces, 3) develop tools (e.g. decision matrix) and guidance to aid in the selection of practices to solve maintenance issues, 4) test the approach and assess the capabilities of county forces to implement pilot projects, and 5) evaluate pilot project implementation and conduct an analysis of economic costs and savings. These objectives were addressed through the following activities: Task #1 – Utilize bridge inventory data and bridge inspection ratings to develop a list of candidate research sites and coordinate with district and county managers to select sites for pilot projects. Task #2 – Conduct a literature review and visit sites to identify natural channel design practices that are feasible and suitable for solving maintenance issues in ODOT Districts 2 and 3. Develop a decision matrix to aid in the selection of practices for a particular site. Task #3 – Collect site data and develop engineering plans, drawings, and technical specifications to guide construction of natural channel design practices. Perform training for county maintenance crews and provide oversight during the construction process. Task #4 – Develop a post-construction monitoring protocol and assess performance of installed practices. Task #5 – Document research findings in a final report. During the project period additional tasks were added to the research through the execution of addendums including: Addendum A Task A.1 - Assist ODOT in obtaining environmental permits needed to implement pilot projects. Addendum B Task B.1 - Acquire experimental construction materials (e.g. concrete cloth) used in pilot project implementation. Addendum C Task C.1 – Determine actual construction costs at multiple project locations and compare findings to original engineering estimates to determine cost savings associated with the use of alternative construction materials (e.g. concrete blocks). Task C.2 – Evaluate the effectiveness of concrete cloth materials used in projects around the state and implement one or more projects utilizing the material in Medina County. Task C.3 – Develop a white paper with rationale for incorporating natural channel design practices into new bridge construction and bridge replacement projects. Task C.4 – Update educational materials and training videos to include footage and images of vegetated, stabilized pilot projects.

4.0 Research Approach

To begin, a systematic approach was developed to identify streams and bridges with documented histories of problems. A GIS database with bridge location information and bridge inspection scores in Districts 2 and 3 was obtained from the ODOT Office of Technical Services. GIS maps of the Bridge Inspection Report ratings for the Channel Alignment, Channel Protection, and Channel Hydraulic Opening metrics were plotted in GIS to identify a geographically diverse set of potential sites and maintenance problem types. As a result, 189 potential sites were selected and additional data were collected including images from the ODOT Bridge Photo Management System; Bridge Inventory Information Sheets; soils data from the NRCS – Web Soil Survey System; and, stream discharge, land use, and slope information from the USGS Streamstats program. Several statistical analyses (Forward Stepwise Multiple Regression, Discriminant Analysis, and Random Forests Analysis) were completed using these data to determine if certain site and watershed variables were useful predictors of the Bridge Inspection Report channel metric scores, which are indicators of stream stability.

To further identify a reasonable subset of candidate sites for further consideration, meetings were organized with district staff and county managers to describe the project and outline project goals, expectations, and information needs. During the meeting, typical maintenance problems and solutions were discussed. Additional discussion focused on understanding the skill level of maintenance personnel, gauging their ability to work around streams, identifying equipment available for construction projects, and assessing their ability to obtain various construction materials (e.g. live stakes, coir matting, quarried rock blocks, etc.) that would be needed to implement natural channel design practices. County managers were also asked to identify any sites that posed maintenance challenges for their crews. Based on the findings of this meeting a subset of 25 candidate sites were identified and subsequently visited with district staff and county managers. At each site a range of possible solutions were discussed with ODOT staff and used to identify potential solutions.

Following site visits another meeting was organized with state, district, and county-level staff to present conceptual design plans for each of the candidate sites, to discuss concerns and alternatives, and to make final selection of pilot project locations and practices. Six additional individual face-to-face meetings were conducted with county managers to determine if any further concerns needed addressed and determine a schedule for data collection, preliminary design and feedback, final design, and proposed construction dates.

Site surveys were conducted using Trimble GPS and Topcon Total Station instruments and data were used to develop topographic base maps as a basis for design in AutoCAD Civil 3D. Hydrology (USGS Streamstats) and hydraulics (Bentley's FlowMaster software) calculations were made for the purpose of floodplain permitting. Property boundaries and road right-of-way information were obtained from county GIS databases and ODOT engineering plans. At each site potential construction access locations were identified and preliminary construction plans and project cost estimates were developed. To facilitate future projects, which utilize natural channel design concepts, standard drawings and specifications were developed for each of the practices included in this research, a list of vendors with specialized construction materials was created, and a spreadsheet tool to aid in the design process was developed. Another spreadsheet tool was developed to support cost estimation for these types of projects using current ODOT labor, equipment, and indirect cost rates.

Preliminary construction plans and cost estimates were shared with ODOT district and county forces. In many instances the proposed designs were modified to address ODOT staff concerns. In most cases the scope and extent of the projects were reduced to try and fit them within existing road right-of-way boundaries and keep project costs below current force account limits ($60,000 per project) outlined in Ohio Revised Code. ODOT staff also made recommendations for alternative construction materials (e.g. concrete blocks in place of quarried rock for vanes) to simplify the construction process and reduce project costs and duration. Based on feedback from ODOT project partners the engineering plans were revised and represent a compromise between the researchers preferred approach for the site, availability of space and access, project costs, and the county crews' ability and willingness to install the practices.

Environmental data were collected at each of the sites and used along with the proposed design documents to develop applications to satisfy environmental permitting requirements. Once environmental clearance was granted, the project team worked with the county and district staff to acquire construction materials, hold pre-construction project meetings, complete construction layout, and provide technical assistance to maintenance crews throughout the construction process. As-built surveys were completed following the conclusion of construction at sites where natural channel design practices were installed. A detailed description of data collection methods, natural channel design practices, and the design process is provided in Appendix A. The construction process at each site was documented with video and photographic images to facilitate the development of case studies and other educational materials.

Additional research activities included: 1) the development of a post-construction monitoring protocol, based on a review of the literature and experience of the project team, which was then tested at each of the sites before and after construction when sites had stabilized, 2) collection of cost data from several pilot projects to make a simple comparison to original project cost estimates, and 3) development of a decision matrix to guide selection of practices that would address specific maintenance issues. Development of the decision matrix was based on literature review, experience, site visits across the two districts, and the outcomes of numerous pilot projects.

5.0 Research Findings and Conclusions

During the pilot project site selection process, local- and watershed-level data were gathered from readily available public sources to determine if channel metric scores from bridge inspection reports were predictable. Multiple forms of statistical analysis were completed and some statistically significant variables were present. Unfortunately, these variables only explained a nominal amount of variation in metric scores. It is likely that more detailed data is needed to identify reliable predictors of site stability, but that level of data collection is impractical to gather and beyond the scope of the current study. Additional details and study results are provided in Appendix B.

The project team, in collaboration with ODOT state, county, and district staff, identified 10 pilot project sites and developed engineering plans, technical specifications, and Clean Water Act permit documents based on an iterative design process with feedback and assistance from ODOT partners. Seven projects were fully designed, permitted, and implemented. Engineering plans and environmental permit documents were completed at two additional sites that were not built by county maintenance crews due to lack of resources or manager concerns over the ability to construct the projects. At one site the district manager elected to utilize a contractor working for ODOT at a nearby intersection to implement a different slope stabilization approach. A brief description of the maintenance problems at each of the pilot project sites and the implemented solutions are provided in Table 1. Several project examples of natural channel design practices are provided in Figure 1. Detailed project descriptions are provided in Appendix C and project videos are available at the STream Restoration, Ecology, and Aquatic Management Solutions website (streams.osu.edu/projects/stream-crossings).

Table 1. List of pilot projects, maintenance problems, and proposed or implemented solutions.

Site	Maintenance Problem	Solution(s)
ASD 603 0614	Bed Aggradation; Loss of Hydraulic Conveyance; Flooding	Cross-vane; Riffles; Channel shaping and realignment; Live stake plantings; Erosion control
FUL 020 0914	Debris accumulation; bank erosion	W-weir; Flexamat; Two-stage channel; Bank grading
MED 042 0589[1]	Channel migration; Erosion	Single-arm vane; Channel realignment
MED 606 0386	Flow alignment; Slope protection	Cross-vane; Flexamat; Rock channel protection
OTT 579 0186	Slope protection	Concrete cloth
SAN 006 1403[2]	Slope protection	Flexamat
SAN 412 0710	Flow alignment; Conveyance	Two-stage channel
WAY 083 0087	Flow alignment; Scour	Single-arm vane; Vegetated rock channel protection
WAY 604 1307	Channel migration; Flow alignment	Single-arm vane; Rock channel protection
WOO 582 1241[3]	Flow alignment; Slope protection	Two-stage channel or single-arm vane; Erosion control

1 – County manager decided not to build the proposed design, but though the project should be bid out for completion.

2 – District engineer placed rip-rap instead.

3 - County manager decided not to build due to concerns over skill of workforce citing project complexity as a concern. All engineering plans and environmental compliance documents were developed, but not submitted to obtain a waterway permit.


Figure 1. Examples of the natural channel design practices used in the research. Top left: Single-arm vane (WAY 083). Top right: Cross vane (ASD 603). Bottom left: W-weir (FUL 020). Bottom right: Two-stage channel (SAN 412).

A decision matrix was developed to identify suitable natural channel design practices that could be used to solve common maintenance problems at bridges in Districts 2 and 3 (see Table 2). The tool was developed considering results of peer-reviewed manuscripts, agency manuals (e.g. FWHA Hydraulic Engineering Circular-23; Bridge Scour and Stream Instability Countermeasures: Experience, Selection, and Design Guidance), information gathered during site visits and discussions with ODOT staff, expert knowledge, experience gained during the pilot project implementation phase of the project, and past history of success in stream restoration projects implemented around the state. Additional details regarding the development of the decision matrix are provided in Appendix D.

Table 2. Decision matrix outlining application of natural channel design practices to solve maintenance issues.

	APPLICATIONS					MAINTENANCE AND MONITORING REQUIREMENTS	CONFIDENCE LEVEL
Stabilization Practice	**Bank Stabilization**	**Bed Stabilization**	**Redirecting Flow**	**Abutment Scour**	**Pier Scour**		
Vanes	◯	⊗	◯	◯	⊗	M	H
Cross vanes	◯	◯	◯	◯	⊗	M	H
W-weirs	◯	◯	◯	◯	⃠	H	L
Two-stage channels	⃠	⃠	⊗	⊗	⊗	L	M

◯ = well suited; ⃠ = moderately well suited; ⊗ = not suitable; L = low; M = moderate; H = high

A post-construction, rapid monitoring protocol was developed as a tool to evaluate the performance of natural channel design practices since current bridge inspection procedures do not consider these practices. The monitoring form (Figure 2) requires the user to document basic project details (e.g. bridge ID, coordinates, etc.) and monitoring locations (Station ID) within the stream, identify any indicators of stream instabilities and their severity, investigate causes of instabilities, determine any potential implications for the instability, and make recommendations for corrective actions. A detailed description of the approach and information on codes used to complete the form are described in Appendix E. Application of the monitoring protocol to pilot projects is provided in Appendix F.

Date	5/8/2014, 8/13/2015	Notes:	Upstream the channel base had been over widened causing a right bank bar to form and further drive lateral migration of the channel to the left. Aggradation downstream from misalignment also reduces slope up through the bridge and may be increasing the lateral extent of channel migration upstream.
Road	**WAY 83 Millersburg Rd**		
Stream	**Savage Run**		
Bridge ID	**WAY 0083-0087**		
lat long	40.6785, -81.9514		
Crew	OSU, EMH&T, PS		
Flow	No flow		

		Observations (confidence)								**Corrective**
Station	**Type**	**Indicators**		**Severity**		**Implications**		**Causes**		**Actions**
US	IC	4 (rt)	very high	4	very high	3	very high	6	very high	9
US	LB	2, 3, 6	very high	3	very high	2	very high	1, 6	very high	9 (vane)
	S	5	medium	2	medium	2	medium	2	high	1
DS	IC	9, 5	high	2	very high	1	very high	2	very high	1
DS	LB & RB	1	very high							

Figure 2. Post-construction monitoring form. Codes for Station, Type, Indicators, Severity, Implications, Causes and Corrective Actions observations are presented and described in Appendix E.

A number of new construction materials were trialed at several project sites including a flexible, concrete cloth material that is rolled out, anchored to soil, wetted, and left to cure in place. This material was used as an alternative to hand placement of rip-rap slope protection under a low-clearance bridge at OTT 579 0186 (Figure 3). Due to the ease of installation, the project team worked with Medina County to test installation and performance of the material in a culvert lining project at MED 224 near Beulah Road. The material was used to provide a durable wear surface for a heavily worn section of a corrugated metal pipe in an effort to extend the useful service life of the structure. Three additional culvert lining projects (two in the City of Canton and one in Butler County) were visited and evaluated to make an independent assessment of the performance of the material. At all locations the material appeared to be performing well and remained in place and functional with little signs of wear. However, none of the projects were much more than one year old and additional monitoring would be prudent. Additional details and photographs of the Medina and Butler County projects are provided in Appendix G.

Figure 3. Application of concrete cloth material. Left: Slope stabilization beneath a low clearance bridge(OTT 579). Right: Culvert lining project in Medina County (MED 224).

ODOT work order documents were obtained to quantify costs related to materials, labor, equipment, and indirect costs incurred at two pilot projects in Wayne County. These two sites were chosen because they represent projects of a reasonable scale and scope that would be replicated frequently in county maintenance programs around the state. Our initial estimates for the Wayne County projects included the application of quarried rock to build vane structures, bank stabilization, and an extensive suite of sediment and erosion control practices to reroute stream flow around the worksite and eliminate or minimize sediment pollution entering the stream during construction. Based on these assumptions the estimated ranges of cost and project durations were $35,000-$40,000 per project and 8-10 days of construction activity per site. Actual costs and time investments were much less than anticipated at $8,000-$10,000 per project with a majority of the work completed within 3-4 days per site. Time and cost savings can be attributed to the use of concrete blocks instead or irregularly shaped quarried rock blocks, which greatly improved the efficiency of vane installation. Additional time and costs savings can be attributed to the skill of the ODOT workforce installing the practices and the purposeful timing of construction to coincide with no flow or low flow conditions in the stream. Construction during no flow and low flow conditions greatly simplified the sediment and erosion control components of the project.

Table 3. Estimated and actual costs of vane installation at Wayne County project sites.

	Initial Estimates		Actual Investment		Cost Reduction
Project	**Cost ($)**	**Time (days)**	**Cost ($)**	**Time (days)**	**(%)**
WAY 083 0087	$39,953	10	$9,416	4	76.4
WAY 604 1307	$33,091	8	$7,902	3	76.1

During the course of this research several challenges were encountered that might be mitigated or eliminated if natural channel design practices are implemented during bridge replacement projects, particularly when sites have a history of frequent maintenance needs. The biggest challenges were: 1) time and effort to mobilize equipment can be a significant percentage of the overall project cost, 2) the Clean Water Act permitting process can be costly and time consuming, and 3) most ODOT engineers are unfamiliar with these practices and not trained in the methods to design them. While these challenges can be addressed, it may be beneficial to consider integration of these practices into new bridge construction, replacement, or rehabilitation projects for a number of reasons. First, most engineering firms that design bridges would have in house expertise or could partner with firms with the appropriate experience to design and integrate these natural channel design practices into bridge construction projects. Secondly, Clean Water Act permitting required for bridge construction could include these practices with little additional effort and cost to the overall project. Furthermore, these practices are commonly viewed as more environmentally sensitive and may make the environmental permitting process easier compared to projects that propose extensive armoring or other hard engineering approaches to protect the bridge structure. Additionally, the equipment utilized in bridge construction should be adequate for installing natural channel design practices around bridges and that equipment has already been mobilized for the bridge project leading to greater efficiency and further cost savings. Lastly, well-designed projects that properly align flow and effectively route debris through the opening should improve performance (e.g. reduce flooding, reduce scour, reduce deposition), which would lead to increased service life for the structure. A white paper outlining potential benefits of integrating natural channel design practices into bridge replacement projects is provided in Appendix H.

6.0 Recommendations for Implementation of Research Findings

The results of this research suggest that implementation of natural channel design practices and use of alternative slope stabilization materials to improve maintenance outcomes at bridges is viable; however, there are important issues that need to be addressed before efficient and widespread adoption of these new approaches is possible. The following recommendations should facilitate adoption: 1) determine if the environmental permitting process associated with implementing some natural channel design practices could be similar in scale and scope to existing maintenance practices covered in the ODOT RGP B, 2) provide opportunities for additional training programs on practice selection, practice design, and proper construction techniques to progressively build institutional capacity to implement these practices, 3) seek out technical assistance to provide onsite construction support, when necessary, to guide installation, reduce uncertainty, and improve project outcomes, and 4) consider implementation of these practices in bridge replacement projects at sites with extensive and challenging maintenance histories. Additionally, consideration should be given to adding various construction materials, such as concrete cloth, to the approved materials list; however, additional monitoring of material performance over longer time frames is warranted.

Appendix A. Data Collection Methods and Practices

Site Investigation Methods

Technical Analysis

This section of the document addresses the technical analysis required to develop the preferred stream channel stabilization methods at each of the project locations, and support the development of construction plans.

A. Field Survey and Property Boundaries

Topographic field survey was completed by university staff to determine grades and elevations of the stream channel and surrounding floodplain, using conventional Total Station survey equipment. As part of this effort, temporary benchmarks were set in the field and documented on the construction plans for the various project sites. This survey also identified planimetric features such as roadways and fence rows, overhead and underground utilities and the location of individual trees along the stream channel. The survey was completed using the Ohio State Plane North horizontal coordinate system and the North American Vertical Datum (NAVD) 1988 system. The ground elevations and other survey points obtained through this effort were used to create a topographic base map for the project area, using AutoCAD Civil 3D tools.

For the most part, property boundaries and road right-of-way were determined from county-wide Geographic Information System (GIS) mapping obtained from each of the counties where projects were locations. This information was supplemented by record or design plans for the roadways provided by ODOT. There often were conflicts between these two data sources and it became the discretion of the designer to resolve that conflict for the purpose of documenting the information on the construction plans.

The road plans provided by ODOT were the only source of information pertaining to channel easements at the bridges where channel improvements were proposed. The level of detail provided on the ODOT plans regarding the channel easements varied based on the how old the plans were. In some cases, we were able to recreate the channel easement on the construction plans based on roadway stations and offset distances. In other cases, we were required to import a scanned image of the road plans into the construction plans and simply digitize the limits of the channel easement. In each case, we made a direct reference to the source of this information in the construction plans for future reference.

In the case of the ASD-0603-0614 project, we also were required to document the flowage easement associated with the downstream Charles Mill Lake dam. This easement is held by the U.S. Army Corps of Engineers (USACE) and limits land use and land disturbance activities within the protected area. For this boundary, we were provided a GIS shapefile by the USACE and used that information for the purpose of project documentation. This boundary does not appear on the construction plans because it is outside of the immediate project area represented on the plans.

For future reference, the work completed for this project should not be considered a definitive resource for property lines, road right-of-way or the channel easement within the individual project areas. Additional field survey and document research would be necessary to more accurately recreate these legal boundaries.

B. Stream Morphology

At each of the project locations where in-stream channel reinforcement improvements were proposed, stream morphology data was calculated to assess the compatibility with stable channel parameters. For the most part, this effort was limited to determining the existing channel geometry and dimensions and comparing this information to the calculated channel bankfull dimensions, using the U.S. Geological Survey's (USGS) report entitled*, Bankfull Characteristics of Ohio Streams and Their Relation to Peak Streamflows*, dated March 2005. The multiple regression equation in the USGS report requires a determination of watershed area (DA) and main-channel slope (MCSL) for the project area to calculate a bankfull width, depth and area, as demonstrated in Table 8, below, excerpted from the USGS report. The DA and MCSL parameters for each project area were derived directly from the USGS StreamStats website.

Figure 1 Excerpt from USGS 2005 Report

Table 8. Multiple-regression equations for estimating bankfull characteristics of rural, unregulated streams in Ohio with map-based explanatory variables.

[*WBF*, bankfull width, in feet; *DBF*, bankfull mean depth, in feet; *ABF*, bankfull cross-sectional area, in square feet; *QBF*, bankfull discharge, in cubic feet per second; *DA*, drainage area, in square miles; *MCSL*, main-channel slope, in feet per mile; *ELEV*, main-channel elevation index, in feet]

Equation number	Equation	Average standard error of prediction (percent)	Coefficient of determination (adjusted r-square)
	Region A		
9	$WBF_A = 9.6\ DA^{0.424}\ MCSL^{0.147}$	23.5	0.921
10	$DBF_A = 51.8\ DA^{0.263}\ ELEV^{-0.516}$	18.8	0.903
11	$ABF_A = 427\ DA^{0.718}\ MCSL^{0.213}\ ELEV^{-0.537}$	27.4	0.963
	Region B		
12	$WBF_B = 15.5\ DA^{0.424}\ MCSL^{0.147}$	23.5	0.921
13	$DBF_B = 62.7\ DA^{0.263}\ ELEV^{-0.516}$	18.8	0.903
14	$ABF_B = 806\ DA^{0.718}\ MCSL^{0.213}\ ELEV^{-0.537}$	27.4	0.963
	Statewide		
15	$QBF = 12925\ DA^{0.951}\ MCSL^{0.684}\ ELEV^{-1.154}$	66.6	0.864

:

Existing channel dimensions were derived from the field survey information and supplemented by engineering field reconnaissance to measure the bank-to-bank dimensions of the channel, and to observe and document any active instabilities in the channel bed and bank. The stable bankfull channel parameters derived through the USGS equations are approximate but were deemed adequate for this project. A more detailed Level I or Level II geomorphic assessment of the existing impaired channel reach and a stable 'reference reach' would be required to more accurately determine stable channel parameters as part of a large-scale stream restoration project.

C. Hydrology & Hydraulics

A simplified hydrologic and hydraulic analysis was performed for the project locations where in-stream channel reinforcement improvements were being proposed. The hydrologic analysis determined peak flood discharge values for a series of recurrence intervals between 1-year and 100-year, inclusive. This analysis was performed using the aforementioned USGS StreamStats website which allows the user to calculated peak flood discharge values using rural regression equations embedded into the website's programming.

The hydraulic calculations were performed using Bentley's FlowMaster program which allows the user to apply the Manning's equation to calculate normal depth and flow velocities using the computed peak flood discharge values. These calculations were used as part of the floodplain compliance effort (discussed further below), where that was required, and to estimate channel velocities. The estimated channel velocities were considered in evaluating the appropriate measures to stabilize eroding channel banks.

D. Restoration Approach and Material Selection

A critical part of the project was identifying the most appropriate measures to be applied to the selected sites. To some degree, site selection was driven by the intent to apply different Alternative Stream Channel Maintenance (ASCM) measures and have ODOT staff gain exposure to those practices. All of the sites exhibited channel instability that was diminishing the flood carrying capacity of the bridge opening and/or causing erosion at the bridge structure. The restoration approaches selected to address these issues are considered self-sustaining, in that they are applied according to the design principles of stream geomorphology.

The goal of this project was to develop solutions that could be implemented by maintenance staff in the ODOT county garages, and then repeated in the future as similar problems arose at other bridges. With this in mind, the restoration approaches described below were advanced in developing the construction plans for the selected sites.

1. Stabilization Products

Of the 10 total sites considered as part of this project, two were selected to develop a best method for slope stabilization beneath the bridge deck – SAN-006-1403 and OTT-0579-0186. At these locations, the previous slope protection had eroded and the application of rock channel protection material was hampered by access and/or limited head-room to use conventional construction equipment. For these locations, various materials were investigated and presented to ODOT District 2 and 3 staff to determine the preferred material for application to each project. Both of the slope stabilization sites noted above are located in District 2; however, the same information was shared with District 3 staff for future reference.

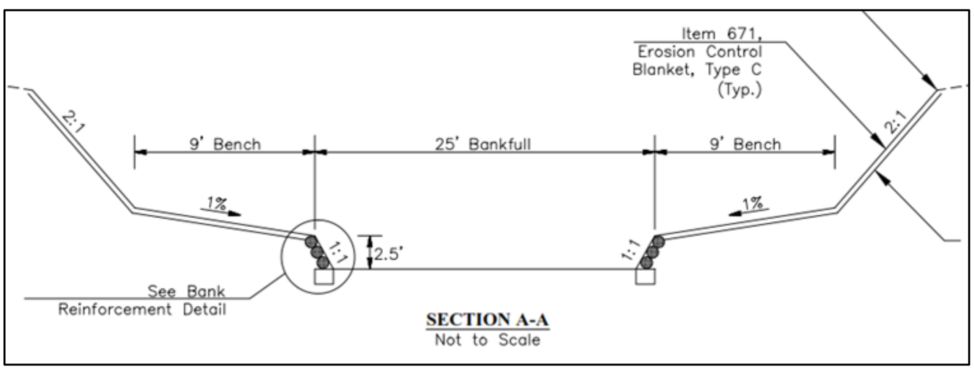
The information presented to the ODOT District included manufacturer information, as well as design and construction information from projects where the material had been previously applied. The materials included in these presentations included Flexmat, also known as Tied Concrete Block Mat (Item 601.12 of the ODOT CMS) and concrete cloth. For the purpose of 'testing' these materials, it was determined to apply Flexamat to MED 606, SAN 6 and FUL 20 and to apply concrete cloth to OTT 579 and as culvert lining to MED 224.

2. In-stream Channel Improvements

Eight sites were designated for in-stream channel improvement measures, which included the methods described below.

- Two-stage channel design keeps low and intermediate flows narrow and provides greater width for high flow capacity. Two-stage channels improve stability and if constructed in alignment with a bridge are less prone to problems of poor alignment, erosion and deposition. The two-stage design approach is commonly applied to agricultural ditches that are frequently entrenched and disconnected from the surrounding floodplain. In the vicinity of bridges, channels are routinely excavated much wider than the naturally functioning channel with a very predictable response. Within over widened sections floodplain bars form to one side, re-narrowing the channel against the opposite bank, re-directing flow towards one side of the bridge opening, with resulting erosion exposing pier and abutment foundations. This condition can be reversed by re-aligning the channel in a two-stage configuration. In the lower stage low and intermediate flow are kept narrow and deep, maintaining stability and sediment transport competence, while the flood carrying capacity is improved by a greater width over the higher stage floodplain bench. The graphics below illustrate two different application of the two-stage ditch design.

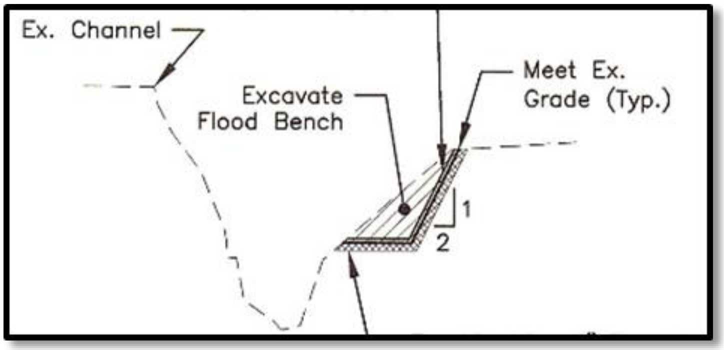
Figure 2 Two-stage channel



Graphical depiction of applying two-stage ditch design on left or right side of a ditch:

This method was chosen for SAN-0412-0712 and WOO-0582-1241; however, the extent of the improvements required at the Wood County project resulted in the decision by ODOT staff to not proceed with this project. A partially completed two-stage design along with a less extensive alternative and environmental documentation was provided for this project location, for use by ODOT in a future design and bid project.

Figure 3 Flow Re-alignment with two-stage channel.



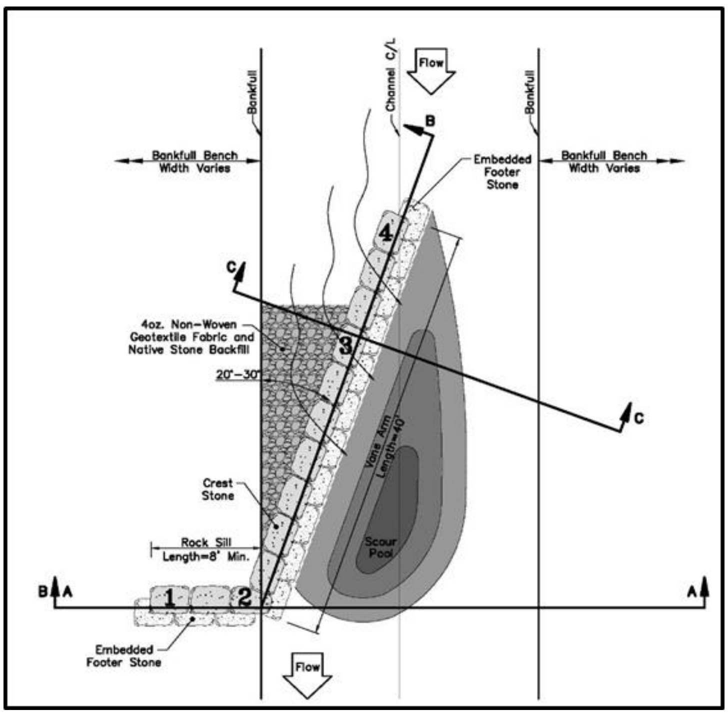
The remaining six project locations were chosen for the application of some type of flow re-alignment method, as well as the application of channel bank reinforcement when necessary. The primary purpose of using the flow re-alignment method is to move the direction of flow away from the channel bank, and bridge piers and abutments, reducing the potential for erosion that can threaten the stability of the bridge. This method also accelerates and concentrates flow, which will move coarse bed load sediment through the bridge opening instead of forming bars that would then diminish the hydraulic capacity of the bridge opening. Flow re-alignment methods include in-stream structures referred to as single-arm vanes, cross-vanes, J-hooks and W-weirs. All of these methods have been applied in some manner to stream restoration projects throughout the country. Provided below is a brief discussion of the primary characteristics of each of these structures.

- ***Vane*** *(Single-arm)*: This is the simplest of the in-stream structures discussed here. The application of this measure is to align the flow with the bridge where the channel has a definite bend upstream of the bridge. The vane slows the flow along the channel bank, not just adjacent to the structure itself but also upstream from the structure. The vane arm shifts the scouring velocity away from the bank and can be used to stop the progression of a point bar that that could threaten channel stability and reduce the hydraulic capacity of a bridge opening.

Vanes and all of the in stream structures must be stable at their downstream end. They can be keyed-in to the channel bank, referred to as a 'sill' or directly abut the bridge structure; a wing wall or pier. The vane the vane extends upstream and at a descending elevation until it intersects with the channel bed at the flowline elevation; the footer for the structure is set below the maximum depth of scour. Recommended design parameters for vanes are: 1) the horizontal angle of the vane arm from the adjacent channel bank should be between 20- and 30-degrees; 2) the vane arm should not extend beyond the middle of the channel; 3) the rate at which the vane arm descends to the channel bed should be between 2% and 7%. The graphics below depict the setting of a single-arm vane in a stream channel.

Figure 4 Photograph depicting the setting of a vane in a stream channel:

Figure 5 Graphic depicting the setting of a vane in a stream channel:



- ***Cross Vane***: A cross vane is essentially two opposing single-arm vanes converging in the middle of a channel. The application of this measure is typically along straighter channels where a pronounced meander pattern has the flow largely against one bank. It also has a greater ability to concentrate and accelerate flow improving sediment transport where capacity may be reduced by aggradation. This type of structure can also be used downstream as well as upstream of a bridge to provide grade control to stabilize the channel flowline and prevent headcutting (the migration of channel bed scour in the upstream direction).

Figure 6 Graphic depicting the setting of a cross vane in a stream channel

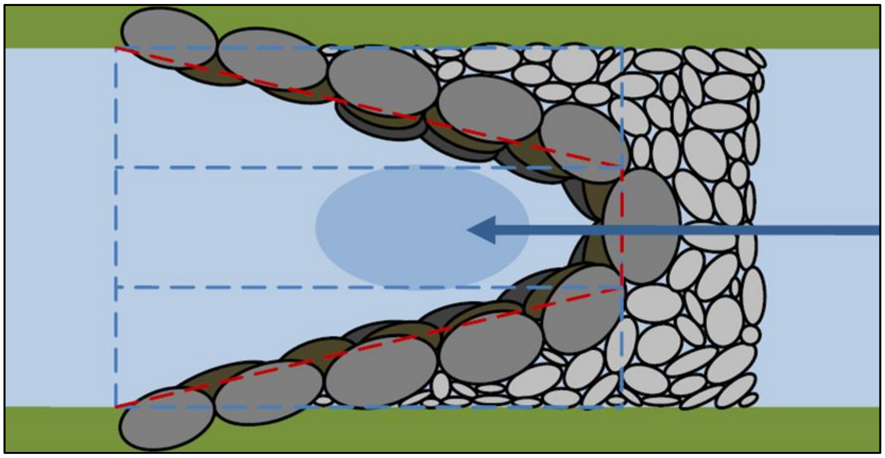
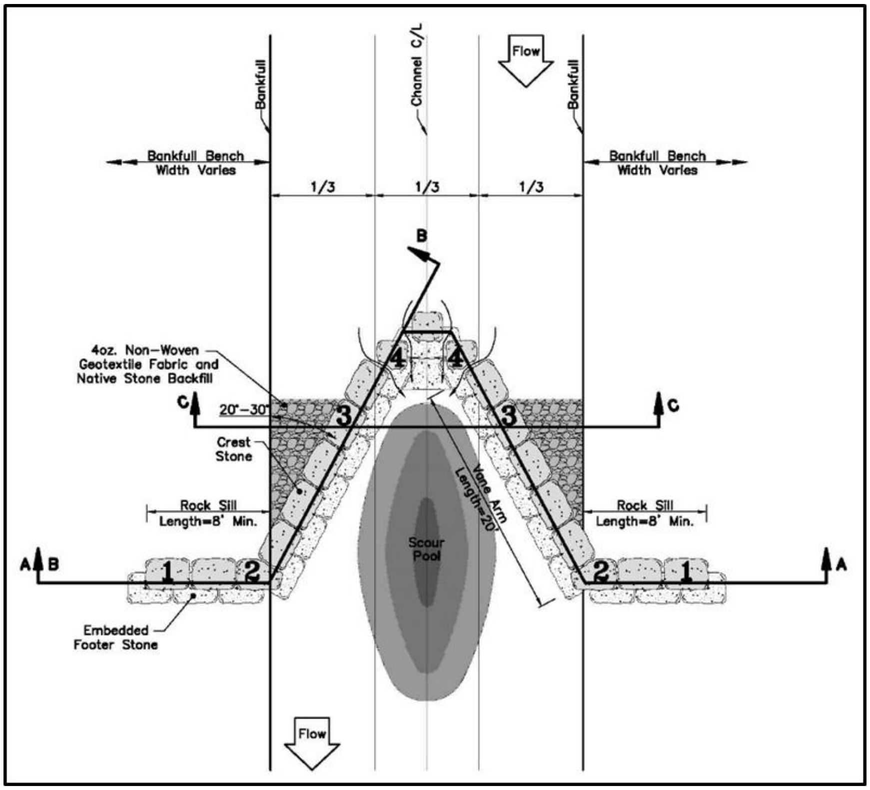


Figure 7 Graphic depicting the setting of a cross vane in a stream channel



- ***J-hook***: A J-hook is a single-arm vane with a curved extension that spans the majority of the channel width. It can be used, like a vane, where a pronounced meander pattern has the flow largely against one bank. Essentially, it is serving the same purpose as a single-arm vane in terms of realigning flow into the middle of the channel, while also providing a grade control feature to stabilize the channel flowline.

Similar to the other in-stream structures, a J-hook will realign the flow away from the channel bank and into the middle of a channel. The 'hook' of this structure should tie-in to the flowline of the channel at the upstream apex and then increase in elevation at the same rate as the vane arm descending from the bankfull elevation. A sill extending into the opposing channel bank may be used at the end of a J-hook if necessary to fully span a wide channel.

Figure 8 Graphic depicting the setting of a J-hook in a stream channel

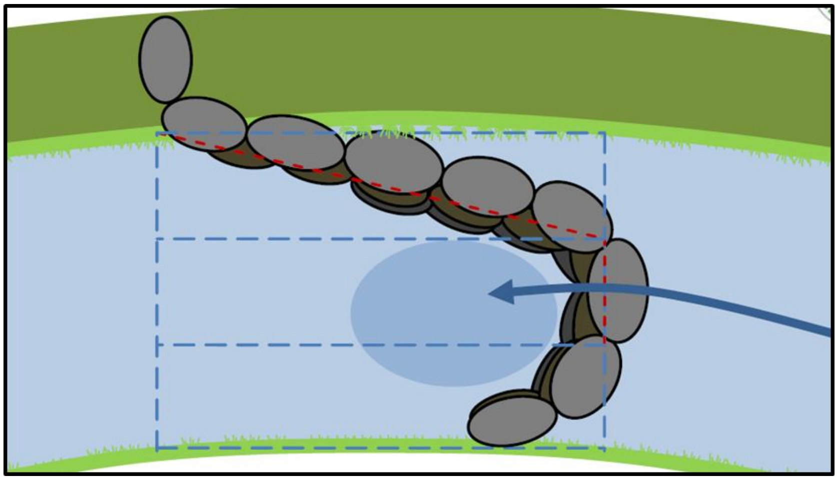
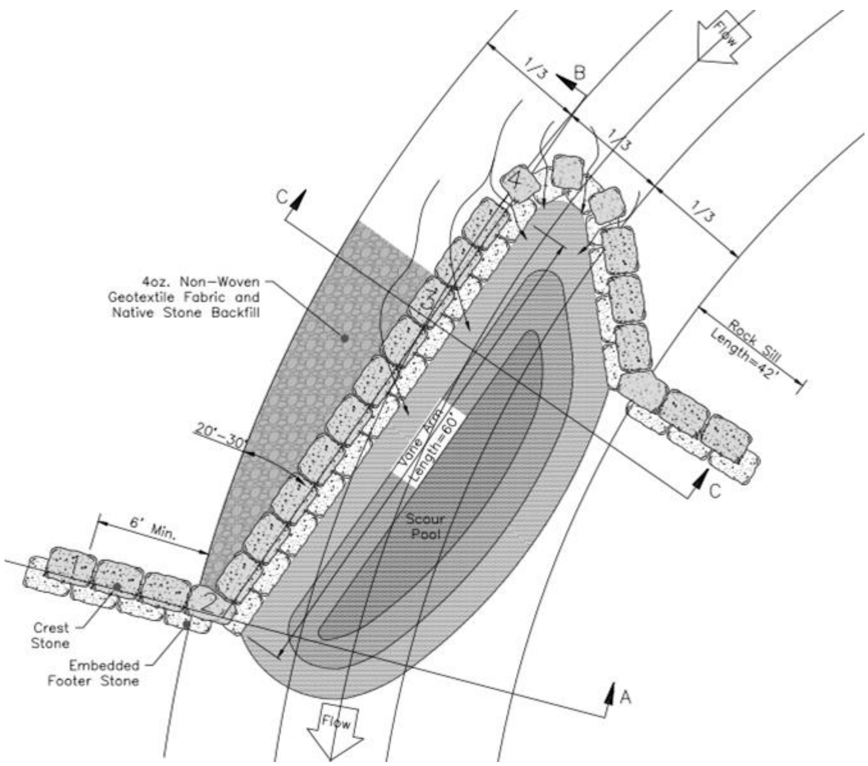


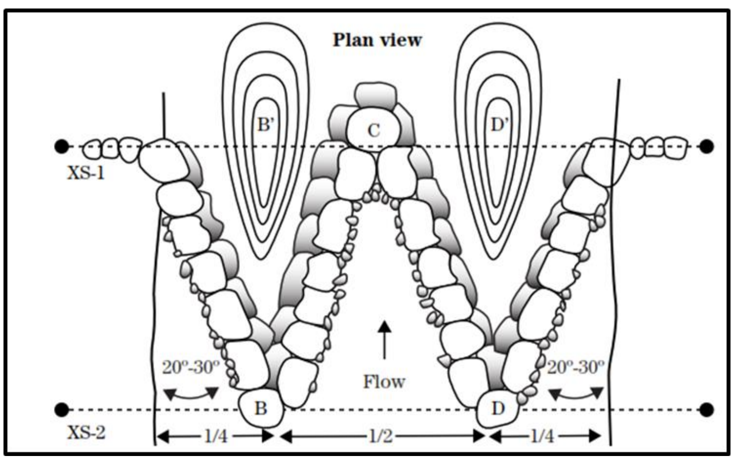
Figure 9 Graphic depicting the setting of a cross vane in a stream channel



- ***W-weir***: A W-weir is basically two cross vanes side-by-side. The structure divides the flow, concentrating it along 2 paths, making it ideal for bridges with mid-channel piers. The design parameters are the same as a cross vane except at the high point in the middle (where the two cross vanes meet) is usually a little lower than where the structure ties into the bridge abutments or banks. The high point in the middle should align directly upstream of the bridge pier and so divides much of the flow, directing it and debris along with it through the middle of the bridge spans.

Figure 10 Photo of W-weir

Figure 11 Graphic depicting the setting of a W-weir in a stream channel



In addition to the direct benefits to channel and bridge stabilization, these in-stream structures also have aquatic habitat benefits. They were initially developed for restoring aquatic life by providing habitat for aquatic species, creating scour holes in the channel bed stabilizing stream banks.

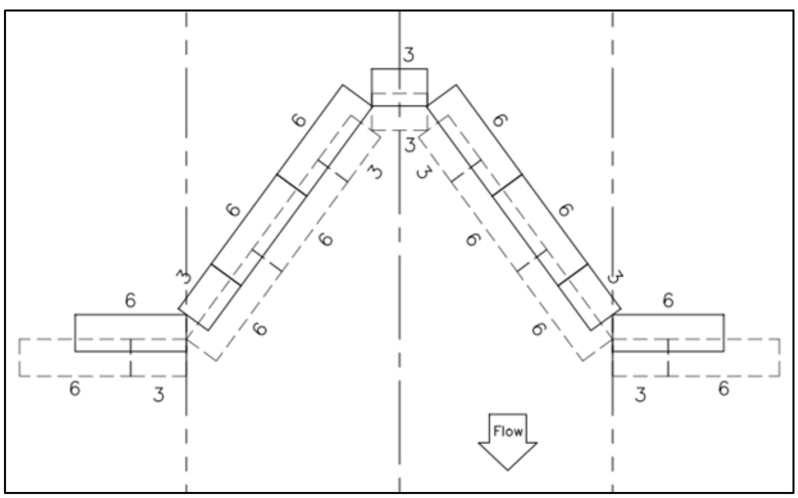
3. Material Selection

Based upon discussions with ODOT District staff, as well as discussions with county maintenance staff, it was decided to use pre-cast concrete blocks in the construction of the in-stream structures described above. Typically, these structures are constructed from quarried stone material that is block-shaped to facilitate placement in accordance with the grades and elevations required by the design parameters; however, that material can be difficult to find in local quarries and can be expensive to purchase and deliver to the site. On the other hand, the pre-cast concrete blocks are readily available from local concrete suppliers and inexpensive to acquire and quick to install.

Figure 12 Block being placed

The concrete blocks are designed to be stackable with corresponding ridges and grooves, and with steel cable handles for easy lifting and placement by conventional construction equipment. The concrete blocks are considered non-native material and we were required to coordinate with ODOT's Office of Environmental Services (OES) and the U.S. Army Corps of Engineers (USACE) to verify that their use would not compromise the environmental permitting process. The graphic below is an example of drawings we prepared to demonstrate the use of the concrete blocks to construct an in-stream structure.

Figure 13 Graphic depicting the setting of a W-weir in a stream channel:



The use of flow re-alignment structures will reduce erosive forces in a stream channel and eliminate the need for large stone material (rip-rap) to protect channel banks and bridge abutments; however, other less obtrusive methods may be necessary to fully protect the stream channel from unwanted bank erosion even when the in-stream structures are also used. Some of the methods applied to the selected project sites are described below.

- ***Erosion control matting***: The required materials and installation methods are prescribed under Items 671 and 712.11 of the ODOT CMS. Manufacturer recommendations for installation are also available. The type of material selected can depend on expected flow velocities and whether the intent is for the material to be temporary (biodegradable) or permanent (non-biodegradable). This material can be easily acquired from local suppliers. Successful application of these materials is heavily dependent on properly overlapping and trenching-in the edges of the material, as well as the proper use of 'staples' as directed by the installation guidelines.

- ***Tied Concrete Block Mat (Flexamat)***: The required materials are prescribed under Items 601.12 and 712.12 of the ODOT CMS. Installations methods are alluded to in the CMS; however, more details regarding the installation methods for different applications of this material are available from the manufacturer, including standard details and written specifications. This material may need to be acquired directly from the manufacturer. Strict adherence to the manufacturer's installation guidelines is critical to the successful application of this material.

- **Coir rolls**: These rolls are constructed from tightly wound coconut fiber and can be purchased in a variety of diameters between 12- and 20-inches. Coir rolls are not prescribed in the ODOT CMS and installation guidelines must be obtained from the manufacturer. Although the use of this material is an effective replacement of rock channel protection to protect a stream bank in many applications, the installation can be labor intensive and, if not properly anchored, coir rolls can be easily dislodged and floated downstream by rising flood waters.

- ***Live stakes/branches***: Live stakes typically consist of harvested willow branches which are planted directly into the stream bank. This material is not prescribed in the ODOT CMS. Live stakes can be applied on their own for channel bank stabilization or in conjunction with other channel bank reinforcement methods, including as a component of vegetated rip-rap or any of the other materials noted above. Live branches provide channel bank stabilization though the development of a dense root-mass that forms as the branches mature into shrubs and small trees. In doing so, they also provide shade cover immediately along the stream channel. Live branches are often applied with other temporary measures to provide channel bank stabilization while the plants mature. The use of proper installation methods are very important to the survivability of planted live stakes, which can be harvested directly from local plant stock (i.e., cuttings from a willow tree) or purchased from a supplier. This material must be planted during its natural dormant season and it is recommended that the holes where the live stakes are planted are pre-drilled. There are other very specific recommendations regarding the use of live stakes which can be obtained from a reputable supplier.

Construction Plan Development

This section of the document describes the process of developing construction plans. It is understood that future efforts by ODOT District and county garage staff to implement ASCM projects may not result in similarly detailed construction plans; however, these plans were prepared to provide ODOT with a template for future consideration. Construction plans were developed for all of the sites where in-stream channel improvements were to be constructed. In addition, standard details have been created for various channel improvement measures, as described later within this section of this document.

Evaluating Site Access

As part of the process of developing construction plans, we initially determined the ability for the project site to be accessed from a public right-of-way, and for all of the channel improvements to be constructed within the established channel easements. ODOT protocols allow for temporary work agreements to be negotiated by individual county garage staff for the sole purpose of construction access; however, a permanent easement would need to be acquired to account for channel improvements constructed outside of the established channel easements. The only exception to this requirement being the construction of non-essential channel improvements.

To eliminate the complexities of attempting to acquire additional easement area, all of the designed channel improvements were confined to the established right-of-way and channel easements. Only one project site, WAY-0604-1307, was partially compromised by the limitations of the available channel easement.

Construction Plan Content

For the purpose of facilitating construction and supporting the necessary permitting, it was determined that the construction plan content described below was necessary. Similar plans could be produced by ODOT District staff as part of future similar projects. The extent to which construction plans were prepared for this project may not be required for future similar projects; however, some level of site drawing will be required to facilitate the environmental compliance process. Additionally, some level of survey control should be established on future projects to allow for the verification of grades and elevations associated with in-stream structures.

A. Plan View/Grading Plan

Each construction plan includes a cover sheet which also provides a plan view of the project site, showing existing topography and other information developed from the field surveying effort described previously. The plan view also demonstrates the extent of the proposed channel improvements with labels referencing other design information contained in the plans. A legend provided on the cover sheet explains most of the information shown in the plan view.

B. Plan Notes

Notes are provided on the cover sheet which reference the various components of the channel improvements to be constructed for each project site. These notes imply a sequence of construction for the project. These notes also reference other pertinent details and construction specifications shown within the construction plan. There are also notes specific to the origin of the channel easement shown on the plan, as well as a reference to any wetland and stream impacts associated with the channel improvements.

C. Staking Plan/Coordinates

The cover sheet also includes a list of survey benchmarks in proximity to the project site. For the most part, these benchmarks are temporary and were established as part of the field survey effort. A table of coordinates is also provided, with a numbering scheme corresponding mainly to channel improvement features shown in the plan view. The purpose of the coordinate information is to allow for a field surveyor to locate the various components of the in-stream structures as part of the construction process, and to ensure the appropriate grades and elevations are achieved during the construction process.

The practical application of this information in the field was that a field surveyor established grade stakes at each of the project sites, prior to the start of construction. The construction crews then used rod-and-level equipment to confirm grades and elevations during the construction process. The locations of in-stream structures were mostly located in the field by measuring distances from other known features, such as a headwall or guardrail. Future similar projects may rely more on station/off-set information to locate in-stream structures, instead of the coordinates developed for these construction plans.

D. Details and Specifications

Each plan includes details and related specifications for the channel stabilization measure(s) selected for that project site. This information was provided in lieu of the standard details discussed below, which could be used as a reference when performing future similar projects.

E. Erosion and Sediment Control

The size of the disturbed area associated with these project sites was less than 1 acre, which means that a Notice of Intent (NOI) is not required from the Ohio EPA. Regardless, each plan included basic information related to erosion and sediment control during construction, mostly related to a stabilized construction access and dewatering the channel through the work area using a pump-around system.

Different methods were used in the field to dewater the channel during the construction of these projects, depending on the size of the channel. Pump around systems were used in smaller channels where the baseflow to be pumped was fairly low. In other situations, the construction team was able to re-direct the channel flow around the work area without the need for a pump-around. In either case, the dewatering of the immediate work area will still require the use of a pump and sediment filter bag.

<u>Standard Details</u>

Many of the details provided in the individual construction plans have been converted to standard details for utilization in future similar channel improvement projects. Future projects may not necessarily be limited to channel maintenance at bridges; the expectation is that these details could be used for new bridge construction or re-construction projects, or for any channel bank stabilization where it is necessary to protect roadway infrastructure. The standard detail provided for a W-weir was developed and published by the State of Maryland. It is more detailed and also broader in application than the other details prepared specifically for this project. We are providing it for reference purposes only. These details prepared for this project are similar to standard details/standard drawings adopted by state agencies throughout the country. They could be adapted for use as an ODOT Standard Drawing after being reviewed though the established approval process.

The use of a standard detail in a construction plan does not preclude the requirement to provide further information to support the construction process. For in-stream structures, elevations, grades and dimensions must also be specified to ensure the structure is properly constructed. For future channel maintenance projects at bridges, where construction is completed by county maintenance garage staff, the additional required information could be based on field measurements and does not necessarily require a formal survey to the extent performed for these projects.

COST ESTIMATING TOOL

An important consideration in determining the feasibility of the various project sites for application of stream channel improvements was the cost of implementation. County maintenance programs have finite operating budgets and must proactively plan for the labor, equipment, and material costs necessary to implement an improvements. Further, the Ohio Revised Code limits the total project cost that a County maintenance program can implement through force account activities to $60,000.

We determined that there are different tools (spreadsheets) being used in the various ODOT Districts, and at the county garage level, to determine project costs. Furthermore, those tools are more applicable to typical roadway maintenance activities. For these reasons, we developed a project-specific cost estimating tool using Microsoft Excel to estimate total construction costs and determine whether they fit within permissible budget limits. In support of developing this tool, we coordinated with District staff to gather cost information associated with maintenance crew labor and equipment. The acquired information is summarized in the table below.

Labor and Equipment Unit Costs:

Classification	Base Rate	Overhead Rate	Total Unit Cost	Unit
Crew	$18.50	80%	$33.30	hr
Surveyor	$20.99	80%	$37.78	hr
Concrete Saw	$80.73	0%	$80.73	hr
Heavy Excavator	$39.23	0%	$39.23	hr
Front End Loader	$36.12	0%	$36.12	hr
Flatbed Truck	$41.63	0%	$41.63	hr
Dump Truck	$86.53	0%	$86.53	hr
Roller	$32.34	0%	$32.34	hr
Mileage	$0.39	0%	$0.39	mi

In order to quantify material costs, we evaluated information from multiple sources, including prior bid tabulations, team project experience, correspondence with material vendors, and proprietary publications (RSMeans CostWorks). Information representing raw material costs, and crew and equipment output, were collected for each material item proposed in the improvements. An overhead rate of 15% was applied to raw material costs following correspondence with ODOT District staff. This information was then tabulated in the cost estimating spreadsheet to develop complete costs for labor, equipment, and materials for each component of the channel improvement projects.

A list of materials included in the cost estimating spreadsheet is provided in the table below. Not all of the materials used in the various project sites is identified in the cost estimating tool, but the items listed in the table below are adequately representative to allow for a reasonable estimate of total project costs for a wide variety of channel improvement projects.

Material Items Included in the Cost Estimating Spreadsheet:

Category	Material Item	
In-stream Structures	(Single-arm) Rock Vanes	Cross Vanes
Slope Protection	Geocell (4”) with concrete infill	Geocell (4”) with soil infill
	Geocell (4”) with stone infill	Grout Filled Bags
	Grout Mattress (ABM), 4”	Tied Concrete Block Mats, 4”
Channel Bank Reinforcement	Riprap, Type A, 4’ Thick	Riprap, Type B, 3’ Thick
	Riprap, Type C, 2’ Thick	Gabions
	Riprap, Type D, 1’ Thick	Tied Concrete Block Mats, 4”
	Toe Protection and Live Stakes	Vegetation for Riprap and Gabions
	Rock Mattresses, 12”	Filter Fabric
Earthwork	Channel Dredging (Maintenance)	Channel Excavation (Realignment)
	Embankment, from onsite	Embankment, import
	Topsoil, Furnished and Placed, 6”	
Erosion Control	Aggregate Filter, 12”	Aggregate Filter, 6”
	Seeding and Mulching, Type 1	Seeding and Mulching, Type 4B
	Erosion Control Mat, Type C	
Incidental	Hauling (add on cost)	

The labor, equipment and material costs are provided as a database within the cost estimating tool spreadsheet. The spreadsheet was prepared to be intuitive and user friendly by providing a combination pick boxes and lookup functions that correlate selected channel improvement items to the embedded cost database. The tool calculates costs for materials, labor, equipment, and hauling in subtotal and total cost formats.

Information at the top of the spreadsheet tool reflects background data regarding the project location, purpose, estimator, and distance from local quarries (for estimate of hauling costs). It is important for the estimator to understand the source of the materials, as hauling costs can substantially affect the overall project cost estimate.

The second section of the tool reflects the various material items to be used in the project. Here, the estimator will select the materials through a pick box and enter an initial quantity value for each item. A second quantity cell is provided with green shading for the estimator to revise the initial quantity for rounding or other purposes. If the second quantity cell is left blank, the calculations will be performed using the initial quantity data.

Screenshot of Cost Estimating Tool for Channel Improvement Projects:

Alternative Channel Maintenance Cost Estimator Tool

ODOT District:	**Text**	D.A. (mi^2):	**1.65**	
County:	**Text**	Stream length (ft.):	**75**	
Route:	**Text**	Wbkf (ft.):	**23**	
Bridge No.:	**Text**	Abkf (ft^2.):	**38.5**	
Estimate Prepared By:	**Text**			
Date:	**Text**			
Project Description:	**Realignment of channel through bridge opening through bank re-construction and armoring with RCP and vegetation. Includes one cross-vane and slope protection**	Dist from Quarry (mi):	**40**	National Lime and Stone Quarry
		Dist from Concrete Plant	**12**	Medina

Item	Materials	Qty	Final Qty	Unit	Unit Cost	Ext Cost
1	Cross Vanes (Use Wbkf = 30 ft Min.)	30	30	Wbkf (FT)	$ 119.93	$ 3,597.81
2	Channel Excavation (Realignment)	73	73	CYD	$ -	$ -
3	Embankment, Imported from Offsite	79	79	CYD	$ 26.45	$ 2,089.55
4	Toe Protection / Live Stakes	180	180	LF	$ 54.25	$ 9,764.65
5	Hauling, 25 MPH, 10 mile cycle, 15minute loading	152	152	CYD	$ -	$ -
6	Seeding and Mulching, Class 4B	100	100	SYD	$ 2.88	$ 287.50
7	Riprap (Dumped Rock), Type C, 2' Thick	89	100	SYD	$ 85.10	$ 8,510.00
8	Erosion Control Mat, Type C	80	100	SYD	$ 2.30	$ 230.00
9	Tied Concrete Block Mats, 4"	160	160	SF	$ 2.88	$ 460.00
10	Topsoil, Furnished and Placed, 6"	100	100	SYD	$ 4.88	$ 487.60
11						
12						
13						
14						
15						
SUBTOTAL MATERIALS						$ 25,427.11

Item	Labor	Qty	Final Qty	Unit	Unit Cost	Ext Cost
16	Labor Required by Materials Entered	112	160	HR	$ 33.30	$ 5,328.00
17	Surveying (hours per person)	16	16	HR	$ 37.78	$ 604.48
18	Additional Labor 2	120	120	HR	$ 33.30	$ 3,996.00
19	Additional Labor 3	120	120	HR	$ 33.30	$ 3,996.00
SUBTOTAL LABOR						$ 13,924.48

Item	Equipment	Qty	Final Qty	Unit	Unit Cost	Ext Cost
20	Heavy Excavator Required by Materials Entered	32	120	HR	$ 39.23	$ 4,707.60
21	Front End Loader Req'd by Materials Entered	8	0	HR	$ 36.12	$ 288.96
22	Roller Required by Materials Entered	8	16	HR	$ 32.34	$ 517.44
23	Flatbed Truck Required by Materials Entered	16	24	HR	$ 41.63	$ 999.00
24	Dump Truck Required by Materials Entered	16	40	HR	$ 86.53	$ 3,461.00
25	Pump Rental	12	12	DAY	$ 125.00	$ 1,500.00
SUBTOTAL EQUIPMENT						$ 11,474.00

Item	Mileage	Qty	Final Qty	Unit	Unit Cost	Ext Cost
27	Mileage 1: 3/4 Ton Pick-up Truck	400	400	MI	$ 0.72	$ 288.00
28	Mileage 2: Dump Truck (2500-3500)	300	300	MI	$ 2.08	$ 624.00
SUBTOTAL MILEAGE						$ 912.00

TOTAL	

The third section of the tool calculates crew labor to perform the work. Labor hours are automatically calculated based on the material quantities selected in the second section of the tool and rounded up to the next full 8 hour increment. Again, a second cell is provided with green shading for the estimator to revise the labor quantity based on additional considerations. Rows are also provided in this section for the estimator to include costs for surveyors and other personnel. These additional labor costs are not automatically calculated by the tool as they are project specific and must be manually entered by the estimator.

The fourth section of the tool calculates equipment costs. As with the crew labor calculation, equipment costs are automatically estimated by the tool based on the material quantities selected in the second section of the tool and rounded up to the next full 8-hour increment. Again, a second cell is provided with green shading for the estimator to revise the equipment usage based on additional considerations. Rows are also provided in this section for the estimator to manually include costs for additional equipment.

The fifth and final section of the tool calculates hauling costs. In this section, the user manually enters vehicle type and applicable unit costs. We recommend calculating hauling costs in this section rather than the material section to allow for an enhanced analysis of the specific vehicles types that will be used in the hauling of the materials.

In the future, the cost database will require maintenance due to changes in market pricing and crew output capabilities. The cost database is included with the estimating tool as a separate tab in the Excel spreadsheet labeled “Backup Costs”. The user can modify the columns for Base Cost, O/H Factor, and Daily Output to reflect current market conditions and crew capabilities.

The cost estimating tool was used to develop a cost estimate for each of the proposed channel improvement projects. The cost estimates were reviewed with District and county garage maintenance staff prior to deciding to proceed with each project site. To the best of our knowledge, the final calculated construction costs determined for all of the channel improvement projects after construction was complete came in below the initial estimates.

ENVIRONMENTAL COMPLIANCE SUMMARY

Achieving Environmental Compliance with all local, state, and federal laws and regulations as they pertain to transportation related projects is a standard part of the ODOT project development process. District and Central Office environmental staff specialize in understanding the process and the steps needed to achieve environmental compliance, including completing the necessary documentation to comply with the National Environmental Policy Act (NEPA). All transportation projects that receive federal financial assistance are required to ensure compliance with NEPA regulations. NEPA compliance includes documenting environmental resources and avoiding, minimizing, and/or mitigating impacts to those resources. The level of documentation required is based on the project type and anticipated environmental impacts.

> Alternative Stream Channel Maintenance projects will require compliance with the National Environmental Policy Act (NEPA) and may need a waterway permit from the US Army Corps of Engineers.

Typical components of the NEPA compliance process include an evaluation of the following:

- Ecological resources – Presence of and impacts to resources including jurisdictional streams, wetlands, or ditches, isolated wetlands, federal or state threatened or endangered species or their habitat, and freshwater mussels;
- Floodplain impacts;
- Hazardous materials and waste management concerns;
- Cultural resources impacts, including historical architectural and archaeological sites;
- Farmland impacts;
- Section 4(f) concerns, including impacts to public parks, recreation areas, wildlife and waterfowl refuges, or significant historic sites; and
- Public involvement.

In addition to NEPA compliance, as with any work that occurs in jurisdictional waterways, Alternative Stream Channel Maintenance (ASCM) projects require receipt of the appropriate waterway permits from the United States Army Corps of Engineers (USACE). In certain circumstances, a permit may also need to be obtained from the Ohio Environmental Protection Agency (Ohio EPA).

- *No work should be done in jurisdictional waterways unless the appropriate waterway permit is obtained and/or there is approval from ODOT environmental staff that no permit is necessary.*

ASCM PROJECT PLANNING

For the ASCM research project, NEPA compliance and waterway permitting were coordinated by the ODOT District Environmental Coordinators (DECs) and staff in Districts 2 and 3, central office environmental staff, and consultants from EMH&T. These parties were engaged during the early planning stages of the project to determine the extent of environmental studies required and the need for waterway permits. During the planning stage, a project schedule was set that included the length of time anticipated to receive NEPA clearance and waterway permits.

- *Stage 1 plans or preliminary plans with an equivalent level of detail were needed to determine the footprint of the project and thus the extent of impacts to any environmental resources present within or near each project area.*

Schedule Considerations

Environmental compliance should be considered in the early planning stages of a project in order to appropriately schedule the necessary environmental studies and obtain any necessary permits. The type of studies needed, the extent of coordination required with other agencies, and the type of waterway permit required will establish the timeline for the project. This process can take 3 to 6 months to complete, depending on the level of environmental impacts. The two essential schedule considerations for the ASCM projects were the following:

NEPA Compliance

NEPA Compliance was required for the ASCM projects due to the federal funding assistance associated with the research initiative. This process involved completion of a low-level Categorical Exclusion (CE) document for each site, using ODOT's On-Line CE/EnviroNet system. The District DEC determined the level of CE document that was required based on the environmental resources present at the project site and the anticipated level of impacts.

> Environmental compliance should be considered in the early planning stages of a project in order to appropriately schedule the necessary environmental studies and obtain any necessary permits.

- All ASCM projects were cleared using the equivalent of C2 level of Categorical Exclusion document, which allows environmental clearance to be handled at the District level.

For the ASCM projects, the timeframe for NEPA compliance was approximately 3 to 6 months. This timeframe included the time needed to generate the necessary engineering plan details so environmental impacts could be assessed. The projects with more extensive environmental impacts took longer to clear.

Waterway Permits

To the extent possible, the projects were designed to minimize impacts to waterways and other environmental resources.

- ➢ *In order to minimize the timing and costs associated with waterway permitting, the projects were designed to meet the thresholds of either ODOT's Regional General Permit (RGP) or the USACE Nationwide Permit (NWP) Program.*

The regulatory thresholds that were pertinent to the ASCM project included the following criteria:

- Removal of accumulated sediment and debris, and placement of any new or additional rip-rap or other material, cannot extend further than 200 feet in any direction from the structure.
- There can be no stream channelization or relocation.
- Temporary construction access and dewatering are allowed, but all temporary fills and structures must be removed and the stream restored to pre-project conditions following completion.

In addition, where possible, the projects were designed so that a Pre-Construction Notification (PCN) and agency coordination and approvals were <u>not</u> required. Due to the nature of the projects, multiple projects entailed PCN triggers that then required a permit document to be prepared and coordinated with the USACE. These triggers included:

- Loss of waters of the United States exceeds 1/10 acre.
- There is a discharge in a special aquatic site, including wetlands.
- The total discharge of fill into a stream is greater than 500 linear feet for combined ephemeral, intermittent, and perennial streams, or the combined temporary or permanent discharges of fill into perennial and intermittent streams for a single and complete crossing is greater than 300 linear feet.

An additional consideration was that the RGP is set up to permit standard ODOT transportation projects. As such, the permit covers linear transportation projects, maintenance projects and temporary impacts.

Due to the fact that the ASCM projects were often related to bank stabilization and improvements to the stream channel's form and function (including restoration), the ACSM projects did not fit well with ODOT's Regional General Permit (RGP) program. This may be a future consideration for ODOT – to include coverage for ASCM-type projects in the next

Timely submission of the waterway permit applications was crucial to meeting the project schedules. The timeframe for waterway permitting ranged from 1 week (for the OTT-579-01.86 project) to 7 months (for the ASD-603-06.14 project). The projects that did not require a PCN could be granted permission to work in the waterway by OES upon issuance of the Waterway Permit Determination. However, projects that required a permit application to the USACE required agency review and approval.

ODOT's Ditch Clean Out Guidance

The ODOT-Office of Environmental Services provided the project team, including the maintenance staff performing the work, a copy of the *OES Stream and Jurisdictional Ditch Clean Out Guidance (v.4.4.14)*. The document summarizes limitations for maintenance crews performing cleanout activities in a stream channel or jurisdictional ditch. Debris or sediment removal from a jurisdictional waterway must meet certain conditions as outlined in the guidance for work to proceed without NEPA clearance (when the project receives federal financial assistance), including:

- No placement of heavy equipment below the Ordinary High Water Mark.
- No widening, deepening, channelization, or relocation of a stream or jurisdictional ditch.
- Work must be conducted during low-flow conditions.
- Material removed must be hauled to an upland disposal site and not placed into another stream, ditch, or wetland.
- The area contains records of threatened or endangered species or other unique ecological features as indicated by the ODNR Biodiversity Database.
- Stream listing in the Ohio Mussel Survey Protocol Appendix A.
- Work will occur during ODNR in-stream work restriction dates as described in the ODOT Ecological Memorandum of Agreement.
- Work is in a Section 9 or 10 waterway.
- Work is in or within 1,000 feet of a National or State Wild and Scenic River.

Before any stream or ditch cleanout activity occurs, the DEC should compare the proposed work to the guidance as well as any additional project restrictions.

ENVIRONMENTAL DOCUMENTATION

As discussed previously, the ASCM projects required certain types of environmental documentation to be completed in order to meet NEPA and Waterway Permitting requirements. Below is both a detailed listing and a summary of the environmental documents needed for these projects. Table 1 provides a summary of this information.

Detailed Listing of Environmental Documentation

The environmental documentation needed for each ASCM project was determined on a case by case basis, but generally included the following:

- *Ecological Survey Report* – Because the ASCM projects involved work in streams and/or wetlands, ecological surveys were performed to inventory the resources in the vicinity of the proposed projects. **These data were summarized in ODOT's standard Level 1 Ecological Survey Reports (ESR).** The ESRs contained analyses of stream quality, aquatic ecosystems, endangered species, wetlands and terrestrial ecosystems for each site. The ESR and any other resource-specific reports were used to coordinate the project impacts with the resource agencies (i.e. Ohio Department of Natural Resources, US Fish and Wildlife Service, etc.) in order to solicit comments and obtain approval. The coordination effort and any subsequent environmental commitments were included in the NEPA document. Ecological coordination resulted in Environmental Commitments (EC) that were required as the project moved forward, such a timing restrictions for tree-cutting.

- *Mussel Survey Reports* - Certain projects required additional separate reports for mussel surveys, which affected the project schedule and cost. Mussel surveys must follow the Ohio Mussel Survey Protocol (OMSP) and can only be conducted between May 1st and October 1st. The need for a mussel survey is triggered by:
    - Impacts to an OMSP Listed (Group 1-4) stream.
    - Impacts to an unlisted stream with a drainage area over 10 square miles.
    - Presence of live mussels.

Table 1 indicates which ACSM projects required a mussel survey.

- *Floodplain Permitting* - The National Flood Insurance Program (NFIP) requires that all development undertaken by ODOT (federally funded or state funded) in a federally identified Special Flood Hazard Area (SFHA) must comply with the performance standards of the respective locally-adopted floodplain regulations. ODOT is required to meet federal NFIP standards or, if applicable, meet local floodplain standards. Floodplain permitting activities are generally required for any site with a designated flood hazard area, as shown on the published Flood Insurance Rate Map (FIRM) for the location. Refer to the more detailed discussion of this process later in this section.

- *Environmental Site Assessments* – Environmental Site Assessment (ESA) investigations address matters regarding the presence of hazardous materials for purposes of managing liability and materials management during construction of ODOT projects. These concerns are typically triggered if the project requires acquisition of new right-of-way (ROW) or deep excavation (generally greater than four feet). **Due to the rural locations of the ASCM projects, most projects were able to be processed with an ESA Screening Memorandum rather than a full ESA Screening Report**. As no suspect parcels were identified at any of the project locations, OES did not require further investigations. However, ESA investigations can result in Environmental Commitments (EC) that will be required as the project moves forward, such as plan notes for handling petroleum contaminated soils or ground water.

- *Cultural Resources* – Section 106 of the National Historic Preservation Act of 1966 requires government agencies to take into account the effects of their actions on historic properties, which may include such resources as archaeological sites, architecturally significant buildings, or historically significant bridge structures. A Section 106 Scoping Request Form detailing the known cultural resources present in the ASCM project areas was submitted to OES to determine if further investigation was needed and to coordinate with the Ohio Historic Preservation Office. **For the ASCM projects, no further cultural investigations were required.** However, cultural resource investigations may result in Environmental Commitments (EC) that will be required as the project moves forward, such as preservation of an historic bridge structure.

- *Farmland* - In accordance with the Farmland Protection Policy Act (FPPA) of 1981, ODOT is required to consider the adverse effects of all federally funded transportation projects on farmland preservation. In addition, Ohio's Farmland Preservation Act requires ODOT to coordinate with the Ohio Department of Agriculture for projects that affect a designated agricultural district. **For the ASCM projects, it was determined that there were no impacts to farmland.** Had there been impacts, the Farmland Protection Policy Act (FPPA) Screening Sheet would have been completed and agency coordination with the National Resources Conservation Service (NRCS) would have been needed.

- *Public Involvement* - The level of Public Involvement (PI) required is dependent on a project's type, complexity, and whether right-of-way is needed. **For the ACSM projects, PI activities were limited to ODOT standard combined property owner notification/request for input letters that were mailed to all adjacent property owners.** The template for these letters were obtained from the DEC. For future projects, the DEC may list the project on the District website or conduct coordination with local stakeholders. PI activities may result in Environmental Commitments (EC) that will be required as the project moves forward, such as a plan note regarding public notification of detours and closures.

- *Waterway Permit Determinations* – Waterway Permit Determination (WPD) packages were completed for each project and submitted for review to the ODOT Office of Environmental Services (OES) Waterway Permits Unit (WPU). The WPD package detailed the waterways that were to be impacted by each project and the type of impacts anticipated (i.e. rock channel protection, vane construction, etc.). The WPU serves as the single point of contact for coordinating all ODOT transportation projects with the USACE, Ohio EPA and U.S. Coast Guard. **The WPU returned an interoffice communication (IOC) indicating what level of waterway permit was required for each project**. The appropriate waterway permit applications were then submitted to the WPU. Oftentimes, the USACE will provide a list of Special Provisions for a project that must be met in order for the NWP to be valid. For the ASCM projects, these Special Provisions became Environmental Commitments and were included with the engineering plans.

- *Pre-Construction Notifications (PCNs)* - Certain impacts to waterways can be authorized by Nationwide Permits (NWP) or the Regional General Permit (RGP), but require notification to USACE through the PCN process. USACE inserts certain "triggers" in the NWPs and RGP that require ODOT to notify USACE of its intent to discharge dredged or fill material into a water of the U.S. **Several of the ASCM projects involved a PCN trigger and required submission of a permit application to the USACE. Other projects did not involve a PCN trigger and required no additional agency coordination.** Table 1 summarizes the waterway permitting requirements for each ASCM project.

Other NEPA compliance issues, such as air quality, noise, Section 4(f), Section 6(f), and environmental justice, were not relevant to the ASCM projects and are unlikely to be triggered by ASCM projects in the future. However, if it is determined that these topics need to be addressed in the CE document, the DEC should be able to conduct the required studies and agency coordination.

All of the above mentioned environmental compliance topics were addressed in the CE document completed for each ASCM project. All projects were cleared using the equivalent of C2 level of Categorical Exclusion document, which allowed environmental clearance to be handled at the District level.

Summary of Environmental Documentation

The environmental documentation needed for the eight ASCM projects conducted in Districts 2 and 3 was evaluated on a site by site basis, and was based on the anticipated impacts identified in the Stage 1 plans. The NEPA documentation and waterway permits that were needed for each project fell into the same general categories:

- Property Owner Notification Letters (Public Involvement)
- Environmental Site Assessment Screening Memorandum
- Section 106 Scoping Request Form
- Level 1 Ecological Survey Report (ESR)
- Floodplain Coordination
- Waterway Permit Determination
- Waterway Permit (if needed)

Generally, the various components of NEPA clearance can be conducted simultaneously. The general flow path and timing associated with environmental documentation and coordination is shown in Figure 1 below:

Generally, the various components of NEPA clearance can be conducted simultaneously.

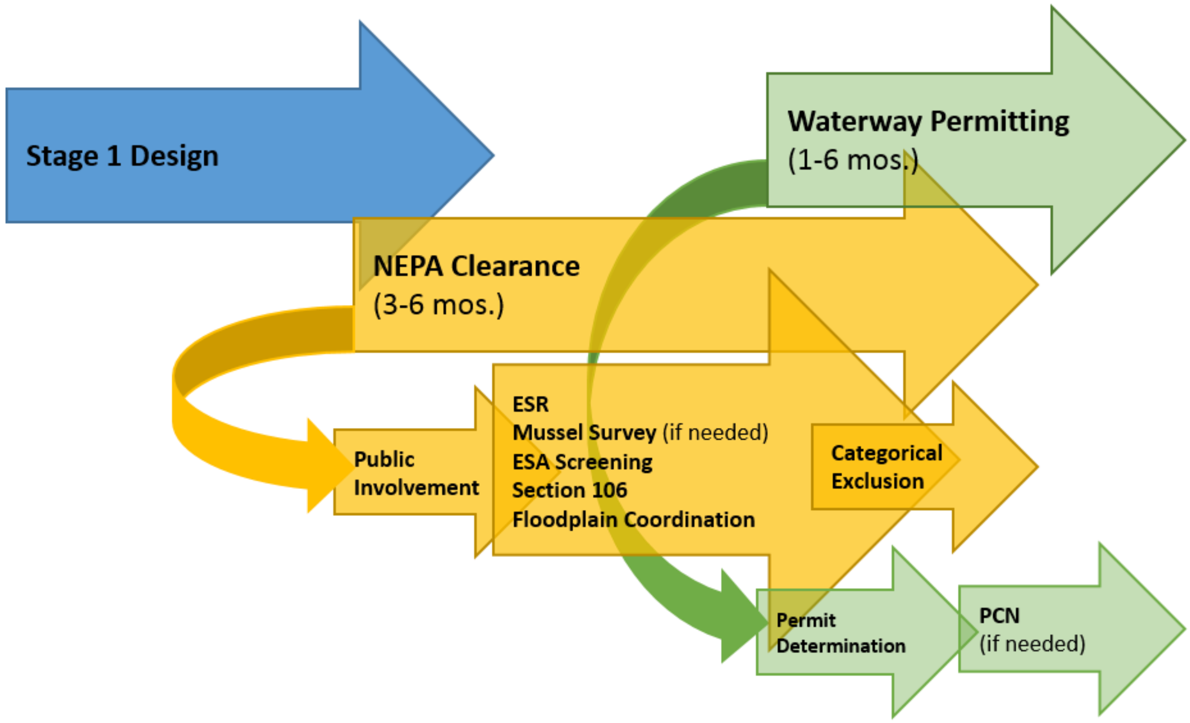


Figure 14 General Project Flow Path

Table 1 below shows a summary of the relevant environmental compliance requirements for the eight ASCM projects. Table 2 indicates the environmental documents prepared and the timing it took to obtain the necessary environmental approvals.

Table 1: Summary of ASCM Environmental Compliance Reviews

Site	Ecological and Waterway Permitting			Floodplains	Hazardous Materials	Cultural Resources	Farmland	Public Involvement
	Level 1 Ecological Survey Report		Waterway Permit Determination					
	Stream and Wetland Impacts	T&E Species (Habitat Present)*	Type of Permit Needed	Coordination Required	ESA Screening Memorandum	Section 106 Scoping Request Form		
ASD-603-06.14	Stream: Yes Wetland: No	No	NWP 27 & 33 with PCN	Yes (Special Flood Hazard Area)	ROW needed, no further ESA work required	Historic resources present, no impacts	Present, no impact	Standard ODOT PI/Notification Letter
MED-606-03.86	Stream: Yes Wetland: Yes	No	Non-Notifying RGP	No	No	No	No	Standard ODOT PI/Notification Letter
WAY-083-00.87	Stream: Yes Wetland: Yes	No	NWP 13 with PCN	Yes (Special Flood Hazard Area)	No	Historic resources present, no impacts	Present, no impact	Standard ODOT PI/Notification Letter
WAY-604-13.07	Stream: Yes Wetland: Yes	Mussels	Non-Notifying RGP	No	No	No	No	Standard ODOT PI/Notification Letter
FUL-020-09.14	Stream: Yes Wetland: No	Mussels	NWP 13 with PCN	Yes (Special Flood Hazard Area)	No	No	Present, no impact	Standard ODOT PI/Notification Letter
OTT-579-01.86	Stream: Yes Wetland: No	Mussels	Non-Notifying NWP 3	Yes (Special Flood Hazard Area)	No	No	No	Standard ODOT PI/Notification Letter
SAN-006-14.03	Stream: Yes Wetland: No	Mussels	None Needed	Yes (Special Flood Hazard Area)	No	No	No	Standard ODOT PI/Notification Letter
SAN-412-07.12	Stream: Yes Wetland: Yes	No	Non-Notifying RGP	Yes (Special Flood Hazard Area)	No	No	Present, no impact	Standard ODOT PI/Notification Letter

* Not including bats. ODOT-OES restricted all tree cutting between April 1 and September 30 regardless of the identification of bat habitat.

Table 2: Summary of ASCM Environmental Compliance Timing								
Site	**Public Involvement**	**ESA Screening**	**Section 106 (Cultural)**	**Ecological Reports**	**Floodplain**	**Permit Determination**	**Waterway Permit**	**NEPA Clearance Data**
ASD-603-06.14	Property Owner Notification Letter mailed 4/24/14	Submitted: 4/23/15, Approved: 6/10/15	Submitted: 5/4/15, Approved: 5/27/15	Submitted: 5/31/15, Agency Coordination completed 7/29/15	Compliance with Local Floodplain Administrator completed 4/8/15	Submitted: 4/30/15, Approved: 8/17/15 (use Ditch Cleanout Guidance)	Submitted: 8/15/15, Issued: 12/1/15	8/19/15
MED-606-03.86	Property Owner Notification Letter mailed 4/24/14	Documentation completed: 7/1/14	Submitted: 6/25/14, Approved: 7/9/14	Submitted: 6/2/14, Agency Coordination completed 8/1/14	Coordination not needed	Submitted: 9/19/14, Approved: 8/27/15 (with Special Provisions)	None Required (Non-Notifying RGP)	10/8/14
WAY-083-00.87	Property Owner Notification Letter mailed 4/24/14	Submitted: 3/24/15, Approved: 4/20/15	Submitted: 3/26/15, Approved: 3/30/15	Submitted: 5/29/15, Agency Coordination completed 9/17/15	Compliance with Local Floodplain Administrator completed 3/30/15	Submitted: 7/18/15, Approved: 7/27/15 (use Ditch Cleanout Guidance)	Submitted: 8/15/15, Issued: 8/18/15	8/19/15
WAY-604-13.07	Property Owner Notification Letter mailed 4/24/14	Documentation completed: 7/16/14	Submitted: 6/25/14, Approved: 7/9/14	Submitted: 6/30/14, Agency Coordination completed 9/19/14	Coordination not needed	Submitted: 8/14/14, Approved: 8/28/14 (with Special Provisions)	None Required (Non-Notifying RGP)	10/8/14
FUL-020-09.14	Property Owner Notification Letter mailed 4/24/14	Submitted: 3/24/15, Approved: 4/20/15	Submitted: 3/25/15, Approved: 3/30/15	Submitted: 4/30/15, Agency Coordination completed 8/4/15	Compliance with Local Floodplain Administrator completed 3/30/15	Submitted: 7/7/15, Approved: 7/27/15 (use Ditch Cleanout Guidance)	Submitted: 8/15/15, Issued: 9/8/15	8/19/15

Table 2: Summary of ASCM Environmental Compliance Timing

Site	Public Involvement	ESA Screening	Section 106 (Cultural)	Ecological Reports	Floodplain	Permit Determination	Waterway Permit	NEPA Clearance Data
OTT-579-01.86	Property Owner Notification Letter mailed 4/24/14	Documentation completed: 7/15/14	Submitted: 6/25/14, Approved: 7/9/14	Submitted: 6/30/14, Agency Coordination completed 10/7/14	Compliance with Local Floodplain Administrator completed 9/25/14	Submitted: 9/19/14, Approved: 9/26/14 (use Ditch Cleanout Guidance)	Non-Notifying NWP 3	10/6/14
SAN-006-14.03	Property Owner Notification Letter sent 4/24/14	Documentation completed: 7/1/14	Submitted: 6/25/14, Approved: 7/9/14	Submitted: 6/30/14, Agency Coordination completed 10/6/14	Compliance with Local Floodplain Administrator completed 9/24/14	Submitted: 9/19/14, Approved: 9/30/14 (use Ditch Cleanout Guidance)	None Needed	10/6/14
SAN-412-07.12	Property Owner Notification Letter mailed 4/24/14	Submitted: 3/24/15, Approved: 4/20/15	Submitted: 3/25/15, Approved: 3/30/15	Submitted: 4/13/15, Agency Coordination completed 6/1/15	Compliance with Local Floodplain Administrator completed 3/30/15	Submitted: 7/8/15, Approved: 7/27/15 (with Special Provisions)	Non-Notifying RGP	8/18/15

FLOODPLAIN PERMITTING

Floodplain permitting activities can vary in complexity depending on several factors, including whether the designated SFHA is an approximate 100-year (Zone A) floodplain, or a detailed (Zone AE) floodplain with a published flood profile and regulatory floodway. The nature of the work being proposed within the floodplain and the specifics of any local floodplain management regulations will also influence the complexity of the floodplain permitting process. ODOT is now implementing its authority under Ohio Revised Code 1521.13 as a State Agency to self-issue permits for compliance with local floodplain management regulations.

On a typical project, the DEC will determine the level of floodplain permitting required, obtain the necessary information from the District Hydraulic Engineer, and complete the 8-Step Decision-Making Process required for the NEPA document. For the ASCM projects, each site was evaluated to determine if it was within a SFHA and the appropriate documentation was produced by EMH&T and sent to local floodplain coordinators to demonstrate compliance. There were eight of the original sites which included a designated SFHA, but two of the sites (WOO-582-1241 and MED-042-0589) did not advance to the permitting phase. The remaining projects that had a SFHA designation included: FUL 020-0914, SAN-006-1403, SAN-412-0712, OTT-579-0186, ASD-603-0614 and WAY-083-0087. All of these projects were mapped with a Zone A floodplain. As such, the technical requirements for documenting compliance with NFIP standards and local floodplain management regulations are diminished.

In each case, we performed the tasks described below.

- We identified the designated floodplain coordinator for each local jurisdiction, and then contacted that person directly to confirm their role as the floodplain coordinator, and to discuss the permitting requirements. In most cases, the local coordinator was unaware of ODOT's self-permitting authority. Regardless, we indicated our intent to provide the minimum required documentation to demonstrate compliance with the local floodplain regulations.

- We prepared basic calculations documenting the hydraulic impact of the proposed channel improvements. These calculations determined the conveyance capacity of the channel under existing and proposed conditions and, in each case, determined no loss of conveyance. This approach is consistent with published guidance on the evaluation of projects within a designated Zone A floodplain.

- The results of the hydraulic calculations were summarized and provided to the local floodplain coordinator with a cover letter. An example of the documentation provided to the local floodplain coordinator regarding the hydraulic calculations is provided below. The submittal to the local floodplain coordinator also included an excerpt from the FIRM depicting the location of the project with respect to designated flood hazards.

Example of Hydraulic Calculation Documentation:

Purpose: Hydraulic calculations were performed to demonstrate the proposed bridge abutment slope protection will not result in a decrease in watercourse conveyance capacity.

Methodology: The calculations were performed using Manning's equation for open channel flow using the FlowMaster computation software. Information regarding the channel slope was extracted from the USGS StreamStats program. The model was executed to solve for the conveyance capacity with a flow elevation just below the bridge low chord elevation. Roughness coefficients used in the analysis are as shown in the table below.

Condition	Roughness coefficient
Existing stream channel and bare soil slope	0.035
Existing concrete bridge abutment walls	0.015
Proposed slope overlay	0.025

Results: The calculations estimated a watercourse conveyance capacity of 935 cubic feet per second (cfs) and 1,013 cfs for the existing and proposed conditions, respectively.

Conclusions: The hydraulic calculations have demonstrated the proposed bridge abutment

- NFIP regulations require specific documentation for watercourse alteration projects, cited in Section 60.3(b)(6) of the NFIP regulations. In this case, written notification to the State (floodplain) Coordinating Office is required, informing them of the project. In the State of Ohio, that office is the Ohio Department of Natural Resources (ODNR), Division of Soil and Water Resources, Floodplain Management Section. As such, for these projects, we provided written correspondence to this office informing them of the project, and advising them of our intent to also document NFIP compliance with the local floodplain coordinator. As an added measure, we provided a similar notification to the Federal Emergency Management Agency (FEMA) Region V office.

- We performed follow-up coordination with the local floodplain coordinator and documented that there were no outstanding questions or concerns. In some cases, the local floodplain coordinator issued a floodplain permit for the project; however, that is not necessary given ODOT's self-permitting authority. In other cases, we simply documented the final coordination to satisfy the NEPA compliance process.

The floodplain permitting process typically required no more than 4 weeks to complete, from the time the initial documentation was submitted to the local floodplain coordinator, to the time when we were able to document our follow-up coordination. This timeframe could vary significantly depending on the complexity of the technical analysis provided to the local floodplain coordinator and their internal process for evaluating the submittal; however, it is still the responsibility of the ODOT District environmental staff to ensure that the requirements for documenting compliance with NFIP compliance have been fulfilled.

SUMMARY

Projects utilizing the ASCM model described here will need to receive NEPA clearance and, in some cases, waterway permits to work in the stream channel. Project managers should engage their DEC as early as possible to begin the NEPA clearance process, which can take from 3 to 6 months, depending on the environmental impacts associated with the project. During this time, managers can move forward with detailed design and work with the DEC to obtain the necessary waterway permits.

Appendix B. Predictors of Channel Stability

An evaluation of the predictability of channel instabilities at bridge crossing

Introduction

Historically, bridge design practices have not given adequate consideration to stream channel morphology and the natural processes of channel aggradation, degradation and lateral migration. Furthermore, these processes are dynamic and apt to change over time as a function of land use changes in the watershed. In addition, the bridge structure, itself, can have a significant impact to channel morphology in the immediate vicinity of the structure. Most design practices do consider the potential for scour at the bridge and the need for engineered practices to harden the channel. However, there are still many instances of state and local agencies needing to perform remedial maintenance at bridges to protect against significant erosion and the deposition of sediment within the bridge opening. The latter case, aggradation, affects the designed carrying capacity of the bridge opening, increasing the potential for local flooding, and can pose a significant maintenance challenge in that it is difficult to remedy initially and will be a recurring problem if not properly addressed. Erosion of the channel bed, or degradation, is typically a longer-term, reach-wide or systemic erosional process that would occur whether or not the bridge was in place. Degradation is a naturally occurring process, but can be accelerated by human activities, such as construction, channel modifications, and urbanization. Both widening and lateral migration can also affect the bridge foundations, particularly in the floodplain or overbank areas as the channel widens or encroaches on piers with shallower foundations set back into the flood plain. Channel instabilities can act in combination with bridge scour to further undermine the safety of bridge foundations. The magnitude of instability that a channel experiences is a function of a variety of factors that include watershed characteristics, stream type, bank vegetation, bed and bank materials, and flow habit.

The primary purpose of this study objective was to determine if any readily available information, such as that contained in BMRP-191 or BR-86 reports, for example, could be used to distinguish between sites that typically require or do not require maintenance. If a variable or combination of variables could be identified that accurately predict which existing sites have been rated as unstable and are in need of maintenance then this knowledge could be applied to identify sites were maintenance will likely be necessary in the future. This would allow designers to take proactive steps during the design phases of bridge replacement projects to make design choices that incorporate countermeasures to avoid any instability that might be likely.

Methods

We utilized a GIS spatial database for all bridges in ODOT Districts 2 and 3 to identify sites with Bridge Inspection Scores which indicated that remedial measures were needed to protect the roadway and bridge system. The database was obtained directly from the ODOT GIS department in September 2012. First, we filtered the database to only include bridges owned by ODOT. For the purpose of this study the county, township, or municipality owned and operated structures were not considered. Sites that had scored below acceptable levels in one or more categories of the channel section of the Bridge Inspection Report (i.e. Channel Alignment, Channel Protection, and/or Channel Hydraulic Opening) were retained in their entirety. To include sites in the analysis that did not require maintenance we randomly selected (using the Microsoft Excel Database and the random number generator function) a subset of additional sites that did not require remedial maintenance from the database. Data from these structures were then gathered from documents and records in readily available data retrieval systems from state agencies and other natural resources database maintained by the federal government. Those data sources are described in the following sections.

Data Sources

Bridge Inventory Information Sheets

Basic data about the bridge structure, roadway, approach, and channel are included in the BMRP-191 Report. The reports were accessed during September through December 2013 downloaded at the following site: http://bmsreports.dot.state.oh.us/bmsreports/jsp/defaultFrames.jsp. Information extracted from the report including the Inventory Bridge Number, Structure File Number, Route Number, Bridge Skew(Item 45), Bridge Type, Number of Total Spans, Max Span (Item 65), Overall Length (Item 133), Channel Protection (Item 75), and Drainage Area (Item 152).

Bridge Inspection Reports

Results of the most recent bridge inspection report were gathered from the BR-86 reports downloaded from: http://bmsreports.dot.state.oh.us/bmsreports/jsp/defaultFrames.jsp. These reports were also accessed between September and December of 2013. The primary information of interest was contained in the Channel subsection of the report that recorded the inspectors' qualitative evaluation of channel condition including the adequacy of the channels Alignment (Item 51), Protection (Item 52), and Hydraulic Opening (Item 53).

StreamStats

Watershed characteristics are quite variable across the study region and we hypothesized that these physical characteristics may be useful variables to include it the stability analysis. The USGS StreamStats program (http://water.usgs.gov/osw/streamstats/ohio.html) was queried to quantify these variables. Data from the website was accessed between September and December of 2013. Watershed variables that were gleaned from watershed delineations of the upstream catchment to each of the structures included drainage area, slope, percent of the watershed in forest land cover, percent of the watershed in water and wetlands land cover, slope (using the USGS 10-85 method), streamflow variability index, mean annual precipitation, and the estimated peak discharge rate for the 2-, 10-, and 100-yr recurrence interval events.

NRCS Web Soil Survey (WSS) Data

The WSS is a spatial database of soil properties for the entire United States maintined by the USDA-NRCS. We used the mapping tool (http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx) to identify the soils in the vicinity of each of the structures included in the study. Once the soil types were identified we downloaded site reports including a Soils Map, Soil Physical Properties, and the Engineering Properties. From the Soils Map we were able to determine the primary soils associations and map unit symbol names. That information was then used to identify additional soils properties in the physical and engineering properties reports. Soil physical properties that were extracted from the report and used in the assessment were depth of soil horizons and their soil erosion factors, K_w and K_f. K_w is an indicator of the erodibility of the whole soil whereas K_f is an indicator of the erodibility of the fine-earth fraction of the soil. K_f includes soil particles <2-mm in size. K values vary from 0.02-0.69 with higher values indicating more erodible soils. Information from the engineering properties report included the liquid and plastic limits which describe the soil moisture content where the soils act as liquids or in a plastic state and soil texture.

Bridge Photos

Photos of each of the sites were downloaded to have a visual representation of the bridge and condition of the structure and channel. Bridge photos were downloaded from the Bridge Photos Management System (http://www2.dot.state.oh.us/sfn/) during September to December of 2013. No specific information from the photos was used in the statistical analysis, but the photos enhanced interpretation of the other databases, such as the Bridge Inventory Inspection reports.

Dependent Variables

The dependent variables in this study included all of the sites and watershed characteristics that describe the site. These variables include: 1) drainage area (DA; square miles or square kilometers), 2) channel slope (SLOPE; %), 3) mean annual precipitation (PREC; inches or centimeters), 4) stream variability index (SVI; dimensionless), 5) fraction of watershed in forested land use (FOREST; %), 6) fraction of watershed in water and wetlands land use (Water; %), 7) the 2-yr peak discharge rate (Q_2; cubic feet per second or cubic meters per second), 8) the 10-yr peak discharge rate (Q_{10}; cubic feet per second or cubic meters per second), 9) the 100-yr peak discharge rate (Q_{100}; cubic feet per second or cubic meters per second), 10) channel skew to the bridge opening (SKEW; degrees), 11) total number of spans (TOTSP; dimensionless), 12) maximum span width (MAXSP; feet or meters), 13) total length (LENGTH; feet or meters), 14) channel protection type (PROT), 15) minimum and maximum liquid limits (MINLL and MAXLL; %), 16) minimum and maximum plasticity limits (MINPL and MAXPL; %), 17) maximum erodibility of the whole soil (MAXKW; dimensionless), 18) maximum erodibility of the fine-earth fraction of the soil (MAXKF; dimensionless), 19) stream power for the 2-yr discharge rate (SP2; lbs/ft/sec or watts/m^2), 20) stream power for the 10-yr discharge rate (SP10; lbs/ft/sec or watts/m^2), 21) stream power for the 100-yr discharge rate (SP100; lbs/ft/sec or watts/m^2). Stream power was calculated by multiplying the discharge rate (e.g. Q2, Q10, or Q100) by channel slope for a site and is an indicator of stream energy and the ability of flow to erode soil. The raw data values are provided in Appendices A (in English Units) and B (in Metric Units).

Independent Variables

The predictor variables in this study are the bridge inspection scores including the channel alignment, channel protection, and channel hydraulic opening. Scores are based on a 1-4 scoring system along a gradient from good to poor in ascending order. Scores of 1 and 2 usually indicate that no maintenance is required whereas scores of 3 and 4 are in need of remedial work. Raw independent variable values are provided in Appendices A (in English Units) and B (in Metric Units).

Statistical Analysis

A number of parametric and non-parametric statistical methods were utilized to determine if relationships existed between the independent and dependent variables. We examined the dataset using forward stepwise multiple regression, discriminant analysis, and random forests analysis. Parametric techniques require that the input data are normally distributed and, if not, transformed to best approximate a Gaussian distribution. Raw data were plotted and visually assessed with a number of transformations (e.g. log, natural log, and square root) using histograms and probability plots. The transformation that resulted in the best normalization of the data was retained for analysis. The statistical techniques and important characteristics of the analysis are briefly described in the following sections.   Forward stepwise multiple regression and discriminant analysis were conducted using Systat 13 (Systat Software, Inc.). Random Forests analysis was conducted using the Predictive Modeler Software Suite (Salford Systems, 2013).

Forward Stepwise Multiple Regression

Multiple regression is a common statistical method to utilize when it is suspected that several independent variables interact to predict the value of an independent variable. The forward stepwise multiple regression procedure was used due to identify the most influential variables among the large number of predictor variables. Individual independent variables are entered into the model and tested using the Lagrange multiplier test and variables which meet threshold criteria are retained. P-values for variables to enter the regression were set to 0.15. The software then looks for combinations of multiple independent variables which describe the variability in the dependent variable. Only the models which described the maximum amount of variability, as indicated by the R^2 statistic, are reported in the results.

Discriminant Analysis

Discriminant analysis uses linear combinations of factors (i.e. independent variables) to separate two or more classes (i.e. dependent variable values). It is operationally similar to Principal Components Analysis (PCA) which describes variability of data, but discriminant analysis attempts to explain which dependent variables results in an optimal separation of the classes.

Random Forests

Random Forests is an ensemble learning technique that utilizes the principles of Classification and Regression Tree analysis to identify important variables that can accurately separate sites into their appropriate classes (i.e. stable or unstable). The approach is different than traditional CART analysis in that it utilizes resampling and bootstrapping techniques. This means that rather than using the entire dataset in the analysis a smaller number of sites and independent variables are randomly selected and the analysis is conducted. The procedure is then repeated hundreds or thousands of times. While each model that is produced may be weaker because only subsets of the data were used the entire ensemble of "weak" models from repeating the analysis actually produces a model that is very "strong". This allows that data to be evaluated in a number of ways in an unbiased means and does not require that any assumptions (e.g. normally distributed) regarding the distribution of the data are met a priori.

Results and Discussion

Data Transformations

The distributions of 14 of the 23 independent variables improved when a data transformation was applied. The transformation used for each variable is reported in Table 1. No data transformations were applied to the dependent variables.

Table 1. Data transformations used for independent variables.

Variable	Transformation	New Name	Variable	Transformation	New Name
DA	Log	LOGDA	LENGTH	Natural Log	LNLENGTH
SLOPE	Log	LOGSLOPE	PROT	None	PROT
PREC	None	PREC	MINLL	None	MINLL
SVI	None	SVI	MAXLL	None	MAXLL
FOREST	Square Root	SQRTFOREST	MINPL	Square Root	SQRTMINPL
WATER	Square Root	SQRTWATER	MAXPL	Square Root	SQRTMAXPL
Q_2	Log	LOGQ2	MAXKW	None	MAXKW
Q_{10}	Log	LOGQ10	MAXKF	None	MAXKF
Q_{100}	Log	LOGQ100	SP2	Natural Log	LNSP2
SKEW	None	SKEW	SP10	Natural Log	LNSP10
TOTSP	None	TOTSP	SP100	Natural Log	LNSP100
MAXSP	Log	LOGMAXSP			

Forward Stepwise Multiple Regression

Channel Alignment

Forward stepwise multiple regression of independent variables against the Channel Alignment score indicated that 5 independent variables were significant (Table 2; p-values<0.05). Sample size was n=189 and 16 sites were removed from the analysis due to incomplete or missing data (Table 3). Despite the presence of multiple significant independent variables the adjusted R^2 value was only 0.123, or in other words it only explained 12.3% of the variability in the Channel Alignment scores.

Table 2. Significant variables in forward stepwise multiple regression analysis of Channel Alignment.

Effect	Coefficient	Standard Error	Std. Coefficient	Tolerance	df	F-Ratio	p-Value
Constant							
SKEW	0.009	0.004	0.162	0.960	1	5.383	0.021
LNLENGTH	-0.217	0.060	-0.253	0.968	1	13.241	0.000
MINLL	0.019	0.008	0.191	0.717	1	5.592	0.019
SQRTMAXPL	-0.141	0.052	-0.199	0.868	1	7.355	0.007
MAXKF	3.323	1.010	0.255	0.775	1	10.829	0.001

Table 3. Statistical results of forward stepwise multiple regression analysis for Channel Alignment.

Dependent Variable	CHANAL
N	189
Multiple R	0.383
Squared Multiple R	0.147
Adjusted Squared Multiple R	0.123
Standard Error of Estimate	0.752

Channel Protection

A similar regression analysis was conducted for the Channel Protection scores. For the analysis of Channel Protection scores 3 variables were identified including SVI, LOGQ2, and SQRTMINPL (Table 4). Twenty-eight sites were eliminated from the analysis and the results indicate that only 7.6% (R^2 value) of the variability in Channel Protection scores were explained by the independent variables (Table 5).

Table 4. Significant variables in forward stepwise multiple regression of Channel Protection.

Effect	Coefficient	Standard Error	Std. Coefficient	Tolerance	t	p-Value
CONSTANT	2.469	0.691	0.000	.	3.572	0.000
SVI	-2.676	0.916	-0.215	0.953	-2.922	0.004
LOGQ2	0.295	0.122	0.176	0.971	2.410	0.017
SQRTMINPL	0.137	0.088	0.114	0.973	1.560	0.121

Table 5. Statistical results of forward stepwise multiple regression for Channel Protection.

Dependent Variable	CHANPRO
N	180
Multiple R	0.303
Squared Multiple R	0.092
Adjusted Squared Multiple R	0.076
Standard Error of Estimate	0.826

Channel Hydraulic Opening

Analysis of the Channel Hydraulic Opening score indicated that 3 independent variables were significant (Table 6) including PREC, LOGMAXSP, and MINLL. Sixteen cases were eliminated due to missing data and ultimately the regression only explained 6.3% of the variability in Channel Hydraulic Opening scores (Table 7).

Table 6. Significant variables in forward stepwise multiple regression of Channel Hydraulic Opening.

Effect	Coefficient	Standard Error	Std. Coefficient	Tolerance	t	p-Value
CONSTANT	-1.816	1.265	0.000	.	-1.435	0.153
PREC	0.101	0.032	0.243	0.829	3.136	0.002
LOGMAXSP	-0.314	0.161	-0.138	0.985	-1.946	0.053
MINLL	0.012	0.007	0.142	0.830	1.836	0.068

Table 7. Statistical results of forward stepwise multiple regression for Channel Hydraulic Opening.

Dependent Variable	CHANHO
N	189
Multiple R	0.279
Squared Multiple R	0.078
Adjusted Squared Multiple R	0.063
Standard Error of Estimate	0.648

Discriminant Analysis

Channel Alignment

Discriminant analysis was conducted using 189 sites with sufficient data to undertake the analysis. Channel Alignment scores only included values of 1, 2, and 3. Combinations of variables which maximally separated the scores were constructed along canonical axes (Figure 1). The core values for each group are highlighted by the circle with the corresponding color. The overall accuracy of the classification into groups was 47% (Table 8). Factors that influenced that canonical axes included LOGSLOPE, SKEW, LNLENGTH, and MAXKF.

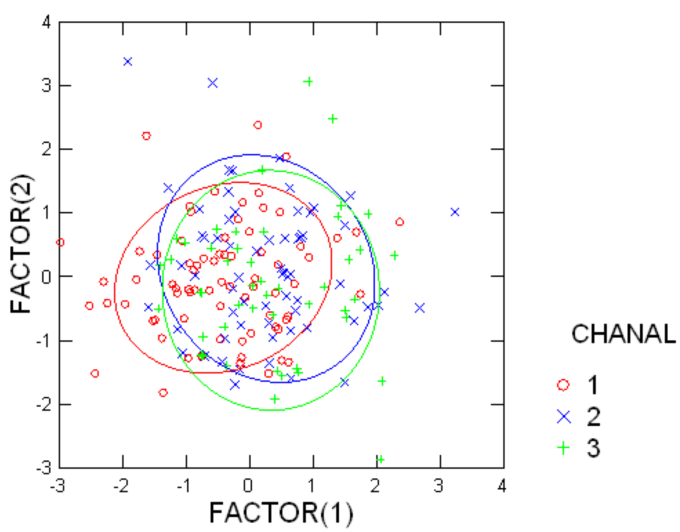


Figure 1. Canonical scores plot for the discriminant analysis of Channel Alignment (CHANAL) scores.

Table 8. Classification matrix for discriminant analysis of Channel Alignment scores.

	1	2	3	%correct
1	43	15	18	57
2	20	21	23	33
3	15	10	24	49
Total	78	46	65	**47**

Channel Protection

Discriminant analysis of Channel Protection scores (values varied from 1-4) indicated that 3 factors (PREC, SVI, and LOGTOTSP) were important for separating groups. Canonical score plots are provided in Figure 2. Overall the classification success rate was 40% (Table 9).

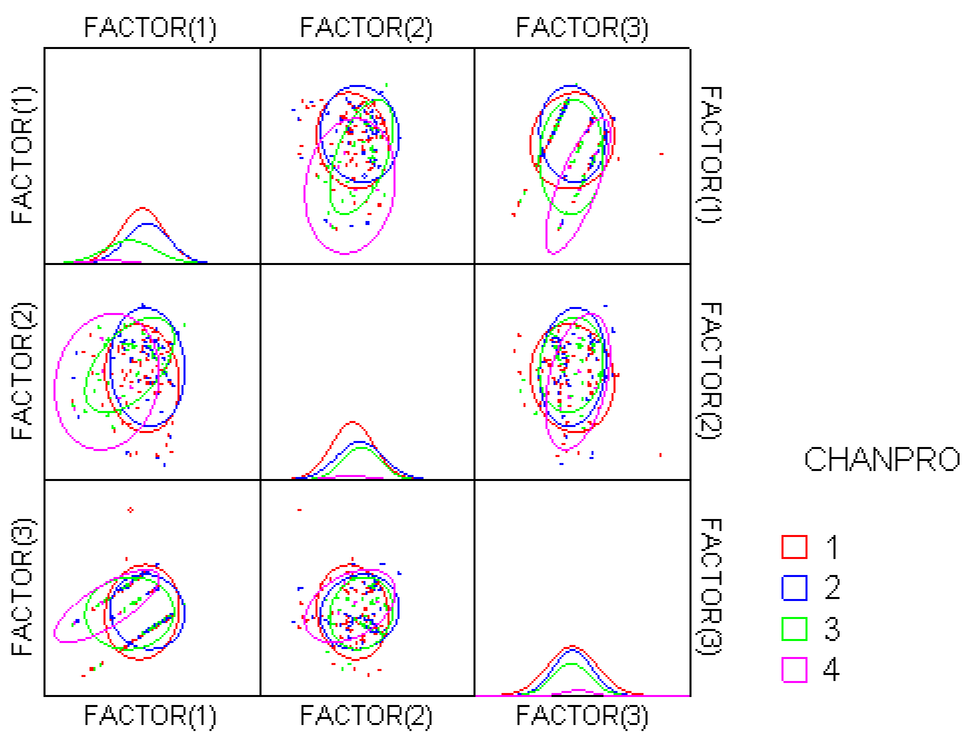


Figure 2. Canonical scores plot for discriminant analysis of Channel Protection (CHANPRO; 4 groups).

Table 9. Classification matrix for discriminant analysis of Channel Protection (CHANPRO; 4 groups).

	1	2	3	4	%correct
1	23	28	16	11	29
2	11	34	9	2	61
3	2	14	9	13	24
4	1	0	0	4	80
Total	37	76	34	30	**40**

A corresponding analysis was conducted, but in this case the Channel Protection scores were aggregated into 2 groups "No Maintenance Needed" (scores of 1 and 2) and "Maintenance Needed" (scores of 3 and 4). Classification success was 72% and factors involved in the construction of the single canonical axis included PREC, SVI, and LOGTOTSP which were the same variables identified in the 4 group discriminant analysis.

Table 10. Classification matrix for discriminant analysis of Channel Protection (CHANPRO; 2 groups).

	1	2	%correct
1	98	36	73
2	18	38	68
Total	116	74	**72**

Channel Hydraulic Opening

Discriminant analysis of Channel Hydraulic Opening scores identified 4 factors (PREC, LNLENGTH, MINLL, and MAXKW) in the construction of 3 canonical axes. Canonical score plots are provided in Figure 3. Overall prediction success rate to actual group membership was 49% (Table 11).

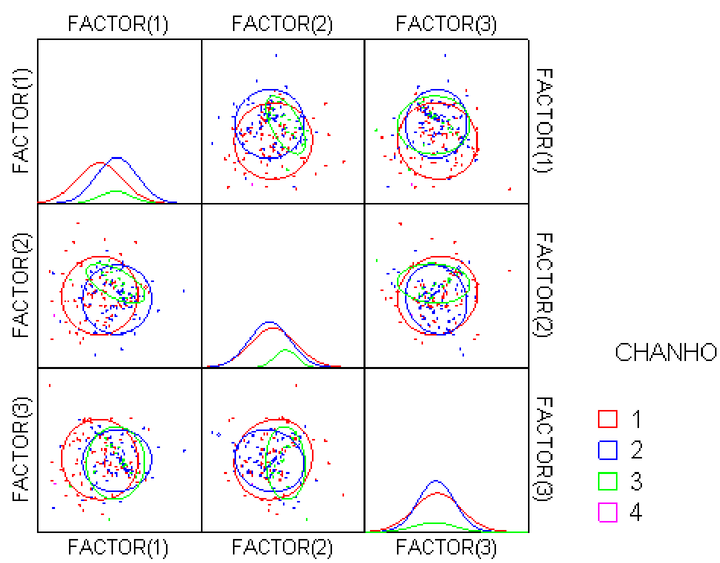


Figure 3. Canonical scores plot for discriminant analysis of Channel Hydraulic Opening.

Table 11. Classification matrix for discriminant analysis of Channel Hydraulic Opening.

	1	2	3	4	%correct
1	34	23	16	11	40
2	15	46	22	3	53
3	0	5	12	1	67
4	0	0	0	1	100
Total	49	74	50	16	**49**

Random Forests

Channel Alignment

The overall prediction success rate of the Random Forests analysis of Channel Alignment was 49.1% (Table 12 and Figure 4). Inspection of the Variable Importance Scores indicated that FOREST (100), DA (81.3), PROT (79.1), SLOPE (73.4), and WATER (70.3) were primary variables that led to successful classification of group membership.

Table 12. Prediction success rate for Random Forests analysis of Channel Alignment score.

Actual Class	Total Class	% Correct	1 (N=67)	2 (N=64)	3 (N=70)
1	82.00	51.22%	42	22	18
2	68.00	41.18%	16	28	24
3	51.00	54.90%	9	14	28
Total:	201.00				
Average:		49.10%			

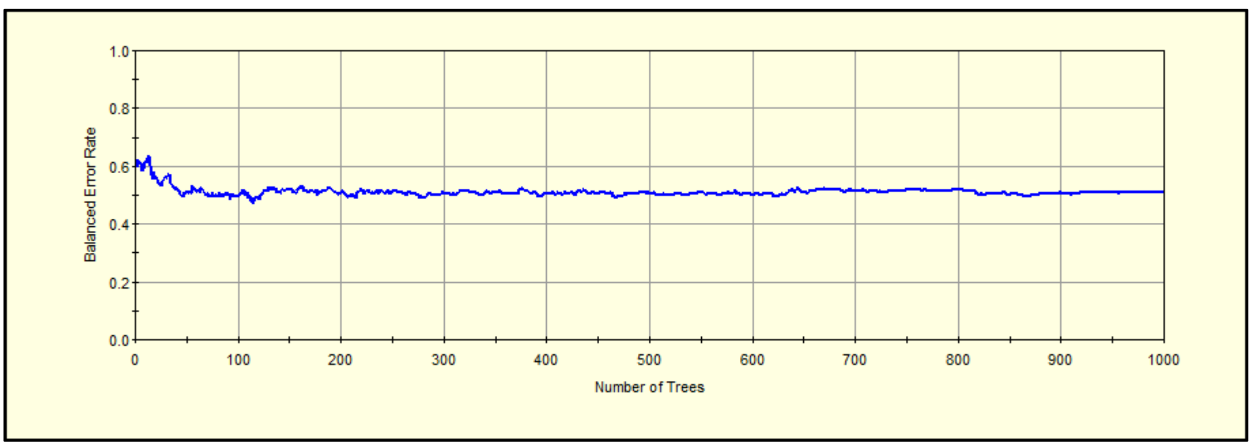


Figure 4. Graph of balanced error rate (expressed as a fraction of 1.0) over 1000 model runs.

Channel Protection

The overall prediction success rate of the Random Forests analysis of Channel Protection (4 groups) was 59.44% (Table 13 and Figure 5). Inspection of the Variable Importance Scores indicated that PROT (100), SLOPE (87.6), SP100 (70.0), MINPL (63.7), and DA (63.6) were primary variables that led to successful classification of group membership.

Table 13. Prediction success rate for Random Forests analysis of Channel Protection (4 groups) scores.

Actual Class	Total Class	% Correct	1(N=57)	2(N=47)	3(N=55)	4(N=30)
1	83.00	45.78%	38	19	18	8
2	60.00	38.33%	16	23	15	6
3	41.00	53.66%	3	5	22	11
4	5.00	100.00%	0	0	0	5
Total:	189.00					
Average:		59.44%				

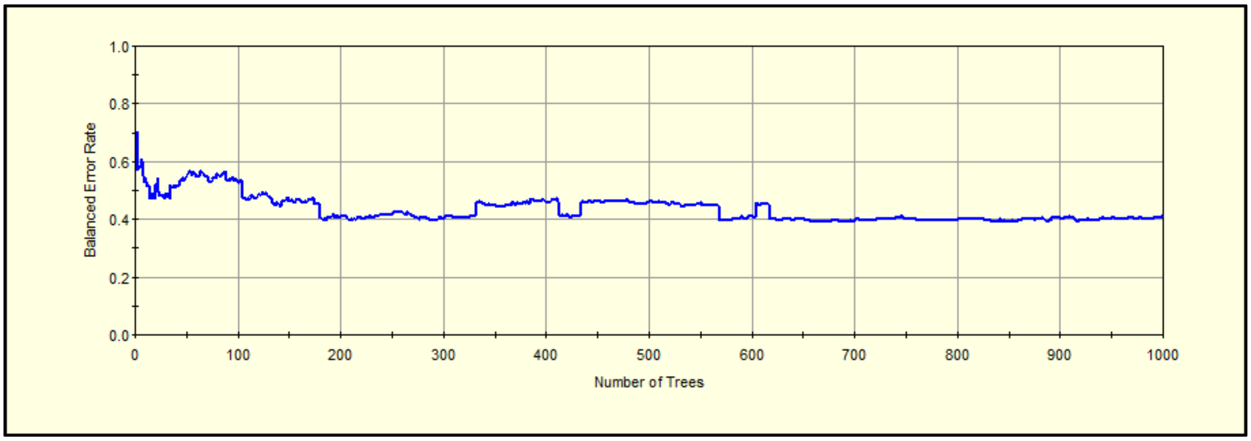


Figure 5. Graph of balanced error rate (expressed as a fraction of 1.0) over 1000 model runs.

For a similar analysis conducted on aggregated data of Channel Protection scores (Group 1 scored 1 and 2, Group 2 scored 3 and 4) the prediction success rate was 60.8% (Table 14 and Figure 5). Inspection of the Variable Importance Scores indicated that SVI (100), SLOPE (88.5), PREC (73.9), and DA (61.9) were primary variables that led to successful classification of group membership.

Table 14. Prediction success rate for Random Forests analysis of Channel Protection (2 groups) scores.

Actual Class	Total Class	% Correct	1(N=48)	2(N=154)
1	143.00	30.07%	43	100
2	59.00	91.53%	5	54
Total:	202.00			
Average:		60.80%		

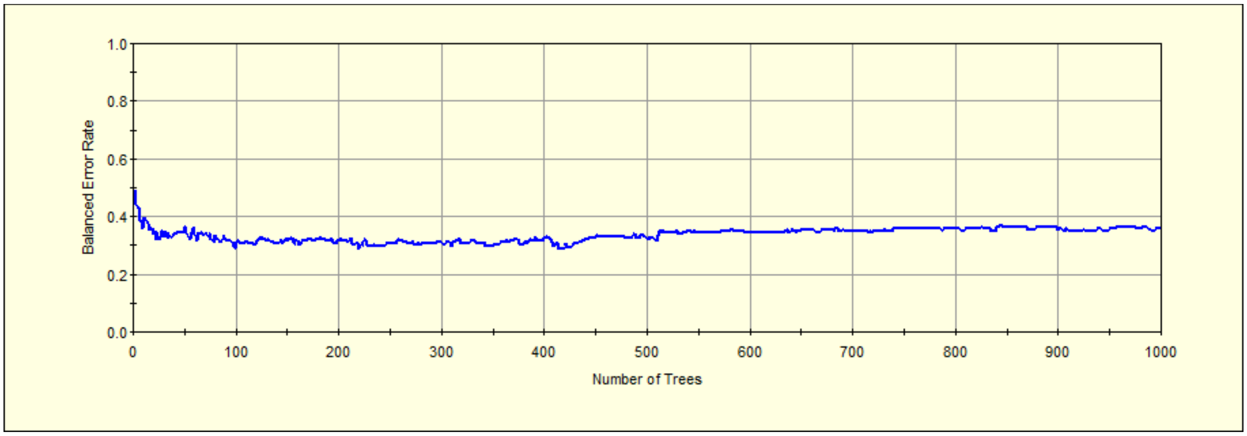


Figure 6. Graph of balanced error rate (expressed as a fraction of 1.0) over 1000 model runs.

Channel Hydraulic Opening

The overall prediction success rate of the Random Forests analysis of Channel Hydraulic Opening was 26.46% (Table 15 and Figure 7). Inspection of the Variable Importance Scores indicated that PREC (100), MAXPL (57.3), and SP100 (48.4) were primary variables that led to successful classification of group membership.

Table 15. Prediction success rate for Random Forests analysis of Channel Hydraulic Opening score.

Actual Class	Total Class	% Correct	1 (N=38)	2 (N=59)	3 (N=58)	4(N=46)
1	92	26.09%	24	16		
2	88	39.77%	10	35		
3	20	40.00%	3	8		
4	1	0.00%	1	0		
Total:	201					
Average:		**26.46%**				

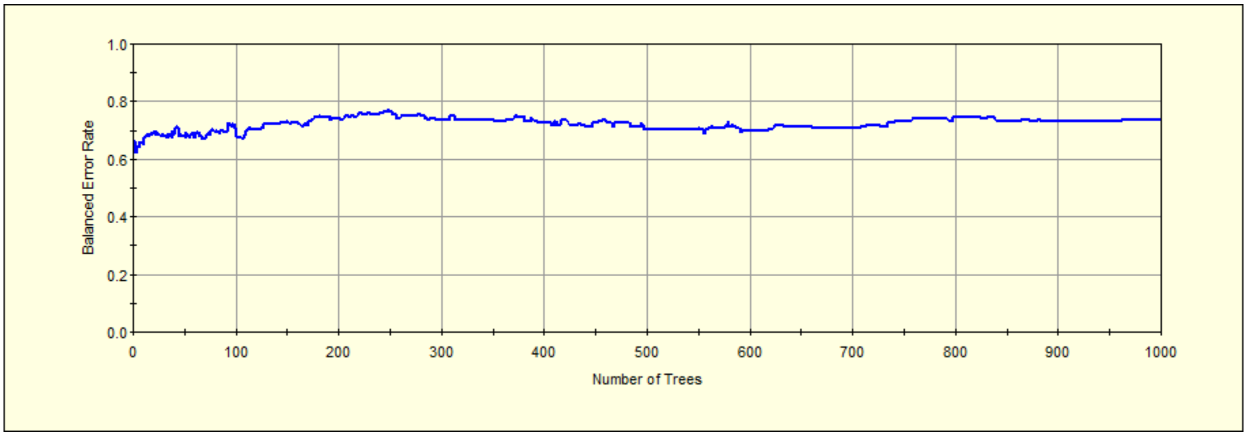


Figure 7. Graph of balanced error rate (expressed as a fraction of 1.0) over 1000 model runs.

Discussion and Summary

Interestingly, none of the forward stepwise multiple regressions provided model results that explained an appreciable amount of variation in the data (6.3%-12.3%) despite the presence of numerous significant predictor variables. The discriminant analysis results were better and indicated that the successful prediction of group membership varied from 40%-72% and in several cases was an improvement over expected success rates based solely on random chance. For example, in an analysis with 4 classes there is a 25% probability that the group will be successfully categorized by random chance alone. Similarly, groups with 3 and 2 classes would have 33% and 50% probability, respectively, of being accurately categorized. In the case of Channel Protection with 2 categories, which had a 72% prediction success rate, represents a 44% improvement in prediction success relative to random chance. So, despite extensive collection of data from these readily available databases we could not improve prediction success greatly relative to random chance. In fact, several of the discriminant analyses led to marginal increases in prediction success that were greater than random chance. Several factors may have contributed to the lack of predictability using these methods. First these approaches assume that the variables are linearly distributed and can be described by linear combinations of variables. While all of the variables were transformed to improve the normality assumption, many of the variables still did not meet the assumption of normality. Furthermore, the processes involved in scour and instability are non-linear and therefore not likely well described by methods using general linear models. Due to the manner in which Random Forests is implemented no data transformations or assumptions of linear relationships need to be met to undertake the analysis. Prediction success rates varied from 26%-61%.

Considering all of the methods employed and the broad range of independent variables utilized in the statistical analysis, it was surprising that none of the approaches yielded results with better prediction success. It seems highly likely that the collection of more site specific data would yield better relationships; however, that would defeat the purpose of using easily obtainable, readily available data for the analysis. For example, in our analysis we used estimates of slope and discharge to estimate stream power, which is an indicator of the erosive energy available at a site. However, this variable describes the energy of the stream regardless of the channel form. Perhaps a better indicator of stream energy would be unit stream power which describes the amount of erosive energy available per unit stream width. Given two streams, one narrow and one wide, with the exact same stream power the narrow stream would have a much higher unit stream power and thus more likely to be unstable. Unfortunately, the calculation of unit stream power would most likely require a site visit for data collection and a hydraulic analysis to determine the width of flow at a particular discharge rate of interest. This additional analysis, while useful, is beyond the scope of this study.

Since it was not possible to identify strong statistical relationships with readily available data for the study region, Dr. Peggy Johnson and her graduate student, Ruma Ashref, conducted a search of the peer reviewed literature to identify the most widely cited factors that lead to instability of channel in the vicinity of bridges. That review is provided in an accompanying document.

Appendices

Appendix A - Raw Data (English Units)

Site[1]	DA[2]	Slope[3]	Prec[4]	SVI[5]	Forest[6]	Water[7]	Q_2[8]	Q_{10}[9]	Q_{100}[10]
8500045	1.88	1.55	36.2	0.552	15.40	1.98	169	389	697
8500843	12.80	0.56	36.1	0.573	16.70	0.64	733	1600	2800
8503451	4.12	1.37	36.2	0.572	30.60	0.50	347	821	1500
8503559	0.88	2.54	36.1	0.571	24.80	0.08	121	310	594
8504024	0.85	1.03	36	0.598	6.27	0.04	74.1	171	294
8506302	31.80	0.31	36.1	0.581	27.20	1.63	1260	2540	4230
8506523	8.09	0.83	36.2	0.622	12.80	0.42	392	843	1400
8500215	136.00	0.15	36.3	0.572	24.50	1.91	3490	6550	10500
8500967	2.12	0.55	36.1	0.59	14.70	0.52	184	415	733
8502668	1.18	0.88	36	0.599	14.40	0.21	91	205	347
8503249	2.35	1.07	36.2	0.644	36.80	0.84	209	485	873
8504326	1.12	2.77	36.4	0.554	23.80	0.03	148	383	737
8504954	1.96	0.45	36.1	0.574	14.40	0.34	172	388	683
8505101	4.02	0.49	36.1	0.607	20.10	0.73	291	640	1120
8505314	0.56	2.99	36	0.571	20.70	0.21	84.9	221	423
2600277	206.00	0.13	35.1	0.495	17.20	5.16	2890	4040	6850
3501922	2.87	0.09	34	0.616	3.89	0.01	141	275	427
3502805	18.00	0.07	33	0.677	2.42	0.02	567	1060	1620
3503186	23.50	0.09	33.6	0.582	3.25	1.40	611	1090	1620
3902102	7.58	0.49	35.1	0.584	18.80	0.59	482	1060	1840
3902161	2.48	0.47	35	0.594	17.20	0.39	207	464	817
4703960	1.63	0.44	34.5	0.768	19.70	1.01	138	304	526
4705432	0.75	0.30	33.2	0.791	26.20	2.13	66	139	233
4706692	2.93	0.31	33.4	0.819	21.00	5.31	168	332	539
301183	6.26	1.13	36	0.564	27.20	0.21	488	865	1150
301299	20.40	0.39	36.1	0.565	20.00	0.99	970	2030	3470
302104	5.13	1.36	35.7	0.563	21.70	0.07	439	1060	1960
1700782	4.47	0.15	36.3	0.683	10.60	0.44	198	387	603
1702068	0.53	0.77	36.2	0.651	9.03	0.99	62.1	144	256
3902102	7.58	0.49	35.1	0.584	18.80	0.59	482	1060	1840
3902161	2.48	0.47	35	0.594	17.20	0.39	207	464	817
4703960	1.60	0.44	34.5	0.768	19.70	1.01	138	304	526
4705432	0.75	0.30	33.2	0.791	26.20	2.13	66	139	233
4706692	2.93	0.31	33.4	0.819	21.00	5.31	168	332	539
5200245	12.10	0.41	36	0.606	32.20	2.51	585	1200	2000
5200695	1.04	0.69	36.6	0.617	10.30	0.96	104	236	418
5200938	27.00	0.25	35.9	0.642	24.90	1.56	1120	2230	3680
5201292	11.40	0.46	36.1	0.643	43.10	0.97	632	1350	2330
5206154	1.18	0.74	36.9	0.631	29.90	0.12	90.4	202	341
5206286	1.35	1.72	37.5	0.602	24.20	0.76	146	353	649
5207266	1.86	1.44	38.8	0.584	32.50	2.17	164	375	667

Appendix A cont'd

Site[1]	DA[2]	Slope[3]	Prec[4]	SVI[5]	Forest[6]	Water[7]	Q_2[8]	Q_{10}[9]	Q_{100}[10]
5207800	0.41	1.27	36.7	0.61	16.70	1.71	51.3	121	216
5208130	1.65	1.79	38.5	0.586	46.90	0.80	171	411	757
300608	9.34	1.05	35.6	0.568	25.00	0.14	667	1560	2840
303945	13.00	0.76	36	0.565	27.70	0.41	795	1790	3180
480357	162.00	0.09	31.9	0.535	10.60	2.28	2590	4390	6380
3502236	6.21	0.12	33	0.655	1.60	0.01	265	521	814
3532631	24.20	0.10	33.6	0.596	3.21	1.36	630	1130	1680
3533514	1.20	0.17	34.8	0.58	8.06	2.68	60.6	115	173
3533654	7.96	0.17	34.6	0.572	1.97	0.68	304	586	907
4700333	10.60	0.39	33	0.778	28.70	5.35	470	922	1500
4707036	27.20	0.33	35.1	0.752	27.20	2.99	1040	2060	3380
5201209	14.10	0.52	36.1	0.642	40.20	1.56	721	1520	2600
5203589	0.12	3.33	37.5	0.606	18.80	1.93	22	55.8	104
5207231	13.00	0.66	38.5	0.594	39.60	2.89	645	1350	2290
5243165	16.30	0.37	35.9	0.664	26.60	1.34	786	1630	2760
7000367	2.80	1.05	36.2	0.533	35.40	5.35	190	404	689
7403933	44.00	0.12	34.7	0.64	4.12	0.61	110	2030	3090
8501505	0.58	1.22	36.1	0.586	6.68	0.30	76.6	187	345
8502447	1.29	1.42	36.1	0.603	11.50	0.48	100	228	391
8504997	0.58	1.22	36.1	0.586	6.68	0.30	76.6	187	345
8600910	4.08	0.39	33.7	0.576	20.80	3.26	170	327	506
8601909	4.89	0.20	33.9	0.541	4.96	1.38	200	386	594
8634270	6.17	0.41	33.9	0.562	5.67	1.09	269	543	865
8703426	95.30	0.06	33	0.51	3.01	0.67	2610	4810	7610
8705399	9.16	0.06	31.5	0.61	1.77	0.88	290	520	768
8500045	1.88	1.55	36.2	0.552	15.40	1.98	169	389	697
7402236	2.31	0.33	35.9	0.692	6.41	0.35	132	275	444
7402732	8.01	0.20	35.2	0.658	5.48	0.52	319	627	981
7402139	13.20	0.15	35.9	0.656	10.60	0.79	441	836	1280
7401388	3.90	0.24	35.2	0.602	9.38	1.30	245	506	845
8600031	1.17	0.54	33.5	0.662	4.75	0.95	77.6	164	267
8600694	64.30	0.05	34	0.584	3.67	1.90	1200	2020	2890
8600996	24.90	0.16	34.9	0.538	20.10	5.82	563	969	1400
8602905	1.27	0.53	33.5	0.622	10.70	1.58	78.4	162	261
8603219	108.00	0.13	35.3	0.532	21.30	7.02	1660	2720	3860
8603243	15.10	0.22	35	0.52	27.10	8.12	379	659	958
8700397	35.60	0.03	37.2	0.675	3.27	0.77	777	1320	1890
8702012	11.70	0.07	31.3	0.592	4.08	2.47	317	548	790
8702284	5.65	0.04	32.3	0.654	4.31	0.58	197	354	520
8702853	14.70	0.13	31.4	0.572	5.99	1.85	429	779	1160
8706069	2.07	0.06	32.9	0.706	1.21	0.00	102	195	297
8707146	30.10	0.05	31.7	0.633	1.42	0.62	734	1290	1890

Appendix A cont'd

Site[1]	DA[2]	Slope[3]	Prec[4]	SVI[5]	Forest[6]	Water[7]	Q_2[8]	Q_{10}[9]	Q_{100}[10]
7007027	6.16	0.76	37	0.62	14.60	1.05	415	921	1620
7007299	6.32	0.47	37	0.609	23.10	1.51	383	814	1390
7007191	1.12	0.91	36.6	0.592	30.00	1.27	111	254	451
7007051	76.00	0.25	36.1	0.544	35.30	1.87	2380	4640	7620
7006268	0.94	1.51	36.1	0.539	44.20	0.56	111	269	496
7004591	1.86	1.30	36.1	0.538	48.50	0.36	189	455	836
7002165	9.64	0.77	36.2	0.515	25.80	1.97	549	1180	2050
7000847	2.24	0.61	36.6	0.574	13.20	1.17	182	403	704
7000243	115.00	0.14	36.3	0.555	35.20	2.53	2920	5390	8540
4800451	46.20	0.06	31.2	0.607	3.54	1.40	981	1690	2460
4800699	8.13	0.13	31.7	0.538	40.70	14.40	199	326	456
4801490	4.69	0.20	31.4	0.56	13.30	1.09	198	383	592
4802667	194.00	0.06	32.1	0.56	17.60	4.45	2530	4020	5590
6200036	44.60	0.07	31.2	0.613	3.68	1.25	974	1700	2480
6201865	33.30	0.06	31.2	0.602	4.11	1.40	759	1310	1910
7203012	30.70	0.18	35.1	0.646	3.92	0.27	921	1780	2770
7200242	35.10	0.11	33.7	0.646	4.24	1.19	872	1580	2360
7200935	4.95	0.23	34	0.65	6.56	1.15	209	407	632
7201117	43.20	0.12	33.6	0.647	4.36	1.11	1040	1890	2840
7201206	15.60	0.16	32.6	0.602	10.70	0.88	708	1420	2340
5238420	0.38	4.32	37	0.605	23.80	0.65	43.8	103	194
4800524	1.79	0.15	32	0.48	2.53	0.62	94.6	186	289
4703189	67.20	0.19	35	0.708	30.50	1.81	2090	4010	6510
7003129	3.46	0.50	36.5	0.616	9.82	1.00	252	551	955
3536157	2.78	0.20	34.7	0.57	1.56	1.68	126	243	373
7202164	12.70	0.26	35	0.642	6.12	0.76	459	899	1410
4802098	190.00	0.05	32.1	0.551	17.90	4.53	2470	3910	5420
8601925	2.93	0.20	34.1	0.535	18.10	4.30	115	212	316
5242088	0.74	0.62	35.4	0.663	23.30	0.42	83.3	194	346
7005075	11.60	0.82	36.6	0.531	51.70	0.74	706	1580	2800
5207622	1.18	0.48	34.8	0.716	16.50	0.41	116	264	465
5242428	0.62	0.74	36.6	0.634	28.90	2.08	64.3	144	251
5205476	1.09	2.31	37.4	0.596	24.40	1.51	84.7	193	330
7242298	1260.00	0.07	36	0.645	9.25	1.08	13300	22200	32100
3503542	4.10	0.05	33	0.673	1.55	0.00	170	317	477
6200184	9.59	0.03	31.2	0.632	3.63	2.44	250	416	585
3501345	2.69	0.14	34.2	0.589	0.81	0.28	134	266	414
302341	1.71	1.91	35.9	0.552	23.10	0.06	195	490	924
1702084	3.65	0.62	36.3	0.649	14.10	0.41	203	435	718
1702297	0.23	0.89	36.5	0.663	12.20	0.00	26.5	62.1	107
1702416	2.36	0.42	36.2	0.652	18.30	0.31	198	443	778
1702424	2.34	0.43	36.2	0.653	18.30	0.31	197	443	779

Appendix A cont'd

Site[1]	DA[2]	Slope[3]	Prec[4]	SVI[5]	Forest[6]	Water[7]	Q_2[8]	Q_{10}[9]	Q_{100}[10]
1702998	0.18	0.30	36.1	0.694	0.00	0.00	19.1	41.9	68.9
1703633	1.39	0.77	36.2	0.667	12.90	0.62	96.2	210	349
1703862	4.75	0.17	36.3	0.668	6.75	0.40	211	416	650
1703870	12.00	0.33	36.5	0.665	11.20	0.40	472	955	1530
2204878	6.56	0.54	34	0.724	34.70	5.26	338	684	1130
3901831	87.60	0.24	36.9	0.606	16.80	1.17	2780	5500	9100
3902439	29.70	0.20	35.8	0.582	10.50	0.92	1200	2410	4010
4706064	1.30	0.94	35.4	0.648	5.11	0.78	131	304	546
5200938	28.00	0.25	35.9	0.642	24.90	1.56	1120	2230	3680
5201497	0.87	1.10	36.2	0.639	38.50	0.88	68.2	152	255
5201586	1.90	1.02	36.4	0.638	31.90	2.64	109	229	372
5201837	2.83	1.30	37.1	0.599	20.80	1.22	169	369	616
5205174	1.72	1.00	36.2	0.646	34.20	2.72	143	316	551
5205654	2.97	1.13	38.2	0.592	41.10	1.86	233	524	926
5206928	3.98	0.83	35.1	0.673	32.00	0.57	314	719	1290
7002521	66.70	0.27	36.2	0.543	33.40	2.01	2150	4220	6930
7003595	37.90	0.46	36.7	0.572	26.30	0.34	1730	3720	6470
7004966	6.49	1.02	38.4	0.521	55.70	0.41	481	1120	2020
7005245	0.63	1.07	36.7	0.584	7.42	0.36	79.6	192	352
7005369	2.24	0.61	36.6	0.574	13.20	1.17	182	404	704
7006691	12.70	0.41	36.3	0.561	19.80	1.20	662	1390	2370
7006845	35.80	0.50	36.7	0.574	26.50	0.32	1670	3630	6340
7006934	0.38	3.28	36.6	0.568	54.30	0.09	64.8	171	332
7007280	1.16	0.49	36.9	0.595	9.84	0.94	108	241	420
7007299	6.32	0.47	37	0.609	23.10	1.51	383	814	1390
8500118	1.96	1.48	36	0.558	21.90	0.23	204	498	924
8500193	4.26	1.16	35.9	0.567	20.90	0.52	348	814	1480
8501629	2.15	1.79	36	0.571	21.10	3.41	177	401	710
8501653	2.15	1.79	36	0.571	21.10	3.41	177	401	710
8502331	0.27	1.73	36	0.6	8.80	0.26	31.4	75.2	131
8502471	1.61	0.87	36.1	0.608	15.20	0.28	163	384	696
8504059	5.90	0.77	36.1	0.58	10.40	0.45	303	650	1080
8504350	6.29	1.31	36	0.559	20.50	0.38	487	1150	2100
8505160	51.30	0.41	36	0.574	16.40	0.58	2090	4390	7550
8505314	0.56	2.99	36	0.571	20.70	0.21	84.9	221	423
8505411	0.13	4.24	36	0.573	74.90	0.53	27.3	73.1	142
8505942	10.10	0.30	36.1	0.595	6.03	0.37	410	828	1320
8505977	3.57	0.56	36.1	0.608	7.97	0.17	204	441	730
8506248	2.97	0.63	36.6	0.59	31.20	3.14	142	284	449
8506337	3.19	0.81	36.1	0.583	17.90	0.65	261	598	1070
2203332	4.90	0.26	34.4	0.622	19.90	3.19	264	525	858
1700391	0.28	0.58	36.4	0.66	1.73	0.37	27.6	61.5	102

Appendix A cont'd

Site[1]	DA[2]	Slope[3]	Prec[4]	SVI[5]	Forest[6]	Water[7]	Q_2[8]	Q_{10}[9]	Q_{100}[10]
5205263	1.66	0.71	35.7	0.663	23.20	0.65	155	354	630
2600374	5.26	0.08	32.9	0.461	3.20	1.29	188	342	507
4703758	0.21	0.43	34.2	0.806	20.50	1.22	27.5	62	108
5246520	1.33	0.59	35.3	0.675	24.40	0.88	124	279	491
7003188	3.78	0.16	36.6	0.605	3.99	0.96	233	475	786
4706250	419.00	0.14	35	0.831	27.10	2.42	8040	14600	23000
8705909	21.60	0.07	31.3	0.593	2.71	1.06	573	1020	1510
4705882	4.00	0.80	35.4	0.649	26.40	0.47	318	729	1300
3534243	9.94	0.09	33	0.644	1.94	0.01	367	703	1080
8504318	4.20	1.70	36.8	0.55	20.80	2.88	304	683	1210
8706158	18.60	0.02	32.9	0.714	2.76	1.42	427	705	989
7403372	0.95	0.52	36.1	0.636	1.87	0.07	73.6	162	270
7201990	6.06	0.21	34.1	0.645	2.17	0.19	270	542	860
304395	3.83	0.72	36	0.622	20.90	1.11	283	630	1110
8705224	1.38	0.05	31.7	0.655	3.16	1.21	63.5	115	169
5233569	5.59	0.42	34.8	0.715	17.90	0.72	368	799	1380
300454	3.78	1.53	35.7	0.563	20.90	0.06	352	859	1600
5206375	0.37	1.68	37.8	0.595	13.00	1.69	34.7	78.4	132
8636974	31.70	0.14	33.9	0.588	11.60	3.80	713	1240	1810
1700464	1.09	0.64	36.2	0.673	7.17	0.03	120	284	515
4702476	1.02	0.49	34.6	0.776	35.40	1.78	91.4	199	342
3533336	10.10	0.21	34.5	0.572	2.75	0.78	374	726	1130
7001819	1.23	0.87	36.3	0.565	41.90	1.63	115	260	459
3900347	0.18	0.33	35.1	0.632	16.10	0.49	25.4	58	101
3500063	1.70	0.16	34.5	0.561	1.13	1.02	88.4	173	266
4805798	0.15	0.33	31.2	0.564	2.09	0.93	14.8	31.4	50.4
8502099	1.35	0.81	36	0.595	13.90	0.57	135	315	564
8706271	18.80	0.14	33.6	0.711	2.14	0.73	579	1090	1670
5236339	0.56	1.48	36.8	0.631	28.60	0.19	54.8	129	224
8602611	3.97	0.12	34	0.564	1.21	0.52	173	334	514
4774485	2.80	0.09	34.1	0.819	35.90	8.08	128	230	348
5244579	67.10	0.34	37.2	0.622	37.70	2.78	2130	4160	6820
5248760	0.76	1.55	37	0.61	13.60	0.05	71.6	170	296
5206871	113.00	0.25	36.3	0.673	34.70	2.34	3140	6040	9820
4701674	1.09	0.24	34.1	0.784	36.60	5.55	75	148	238
5205387	1.30	0.59	35.3	0.694	19.20	0.48	127	292	519
5242851	0.15	1.21	36.4	0.645	13.30	1.09	24.5	59.3	109
4703510	10.70	0.42	33	0.775	28.50	5.31	478	942	1540

Appendix A cont'd

Site[1]	Skew[11]	TotSp[12]	MaxSp[13]	Length[14]	Prot[15]	MinLL[16]	MaxLL[17]	MinPL[18]	MaxPL[19]
8500045	10	1	16	18	GRASS	25	30	5	9
8500843	30	2	12	25	CONCRETE	25	27.5	4	5
8503451	0	2	20	44	GRASS	25	27.5	4	5
8503559	0	1	64	65	RIP RAP	25	30	5	9
8504024	30	1	20	22	GRASS	25	30	5	9
8506302	0	3	40	113	GRASS	25	27.5	4	5
8506523	5	1	65	66	RIP RAP	25	27.5	4	5
8500215	24	3	94	255	GRASS	25	30	3	7
8500967	0	1	14	16	GRASS	25	30	3	7
8502668	45	1	10	14	GRASS	25	30	3	7
8503249	21	1	10	12	GRASS	25	30	3	7
8504326	0	1	13	13	GRASS	30	41	3	9
8504954	30	1	14	14	GRASS	25	30	3	7
8505101	30	1	15	15	GRASS	25	30	3	7
8505314	34	2	8	18	GRASS	30	36	3	9
2600277	15	3	43	133	STONE	27.5	51.5	3.5	11
3501922	0	3	20	60	STONE	26	51.5	4	12.5
3502805	0	3	30	81	STONE	20	56.5	4	5
3503186	25	3	25	73	STONE	32.5	40	4	6
3902102	21	1	19	22	GRASS	25	27.5	4	5
3902161	4	1	12	12	RIP RAP	25	30	3.5	7
4703960	0	1	14	14	GRASS	25	30	3.5	7
4705432	0	1	10	13	GRASS	25	30	3.5	7
4706692	0	1	16	19	GABIONS	26	51.5	4	11
301183	10	2	12	28	RIP RAP	29	36	2.5	5.5
301299	0	3	35	99	CONCRETE	29	36	2.5	5.5
302104	0	3	31	86	CONCRETE	27.5	35	4.5	5.5
1700782	30	1	32	36	GRASS	29	36	2.5	5.5
1702068	7	1	12	15	GRASS	29	36	2.5	5.5
3902102	21	1	19	22	GRASS	25	27.5	4	5
3902161	4	1	12	12	RIP RAP	25	30	3.5	7
4703960	0	1	14	16	GRASS	32.5	45	4.5	7
4705432	0	1	10	13	GRASS	25	30	3	7
4706692	0	1	16	19	GABIONS	26	51.5	4	11
5200245	45	2	17	34	CONCRETE	30	30	3	3
5200695	5	1	10	12	GRASS	17.5	30	3	5.5
5200938	0	3	53	148	RIP RAP		30		4
5201292	20	3	45	124	RIP RAP	15	30	3	4
5206154	15	1	19	22	CONCRETE	15	30	3	4
5206286	28	1	14	16	RIP RAP	30	30	3	3
5207266	36	1	11	11	GRASS	30	42.5	3	7

Appendix A cont'd

Site[1]	Skew[11]	TotSp[12]	MaxSp[13]	Length[14]	Prot[15]	MinLL[16]	MaxLL[17]	MinPL[18]	MaxPL[19]
5207800	30	2	6	16	GRASS	30	40	4	13
5208130	25	3	18	18	STONE	15	30	3	5
300608	0	3	40	113	RIP RAP	29	36	2.5	5.5
303945	25	3	45	122	STONE	27.5	36	2.5	5.5
480357	25	1	40	41	STONE	48.5	85	4	5
3502236	0	1	35	40	STONE	15	32.5	3.5	5
3532631	20	1	30	31	RIP RAP	15	32.5	3.5	5
3533514	0	1	20	20	STONE	26	51.5	4	11
3533654	25	1	52	62		15	32.5	3.5	5
4700333	10	2	17	37	CONCRETE	27.5	32.5	4.5	7
4707036	0	1	56	57	RIP RAP	25	27.5	4	5
5201209	30	3	75	200	RIP RAP	15	30	3	4
5203589	17	3	127	177		30	32.5	3	5
5207231	27	3	38	133	GRASS	30	30	3	3
5243165	47	2	53	106	RIP RAP				
7000367	17	1	14	14	RIP RAP	26.5	26.5	5	5
7403933	30	3	35	99	STONE	22.5	32.5	2	6.5
8501505	18	3	37	106		27.5	42.5	3.5	7.5
8502447	0	3	6	26		25	30	3	7
8504997	0	1	14	14	RIP RAP	25	30	3	7
8600910	8	1	31	34	RIP RAP	32.5	37.5	3.5	6
8601909	15	3	20	55	STONE	25	50	5	12.5
8634270	0	1	25	29		32.5	37.5	4	6
8703426	8	3	45	119	STONE	47	56	3.5	4.5
8705399	15	1	24	27	STONE	47	56	3.5	4.5
8500045	10	1	16	18	GRASS	25	30	5	9
7402236	0	2	10	23	STONE	29	36	5.5	10.5
7402732	30	3	25	73	STONE	29	50	5.5	27.5
7402139	30	3	24	67	GRASS	27.5	30	5	6
7401388	26	2	13	30	RIP RAP	30	50	9	27.5
8600031	0	2	9	22	RIP RAP	31.5	50	9	37
8600694	30	3	50	133	STONE	29	37.5	5.5	13
8600996	10	3	30	80	RIP RAP	15	36	3	10.5
8602905	6	1	11	13		29	53	5.5	35
8603219	38	3	65	172	STONE	15	32.5	5	5
8603243	15	3	30	80	STONE	32.5	51.5	7.5	29
8700397	30	3	52	138	STONE	30	40	10	20
8702012	38	1	20	23		50	55	27.5	30
8702284	30	1	14	15	RIP RAP	12.5	56	5	31.5
8702853	0	1	31	37	RIP RAP	30	40	12.5	30
8706069	0	3	40	106	RIP RAP	47	56	25	31.5
8707146	40	3	35	94	STONE	47	56	25	31.5

Appendix A cont'd

Site[1]	Skew[11]	TotSp[12]	MaxSp[13]	Length[14]	Prot[15]	MinLL[16]	MaxLL[17]	MinPL[18]	MaxPL[19]
7007027	23	1	32	34	GRASS	22.5	40	2	14.5
7007299	7	3	18	54	GRASS	22.5	32.5	6.5	10.5
7007191	0	1	10	12	GRASS	22.5	37.5	6.5	14
7007051	25	3	58	159	RIP RAP	10.5	32.5	5	11
7006268	0	1	12	14	RIP RAP	25	27.5	4	5
7004591	16	1	15	19	GRASS	25	27.5	4	5
7002165	0	2	14	28	STONE	25	27.5	4	5
7000847	0	1	17	17	GRASS	22.5	32.5	6.5	10.5
7000243	26	1	138	146	GRASS	22.5	32.5	6.5	10.5
4800451	30	3	35	93	CONCRETE	30	37.5	9	13
4800699	45	2	11	28		29	36	5.5	10.5
4801490	0	1	12	16		30	37.5	9	13
4802667	0	1	126	131	STONE				
6200036	0	3	30	80	CONCRETE	47.5	52.5	24	25
6201865	30	3	35	93	CONCRETE	32	60	12.5	31.5
7203012	55	1	46	54	STONE	35	55	14	26
7200242	36	2	65	133	STONE	22.5	32.5	7	10.5
7200935	39	2	124	254		52.5	52.5	25	27
7201117	15	3	35	93	STONE	22.5	32.5	7	10.5
7201206	5	1	31	33		30	35	9	11.5
5238420	10	3	20	52	STONE		30		14.5
4800524	42	1	23	27	RIP RAP	25	30	5	13
4703189	0	3	53	146	RIP RAP	27.5	30	7	7.5
7003129	23	2	38	79	GRASS	32.5	47.5	9	27.5
3536157	10	1	18	20	RIP RAP	26	51.5	6	29
7202164	0	1	20	22	STONE	22.5	50	2.5	27.5
4802098	1	3	49	151	RIP RAP				
8601925	30	1	16	19		34	51.5	7.5	29
5242088	35	1	6	10	GRASS	15	30	4	14.5
7005075	0	1	50	54	GRASS	22.5	32.5	4	10.5
5207622	30	1	12	12	RIP RAP	15	45	4	21
5242428	45	1	14	14	GRASS	30	47.5	7	26
5205476	0	1	12	14	RIP RAP	17.5	30	4	13
7242298	17	5	88	448	CONCRETE	25	51.5	5	29
3503542	0	1	12	15		47	56	25	31.5
6200184	30	3	30	80	STONE				
3501345	40	1	12	14	RIP RAP	30	56.5	12.5	31.5
302341	30	1	14	14	RIP RAP				
1702084	15	1	31	34	GRASS	29	36	5.5	10.5
1702297	30	2	6	14	GRASS	32.5	40	10	18
1702416	0	1	16	18	GRASS	29	36	5.5	10.5
1702424	0	1	12	14	RIP RAP	29	36	5.5	19.5

Appendix A cont'd

Site[1]	Skew[11]	TotSp[12]	MaxSp[13]	Length[14]	Prot[15]	MinLL[16]	MaxLL[17]	MinPL[18]	MaxPL[19]
1702998	12	2	57	119	RIP RAP	30	40	7	20
1703633	0	1	12	14	GRASS	29	36	5.5	10.5
1703862	0	1	10	12	GRASS	29	36	5.5	10.5
1703870	20	3	30	80	STONE	29	36	5.5	10.5
2204878	0	3	20	54	RIP RAP	25	30	5	9
3901831	0	3	52	145	RIP RAP	7.5	30	1	7
3902439	25	3	48	126	RIP RAP	7.5	7.5	1	2
4706064	0	1	16	18	GRASS	25	30	5	9
5200938	0	3	53	146	RIP RAP		30	4	14.5
5201497	0	1	18	21	RIP RAP	15	30	4	14.5
5201586	0	1	20	21	RIP RAP	15	30	4	14.5
5201837	30	3	20	61	STONE	15	30	4	14.5
5205174	3	1	10	12	GRASS		30	4	14.5
5205654	66	1	10	11	RIP RAP	15	30	4	14.5
5206928	0	1	18	20	RIP RAP	30	30	7	7
7002521	0	3	43	132	GABIONS	22.5	32.5	6.5	10.5
7003595	35	3	106	256	GRASS				
7004966	40	3	35	96	RIP RAP	17.5	32.5	5	11
7005245	15	1	20	24	RIP RAP	22.5	40	6.5	20
7005369	0	1	26	28	GRASS	22.5	32.5	6.5	10.5
7006691	30	3	43	119	GRASS	25	27.5	4	5
7006845	15	3	45	125	RIP RAP	25	27.5	4	5
7006934	0	1	12	14	GRASS	25	27.5	4	5
7007280	17	1	10	12	GRASS	32.5	47.5	9.5	20
7007299	7	3	18	54	GRASS	22.5	32.5	6.5	10.5
8500118	0	1	14	14	RIP RAP	22.5	42.5	4	22.5
8500193	23	1	40	43	GRASS		30	5	9
8501629	30	3	53	145	GRASS	25	41	5	21
8501653	30	3	53	145	GRASS	25	41	5	21
8502331	28	1	27	30	RIP RAP	15	32.5	3.5	9.5
8502471	26	1	10	10	RIP RAP	25	30	5	9
8504059	0	1	24	27	GRASS	25	30	5	9
8504350	25	3	25	73	STONE	37.5	47.5	13	22.5
8505160	5	3	55	152	RIP RAP	25	30	5	9
8505314	34	2	8	18	GRASS	37.5	47.5	13	22.5
8505411	0	1	9	11	GRASS	7.5	7.5	1	2
8505942	30	1	76	81	GRASS	15	30	4	9
8505977	10	3	23	67	RIP RAP	25	37	5	15.5
8506248	33	1	12	14	GRASS	25	30	5	9
8506337	30	1	30	32	GRASS	25	27.5	4	5
2203332	10	1	20	23	GRASS	25	30	5	9
1700391	7	3	18	48	GRASS	30	82.5	8.5	21

Appendix A cont'd

Site[1]	Skew[11]	TotSp[12]	MaxSp[13]	Length[14]	Prot[15]	MinLL[16]	MaxLL[17]	MinPL[18]	MaxPL[19]
5205263	0	1	10	12	STONE	30	30	7	7
2600374	39	1	42	44	STONE	27.5	51.5	6.5	29
4703758	10	1	16	19	GRASS	40	50	18.5	27.5
5246520	0	1	12	14	RIP RAP	15	30	4	14.5
7003188	10	1	14	16	RIP RAP	22.5	40	6.5	20
4706250	20	12	119	1421	RIP RAP	10	25	1	7
8705909	16	3	43	115	STONE				
4705882	6	3	18	54	RIP RAP	25	27.5	4	5
3534243	0	1	14	16	RIP RAP	34	51.5	15	29
8504318	0	1	45	46	RIP RAP	30	32.5	7	12.5
8706158	0	3	20	54	STONE	49.5	76.5	25	31.5
7403372	7	1	10	10	CONCRETE	31.5	43.5	8.5	20
7201990	36	1	18	20	RIP RAP	22.5	35	7	11.5
304395	15	1	4	45	RIP RAP	25	27.5	4	5
8705224	13	1	14	17		30	42.5	12.5	20
5233569	0	1	30	36		15	40	4	20
300454	30	3	45	128	STONE	25	27.5	4	5
5206375	8	2	4	12	GRASS	30	30	7	7
8636974	0	2	72	76	GRASS	32.5	37.5	9	13
1700464	0	1	20	21	RIP RAP	32.5	37.5	9	13
4702476	0	1	10	12	GRASS	25	30	5	9
3533336	45	1	37	39	STONE	10	50	2	27.5
7001819	3	1	12	14	CONCRETE	22.5	32.5	6.5	10.5
3900347	10	1	41	42	RIP RAP	25	27.5	4	5
3500063	0	2	11	25	CONCRETE	34	60	15	35
4805798	25	1	13	13					
8502099	39	1	12	12	CONCREETE	25	31.5	4	7.5
8706271	12	3	25	67	STONE	30	42.5	12.5	20
5236339	45	1	16	17	GRASS	15	30	4	14.5
8602611	30	1	16	16		29	36	5.5	10.5
4774485	17	2	7	17		32.5	50	9.5	27.5
5244579	30	3	55	147	RIP RAP	30	30	7	7
5248760	35	1	17	17	RIP RAP	30	30	7	7
5206871	25	3	63	172	GABIONS	15	30	4	14.5
4701674	0	1	13	13	RIP RAP	32.5	45	9.5	21
5205387	0	2	9	21	GRASS	30	40	7	20
5242851	0	2	10	10	GRASS	27.5	32.5	7	9.5
4703510	0	3	28	80	GRASS	27.5	30	7	7.5

Appendix A cont'd

Site[1]	$MaxK_w$[20]	$MaxK_f$[21]	SP_2[22]	SP_{10}[23]	SP_{100}[24]	ChanAl[25]	ChanPro[26]	ChanPro2[27]	ChanHO[28]
8500045	0.37	0.49	163.4	376.1	673.8	3	2	1	2
8500843	0.37	0.43	255.6	557.8	976.2	2	3	2	2
8503451	0.37	0.43	296.1	700.5	1279.9	3	3	2	3
8503559	0.37	0.49	191.6	490.9	940.7	3	3	2	3
8504024	0.37	0.49	47.7	110.1	189.4	3	3	2	3
8506302	0.37	0.43	242.7	489.3	814.9	3	3	2	3
8506523	0.37	0.43	203.8	438.4	728.0	3	3	2	2
8500215	0.37	0.49	334.9	628.6	1007.6	1	3	2	2
8500967	0.37	0.49	63.5	143.2	253.0	1	3	2	2
8502668	0.37	0.49	49.7	111.9	189.5	3	2	1	2
8503249	0.38	0.49	139.3	323.3	581.9	3	3	2	2
8504326	0.37	0.43	255.4	660.8	1271.7	1	3	2	3
8504954	0.37	0.49	48.2	108.7	191.3	3	3	2	2
8505101	0.37	0.49	89.8	197.4	345.5	3	3	2	1
8505314	0.37	0.37	158.5	412.7	789.9	3	3	2	2
2600277	0.28	0.55	233.3	326.1	552.9	2	3	2	1
3501922	0.37	0.37	8.3	16.2	25.1	1	3	2	2
3502805	0.32	0.37	26.3	49.1	75.1	1	3	2	1
3503186	0.37	0.43	35.2	62.9	93.4	3	3	2	1
3902102	0.37	0.43	146.4	322.0	558.9	2	1	1	1
3902161	0.37	0.49	60.9	136.5	240.4	3	1	1	2
4703960	0.37	0.49	38.2	84.1	145.5	3	1	1	2
4705432	0.37	0.49	12.2	25.6	43.0	3	1	1	2
4706692	0.37	0.37	32.8	64.7	105.1	3	2	1	2
301183	0.37	0.43	344.9	611.3	812.7	2	3	2	2
301299	0.37	0.43	236.2	494.2	844.8	3	3	2	3
302104	0.37	0.55	373.5	902.0	1667.8	3	1	1	3
1700782	0.37	0.43	19.0	37.1	57.8	3	2	1	3
1702068	0.37	0.43	29.9	69.3	123.1	3	1	1	3
3902102	0.37	0.43	146.4	322.0	558.9	2	1	1	1
3902161	0.37	0.49	60.9	136.5	240.4	3	1	1	2
4703960	0.37	0.49	38.2	84.1	145.5	3	1	1	2
4705432	0.37	0.49	12.2	25.6	43.0	3	1	1	2
4706692	0.37	0.37	32.8	64.7	105.1	3	2	1	2
5200245	0.37	0.43	150.0	307.7	512.9	2	3	2	3
5200695	0.37	0.37	44.9	101.8	180.3	3	2	1	2
5200938	0.32	0.55	173.4	345.2	569.7	3	3	2	3
5201292	0.37	0.49	182.2	389.3	671.9	3	3	2	2
5206154	0.37	0.49	41.9	93.6	158.0	3	1	1	2
5206286	0.37	0.43	156.7	378.8	696.4	3	2	1	2
5207266	0.43	0.43	147.1	336.4	598.3	3	3	2	2

Appendix A cont'd

Site[1]	MaxK$_w$[20]	MaxK$_f$[21]	SP$_2$[22]	SP$_{10}$[23]	SP$_{100}$[24]	ChanAl[25]	ChanPro[26]	ChanPro2[27]	ChanHO[28]
5207800	0.37	0.43	40.8	96.2	171.8	3	2	1	3
5208130	0.37	0.49	190.6	458.0	843.6	3	2	1	2
300608	0.37	0.43	435.9	1019.5	1856.1	1	1	1	1
303945	0.37	0.43	376.8	848.3	1507.0	2	1	1	1
480357	0.32	0.37	151.2	256.3	372.5	1	1	1	2
3502236	0.37	0.37	20.1	39.6	61.9	2	2	1	1
3532631	0.37	0.37	37.6	67.4	100.3	1	1	1	2
3533514	0.32	0.37	6.4	12.2	18.4	1	1	1	2
3533654	0.37	0.37	31.4	60.6	93.8				
4700333	0.37	0.37	115.0	225.6	367.0	2	1	1	2
4707036	0.37	0.43	215.1	426.0	699.0	1	1	1	1
5201209	0.37	0.49	234.3	494.0	845.0	1	1	1	1
5203589	0.49	0.55	45.8	116.1	216.3				
5207231	0.37	0.43	266.0	556.8	944.5	2	2	1	1
5243165			183.0	379.5	642.6	2	1	1	1
7000367	0.32	0.37	124.6	265.0	451.9	1	1	1	1
7403933	0.37	0.43	8.0	147.3	224.2	1	1	1	1
8501505	0.37	0.49	58.1	141.9	261.8			2	
8502447	0.37	0.49	88.6	202.1	346.6	2	2	1	2
8504997	0.37	0.49	58.1	141.9	261.8	2	1	1	2
8600910	0.37	0.43	41.0	78.8	122.0	1	1	1	1
8601909	0.37	0.55	25.5	49.3	75.8	1	1	1	1
8634270	0.37	0.43	68.7	138.6	220.8	1		2	1
8703426	0.32	0.37	98.7	181.9	287.8	1	2	1	1
8705399	0.32	0.37	10.7	19.1	28.2	2	1	1	1
8500045	0.37	0.49	163.4	376.1	673.8	3	2	1	2
7402236	0.37	0.43	26.8	55.9	90.3	3	1	1	3
7402732	0.37	0.43	40.0	78.5	122.9	2	4	2	1
7402139	0.32	0.43	42.5	80.6	123.4	3	1	1	3
7401388	0.43	0.43	36.2	74.8	124.8	3		2	2
8600031	0.43	0.43	26.0	54.9	89.3	3	1	1	2
8600694	0.37	0.43	40.4	68.0	97.3	1	4	2	2
8600996	0.37	0.43	55.0	94.7	136.8	1	3	2	1
8602905	0.37	0.43	25.9	53.4	86.1	3		2	1
8603219	0.32	0.32	130.5	213.8	303.4	1	3	2	1
8603243	0.37	0.43	52.9	91.9	133.6	1	4	2	1
8700397	0.32	0.43	15.2	25.9	37.1	3	2	1	1
8702012	0.32	0.32	13.0	22.4	32.3	3		2	1
8702284	0.32	0.37	5.2	9.4	13.8	2	3	2	1
8702853	0.32	0.43	34.3	62.2	92.7	2	3	2	4
8706069	0.32	0.37	3.6	6.8	10.4	1	3	2	1
8707146	0.32	0.37	22.4	39.3	57.6	3	3	2	3

Appendix A cont'd

Site[1]	$MaxK_w$[20]	$MaxK_f$[21]	SP_2[22]	SP_{10}[23]	SP_{100}[24]	ChanAl[25]	ChanPro[26]	ChanPro2[27]	ChanHO[28]
7007027	0.37	0.64	196.7	436.5	767.7	3	3	2	2
7007299	0.37	0.43	112.3	238.6	407.4	1	2	1	3
7007191	0.37	0.64	62.8	143.8	255.3	3	3	2	2
7007051	0.37	0.64	376.9	734.8	1206.7	3	2	1	1
7006268	0.37	0.43	104.6	253.4	467.2	2	3	2	2
7004591	0.37	0.43	153.2	368.9	677.8	2	3	2	2
7002165	0.37	0.43	264.7	569.0	988.5	2	3	2	2
7000847	0.37	0.43	69.3	153.4	267.9	3	2	1	3
7000243	0.37	0.43	255.0	470.7	745.9	3	2	1	3
4800451	0.37	0.43	37.9	65.3	95.1	1	3	2	2
4800699	0.37	0.43	16.6	27.2	38.0	2		2	1
4801490	0.37	0.43	24.1	46.6	72.1	3		2	1
4802667			88.5	140.6	195.5	1	3	2	1
6200036	0.28	0.28	40.2	70.1	102.3	1	4	2	2
6201865	0.43	0.43	28.9	49.9	72.7	1	3	2	1
7203012	0.32	0.37	101.1	195.4	304.1	3	1	1	2
7200242	0.37	0.43	61.6	111.7	166.8	2	4	2	1
7200935	0.28	0.28	29.4	57.2	88.9	2	3	2	1
7201117	0.37	0.43	79.3	144.1	216.5	1	3	2	1
7201206	0.37	0.43	70.5	141.5	233.1	3		2	1
5238420	0.32	0.55	118.0	277.5	522.7	1	1	1	1
4800524	0.43	0.43	8.8	17.2	26.7	2	1	1	2
4703189	0.32	0.43	243.8	467.7	759.4	1	1	1	1
7003129	0.37	0.43	78.0	170.6	295.7	2	1	1	2
3536157	0.32	0.37	15.9	30.7	47.2	1	1	1	1
7202164	0.37	0.43	73.8	144.5	226.6	1	2	1	2
4802098			82.3	130.3	180.6	1	2	1	1
8601925	0.32	0.32	14.1	26.1	38.8	2		2	1
5242088	0.37	0.49	32.0	74.5	132.9	2	1	1	1
7005075	0.37	0.55	362.1	810.4	1436.1	2	2	1	1
5207622	0.43	0.49	34.5	78.6	138.5	2	2	1	2
5242428	0.43	0.55	29.7	66.5	116.0	2	2	1	2
5205476	0.37	0.37	122.1	278.3	475.8	1	1	1	1
7242298	0.32	0.55	573.7	957.6	1384.7	1	1	1	1
3503542	0.32	0.37	4.9	9.2	13.9	1		2	1
6200184			5.3	8.8	12.4	2	2	1	1
3501345	0.37	0.37	11.6	22.9	35.7	1	1	1	1
302341			232.8	584.9	1102.9	1	1	1	2
1702084	0.37	0.43	78.0	167.1	275.8	2	2	1	2
1702297	0.28	0.32	14.7	34.3	59.2	2	2	1	3
1702416	0.37	0.43	51.5	115.2	202.3	2	2	1	2
1702424	0.37	0.43	52.8	118.8	209.0	1	1	1	2

Appendix A cont'd

Site[1]	MaxK$_w$[20]	MaxK$_f$[21]	SP$_2$[22]	SP$_{10}$[23]	SP$_{100}$[24]	ChanAl[25]	ChanPro[26]	ChanPro2[27]	ChanHO[28]
1702998	0.37	0.43	3.6	7.9	12.9	1	1	1	2
1703633	0.37	0.43	46.0	100.5	167.0	2	1	1	2
1703862	0.37	0.43	22.2	43.9	68.5	2	2	1	2
1703870	0.37	0.43	95.9	194.1	311.0	2	2	1	2
2204878	0.37	0.49	114.6	232.0	383.3	2	1	1	1
3901831	0.37	0.55	417.3	825.5	1365.8	1	1	1	1
3902439	0.37	0.37	153.2	307.6	511.8	2	1	1	2
4706064	0.37	0.49	76.5	177.5	318.8	2	2	1	1
5200938	0.32	0.55	173.4	345.2	569.7	3	3	2	3
5201497	0.37	0.49	46.9	104.5	175.4	1	1	1	2
5201586	0.37	0.49	69.7	146.4	237.8	1	1	1	2
5201837	0.37	0.49	137.4	300.0	500.9	2	1	1	2
5205174	0.32	0.55	89.2	197.2	343.8	2	2	1	2
5205654	0.37	0.49	163.6	367.8	650.1	2	2	1	2
5206928	0.37	0.43	162.5	372.2	667.8	1	2	1	1
7002521	0.37	0.43	368.4	723.2	1187.6	2	2	1	2
7003595			496.8	1068.3	1858.1	1	1	1	1
7004966	0.37	0.64	307.0	714.8	1289.1	2	2	1	2
7005245	0.37	0.43	53.1	128.0	234.6	2	2	1	2
7005369	0.37	0.43	69.5	154.2	268.7	2	2	1	2
7006691	0.37	0.43	167.4	351.5	599.4	2	2	1	1
7006845	0.37	0.43	521.0	1132.6	1978.1	2	2	1	2
7006934	0.37	0.43	132.5	349.6	678.8	2	2	1	1
7007280	0.37	0.43	32.9	73.5	128.1	2	2	1	1
7007299	0.37	0.43	112.3	238.6	407.4	1	2	1	2
8500118	0.37	0.43	188.5	460.2	853.9	2	2	1	1
8500193	0.37	0.55	252.9	591.6	1075.7	2	2	1	1
8501629	0.37	0.49	197.5	447.4	792.1	1	1	1	1
8501653	0.37	0.49	197.5	447.4	792.1	1	1	1	1
8502331	0.37	0.49	34.0	81.3	141.7	2	2	1	1
8502471	0.37	0.49	88.8	209.2	379.2	2	2	1	2
8504059	0.37	0.49	146.5	314.2	522.0	2	2	1	2
8504350	0.32	0.32	399.4	943.2	1722.4	2	2	1	2
8505160	0.37	0.49	536.0	1125.8	1936.2	2	2	1	2
8505314	0.32	0.32	158.5	412.7	789.9	3	3	2	2
8505411	0.37	0.37	72.3	193.5	375.9	2	2	1	2
8505942	0.37	0.55	76.6	154.6	246.5	2	2	1	2
8505977	0.43	0.55	71.6	154.8	256.2	1	1	1	1
8506248	0.37	0.49	55.5	111.1	175.6	1	1	1	1
8506337	0.37	0.43	132.6	303.9	543.8	2	2	1	2
2203332	0.37	0.49	42.4	84.4	137.9	2	2	1	2
1700391	0.43	0.43	10.0	22.4	37.1	1	1	1	2

Appendix A cont'd

Site[1]	$MaxK_w$[20]	$MaxK_f$[21]	SP_2[22]	SP_{10}[23]	SP_{100}[24]	ChanAl[25]	ChanPro[26]	ChanPro2[27]	ChanHO[28]
5205263	0.37	0.43	68.5	156.5	278.5	1	1	1	1
2600374	0.32	0.32	9.1	16.5	24.5	1	1	1	1
4703758	0.32	0.37	7.4	16.8	29.2	1	1	1	2
5246520	0.37	0.49	45.4	102.2	179.9	1	1	1	1
7003188	0.37	0.43	22.7	46.3	76.6	1	1	1	1
4706250	0.37	0.55	710.7	1290.6	2033.2	1	1	1	1
8705909			26.6	47.4	70.1	1	1	1	1
4705882	0.37	0.43	159.0	364.4	649.9	1	1	1	1
3534243	0.32	0.32	20.7	39.6	60.9	1	1	1	1
8504318	0.43	0.43	322.6	724.8	1284.1	1	1	1	1
8706158	0.32	0.37	6.4	10.6	14.8	1	1	1	2
7403372	0.37	0.37	24.0	52.8	88.1	1	1	1	1
7201990	0.37	0.43	34.8	69.8	110.8	1	1	1	1
304395	0.37	0.43	126.8	282.2	497.2	1	1	1	1
8705224	0.32	0.37	2.0	3.7	5.4	1		2	1
5233569	0.43	0.49	96.5	209.6	362.1	1		2	1
300454	0.37	0.43	335.3	818.2	1524.1	1	1	1	1
5206375	0.37	0.43	36.4	82.2	138.4	1	1	1	2
8636974	0.37	0.43	61.2	106.4	155.3	1	1	1	1
1700464	0.37	0.43	48.2	114.1	206.9	1	1	1	2
4702476	0.37	0.49	27.8	60.4	103.9	2	2	1	2
3533336	0.37	0.37	49.5	96.1	149.6	1	2	1	1
7001819	0.37	0.43	62.4	141.0	249.0	1	1	1	1
3900347	0.37	0.43	5.3	12.1	21.0	1	1	1	1
3500063	0.43	0.43	9.1	17.7	27.3	2	2	1	2
4805798			3.0	6.4	10.2				
8502099	0.37	0.43	68.4	159.7	285.9	1	1	1	1
8706271	0.32	0.37	52.2	98.3	150.6	1	1	1	1
5236339	0.37	0.49	50.6	119.2	207.0	1	1	1	1
8602611	0.37	0.43	13.2	25.5	39.2	1		2	1
4774485	0.43	0.43	7.0	12.6	19.0	2	2	1	2
5244579	0.37	0.43	445.6	870.2	1426.6	1	1	1	1
5248760	0.37	0.43	69.4	164.7	286.9	2	1	1	1
5206871	0.37	0.49	493.6	949.4	1543.5	1	1	1	1
4701674	0.43	0.43	11.4	22.6	36.3	1	1	1	2
5205387	0.43	0.43	47.0	108.0	192.0	2	2	1	2
5242851	0.37	0.37	18.5	44.9	82.4	1	1	1	2
4703510	0.32	0.43	124.8	246.0	402.2	2	2	1	1

Appendix B – Raw Data (Metric Units)

Site[1]	DA[2]	Slope[3]	Prec[4]	SVI[5]	Forest[6]	Water[7]	Q_2[8]	Q_{10}[9]	Q_{100}[10]
8500045	4.87	1.55	91.9	0.552	15.4	2.0	4.79	11.02	19.75
8500843	33.15	0.56	91.7	0.573	16.7	0.6	20.76	45.33	79.32
8503451	10.67	1.37	91.9	0.572	30.6	0.5	9.83	23.26	42.49
8503559	2.28	2.54	91.7	0.571	24.8	0.1	3.43	8.78	16.83
8504024	2.20	1.03	91.4	0.598	6.3	0.0	2.10	4.84	8.33
8506302	82.36	0.31	91.7	0.581	27.2	1.6	35.69	71.95	119.83
8506523	20.95	0.83	91.9	0.622	12.8	0.4	11.10	23.88	39.66
8500215	352.24	0.15	92.2	0.572	24.5	1.9	98.87	185.55	297.45
8500967	5.49	0.55	91.7	0.59	14.7	0.5	5.21	11.76	20.76
8502668	3.06	0.88	91.4	0.599	14.4	0.2	2.58	5.81	9.83
8503249	6.09	1.07	91.9	0.644	36.8	0.8	5.92	13.74	24.73
8504326	2.90	2.77	92.5	0.554	23.8	0.0	4.19	10.85	20.88
8504954	5.08	0.45	91.7	0.574	14.4	0.3	4.87	10.99	19.35
8505101	10.41	0.49	91.7	0.607	20.1	0.7	8.24	18.13	31.73
8505314	1.45	2.99	91.4	0.571	20.7	0.2	2.41	6.26	11.98
2600277	533.54	0.13	89.2	0.495	17.2	5.2	81.87	114.45	194.05
3501922	7.43	0.09	86.4	0.616	3.9	0.0	3.99	7.79	12.10
3502805	46.62	0.07	83.8	0.677	2.4	0.0	16.06	30.03	45.89
3503186	60.87	0.09	85.3	0.582	3.3	1.4	17.31	30.88	45.89
3902102	19.63	0.49	89.2	0.584	18.8	0.6	13.65	30.03	52.12
3902161	6.42	0.47	88.9	0.594	17.2	0.4	5.86	13.14	23.14
4703960	4.22	0.44	87.6	0.768	19.7	1.0	3.91	8.61	14.90
4705432	1.94	0.30	84.3	0.791	26.2	2.1	1.87	3.94	6.60
4706692	7.59	0.31	84.8	0.819	21.0	5.3	4.76	9.41	15.27
301183	16.21	1.13	91.4	0.564	27.2	0.2	13.82	24.50	32.58
301299	52.84	0.39	91.7	0.565	20.0	1.0	27.48	57.51	98.30
302104	13.29	1.36	90.7	0.563	21.7	0.1	12.44	30.03	55.52
1700782	11.58	0.15	92.2	0.683	10.6	0.4	5.61	10.96	17.08
1702068	1.37	0.77	91.9	0.651	9.0	1.0	1.76	4.08	7.25
3902102	19.63	0.49	89.2	0.584	18.8	0.6	13.65	30.03	52.12
3902161	6.42	0.47	88.9	0.594	17.2	0.4	5.86	13.14	23.14
4703960	4.14	0.44	87.6	0.768	19.7	1.0	3.91	8.61	14.90
4705432	1.94	0.30	84.3	0.791	26.2	2.1	1.87	3.94	6.60
4706692	7.59	0.31	84.8	0.819	21.0	5.3	4.76	9.41	15.27
5200245	31.34	0.41	91.4	0.606	32.2	2.5	16.57	33.99	56.66
5200695	2.69	0.69	93.0	0.617	10.3	1.0	2.95	6.69	11.84
5200938	69.93	0.25	91.2	0.642	24.9	1.6	31.73	63.17	104.25
5201292	29.53	0.46	91.7	0.643	43.1	1.0	17.90	38.24	66.01
5206154	3.06	0.74	93.7	0.631	29.9	0.1	2.56	5.72	9.66
5206286	3.50	1.72	95.3	0.602	24.2	0.8	4.14	10.00	18.39
5207266	4.82	1.44	98.6	0.584	32.5	2.2	4.65	10.62	18.90

Appendix B cont'd

Site[1]	DA[2]	Slope[3]	Prec[4]	SVI[5]	Forest[6]	Water[7]	Q_2[8]	Q_{10}[9]	Q_{100}[10]
5207800	1.06	1.27	93.2	0.61	16.7	1.7	1.45	3.43	6.12
5208130	4.27	1.79	97.8	0.586	46.9	0.8	4.84	11.64	21.44
300608	24.19	1.05	90.4	0.568	25.0	0.1	18.90	44.19	80.45
303945	33.67	0.76	91.4	0.565	27.7	0.4	22.52	50.71	90.08
480357	419.58	0.09	81.0	0.535	10.6	2.3	73.37	124.36	180.74
3502236	16.08	0.12	83.8	0.655	1.6	0.0	7.51	14.76	23.06
3532631	62.68	0.10	85.3	0.596	3.2	1.4	17.85	32.01	47.59
3533514	3.11	0.17	88.4	0.58	8.1	2.7	1.72	3.26	4.90
3533654	20.62	0.17	87.9	0.572	2.0	0.7	8.61	16.60	25.69
4700333	27.45	0.39	83.8	0.778	28.7	5.4	13.31	26.12	42.49
4707036	70.45	0.33	89.2	0.752	27.2	3.0	29.46	58.36	95.75
5201209	36.52	0.52	91.7	0.642	40.2	1.6	20.42	43.06	73.65
5203589	0.31	3.33	95.3	0.606	18.8	1.9	0.62	1.58	2.95
5207231	33.67	0.66	97.8	0.594	39.6	2.9	18.27	38.24	64.87
5243165	42.22	0.37	91.2	0.664	26.6	1.3	22.27	46.18	78.19
7000367	7.25	1.05	91.9	0.533	35.4	5.4	5.38	11.44	19.52
7403933	113.96	0.12	88.1	0.64	4.1	0.6	3.12	57.51	87.54
8501505	1.50	1.22	91.7	0.586	6.7	0.3	2.17	5.30	9.77
8502447	3.34	1.42	91.7	0.603	11.5	0.5	2.83	6.46	11.08
8504997	1.50	1.22	91.7	0.586	6.7	0.3	2.17	5.30	9.77
8600910	10.57	0.39	85.6	0.576	20.8	3.3	4.82	9.26	14.33
8601909	12.67	0.20	86.1	0.541	5.0	1.4	5.67	10.93	16.83
8634270	15.98	0.41	86.1	0.562	5.7	1.1	7.62	15.38	24.50
8703426	246.83	0.06	83.8	0.51	3.0	0.7	73.94	136.26	215.58
8705399	23.72	0.06	80.0	0.61	1.8	0.9	8.22	14.73	21.76
8500045	4.87	1.55	91.9	0.552	15.4	2.0	4.79	11.02	19.75
7402236	5.98	0.33	91.2	0.692	6.4	0.4	3.74	7.79	12.58
7402732	20.75	0.20	89.4	0.658	5.5	0.5	9.04	17.76	27.79
7402139	34.19	0.15	91.2	0.656	10.6	0.8	12.49	23.68	36.26
7401388	10.10	0.24	89.4	0.602	9.4	1.3	6.94	14.33	23.94
8600031	3.03	0.54	85.1	0.662	4.8	1.0	2.20	4.65	7.56
8600694	166.54	0.05	86.4	0.584	3.7	1.9	33.99	57.22	81.87
8600996	64.49	0.16	88.6	0.538	20.1	5.8	15.95	27.45	39.66
8602905	3.29	0.53	85.1	0.622	10.7	1.6	2.22	4.59	7.39
8603219	279.72	0.13	89.7	0.532	21.3	7.0	47.03	77.05	109.35
8603243	39.11	0.22	88.9	0.52	27.1	8.1	10.74	18.67	27.14
8700397	92.20	0.03	94.5	0.675	3.3	0.8	22.01	37.39	53.54
8702012	30.30	0.07	79.5	0.592	4.1	2.5	8.98	15.52	22.38
8702284	14.63	0.04	82.0	0.654	4.3	0.6	5.58	10.03	14.73
8702853	38.07	0.13	79.8	0.572	6.0	1.9	12.15	22.07	32.86
8706069	5.36	0.06	83.6	0.706	1.2	0.0	2.89	5.52	8.41
8707146	77.96	0.05	80.5	0.633	1.4	0.6	20.79	36.54	53.54

Appendix B cont'd

Site[1]	DA[2]	Slope[3]	Prec[4]	SVI[5]	Forest[6]	Water[7]	Q_2[8]	Q_{10}[9]	Q_{100}[10]
7007027	15.95	0.76	94.0	0.62	14.6	1.1	11.76	26.09	45.89
7007299	16.37	0.47	94.0	0.609	23.1	1.5	10.85	23.06	39.38
7007191	2.90	0.91	93.0	0.592	30.0	1.3	3.14	7.20	12.78
7007051	196.84	0.25	91.7	0.544	35.3	1.9	67.42	131.44	215.86
7006268	2.43	1.51	91.7	0.539	44.2	0.6	3.14	7.62	14.05
7004591	4.82	1.30	91.7	0.538	48.5	0.4	5.35	12.89	23.68
7002165	24.97	0.77	91.9	0.515	25.8	2.0	15.55	33.43	58.07
7000847	5.80	0.61	93.0	0.574	13.2	1.2	5.16	11.42	19.94
7000243	297.85	0.14	92.2	0.555	35.2	2.5	82.72	152.69	241.93
4800451	119.66	0.06	79.2	0.607	3.5	1.4	27.79	47.88	69.69
4800699	21.06	0.13	80.5	0.538	40.7	14.4	5.64	9.24	12.92
4801490	12.15	0.20	79.8	0.56	13.3	1.1	5.61	10.85	16.77
4802667	502.46	0.06	81.5	0.56	17.6	4.5	71.67	113.88	158.36
6200036	115.51	0.07	79.2	0.613	3.7	1.3	27.59	48.16	70.25
6201865	86.25	0.06	79.2	0.602	4.1	1.4	21.50	37.11	54.11
7203012	79.51	0.18	89.2	0.646	3.9	0.3	26.09	50.42	78.47
7200242	90.91	0.11	85.6	0.646	4.2	1.2	24.70	44.76	66.86
7200935	12.82	0.23	86.4	0.65	6.6	1.2	5.92	11.53	17.90
7201117	111.89	0.12	85.3	0.647	4.4	1.1	29.46	53.54	80.45
7201206	40.40	0.16	82.8	0.602	10.7	0.9	20.06	40.23	66.29
5238420	0.98	4.32	94.0	0.605	23.8	0.7	1.24	2.92	5.50
4800524	4.64	0.15	81.3	0.48	2.5	0.6	2.68	5.27	8.19
4703189	174.05	0.19	88.9	0.708	30.5	1.8	59.21	113.60	184.42
7003129	8.96	0.50	92.7	0.616	9.8	1.0	7.14	15.61	27.05
3536157	7.20	0.20	88.1	0.57	1.6	1.7	3.57	6.88	10.57
7202164	32.89	0.26	88.9	0.642	6.1	0.8	13.00	25.47	39.94
4802098	492.10	0.05	81.5	0.551	17.9	4.5	69.97	110.76	153.54
8601925	7.59	0.20	86.6	0.535	18.1	4.3	3.26	6.01	8.95
5242088	1.92	0.62	89.9	0.663	23.3	0.4	2.36	5.50	9.80
7005075	30.04	0.82	93.0	0.531	51.7	0.7	20.00	44.76	79.32
5207622	3.06	0.48	88.4	0.716	16.5	0.4	3.29	7.48	13.17
5242428	1.61	0.74	93.0	0.634	28.9	2.1	1.82	4.08	7.11
5205476	2.82	2.31	95.0	0.596	24.4	1.5	2.40	5.47	9.35
7242298	3263.40	0.07	91.4	0.645	9.3	1.1	376.77	628.90	909.35
3503542	10.62	0.05	83.8	0.673	1.6	0.0	4.82	8.98	13.51
6200184	24.84	0.03	79.2	0.632	3.6	2.4	7.08	11.78	16.57
3501345	6.97	0.14	86.9	0.589	0.8	0.3	3.80	7.54	11.73
302341	4.43	1.91	91.2	0.552	23.1	0.1	5.52	13.88	26.18
1702084	9.45	0.62	92.2	0.649	14.1	0.4	5.75	12.32	20.34
1702297	0.60	0.89	92.7	0.663	12.2	0.0	0.75	1.76	3.03
1702416	6.11	0.42	91.9	0.652	18.3	0.3	5.61	12.55	22.04
1702424	6.06	0.43	91.9	0.653	18.3	0.3	5.58	12.55	22.07

Appendix B cont'd

Site[1]	DA[2]	Slope[3]	Prec[4]	SVI[5]	Forest[6]	Water[7]	Q_2[8]	Q_{10}[9]	Q_{100}[10]
1702998	0.47	0.30	91.7	0.694	0.0	0.0	0.54	1.19	1.95
1703633	3.60	0.77	91.9	0.667	12.9	0.6	2.73	5.95	9.89
1703862	12.30	0.17	92.2	0.668	6.8	0.4	5.98	11.78	18.41
1703870	31.08	0.33	92.7	0.665	11.2	0.4	13.37	27.05	43.34
2204878	16.99	0.54	86.4	0.724	34.7	5.3	9.58	19.38	32.01
3901831	226.88	0.24	93.7	0.606	16.8	1.2	78.75	155.81	257.79
3902439	76.92	0.20	90.9	0.582	10.5	0.9	33.99	68.27	113.60
4706064	3.37	0.94	89.9	0.648	5.1	0.8	3.71	8.61	15.47
5200938	72.52	0.25	91.2	0.642	24.9	1.6	31.73	63.17	104.25
5201497	2.25	1.10	91.9	0.639	38.5	0.9	1.93	4.31	7.22
5201586	4.92	1.02	92.5	0.638	31.9	2.6	3.09	6.49	10.54
5201837	7.33	1.30	94.2	0.599	20.8	1.2	4.79	10.45	17.45
5205174	4.45	1.00	91.9	0.646	34.2	2.7	4.05	8.95	15.61
5205654	7.69	1.13	97.0	0.592	41.1	1.9	6.60	14.84	26.23
5206928	10.31	0.83	89.2	0.673	32.0	0.6	8.90	20.37	36.54
7002521	172.75	0.27	91.9	0.543	33.4	2.0	60.91	119.55	196.32
7003595	98.16	0.46	93.2	0.572	26.3	0.3	49.01	105.38	183.29
7004966	16.81	1.02	97.5	0.521	55.7	0.4	13.63	31.73	57.22
7005245	1.63	1.07	93.2	0.584	7.4	0.4	2.25	5.44	9.97
7005369	5.80	0.61	93.0	0.574	13.2	1.2	5.16	11.44	19.94
7006691	32.89	0.41	92.2	0.561	19.8	1.2	18.75	39.38	67.14
7006845	92.72	0.50	93.2	0.574	26.5	0.3	47.31	102.83	179.60
7006934	0.98	3.28	93.0	0.568	54.3	0.1	1.84	4.84	9.41
7007280	3.00	0.49	93.7	0.595	9.8	0.9	3.06	6.83	11.90
7007299	16.37	0.47	94.0	0.609	23.1	1.5	10.85	23.06	39.38
8500118	5.08	1.48	91.4	0.558	21.9	0.2	5.78	14.11	26.18
8500193	11.03	1.16	91.2	0.567	20.9	0.5	9.86	23.06	41.93
8501629	5.57	1.79	91.4	0.571	21.1	3.4	5.01	11.36	20.11
8501653	5.57	1.79	91.4	0.571	21.1	3.4	5.01	11.36	20.11
8502331	0.70	1.73	91.4	0.6	8.8	0.3	0.89	2.13	3.71
8502471	4.17	0.87	91.7	0.608	15.2	0.3	4.62	10.88	19.72
8504059	15.28	0.77	91.7	0.58	10.4	0.5	8.58	18.41	30.59
8504350	16.29	1.31	91.4	0.559	20.5	0.4	13.80	32.58	59.49
8505160	132.87	0.41	91.4	0.574	16.4	0.6	59.21	124.36	213.88
8505314	1.45	2.99	91.4	0.571	20.7	0.2	2.41	6.26	11.98
8505411	0.34	4.24	91.4	0.573	74.9	0.5	0.77	2.07	4.02
8505942	26.16	0.30	91.7	0.595	6.0	0.4	11.61	23.46	37.39
8505977	9.25	0.56	91.7	0.608	8.0	0.2	5.78	12.49	20.68
8506248	7.69	0.63	93.0	0.59	31.2	3.1	4.02	8.05	12.72
8506337	8.26	0.81	91.7	0.583	17.9	0.7	7.39	16.94	30.31
2203332	12.69	0.26	87.4	0.622	19.9	3.2	7.48	14.87	24.31
1700391	0.73	0.58	92.5	0.66	1.7	0.4	0.78	1.74	2.89

Appendix B cont'd

Site[1]	DA[2]	Slope[3]	Prec[4]	SVI[5]	Forest[6]	Water[7]	Q_2[8]	Q_{10}[9]	Q_{100}[10]
5205263	4.30	0.71	90.7	0.663	23.2	0.7	4.39	10.03	17.85
2600374	13.62	0.08	83.6	0.461	3.2	1.3	5.33	9.69	14.36
4703758	0.54	0.43	86.9	0.806	20.5	1.2	0.78	1.76	3.06
5246520	3.44	0.59	89.7	0.675	24.4	0.9	3.51	7.90	13.91
7003188	9.79	0.16	93.0	0.605	4.0	1.0	6.60	13.46	22.27
4706250	1085.21	0.14	88.9	0.831	27.1	2.4	227.76	413.60	651.56
8705909	55.94	0.07	79.5	0.593	2.7	1.1	16.23	28.90	42.78
4705882	10.36	0.80	89.9	0.649	26.4	0.5	9.01	20.65	36.83
3534243	25.74	0.09	83.8	0.644	1.9	0.0	10.40	19.92	30.59
8504318	10.88	1.70	93.5	0.55	20.8	2.9	8.61	19.35	34.28
8706158	48.17	0.02	83.6	0.714	2.8	1.4	12.10	19.97	28.02
7403372	2.46	0.52	91.7	0.636	1.9	0.1	2.08	4.59	7.65
7201990	15.70	0.21	86.6	0.645	2.2	0.2	7.65	15.35	24.36
304395	9.92	0.72	91.4	0.622	20.9	1.1	8.02	17.85	31.44
8705224	3.57	0.05	80.5	0.655	3.2	1.2	1.80	3.26	4.79
5233569	14.48	0.42	88.4	0.715	17.9	0.7	10.42	22.63	39.09
300454	9.79	1.53	90.7	0.563	20.9	0.1	9.97	24.33	45.33
5206375	0.96	1.68	96.0	0.595	13.0	1.7	0.98	2.22	3.74
8636974	82.10	0.14	86.1	0.588	11.6	3.8	20.20	35.13	51.27
1700464	2.82	0.64	91.9	0.673	7.2	0.0	3.40	8.05	14.59
4702476	2.64	0.49	87.9	0.776	35.4	1.8	2.59	5.64	9.69
3533336	26.16	0.21	87.6	0.572	2.8	0.8	10.59	20.57	32.01
7001819	3.19	0.87	92.2	0.565	41.9	1.6	3.26	7.37	13.00
3900347	0.47	0.33	89.2	0.632	16.1	0.5	0.72	1.64	2.86
3500063	4.40	0.16	87.6	0.561	1.1	1.0	2.50	4.90	7.54
4805798	0.39	0.33	79.2	0.564	2.1	0.9	0.42	0.89	1.43
8502099	3.50	0.81	91.4	0.595	13.9	0.6	3.82	8.92	15.98
8706271	48.69	0.14	85.3	0.711	2.1	0.7	16.40	30.88	47.31
5236339	1.45	1.48	93.5	0.631	28.6	0.2	1.55	3.65	6.35
8602611	10.28	0.12	86.4	0.564	1.2	0.5	4.90	9.46	14.56
4774485	7.25	0.09	86.6	0.819	35.9	8.1	3.63	6.52	9.86
5244579	173.79	0.34	94.5	0.622	37.7	2.8	60.34	117.85	193.20
5248760	1.97	1.55	94.0	0.61	13.6	0.0	2.03	4.82	8.39
5206871	292.67	0.25	92.2	0.673	34.7	2.3	88.95	171.10	278.19
4701674	2.82	0.24	86.6	0.784	36.6	5.6	2.12	4.19	6.74
5205387	3.37	0.59	89.7	0.694	19.2	0.5	3.60	8.27	14.70
5242851	0.39	1.21	92.5	0.645	13.3	1.1	0.69	1.68	3.09
4703510	27.71	0.42	83.8	0.775	28.5	5.3	13.54	26.69	43.63

Appendix B cont'd

Site[1]	Skew[11]	TotSp[12]	MaxSp[13]	Length[14]	Prot[15]	MinLL[16]	MaxLL[17]	MinPL[18]	MaxPL[19]
8500045	10	1	4.88	5.49	GRASS	25.0	30.0	5.0	9.0
8500843	30	2	3.66	7.62	CONCRETE	25.0	27.5	4.0	5.0
8503451	0	2	6.10	13.41	GRASS	25.0	27.5	4.0	5.0
8503559	0	1	19.51	19.81	RIP RAP	25.0	30.0	5.0	9.0
8504024	30	1	6.10	6.71	GRASS	25.0	30.0	5.0	9.0
8506302	0	3	12.19	34.44	GRASS	25.0	27.5	4.0	5.0
8506523	5	1	19.81	20.12	RIP RAP	25.0	27.5	4.0	5.0
8500215	24	3	28.65	77.72	GRASS	25.0	30.0	3.0	7.0
8500967	0	1	4.27	4.88	GRASS	25.0	30.0	3.0	7.0
8502668	45	1	3.05	4.27	GRASS	25.0	30.0	3.0	7.0
8503249	21	1	3.05	3.66	GRASS	25.0	30.0	3.0	7.0
8504326	0	1	3.96	3.96	GRASS	30.0	41.0	3.0	9.0
8504954	30	1	4.27	4.27	GRASS	25.0	30.0	3.0	7.0
8505101	30	1	4.57	4.57	GRASS	25.0	30.0	3.0	7.0
8505314	34	2	2.44	5.49	GRASS	30.0	36.0	3.0	9.0
2600277	15	3	13.11	40.54	STONE	27.5	51.5	3.5	11.0
3501922	0	3	6.10	18.29	STONE	26.0	51.5	4.0	12.5
3502805	0	3	9.14	24.69	STONE	20.0	56.5	4.0	5.0
3503186	25	3	7.62	22.25	STONE	32.5	40.0	4.0	6.0
3902102	21	1	5.79	6.71	GRASS	25.0	27.5	4.0	5.0
3902161	4	1	3.66	3.66	RIP RAP	25.0	30.0	3.5	7.0
4703960	0	1	4.27	4.27	GRASS	25.0	30.0	3.5	7.0
4705432	0	1	3.05	3.96	GRASS	25.0	30.0	3.5	7.0
4706692	0	1	4.88	5.79	GABIONS	26.0	51.5	4.0	11.0
301183	10	2	3.66	8.53	RIP RAP	29.0	36.0	2.5	5.5
301299	0	3	10.67	30.18	CONCRETE	29.0	36.0	2.5	5.5
302104	0	3	9.45	26.21	CONCRETE	27.5	35.0	4.5	5.5
1700782	30	1	9.75	10.97	GRASS	29.0	36.0	2.5	5.5
1702068	7	1	3.66	4.57	GRASS	29.0	36.0	2.5	5.5
3902102	21	1	5.79	6.71	GRASS	25.0	27.5	4.0	5.0
3902161	4	1	3.66	3.66	RIP RAP	25.0	30.0	3.5	7.0
4703960	0	1	4.27	4.88	GRASS	32.5	45.0	4.5	7.0
4705432	0	1	3.05	3.96	GRASS	25.0	30.0	3.0	7.0
4706692	0	1	4.88	5.79	GABIONS	26.0	51.5	4.0	11.0
5200245	45	2	5.18	10.36	CONCRETE	30.0	30.0	3.0	3.0
5200695	5	1	3.05	3.66	GRASS	17.5	30.0	3.0	5.5
5200938	0	3	16.15	45.11	RIP RAP		30.0		4.0
5201292	20	3	13.72	37.80	RIP RAP	15.0	30.0	3.0	4.0
5206154	15	1	5.79	6.71	CONCRETE	15.0	30.0	3.0	4.0
5206286	28	1	4.27	4.88	RIP RAP	30.0	30.0	3.0	3.0
5207266	36	1	3.35	3.35	GRASS	30.0	42.5	3.0	7.0

Appendix B cont'd

Site[1]	Skew[11]	TotSp[12]	MaxSp[13]	Length[14]	Prot[15]	MinLL[16]	MaxLL[17]	MinPL[18]	MaxPL[19]
5207800	30	2	1.83	4.88	GRASS	30.0	40.0	4.0	13.0
5208130	25	3	5.49	5.49	STONE	15.0	30.0	3.0	5.0
300608	0	3	12.19	34.44	RIP RAP	29.0	36.0	2.5	5.5
303945	25	3	13.72	37.19	STONE	27.5	36.0	2.5	5.5
480357	25	1	12.19	12.50	STONE	48.5	85.0	4.0	5.0
3502236	0	1	10.67	12.19	STONE	15.0	32.5	3.5	5.0
3532631	20	1	9.14	9.45	RIP RAP	15.0	32.5	3.5	5.0
3533514	0	1	6.10	6.10	STONE	26.0	51.5	4.0	11.0
3533654	25	1	15.85	18.90		15.0	32.5	3.5	5.0
4700333	10	2	5.18	11.28	CONCRETE	27.5	32.5	4.5	7.0
4707036	0	1	17.07	17.37	RIP RAP	25.0	27.5	4.0	5.0
5201209	30	3	22.86	60.96	RIP RAP	15.0	30.0	3.0	4.0
5203589	17	3	38.71	53.95		30.0	32.5	3.0	5.0
5207231	27	3	11.58	40.54	GRASS	30.0	30.0	3.0	3.0
5243165	47	2	16.15	32.31	RIP RAP				
7000367	17	1	4.27	4.27	RIP RAP	26.5	26.5	5.0	5.0
7403933	30	3	10.67	30.18	STONE	22.5	32.5	2.0	6.5
8501505	18	3	11.28	32.31		27.5	42.5	3.5	7.5
8502447	0	3	1.83	7.92		25.0	30.0	3.0	7.0
8504997	0	1	4.27	4.27	RIP RAP	25.0	30.0	3.0	7.0
8600910	8	1	9.45	10.36	RIP RAP	32.5	37.5	3.5	6.0
8601909	15	3	6.10	16.76	STONE	25.0	50.0	5.0	12.5
8634270	0	1	7.62	8.84		32.5	37.5	4.0	6.0
8703426	8	3	13.72	36.27	STONE	47.0	56.0	3.5	4.5
8705399	15	1	7.32	8.23	STONE	47.0	56.0	3.5	4.5
8500045	10	1	4.88	5.49	GRASS	25.0	30.0	5.0	9.0
7402236	0	2	3.05	7.01	STONE	29.0	36.0	5.5	10.5
7402732	30	3	7.62	22.25	STONE	29.0	50.0	5.5	27.5
7402139	30	3	7.32	20.42	GRASS	27.5	30.0	5.0	6.0
7401388	26	2	3.96	9.14	RIP RAP	30.0	50.0	9.0	27.5
8600031	0	2	2.74	6.71	RIP RAP	31.5	50.0	9.0	37.0
8600694	30	3	15.24	40.54	STONE	29.0	37.5	5.5	13.0
8600996	10	3	9.14	24.38	RIP RAP	15.0	36.0	3.0	10.5
8602905	6	1	3.35	3.96		29.0	53.0	5.5	35.0
8603219	38	3	19.81	52.43	STONE	15.0	32.5	5.0	5.0
8603243	15	3	9.14	24.38	STONE	32.5	51.5	7.5	29.0
8700397	30	3	15.85	42.06	STONE	30.0	40.0	10.0	20.0
8702012	38	1	6.10	7.01		50.0	55.0	27.5	30.0
8702284	30	1	4.27	4.57	RIP RAP	12.5	56.0	5.0	31.5
8702853	0	1	9.45	11.28	RIP RAP	30.0	40.0	12.5	30.0
8706069	0	3	12.19	32.31	RIP RAP	47.0	56.0	25.0	31.5
8707146	40	3	10.67	28.65	STONE	47.0	56.0	25.0	31.5

Appendix B cont'd

Site[1]	Skew[11]	TotSp[12]	MaxSp[13]	Length[14]	Prot[15]	MinLL[16]	MaxLL[17]	MinPL[18]	MaxPL[19]
7007027	23	1	9.75	10.36	GRASS	22.5	40.0	2.0	14.5
7007299	7	3	5.49	16.46	GRASS	22.5	32.5	6.5	10.5
7007191	0	1	3.05	3.66	GRASS	22.5	37.5	6.5	14.0
7007051	25	3	17.68	48.46	RIP RAP	10.5	32.5	5.0	11.0
7006268	0	1	3.66	4.27	RIP RAP	25.0	27.5	4.0	5.0
7004591	16	1	4.57	5.79	GRASS	25.0	27.5	4.0	5.0
7002165	0	2	4.27	8.53	STONE	25.0	27.5	4.0	5.0
7000847	0	1	5.18	5.18	GRASS	22.5	32.5	6.5	10.5
7000243	26	1	42.06	44.50	GRASS	22.5	32.5	6.5	10.5
4800451	30	3	10.67	28.35	CONCRETE	30.0	37.5	9.0	13.0
4800699	45	2	3.35	8.53		29.0	36.0	5.5	10.5
4801490	0	1	3.66	4.88		30.0	37.5	9.0	13.0
4802667	0	1	38.40	39.93	STONE				
6200036	0	3	9.14	24.38	CONCRETE	47.5	52.5	24.0	25.0
6201865	30	3	10.67	28.35	CONCRETE	32.0	60.0	12.5	31.5
7203012	55	1	14.02	16.46	STONE	35.0	55.0	14.0	26.0
7200242	36	2	19.81	40.54	STONE	22.5	32.5	7.0	10.5
7200935	39	2	37.80	77.42		52.5	52.5	25.0	27.0
7201117	15	3	10.67	28.35	STONE	22.5	32.5	7.0	10.5
7201206	5	1	9.45	10.06		30.0	35.0	9.0	11.5
5238420	10	3	6.10	15.85	STONE		30.0		14.5
4800524	42	1	7.01	8.23	RIP RAP	25.0	30.0	5.0	13.0
4703189	0	3	16.15	44.50	RIP RAP	27.5	30.0	7.0	7.5
7003129	23	2	11.58	24.08	GRASS	32.5	47.5	9.0	27.5
3536157	10	1	5.49	6.10	RIP RAP	26.0	51.5	6.0	29.0
7202164	0	1	6.10	6.71	STONE	22.5	50.0	2.5	27.5
4802098	1	3	14.94	46.02	RIP RAP				
8601925	30	1	4.88	5.79		34.0	51.5	7.5	29.0
5242088	35	1	1.83	3.05	GRASS	15.0	30.0	4.0	14.5
7005075	0	1	15.24	16.46	GRASS	22.5	32.5	4.0	10.5
5207622	30	1	3.66	3.66	RIP RAP	15.0	45.0	4.0	21.0
5242428	45	1	4.27	4.27	GRASS	30.0	47.5	7.0	26.0
5205476	0	1	3.66	4.27	RIP RAP	17.5	30.0	4.0	13.0
7242298	17	5	26.82	136.55	CONCRETE	25.0	51.5	5.0	29.0
3503542	0	1	3.66	4.57		47.0	56.0	25.0	31.5
6200184	30	3	9.14	24.38	STONE				
3501345	40	1	3.66	4.27	RIP RAP	30.0	56.5	12.5	31.5
302341	30	1	4.27	4.27	RIP RAP				
1702084	15	1	9.45	10.36	GRASS	29.0	36.0	5.5	10.5
1702297	30	2	1.83	4.27	GRASS	32.5	40.0	10.0	18.0
1702416	0	1	4.88	5.49	GRASS	29.0	36.0	5.5	10.5
1702424	0	1	3.66	4.27	RIP RAP	29.0	36.0	5.5	19.5

Appendix B cont'd

Site[1]	Skew[11]	TotSp[12]	MaxSp[13]	Length[14]	Prot[15]	MinLL[16]	MaxLL[17]	MinPL[18]	MaxPL[19]
1702998	12	2	17.37	36.27	RIP RAP	30.0	40.0	7.0	20.0
1703633	0	1	3.66	4.27	GRASS	29.0	36.0	5.5	10.5
1703862	0	1	3.05	3.66	GRASS	29.0	36.0	5.5	10.5
1703870	20	3	9.14	24.38	STONE	29.0	36.0	5.5	10.5
2204878	0	3	6.10	16.46	RIP RAP	25.0	30.0	5.0	9.0
3901831	0	3	15.85	44.20	RIP RAP	7.5	30.0	1.0	7.0
3902439	25	3	14.63	38.40	RIP RAP	7.5	7.5	1.0	2.0
4706064	0	1	4.88	5.49	GRASS	25.0	30.0	5.0	9.0
5200938	0	3	16.15	44.50	RIP RAP		30.0	4.0	14.5
5201497	0	1	5.49	6.40	RIP RAP	15.0	30.0	4.0	14.5
5201586	0	1	6.10	6.40	RIP RAP	15.0	30.0	4.0	14.5
5201837	30	3	6.10	18.59	STONE	15.0	30.0	4.0	14.5
5205174	3	1	3.05	3.66	GRASS		30.0	4.0	14.5
5205654	66	1	3.05	3.35	RIP RAP	15.0	30.0	4.0	14.5
5206928	0	1	5.49	6.10	RIP RAP	30.0	30.0	7.0	7.0
7002521	0	3	13.11	40.23	GABIONS	22.5	32.5	6.5	10.5
7003595	35	3	32.31	78.03	GRASS				
7004966	40	3	10.67	29.26	RIP RAP	17.5	32.5	5.0	11.0
7005245	15	1	6.10	7.32	RIP RAP	22.5	40.0	6.5	20.0
7005369	0	1	7.92	8.53	GRASS	22.5	32.5	6.5	10.5
7006691	30	3	13.11	36.27	GRASS	25.0	27.5	4.0	5.0
7006845	15	3	13.72	38.10	RIP RAP	25.0	27.5	4.0	5.0
7006934	0	1	3.66	4.27	GRASS	25.0	27.5	4.0	5.0
7007280	17	1	3.05	3.66	GRASS	32.5	47.5	9.5	20.0
7007299	7	3	5.49	16.46	GRASS	22.5	32.5	6.5	10.5
8500118	0	1	4.27	4.27	RIP RAP	22.5	42.5	4.0	22.5
8500193	23	1	12.19	13.11	GRASS		30.0	5.0	9.0
8501629	30	3	16.15	44.20	GRASS	25.0	41.0	5.0	21.0
8501653	30	3	16.15	44.20	GRASS	25.0	41.0	5.0	21.0
8502331	28	1	8.23	9.14	RIP RAP	15.0	32.5	3.5	9.5
8502471	26	1	3.05	3.05	RIP RAP	25.0	30.0	5.0	9.0
8504059	0	1	7.32	8.23	GRASS	25.0	30.0	5.0	9.0
8504350	25	3	7.62	22.25	STONE	37.5	47.5	13.0	22.5
8505160	5	3	16.76	46.33	RIP RAP	25.0	30.0	5.0	9.0
8505314	34	2	2.44	5.49	GRASS	37.5	47.5	13.0	22.5
8505411	0	1	2.74	3.35	GRASS	7.5	7.5	1.0	2.0
8505942	30	1	23.16	24.69	GRASS	15.0	30.0	4.0	9.0
8505977	10	3	7.01	20.42	RIP RAP	25.0	37.0	5.0	15.5
8506248	33	1	3.66	4.27	GRASS	25.0	30.0	5.0	9.0
8506337	30	1	9.14	9.75	GRASS	25.0	27.5	4.0	5.0
2203332	10	1	6.10	7.01	GRASS	25.0	30.0	5.0	9.0
1700391	7	3	5.49	14.63	GRASS	30.0	82.5	8.5	21.0

Appendix B cont'd

Site[1]	Skew[11]	TotSp[12]	MaxSp[13]	Length[14]	Prot[15]	MinLL[16]	MaxLL[17]	MinPL[18]	MaxPL[19]
5205263	0	1	3.05	3.66	STONE	30.0	30.0	7.0	7.0
2600374	39	1	12.80	13.41	STONE	27.5	51.5	6.5	29.0
4703758	10	1	4.88	5.79	GRASS	40.0	50.0	18.5	27.5
5246520	0	1	3.66	4.27	RIP RAP	15.0	30.0	4.0	14.5
7003188	10	1	4.27	4.88	RIP RAP	22.5	40.0	6.5	20.0
4706250	20	12	36.27	433.12	RIP RAP	10.0	25.0	1.0	7.0
8705909	16	3	13.11	35.05	STONE				
4705882	6	3	5.49	16.46	RIP RAP	25.0	27.5	4.0	5.0
3534243	0	1	4.27	4.88	RIP RAP	34.0	51.5	15.0	29.0
8504318	0	1	13.72	14.02	RIP RAP	30.0	32.5	7.0	12.5
8706158	0	3	6.10	16.46	STONE	49.5	76.5	25.0	31.5
7403372	7	1	3.05	3.05	CONCRETE	31.5	43.5	8.5	20.0
7201990	36	1	5.49	6.10	RIP RAP	22.5	35.0	7.0	11.5
304395	15	1	1.22	13.72	RIP RAP	25.0	27.5	4.0	5.0
8705224	13	1	4.27	5.18		30.0	42.5	12.5	20.0
5233569	0	1	9.14	10.97		15.0	40.0	4.0	20.0
300454	30	3	13.72	39.01	STONE	25.0	27.5	4.0	5.0
5206375	8	2	1.22	3.66	GRASS	30.0	30.0	7.0	7.0
8636974	0	2	21.95	23.16	GRASS	32.5	37.5	9.0	13.0
1700464	0	1	6.10	6.40	RIP RAP	32.5	37.5	9.0	13.0
4702476	0	1	3.05	3.66	GRASS	25.0	30.0	5.0	9.0
3533336	45	1	11.28	11.89	STONE	10.0	50.0	2.0	27.5
7001819	3	1	3.66	4.27	CONCRETE	22.5	32.5	6.5	10.5
3900347	10	1	12.50	12.80	RIP RAP	25.0	27.5	4.0	5.0
3500063	0	2	3.35	7.62	CONCRETE	34.0	60.0	15.0	35.0
4805798	25	1	3.96	3.96					
8502099	39	1	3.66	3.66	CONCREETE	25.0	31.5	4.0	7.5
8706271	12	3	7.62	20.42	STONE	30.0	42.5	12.5	20.0
5236339	45	1	4.88	5.18	GRASS	15.0	30.0	4.0	14.5
8602611	30	1	4.88	4.88		29.0	36.0	5.5	10.5
4774485	17	2	2.13	5.18		32.5	50.0	9.5	27.5
5244579	30	3	16.76	44.81	RIP RAP	30.0	30.0	7.0	7.0
5248760	35	1	5.18	5.18	RIP RAP	30.0	30.0	7.0	7.0
5206871	25	3	19.20	52.43	GABIONS	15.0	30.0	4.0	14.5
4701674	0	1	3.96	3.96	RIP RAP	32.5	45.0	9.5	21.0
5205387	0	2	2.74	6.40	GRASS	30.0	40.0	7.0	20.0
5242851	0	2	3.05	3.05	GRASS	27.5	32.5	7.0	9.5
4703510	0	3	8.53	24.38	GRASS	27.5	30.0	7.0	7.5

Appendix B cont'd

Site[1]	$MaxK_w$[20]	$MaxK_f$[21]	SP_2[22]	SP_{10}[23]	SP_{100}[24]	ChanAl[25]	ChanPro[26]	ChanPro2[27]	ChanHO[28]
8500045	0.37	0.49	727.6	1674.8	3000.9	3	2	1	2
8500843	0.37	0.43	1138.1	2484.3	4347.5	2	3	2	2
8503451	0.37	0.43	1318.6	3119.9	5700.2	3	3	2	3
8503559	0.37	0.49	853.4	2186.4	4189.4	3	3	2	3
8504024	0.37	0.49	212.6	490.5	843.3	3	3	2	3
8506302	0.37	0.43	1081.0	2179.1	3629.0	3	3	2	3
8506523	0.37	0.43	907.8	1952.3	3242.2	3	3	2	2
8500215	0.37	0.49	1491.6	2799.4	4487.5	1	3	2	2
8500967	0.37	0.49	282.8	637.8	1126.5	1	3	2	2
8502668	0.37	0.49	221.3	498.5	843.8	3	2	1	2
8503249	0.38	0.49	620.4	1439.7	2591.5	3	3	2	2
8504326	0.37	0.43	1137.3	2943.1	5663.4	1	3	2	3
8504954	0.37	0.49	214.6	484.0	852.0	3	3	2	2
8505101	0.37	0.49	399.8	879.2	1538.6	3	3	2	1
8505314	0.37	0.37	706.0	1837.8	3517.7	3	3	2	2
2600277	0.28	0.55	1038.9	1452.3	2462.5	2	3	2	1
3501922	0.37	0.37	37.0	72.1	111.9	1	3	2	2
3502805	0.32	0.37	117.0	218.7	334.2	1	3	2	1
3503186	0.37	0.43	156.9	280.0	416.1	3	3	2	1
3902102	0.37	0.43	652.0	1433.8	2488.9	2	1	1	1
3902161	0.37	0.49	271.3	608.1	1070.7	3	1	1	2
4703960	0.37	0.49	170.0	374.4	647.8	3	1	1	2
4705432	0.37	0.49	54.2	114.1	191.3	3	1	1	2
4706692	0.37	0.37	145.9	288.3	468.1	3	2	1	2
301183	0.37	0.43	1536.0	2722.6	3619.6	2	3	2	2
301299	0.37	0.43	1051.7	2201.0	3762.3	3	3	2	3
302104	0.37	0.55	1663.6	4017.0	7427.6	3	1	1	3
1700782	0.37	0.43	84.5	165.2	257.4	3	2	1	3
1702068	0.37	0.43	133.0	308.5	548.4	3	1	1	3
3902102	0.37	0.43	652.0	1433.8	2488.9	2	1	1	1
3902161	0.37	0.49	271.3	608.1	1070.7	3	1	1	2
4703960	0.37	0.49	170.0	374.4	647.8	3	1	1	2
4705432	0.37	0.49	54.2	114.1	191.3	3	1	1	2
4706692	0.37	0.37	145.9	288.3	468.1	3	2	1	2
5200245	0.37	0.43	668.2	1370.6	2284.3	2	3	2	3
5200695	0.37	0.37	199.8	453.4	803.0	3	2	1	2
5200938	0.32	0.55	772.2	1537.6	2537.3	3	3	2	3
5201292	0.37	0.49	811.6	1733.7	2992.3	3	3	2	2
5206154	0.37	0.49	186.5	416.8	703.6	3	1	1	2
5206286	0.37	0.43	697.7	1687.0	3101.6	3	2	1	2
5207266	0.43	0.43	655.2	1498.1	2664.6	3	3	2	2

Appendix B cont'd

Site[1]	$MaxK_w$[20]	$MaxK_f$[21]	SP_2[22]	SP_{10}[23]	SP_{100}[24]	ChanAl[25]	ChanPro[26]	ChanPro2[27]	ChanHO[28]
5207800	0.37	0.43	181.7	428.6	765.1	3	2	1	3
5208130	0.37	0.49	848.7	2039.9	3757.2	3	2	1	2
300608	0.37	0.43	1941.4	4540.6	8266.2	1	1	1	1
303945	0.37	0.43	1677.9	3778.0	6711.7	2	1	1	1
480357	0.32	0.37	673.4	1141.4	1658.9	1	1	1	2
3502236	0.37	0.37	89.7	176.3	275.5	2	2	1	1
3532631	0.37	0.37	167.5	300.4	446.5	1	1	1	2
3533514	0.32	0.37	28.7	54.5	82.0	1	1	1	2
3533654	0.37	0.37	140.0	269.9	417.7				
4700333	0.37	0.37	512.1	1004.5	1634.3	2	1	1	2
4707036	0.37	0.43	957.9	1897.4	3113.3	1	1	1	1
5201209	0.37	0.49	1043.6	2200.1	3763.3	1	1	1	1
5203589	0.49	0.55	203.8	516.9	963.4				
5207231	0.37	0.43	1184.8	2479.8	4206.5	2	2	1	1
5243165			815.0	1690.1	2861.8	2	1	1	1
7000367	0.32	0.37	555.0	1180.1	2012.7	1	1	1	1
7403933	0.37	0.43	35.5	656.0	998.6	1	1	1	1
8501505	0.37	0.49	258.8	631.9	1165.8			2	
8502447	0.37	0.49	394.7	900.0	1543.5	2	2	1	2
8504997	0.37	0.49	258.8	631.9	1165.8	2	1	1	2
8600910	0.37	0.43	182.5	351.1	543.3	1	1	1	1
8601909	0.37	0.55	113.7	219.4	337.7	1	1	1	1
8634270	0.37	0.43	305.8	617.3	983.4	1		2	1
8703426	0.32	0.37	439.6	810.1	1281.7	1	2	1	1
8705399	0.32	0.37	47.5	85.1	125.7	2	1	1	1
8500045	0.37	0.49	727.6	1674.8	3000.9	3	2	1	2
7402236	0.37	0.43	119.5	249.0	401.9	3	1	1	3
7402732	0.37	0.43	178.0	349.8	547.3	2	4	2	1
7402139	0.32	0.43	189.4	359.1	549.7	3	1	1	3
7401388	0.43	0.43	161.2	332.9	555.9	3		2	2
8600031	0.43	0.43	115.6	244.3	397.7	3	1	1	2
8600694	0.37	0.43	180.0	303.0	433.5	1	4	2	2
8600996	0.37	0.43	245.1	421.8	609.4	1	3	2	1
8602905	0.37	0.43	115.1	237.9	383.3	3		2	1
8603219	0.32	0.32	581.0	952.0	1351.0	1	3	2	1
8603243	0.37	0.43	235.4	409.3	595.0	1	4	2	1
8700397	0.32	0.43	67.9	115.3	165.1	3	2	1	1
8702012	0.32	0.32	57.7	99.8	143.9	3		2	1
8702284	0.32	0.37	23.3	41.9	61.6	2	3	2	1
8702853	0.32	0.43	152.6	277.2	412.7	2	3	2	4
8706069	0.32	0.37	15.9	30.5	46.4	1	3	2	1
8707146	0.32	0.37	99.7	175.2	256.7	3	3	2	3

Appendix B cont'd

Site[1]	MaxK$_w$[20]	MaxK$_f$[21]	SP$_2$[22]	SP$_{10}$[23]	SP$_{100}$[24]	ChanAl[25]	ChanPro[26]	ChanPro2[27]	ChanHO[28]
7007027	0.37	0.64	875.9	1943.9	3419.2	3	3	2	2
7007299	0.37	0.43	499.9	1062.5	1814.4	1	2	1	3
7007191	0.37	0.64	279.8	640.4	1137.0	3	3	2	2
7007051	0.37	0.64	1678.6	3272.5	5374.3	3	2	1	1
7006268	0.37	0.43	465.6	1128.4	2080.7	2	3	2	2
7004591	0.37	0.43	682.4	1642.8	3018.5	2	3	2	2
7002165	0.37	0.43	1178.9	2534.0	4402.2	2	3	2	2
7000847	0.37	0.43	308.5	683.0	1193.1	3	2	1	3
7000243	0.37	0.43	1135.8	2096.5	3321.7	3	2	1	3
4800451	0.37	0.43	168.8	290.9	423.4	1	3	2	2
4800699	0.37	0.43	73.8	121.0	169.2	2		2	1
4801490	0.37	0.43	107.3	207.6	320.9	3		2	1
4802667			394.2	626.3	870.9	1	3	2	1
6200036	0.28	0.28	178.9	312.3	455.6	1	4	2	2
6201865	0.43	0.43	128.6	222.0	323.7	1	3	2	1
7203012	0.32	0.37	450.3	870.4	1354.4	3	1	1	2
7200242	0.37	0.43	274.5	497.3	742.8	2	4	2	1
7200935	0.28	0.28	130.9	254.9	395.8	2	3	2	1
7201117	0.37	0.43	353.1	641.6	964.1	1	3	2	1
7201206	0.37	0.43	314.1	630.1	1038.3	3		2	1
5238420	0.32	0.55	525.6	1236.0	2328.1	1	1	1	1
4800524	0.43	0.43	39.0	76.7	119.1	2	1	1	2
4703189	0.32	0.43	1085.7	2083.2	3381.9	1	1	1	1
7003129	0.37	0.43	347.5	759.8	1316.9	2	1	1	2
3536157	0.32	0.37	71.0	136.9	210.1	1	1	1	1
7202164	0.37	0.43	328.6	643.5	1009.3	1	2	1	2
4802098			366.6	580.3	804.5	1	2	1	1
8601925	0.32	0.32	62.9	116.0	173.0	2		2	1
5242088	0.37	0.49	142.5	331.9	591.9	2	1	1	1
7005075	0.37	0.55	1612.7	3609.2	6396.0	2	2	1	1
5207622	0.43	0.49	153.9	350.2	616.8	2	2	1	2
5242428	0.43	0.55	132.3	296.3	516.5	2	2	1	2
5205476	0.37	0.37	543.9	1239.3	2119.0	1	1	1	1
7242298	0.32	0.55	2555.1	4264.9	6166.8	1	1	1	1
3503542	0.32	0.37	22.0	41.0	61.8	1		2	1
6200184			23.6	39.2	55.1	2	2	1	1
3501345	0.37	0.37	51.5	102.2	159.1	1	1	1	1
302341			1036.6	2604.8	4911.9	1	1	1	2
1702084	0.37	0.43	347.2	744.1	1228.2	2	2	1	2
1702297	0.28	0.32	65.3	153.0	263.6	2	2	1	3
1702416	0.37	0.43	229.3	513.0	900.9	2	2	1	2
1702424	0.37	0.43	235.4	529.3	930.7	1	1	1	2

Appendix B cont'd

Site[1]	$MaxK_w$[20]	$MaxK_f$[21]	SP_2[22]	SP_{10}[23]	SP_{100}[24]	ChanAl[25]	ChanPro[26]	ChanPro2[27]	ChanHO[28]
1702998	0.37	0.43	16.0	35.1	57.7	1	1	1	2
1703633	0.37	0.43	205.1	447.6	743.9	2	1	1	2
1703862	0.37	0.43	99.1	195.3	305.2	2	2	1	2
1703870	0.37	0.43	427.3	864.6	1385.1	2	2	1	2
2204878	0.37	0.49	510.6	1033.2	1706.9	2	1	1	1
3901831	0.37	0.55	1858.3	3676.4	6082.8	1	1	1	1
3902439	0.37	0.37	682.1	1369.9	2279.4	2	1	1	2
4706064	0.37	0.49	340.6	790.4	1419.6	2	2	1	1
5200938	0.32	0.55	772.2	1537.6	2537.3	3	3	2	3
5201497	0.37	0.49	208.9	465.6	781.1	1	1	1	2
5201586	0.37	0.49	310.4	652.1	1059.3	1	1	1	2
5201837	0.37	0.49	612.0	1336.2	2230.6	2	1	1	2
5205174	0.32	0.55	397.4	878.2	1531.2	2	2	1	2
5205654	0.37	0.49	728.5	1638.2	2895.1	2	2	1	2
5206928	0.37	0.43	723.9	1657.5	2973.9	1	2	1	1
7002521	0.37	0.43	1640.8	3220.6	5288.9	2	2	1	2
7003595			2212.7	4757.8	8275.1	1	1	1	1
7004966	0.37	0.64	1367.1	3183.3	5741.2	2	2	1	2
7005245	0.37	0.43	236.3	570.0	1044.9	2	2	1	2
7005369	0.37	0.43	309.4	686.8	1196.8	2	2	1	2
7006691	0.37	0.43	745.6	1565.6	2669.5	2	2	1	1
7006845	0.37	0.43	2320.5	5044.0	8809.5	2	2	1	2
7006934	0.37	0.43	590.0	1557.1	3023.0	2	2	1	1
7007280	0.37	0.43	146.7	327.3	570.3	2	2	1	1
7007299	0.37	0.43	499.9	1062.5	1814.4	1	2	1	2
8500118	0.37	0.43	839.6	2049.7	3803.1	2	2	1	1
8500193	0.37	0.55	1126.5	2634.9	4790.7	2	2	1	1
8501629	0.37	0.49	879.4	1992.4	3527.7	1	1	1	1
8501653	0.37	0.49	879.4	1992.4	3527.7	1	1	1	1
8502331	0.37	0.49	151.2	362.2	630.9	2	2	1	1
8502471	0.37	0.49	395.5	931.7	1688.8	2	2	1	2
8504059	0.37	0.49	652.3	1399.3	2324.9	2	2	1	2
8504350	0.32	0.32	1778.9	4200.7	7670.8	2	2	1	2
8505160	0.37	0.49	2387.1	5014.0	8623.2	2	2	1	2
8505314	0.32	0.32	706.0	1837.8	3517.7	3	3	2	2
8505411	0.37	0.37	321.9	861.8	1674.2	2	2	1	2
8505942	0.37	0.55	341.0	688.6	1097.7	2	2	1	2
8505977	0.43	0.55	318.9	689.4	1141.1	1	1	1	1
8506248	0.37	0.49	247.4	494.8	782.2	1	1	1	1
8506337	0.37	0.43	590.7	1353.4	2421.7	2	2	1	2
2203332	0.37	0.49	189.0	375.8	614.2	2	2	1	2
1700391	0.43	0.43	44.7	99.7	165.4	1	1	1	2

Appendix B cont'd

Site[1]	$MaxK_w$[20]	$MaxK_f$[21]	SP_2[22]	SP_{10}[23]	SP_{100}[24]	ChanAl[25]	ChanPro[26]	ChanPro2[27]	ChanHO[28]
5205263	0.37	0.43	305.1	696.8	1240.1	1	1	1	1
2600374	0.32	0.32	40.5	73.6	109.1	1	1	1	1
4703758	0.32	0.37	33.1	74.7	130.2	1	1	1	2
5246520	0.37	0.49	202.3	455.2	801.1	1	1	1	1
7003188	0.37	0.43	101.2	206.3	341.3	1	1	1	1
4706250	0.37	0.55	3165.3	5748.0	9055.0	1	1	1	1
8705909			118.5	211.0	312.3	1	1	1	1
4705882	0.37	0.43	708.0	1623.0	2894.3	1	1	1	1
3534243	0.32	0.32	92.1	176.5	271.1	1	1	1	1
8504318	0.43	0.43	1436.8	3228.2	5719.0	1	1	1	1
8706158	0.32	0.37	28.5	47.1	66.1	1	1	1	2
7403372	0.37	0.37	106.9	235.3	392.2	1	1	1	1
7201990	0.37	0.43	154.9	310.9	493.4	1	1	1	1
304395	0.37	0.43	564.5	1256.7	2214.2	1	1	1	1
8705224	0.32	0.37	9.0	16.3	23.9	1		2	1
5233569	0.43	0.49	430.0	933.6	1612.5	1		2	1
300454	0.37	0.43	1493.3	3644.1	6787.6	1	1	1	1
5206375	0.37	0.43	162.0	366.0	616.3	1	1	1	2
8636974	0.37	0.43	272.4	473.8	691.6	1	1	1	1
1700464	0.37	0.43	214.7	508.2	921.6	1	1	1	2
4702476	0.37	0.49	123.6	269.2	462.6	2	2	1	2
3533336	0.37	0.37	220.5	428.0	666.1	1	2	1	1
7001819	0.37	0.43	277.8	628.1	1108.9	1	1	1	1
3900347	0.37	0.43	23.5	53.7	93.6	1	1	1	1
3500063	0.43	0.43	40.3	78.9	121.4	2	2	1	2
4805798			13.4	28.4	45.6				
8502099	0.37	0.43	304.8	711.3	1273.5	1	1	1	1
8706271	0.32	0.37	232.5	437.7	670.7	1	1	1	1
5236339	0.37	0.49	225.6	531.0	922.0	1	1	1	1
8602611	0.37	0.43	58.7	113.4	174.5	1		2	1
4774485	0.43	0.43	31.1	55.9	84.6	2	2	1	2
5244579	0.37	0.43	1984.3	3875.5	6353.6	1	1	1	1
5248760	0.37	0.43	309.0	733.7	1277.5	2	1	1	1
5206871	0.37	0.49	2198.1	4228.1	6874.2	1	1	1	1
4701674	0.43	0.43	50.9	100.5	161.6	1	1	1	2
5205387	0.43	0.43	209.2	481.0	855.0	2	2	1	2
5242851	0.37	0.37	82.5	199.8	367.2	1	1	1	2
4703510	0.32	0.43	556.0	1095.7	1791.3	2	2	1	1

Appendix C. Pilot Project Summaries

WAY 83 - State Route 83 and Savage Run in Wayne County, Ohio

The site exhibits channel instability problems, including channel migration that is undermining the left bank wing wall and bar deposition reducing hydraulic capacity. This crossing has two spans, each 22 feet. The bridge is a 44 foot two-span concrete bridge with reinforced piles. The channel in the vicinity of the bridge had originally been constructed with a base width to match both spans. Regional curves of bankfull channel dimensions suggest a channel 25 to 26 feet wide. Measurements of stable reaches upstream with herbaceous vegetation are about 24 feet wide, close to a single 22 span of the bridge.

The realigned channel utilized one span for low and intermediate flows and left the floodplain bar so that both spans would flow during high events, generally accessed only a few times annually to biannually.

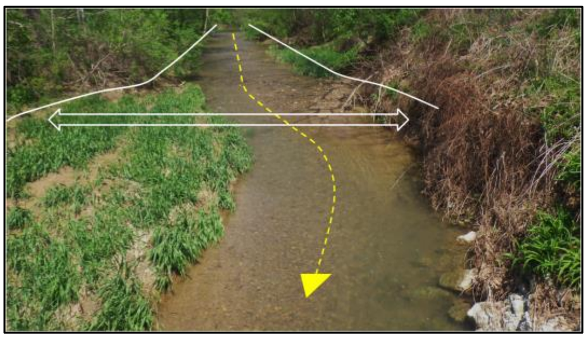


Figure 15 The channel in the vicinity of the bridge had originally been constructed much wider than the stable channel in the area.

Figure 16 Poor channel alignment from a floodplain bar forming and driving bank erosion.

Figure 17 The highlighted portion of the floodplain bar was removed to align low and intermediate flows with one span. The second span provides hydraulic capacity for large events.

After the channel was realigned with the bridge, a block vane was used to prevent channel migration and to keep the channel in alignment with the bridge. Note that the downstream end of the vane touches the bridge abutment. Also, at the downstream end, where the vane is highest, an additional footer layer of block was placed to ensure the footer is below the maximum depth of scour. The bank opposite the vane is armored with buried riprap.

Figure 18 As-built viewed from channel centerline looking downstream.

Figure 19 The bank opposite the vane was armored with buried riprap.

The vane abutting the bridge structure is an alternative to constructing it farther upstream. This option moves the scour hole closer to the entrance of the bridge and simplifies the structure with no sill or armoring needed between vane and bridge.

Figure 20 The downstream end of the vane at the bridge abutment.

Figure 21 Moderate flow is shifted smoothly to the center of the span without turbulence or eddies.

Figure 22 The project after several moderate flows.

The project was constructed October, 2015 over three days. Construction of the vane itself was done in 4.5 hours. The project has been observed for one year and is functioning exceptionally well.

WAY 604 - State Route 604 and Steel Ditch in Wayne County, Ohio

The channel alignment upstream was poor and causing scour at the right abutment/wing-wall. The meander pattern appears to have migrated down valley and, at one time, the channel upstream was over widened. It appeared that both the over-widening and meander pattern migration led to a bar forming off the left bank and bank erosion of the right bank.

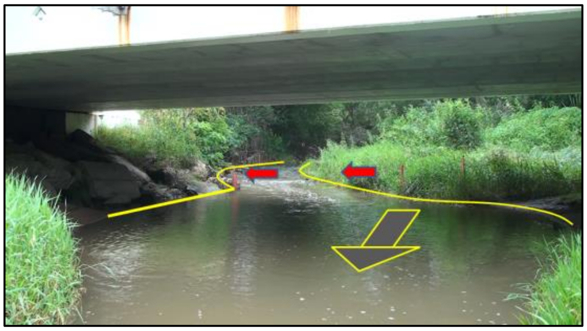


Figure 23 Looking upstream the channel has migrated river right and a floodplain bar forming on river left.

A vane was installed along the right bank upstream of the bridge to re-align the flow with the bridge. Rather than abutting the wing wall, riprap was placed at the bridge abutment and wing wall and the vane begins about 20 feet upstream. The bar was not lowered and had only minimal grading at the point of the bar as required for construction of the vane and re-seeding.

Figure 24 The footer course of block of the vane and the sill being set.

The vane was constructed of concrete block in the standard layout of 30 degrees off the channel bank and at 7% slope.


Figure 25 The sill, at right angles with the bank, is visible prior to backfill and placement of buried riprap.

After winter and spring high flows following construction, deposition is evident along the right bank upstream where scour had been occurring. The vane is intended to shift the main current off the bank, not just along the vane itself, but protect the bank upstream, 2 or more times the length of the vane.

The experience and performance with this project leads us to think that moving the vane downstream to abut the wing-wall might be preferable for results and simplicity. By having the vane abut the bridge wing-wall the risk of scour around the vane and between the vane and the bridge structure would be reduced without the use of bank armoring.


Figure 26 After one winter and spring high flows note the stability on the river right bank and the location of the scour downstream from mid-way along the vane.

The upstream end of the vane intercepted the channel bed in an existing riffle. Subsequent to construction, much of the riffle has been replaced by a scour hole. The bed has become lower, exposing the upstream end of the vane. We wonder if a smooth transition, tangent between the vane and the streambed, might be preferable to the 1.5 foot elevation the upstream end of the vane now has above the stream bed. No instabilities or debris accumulation have yet been observed. On future projects, we will consider extending the vane farther upstream, buried down into the channel bed, as insurance.

Figure 27 The upstream end of the vane is stable but has become more exposed from the vane inducing scour of a riffle.

MED 606 – State Route 606 and E. Br Rocky River Trib in Medina Co, Ohio

Channel alignment was poor upstream of the bridge. The channel was far to the right of center. The right bank was eroding and a bar had formed from the left bank across more than half the bridge opening. The bridge has 3 spans, with the middle span similar to the natural bankfull channel width; however, the channel formed around both sides of the right set of piers.

Three factors appear to have contributed to the existing problems. First, the channel had at one time been over widened in the approach to the bridge, prompting bar formation. Second, the channel meander pattern appears to have migrated down valley, perhaps aggravated by some fill placed up stream. And third, this stream, like others in the area, are known to have high bedload, as is evident from the prevalence of active bars of coarse gravel and cobble and lateral channel migration. Together, these factors have continued to drive the channel into the right bank, eroding it and causing the alignment to become worse.

Figure 28 The floodplain bar with trees growing on it viewed looking downstream from the left bank.

Figure 29 Poor alignment of low and intermediate flows with debris collecting on the right piers.

Work occurred in two phases, the first in 2014 when a remote control excavator was used under the bridge deck to remove sediment accumulations and place rip rap under both side spans.

Figure 30 The remote control excavator removed sediment and placed rock under the bridge deck.

The second phase, in 2015, included realigning the channel upstream and constructing a cross vane. To improve sediment transport, the cross vane was intended to concentrate and accelerate flow through the middle span.

Figure 31 Viewed looking downstream at the cross vane.

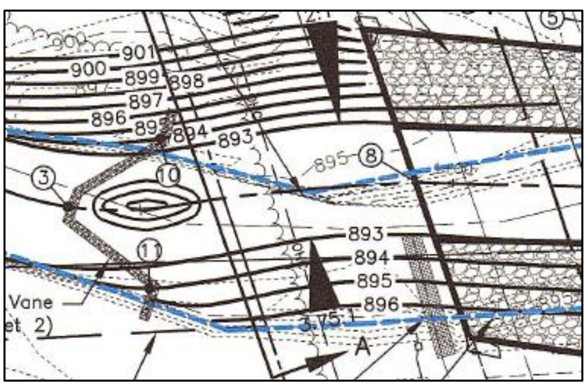


Figure 32 The construction plans. Note the narrow bed width between the vane and the bridge.

Shortly after construction, bed material started to accumulate upstream from the bridge, in the area where scour was intended to occur.

Figure 33 Looking upstream from the bridge at the cross vane and accumulating bed material.

After one season of high flows, the project has not performed satisfactorily. Bed material has accumulated between the cross vane and the bridge, a bar has begun to re-form in the left side of the channel and the alignment is developing off to the right of center toward the right piers.

Figure 34 Looking downstream the vane mostly obscured by accumulated bed material. Note the channel width should be similar to the width between the piers.

Three factors appear to have contributed to the new problems. First, we constructed the cross vane lower than designed, with little slope from the middle up to the banks. Second, we over widened the channel upstream from the bridge, in particular, the right bank is much wider than designed. Third, to most effectively concentrate and accelerate flow at and through the bridge, we now think the downstream end of the vane should abut the bridge, either tied into the abutment slopes or directly to the piers with rock stabilization between the piers and abutment slopes.

Adjustments are planned for alleviating the existing problems. We will add an additional layer of block to the entire cross vane and regrade the right bank to narrow channel upstream from the bridge.

ASH 603 –State Route 603 and Black Fork Trib in Ashland County, Ohio

Road flooding was occurring several times a year. Bed aggradation through the channel reach had left little clearance under the bridge and extremely limited flow capacity. Debris accumulation was a perpetual maintenance burden.

The stream naturally has a large amount of bedload sediment. The bedload supply increased further, in recent years, by channel instability in the watershed. Throughout the watershed the stream has adequate sediment transport competence, until it meets the broad flat floodplain of Black Fork Mohican River. It is made even flatter by backwater from the Charles Mill Lake dam. State Route 603 crosses at the natural transition from a single thread channel to an alluvial fan. In the past, channelization had extended the stream through the alluvial fan to the river. However, sediment has completely filled the channelized reach. Flows have been actively developing new courses that dissipate and disappear well before reaching the river.

Figure 35 Minimal capacity from aggradation and debris.

Figure 36 Aggradation downstream reduced slope and at the bridge.

The design objectives were 1) to maximize sediment transport downstream, 2) increase flow capacity by lowering the grade under the bridge, and 3) upstream, prevent the channel from down-cutting where the first two objectives required the channel to be steepened. The channel profile, dimension and pattern were all used to help achieve these objectives. A block cross vane was constructed abutting the wing walls to concentrate and accelerate flows through the bridge.

Figure 37 Constructing a channel downstream.

The channel downstream was constructed to maximize sediment transport. To do this, the slope was made as steep as the site allowed, the channel was constructed narrow and deep, plan form was laid out with large radius of curvature and minimum cross over lengths, bed form was made fairly uniform, and bank roughness minimized.

Figure 38 Channel downstream.

Concrete block was used for the cross vane. The cross vane was constructed abutting the bridge structure. Also, the downstream/inside face of the vane was constructed tangent to the bridge abutments.

Figure 39 The first footer blocks set in place.

It was necessary to over-excavate under the deck to gain access with equipment.   It is anticipated that the over-excavation will partially refill with bed material.

Figure 40 Over-excavating under the deck for access with equipment.

Figure 41 The cross vane as-built.

Figure 42 One of 2 grade control riffles constructed upstream.

Flow in the stream is ephemeral. Construction was completed in August, 2016, with no flow during construction and no significant flows prior to this report.

FUL 20 - State Route 20 and Bean Creek in Fulton County, Ohio

Debris collecting on one of the bridge piers had been an ongoing maintenance burden. The bridge consists of three spans and the width of the natural channel is about 1.5 times wider than each of the spans. The far right span has developed a floodplain bar and the channel is split between the center and left spans. Historic channelization (straightening and lowering) of this large (206 sq.mi.) river have made it prone to adjustments. Two abandon bridge abutments just upstream of this bridge have been sufficient to initiate some lateral migration.

Figure 43 Debris accumulation on the left pier and erosion on the right bank.

Figure 44 Viewed looking downstream, a low bar on left and a high depositional floodplain bar in the right span.

A w-weir was constructed to direct flow (and debris) around the pier and away from the eroding bank. Also, a floodplain bench was lowered and expanded through the right span.

Figure 45 Intermediate flow over w-weir with floodplain bench visible through the far span.

This site is not ideal for the application of an instream structure. The river is much larger than where structures are typically used and it has a sand bed channel that is less stable than gravel or cobble. Also, the sand bed made the excavation and water management during construction much more challenging.

Figure 46 Construction in a sand bed channel by diverting flow and dewatering with a 6 inch pump.

To increase stability, rock was placed around the block of the upstream end of the w-weir and the footer block was placed extra deep. Having the weir abut the pier is also believed to make the structure more stable. The maximum height of the w-weir was only about ¾ of the channel depth. Typically, these types of structures are constructed to up to the bankfull stage or level with the top of the channel bank. However, the high banks here would have made that very difficult. It appears that having the weir abut the bridge structure allows the vane to be lower without creating the turbulence expected if a low structure were tied into a high bank.

Figure 47 The right end of the w-weir abutting the pier.

Figure 48 Placing concrete block.

The structure is actually a modified w-weir. It has three segments instead of four, with the left half of the structure similar to a single segment vane rather than a cross vane. This was done because of the dominate flow to the right and the low bar forming on the left. The left bank was armored to assure the modified w-weir would not cause bank erosion.

Figure 49 Placing Flexamat to for bank stabilization.

Construction was done in November, 2015. Since then, three high flows (1.1 RI) occurred, two of which were observed. The structure was submerged. No turbulence or drop over the w-weir was perceptible. However, the flow and the path of small debris could be seen clearly shifting away from the pier and directed through the spans.

Figure 50 High flow with w-weir submerged and shifting flow away from the pier.


Figure 51 The structure after one season.

After one year, the structure appears to be functioning well with no debris accumulating on the pier. The block on the far left end has shifted and the left bar has scoured away. Maintenance may eventually be required on the left side of the channel if the low bar does not re-develop.

SAN 412 - State Route 412 and Fuller Creek in Sandusky County, Ohio

The flow capacity through the bridge was reduced due to bars obstructing flow and creating poor flow alignment. Scour was occurring at the right abutment upstream and the left downstream.

Originally, the channel cross section had been constructed overly wide. In the vicinity of the bridge the channel width had been more than twice the width of the naturally forming channel. Under the bridge, without sunlight and thus without the influence of vegetation, bars have not formed and the over wide cross section remains stable. However, up and downstream of the bridge, with the influence of vegetation, the over wide cross section narrowed to a predictable natural width, but with poor alignment.

A two-stage cross sectional geometry was constructed as an alternative approach to restoring flow capacity. Reduced maintenance is anticipated by aligning the channel and lowering the bars to a compound form with low floodplain.

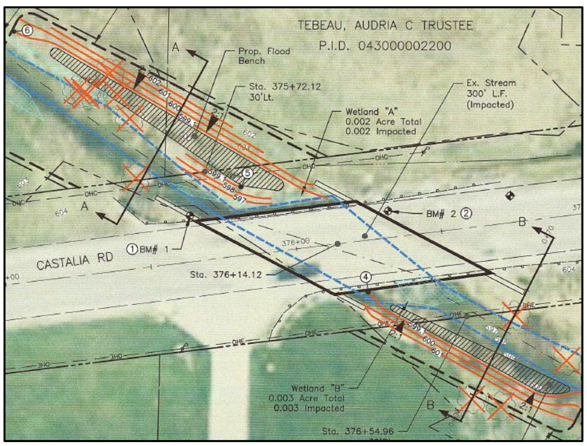


Figure 52 Plan view with flow from right to left.


Figure 53 Excavation at the bench stage and above.

Construction in October 2015 took three days and predominantly earthwork, simply lowering and widening the bars. Little work was done below the new bench stage and no work was done to the channel bed.

Figure 54 The width is increased only for high flows above the bench stage.

Figure 55 Minimal excavation below the bench stage to align the low and intermediate flows.

Figure 56 Viewed from the bridge downstream as-built.

Figure 57 The first season following construction.

After one high flow season, the erosion on the left bank has stopped and has deposition and new vegetation. Deposition is not yet accumulating on the floodplain bars. We expect the bars to eventually aggrade but at a slow enough rate so that less maintenance will be needed compared to the maintenance requirements experienced with the entire channel over widened to the stream bed elevation as is commonly done.

OTT 579 - State Route 579 and Crane Creek in Ottawa County, Ohio

After bridge maintenance to repair badly corroded piers, the abutment slopes were re-stabilized. The abutment slopes were bare and had experienced some scour. Access was limited by low clearance under the bridge deck.

Figure 58 The left bank prior to construction.

Figure 59 Exposed slopes prior to construction.

Concrete cloth will be used as an alternative to the traditional technique of placing rock. Concrete cloth has the advantage of easy installation without requiring equipment.

Figure 60 Cutting the concrete cloth with utility knife.

Figure 61 Moving concrete cloth into position.

Figure 62 Lining up strips for 4 inch overlap.

Figure 63 Screws to fasten overlapping strips.

Construction was in October, 2015, and proceeded as anticipated, with hand labor and no machine access needed. After one season of high flows (winter/spring 2016), the material appears as it did when installed.


Figure 64 A season after construction.

WOO 582 - State Route 582 and Toussaint Creek in Wood County, Ohio

The channel is poorly aligned with flows, not through the middle of the span, but directly at the piers on the right side of the bridge. Continued bar development and bank erosion appear to be making the problem worse. This project has not yet been constructed.

Figure 51 Poorly aligned channel viewed looking upstream.

Figure 52 Looking upstream. Bar deposition and active bank erosion.

Past over widening of the channel in the vicinity of the bridge initiated the alignment problem. Within the widened sections upstream and down, a floodplain bar predictably formed, re-narrowing the channel against the opposite bank. Once initiated, the meander pattern has continued to develop and worsen the alignment. The right piers are now mid-channel and are obstructing flows and collecting debris.

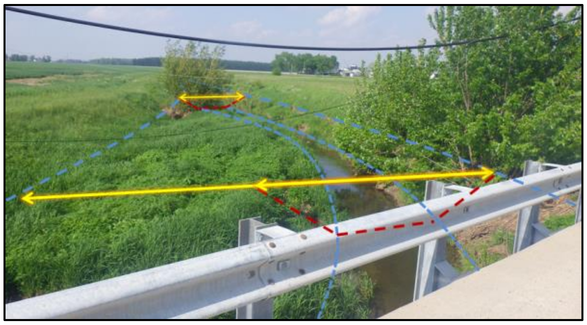


Figure 53 The additional width excavated at the bridge predictably lead to this asymmetric compound form.

One proposal is that the channel and bars be reconfigured with a compound cross sectional shape in proper alignment. When a cross section is constructed overly wide, a compound cross sectional form predictably develops on its' own. If it develops on its own, then the bar forms on one side and the channel is pushed into the opposite bank. So if a compound channel were constructed, it could be made to aligned with the bridge and be less prone maintenance problems.

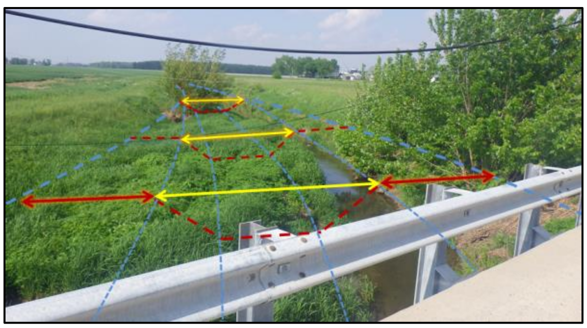


Figure 54 The constructed two-stage channel option.

Another option for this site, that would require significantly less disturbance, is to simply construct a single vane upstream from the right pier and let the current adjust and maintain alignment. One advantage of vanes is that they influence the flow well upstream of the structure, adjusting the flow and providing bank protection 2 to 3 times longer than the structure itself. The structures long gradual affect would shift the current off the right bank and direct it through the middle span. This could be accomplished without additional earthwork, except as required to install the structure.

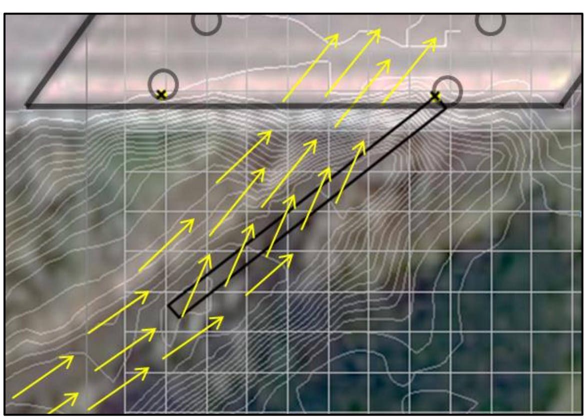


Figure 55 A single vane upstream on the right pier to stop the bank erosion and align the dominant through the middle span.

Figure 56 The location of a vane that would stop and scour the advancing point bar.

MED 42 - State Route 42 and East Fork Black River in Medina County, Ohio

The toe of the roadway embankment has eroded. Continued erosion and slope failure appear likely. Other than the immediate threat to the embankment and roadway, the channel under the bridge is functioning well. The channel alignment is not ideal and there is some woody debris in the channel; however, these do not appear to be problems. This project has not yet been constructed.

Figure 565 Looking upstream at the eroding roadway embankment.

The problem is being caused by the downstream migration of the meander pattern. The meander upstream on the right side of the valley has moved down valley and is now eroding the road embankment just to the right of the bridge abutment. Fortunately, the second bend upstream does not appear to have moved as much or as rapidly and it is not crowding the problem bend.

Figure 58 The first bend upstream has moved down valley.

The project proposes to realign the channel with the bridge. To keep the alignment, a block vane will be constructed at the right pier. The vane has an advantage over simply armoring the bank, in that the vane protects not just the bridge abutment and adjacent bank, but it also affects the flow farther upstream beyond the right-of-way.

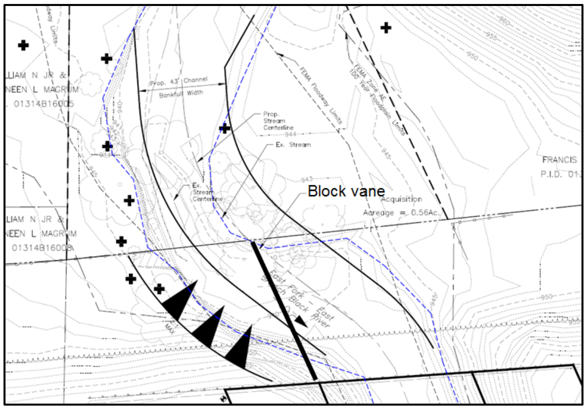


Figure 59 Plan upstream showing realigned channel and block vane.

Figure 60 Looking downstream at the section of channel to be moved left.

SAN 6 - State Route 6 and Muskellunge Creek in Sandusky County, Ohio

The abutment slopes under the deck were to be re-stabilized after structural maintenance to the bridge deck is done. The abutment slopes were exposed and had experienced some scour. Access was limited by low clearance under the bridge deck.

Figure 61 Exposed slopes under the deck.

Armoring the exposed slopes under the deck was to be achieved with Flexamat. The material was to be unrolled on one side of the bridge and pulled through the areas with low clearance.

Figure 62 Flexamat.

Also, the two-span bridge has a central pier mid-channel that is exposed to low and intermediate flows and prone to accumulating debris. This has reportedly not been a significant enough maintenance burden or structural threat to warrant construction of a w-weir to divert flow around the pier.


Figure 63 Looking downstream at the central pier.

Concrete rubble, made available from the bridge deck maintenance, was placed on the most exposed areas, negating the need for placing Flexamat.


Figure 64 Concrete rubble placed instead of Flexamat.

Appendix D. Decision Matrix Documentation

Alternative Stream Channel Maintenance at Bridge Crossings

Selection Toolbox, Procedure, and Recommendations

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INTRODUCTION

There are many techniques available for countering stream channel instability and scour at bridges. Countermeasures can be categorized into three groups: armor, hydraulic control, and grade control. The selection of countermeasures is dependent on the application and whether the problem is local scour at the pier or abutment, contraction scour across the bed at the bridge opening, reach-wide channel degradation, or lateral channel movement or widening. The feasibility of and confidence in each of the various countermeasures is a function of multiple factors, including effectiveness, cost, maintenance, constraints, and the ability to detect failure. Some countermeasures have been systematically tested, while others may have been laboratory tested, but not field tested. Others cannot be used effectively within existing right-of-ways. There is a wide range of costs associated with the initial design and construction of the measures as well as the maintenance costs. The ability to detect failure or impending failure of any of the countermeasures is important to assuring that the bridge will be protected during high flow events.

In this report, we propose a simple countermeasure selection method, based on HEC-23 and other recent studies, that will be specific to the ODOT districts considered in this proposal, require minimal data, and consider right-of-way restrictions. The method will be based on the type of application, such as bank protection or grade control, and the suitability within the physiographic region and stream type.

RECENT ADVANCES IN SCOUR AND CHANNEL INSTABILITY PRACTICES

Recent Countermeasure Studies

Hydraulic Engineering Circular 23 (HEC-23) (Lagasse et al. 2009) is the Federal Highway Agency manual for scour and stream channel instability countermeasures. Table 2-1 of HEC-23 provides a very good summary of the uses and applications of the countermeasures in the manual. The authors surveyed all of the state DOTs as well as consultants and FHWA regions to determine the experiences with the various countermeasures. HEC-23 presents general discussions and design guidelines for 19 countermeasures, ranging from riprap to soil cement to articulated concrete blocks. Biotechnical countermeasures discussed in the manual include live staking and vegetated riprap; however the primary focus is on armoring banks, slopes, and beds. The manual is meant to provide an overview of options, but does not address common limitations, such as right of ways, and does not address specific regions of the country.

A risk-based method for selection countermeasures was proposed by Johnson and Niezgoda (2004) using a failure modes and effects analysis. The method is a relatively simple, systematic technique for assigning relative risk to scour countermeasure choices at the design phase and takes into consideration economic, environmental, and social benefits. The resulting ratings can be used to determine components of the design that require particular attention to prevent failure of the countermeasure and to adequately protect the bridge, as well as justification for decision making.

In a recent study for the National Cooperative Highway Research Program (NCHRP 24-33), Sotiropoulos (2013) and Radspinner et al. (2013) conducted an review of the current use of in-stream structures for stabilizing stream channels, focusing on five of the most commonly used structures: rock vanes, J-hooks, bend-way weirs, cross vanes, and w-weirs. They conducted laboratory and field experiments and computational studies in order to develop engineering guidelines, design methods, and recommended specifications for in-stream structure installation, monitoring, and maintenance. Their study provided significant results relevant to this study. The literature review, survey of practitioners, and experiments showed that a single rock vane or weir did not adequately control erosion on meander bends and that the size, angle, and spacing of these structures would require at least 100 feet of stream length, well outside of most ROWs.

Based on the demand for more environmentally sensitive, sustainable countermeasures for treating stream bank stability in the vicinity of highways, the NCHRP funded project 24-39 titled Evaluation and Assessment of Environmentally Sensitive Stream Bank Protection Measures. This project is currently underway. The objectives of the research are to produce guidelines for appropriate selection, design, installation, and maintenance of environmentally sensitive stream bank stabilization and protection measures (Lagasse et al., 2013). The guidelines will be based on a literature review, assessments of current field installations, and laboratory testing.

Stream Stabilization Practices

The type of protection that is used at a bridge depends on the nature of the problem. Lagasse et al. (2009) provide a comparison of a selected group of countermeasures by qualitatively describing the functional application (i.e., local scour, contraction scour, and channel instability), suitable river environment (river type and size, flow conditions, and physical condition), maintenance, and installation experience. At existing bridges, the bridge engineer can choose from one of two categories of countermeasures: armor the channel bed and banks or alter the flow alignment. These methods can also be used in combination.

By far, the most common treatment for protecting bridges from scour is armor, particularly riprap. Other types of armor include precast concrete units, grout filled bags, foundation extensions, and concrete aprons. All of these measures armor the bed or bank material against erosive forces. They do not break up vortices or redirect the flow. If sized, graded, and placed well, armor can be a very effective measure for preventing scour at both piers and abutments and locally halting channel instability. However, for bridges with narrow waterway openings, armor can cause further contraction of the waterway opening and actually exacerbate scour. At vertical wall abutments, riprap and other armor may be ineffective due to the steepness of the banks. Detailed information on riprap, gabions, rock mattresses, vegetated riprap, grout bags/mattresses, and articulated concrete blocks, along with their design guidelines, can be found in HEC-23.

One armoring technique not covered in HEC-23 is geocells. Geocells are relatively inexpensive countermeasures used for slope protection. The cells are connected in expandable panels made from high-density polyethylene, polyester or another polymer material. When expanded during installation, the interconnected strips form the walls of a flexible, three-dimensional cellular structure into which specified infill materials, such as soil, sand, aggregate, or cement, are placed and compacted. The result is a free-draining system that prevents mass movements by providing confinement through tensile reinforcement (Geosynthetics, 2013). Geocells have been widely used for slope protection in highway applications and many others. Design and installation guidelines are provided at websites, such as Strata and other makers of geocells.

Flow altering devices can be used to realign the flow to mitigate against local and contraction scour as well as bank widening and lateral migration. These measures include submerged (Iowa) vanes, bendway weirs, rock vanes, and cross vanes and have been used for many years to deflect flows and sediment and to control spiral flow in bends and erosion at banks. Each of these flow altering devices is described briefly below.

In experimental studies, it was found that submerged vanes were effective over a wide range of flow depths from two to eight times the vane height (Odgaard, 2009). Submerged vanes are typically constructed from sheet pile or reinforced concrete founded on adequately deep pilings, but could also be made of large rocks or wood with footers of adequate depth to resist erosional forces. Odgaard (2009) provides design and construction guidelines.

Bendway weirs are low elevation stone sills, very similar to vanes, used to improve lateral stream stability and flow alignment problems (Lagassee et al. 2009). Bendway weirs are typically not visible at bankfull flow and redirect flow by causing it to pass perpendicularly over the weir. They are made from stone, tree trunks, or grout filled bags. Lagasse et al. 2009), provide design guidelines.

Vanes and cross vanes are stream restoration or stabilization structures promoted by Rosgen (1996) to improve lateral stability and flow alignment and, in the case of cross vanes, provide some grade control on degrading beds. Like submerged Iowa vanes, these structures tend to be very effective in flow depths up to about five times their height. Johnson et al. (2001; 2002) tested these structures in a laboratory flume at a single span model bridge to assess their ability to move scour away from pier and abutment foundations, thereby reducing scour at bridges.

The results showed that scour at the pier or abutment was generally reduced on the order of 65–90%, depending on flow conditions and the structure configuration. The scour was moved away from the abutment or pier into the center of the channel. These structures have not yet been systematically tested in the field; however, preliminary design criteria for these structures and their appropriate applications, in terms of bridge and stream types, are given in Johnson et al. (2001, 2002).

Incorporating Stream Stabilization Practices into Bridge Countermeasures

Managing rivers and streams that include one or more road crossings requires some knowledge of the flow hydraulics over a range of flows in order to create a smooth, stable transition through the bridge opening. In-stream structures, such as vanes and weirs, can help to transition flow, sediment, and debris through a bridge opening. However, other issues create additional difficulties for stream management at road crossings. Bridges are commonly owned by the federal, state, county, or local governments. The bridge owner will also typically own a right-of-way in the stream channel some distance upstream and downstream of the road crossing. For example, the bridge owner may have a 50-foot right-of-way on either side of a bridge. Within the right-of-ways, other agencies, watershed organizations, or private firms cannot place structures or modify channels without permission from the bridge owner. The bridge owner, on the other hand, cannot modify the channel outside of the right-of-way. Eliciting cooperation from the various agencies as part of a stream management project is sometimes limited since the bridge owner is liable for the structure, any lives lost, or other damage in the case of a bridge failure. It may also be difficult for the bridge owner to make modifications that would improve flows through a bridge opening because the bridge owner may not be able to obtain floodplain easements outside of the rights-of-way for their bridge.

In an attempt to address some of these issues, Johnson et al. (2010) created a suite of scenarios for bridge-stream intersections and suggested options for creating stable transitions. Much of this work was based on the research findings and preliminary design guidance developed by Johnson et al. (2001; 2002) for the use of vanes and cross vanes at bridges. Since that time, studies addressing the use of in-stream structure in heavy bedload streams (Newlin and Johnson (2009)) and along stream meanders (Sotiropoulos, 2013; Radspinner et al., 2013) have been conducted and their results can also be incorporated into such scenarios. The scenarios included the following:

1. Meander at a bridge
2. Flow contraction
3. Straight channel, poor alignment
4. Meandering channel, poor alignment
5. Unstable banks near bridge
6. Bed degradation in the vicinity of bridge or culvert.
7. Debris accumulation against a mid-channel pier.

Scenarios 1, 2, 4, and 5 are particularly relevant to the current study and will be further developed as part of the study. Johnson et al. (2010) found submerged vanes to be the best suited for improving channel alignment at bridges.

ODOT DISTRICTS 2 AND 3 PHYSICAL SETTING AND APPROPRIATE COUNTERMEASURES

Physiographic Regions

Districts 2 and 3 are in the northern, central part of Ohio. The general physical setting each of the districts are described below based on their physiographic settings. The physiographic regions of Ohio are shown in Figure 1 and described in more detail at Brockman (1998).

District 2 sites are located in Lucas, Wood, Ottawa, and Sandusky Counties. All sites were in the Huron-Erie Lake Plains physiographic region in the Central Lowlands. The Huron-Erie Lake Plain Region of the Central Lowlands covers a large area of Ice-Age lake-bottom land in northwestern Ohio and a narrow band between Lake Erie and the Portage Escarpment across extreme northwestern Ohio. The lake plains are flat lying with low (10 feet) to extremely low (five feet) relief (Schiefer, 2002).

Streams in the Central Lowlands can be ephemeral, intermittent or perennial (Johnson, 2006). The Central Lowlands are covered with thick deposits of loess (Simon and Rinaldi, 2000). Simon and Rinaldi (2000) determined that the combination of easily erodible soils and extensive human disturbance has produced thousands of miles of highly unstable streams in Midwest. Channels modified for agricultural drainage are pervasive in the western part of the Lake Plain where drainage density is about two miles of stream per square mile of drainage area, the lowest in the state (Brockman, 1996).

District 2 is within the Lake Erie drainage basin. Surficial deposits in the Lake Plains portion of the basin consist of wave-planed glacial till and lacustrine deposits of fine sand, silt and clay (Schiefer, 2002). Streams draining to Lake Erie are generally smaller and less numerous than those draining to the Ohio River. Mean annual flows or yields of streams draining to Lake Erie are generally lower than those draining to the Ohio River due to latitudinal variation in mean annual precipitation (Schiefer, 2002). The larger streams west of Sandusky gather headwaters in end moraines of the Till Plains and flow at relatively low gradient to the Lake Plain where they continue at very low gradient to Lake Erie (Schiefer, 2002). These are the some of the lowest yielding streams in the state mainly due to relatively low mean annual precipitation (Schiefer, 2002). The larger streams west of Sandusky gather headwaters in end moraines of the Till Plains and flow at relatively low gradient to the Lake Plain where they continue at very low gradient to Lake Erie (Schiefer, 2002).). These are the some of the lowest yielding streams in the state mainly due to relatively low mean annual precipitation (Schiefer, 2002). The gradient of these streams are lower than those in District 3. Rock exposures along streams in the basin are common; the effect of ground water discharge from the rock on base flows is not great.

District 3 sites are located in Medina, Richland, and Wayne counties. District 3 sites lie in the Glaciated Allegheny Plateau within the Appalachian Highlands province and the Till Plains of the Central Lowland. The land in the Till Plains is gently rolling, for the most part, and covered with glacial deposits of moderate (100 ft to 200 ft) to moderately low (25 ft to 60 ft) relief.

Surficial deposits in the Till Plains portion of the basin consist of glacial drift and lacustrine deposits (Schiefer, 2002). In Allegheny Plateaus in Ohio the Flushing Divide forms the western boundary of the highland area and the eastern boundary of the Muskingum River and Little Muskingum River. The western boundary of the highland area is drained by relatively short tributaries to the Ohio River (Schiefer, 2002).

Medina, Richland and Wayne counties include the Lake Erie Tributaries between Sandusky River and Cuyahoga River. All of these streams are relatively short with moderate gradients (Schiefer, 2002). Streams in Appalachian Highlands region are generally meandering and perennial; however, the pattern is greatly influenced by slope, geology, bed materials (Mills et al., 1987; Palone and Todd). The geology is generally comprised of more resistant material. Hack (1965) showed that slopes in the Shenandoah Valley are much steeper (about seven times) than those in the Martinsburg shale areas, while streams in the carbonate rock areas had slopes in between those of the Shenandoah Valley and Martinsburg shale areas. Channel patterns in this region are also controlled by bedrock (Palone and Todd, 1998). The bedrock exposures and rough terrain tends to create waterfalls and fast-moving streams across the region (Maryland Department of Natural Resources, 2002).

Figure 1. Physiographic regions of Ohio (from Brockman, 1998)

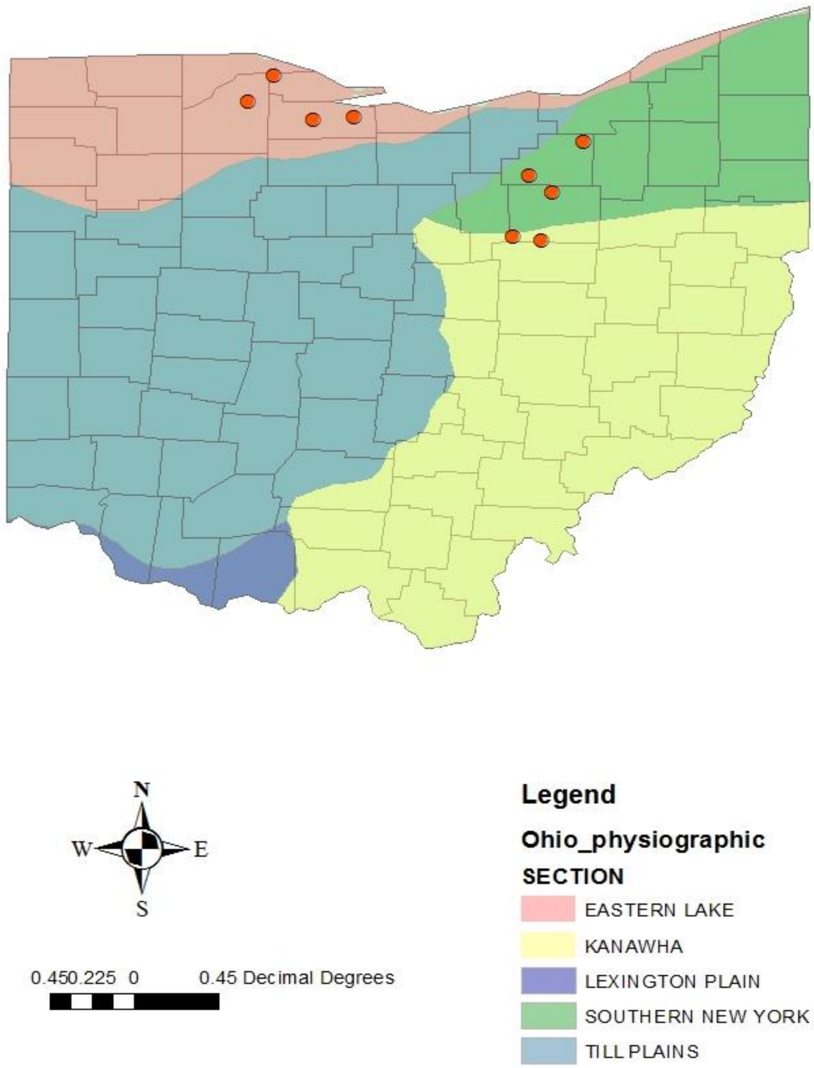

Figure 2. District 2 and District 3 sites in different physiographic sections.

Other State Experiences in Same Regions

U.S. Army Corps of Engineers, Vicksburg District (WET 1990) carried out a study to evaluate the performance of alternative stream bank erosion protection techniques. Field investigations in the Yazoo River Basin in Mississippi clearly showed that rudimentary countermeasures, such as used tire revetment were generally unsuccessful in bends with even low to moderate radial stress (WET 1990). The study showed that stone structures including longitudinal stone dikes and stone spurs performed well in reaches of high radial stress. In HEC-23, it is stated that riprap installations on the stream banks, at bridge abutments and in the stream bed have failed to stop lateral erosion at some sites in Mississippi. At one site, riprap placed on the banks and bed of a stream resulted in severe bed scour and bank erosion downstream of the riprap. Successful rock riprap installations at bends were found in five sites in Mississippi (HEC-23). Other successful rock riprap study sites were sites where bank revetment was used in conjunction with other countermeasures, such as spurs or retards. Well designed concrete paving is satisfactory as fill slope revetment, as revetment on streams having low gradients, particularly in Illinois and Texas (HEC-23).

Bendway weirs have become popular control measures for bank erosion along small meandering streams in the agricultural Midwest. In Illinois, bendway weirs have been installed at hundreds of sites over the last several years (Rhoads, 2003). In Illinois, bendway weirs have been used to stabilize stream banks and control bank erosion, particularly in channel bends along meandering rivers. Bendway weirs usually are implemented where bank erosion and lateral migration of a meander bend is perceived to represent stream channel instability. At present no or little information is available on post-implementation performance of bendway weirs in relation to project objectives. Rhoads (2003) provides potential locations for long-term monitoring of weir performance. Several meander bends including Sugar Creek (McLean County), the Embarras River (Cumberland County), and the Conine site along Big Creek (Clark County) showed evidence of ongoing erosion despite the presence of bendway weirs (Rhoads, 2003). The installation of weirs on a particular bend does not reduce rates of erosion on adjacent, unprotected bends and possibly could alter patterns or rates of erosion on these bends (Rhoads, 2003). A modeling study funded by Illinois Water Resource Center was done to evaluate weir design criteria relative to their effectiveness in arresting bank erosion (Abad, 2008).

Grout filled mattress (mats) are comprised of a double layer of strong synthetic fabric, typically woven nylon or polyester, sewn into a series of pillow-shaped compartments that are connected internally by ducts. Primarily it is widely used for local scour at abutments and lateral stream stability in Iowa and Illinois. Iowa Department of Transportation (2004) provided the minimum property requirements for the Geotextile comprising the fabric form. Lagasse et al (2001) presents analyses of the hydraulic stability of these mats that make possible determination of mat thickness for a desired factor of safety against sliding of the unanchored mat.

The most common types of countermeasures used in Indiana are riprap, metal sheet piling, metal retaining walls with metal piles, timber retaining walls with timber piles, concrete retaining walls with concrete piles, sand bags, concrete slope wall, vegetation and other (INDOT Bridge Inspection Manual, 2010). Indiana Department of Transportation (INDOT) has their design manual for riprap.

Appropriate Countermeasures for ODOT Districts 2 and 3 Based on HEC-23, separated by Physiographic Regions and State Experiences

A list of countermeasures, based on the literature review, physiographic regions, and other state experiences, that are appropriate for use in Districts 2 and 3 are given in Tables 1, 2 and 3. There are some countermeasures that are used wisely regardless of the physiographic regions. Table 4 lists the widely used countermeasures. Note that Tables 1-4 do not address the issue of applicability of the various countermeasures within a relatively short right of way. Also note that these tables based on information compiled for HEC-23, as this was resulted from surveys conducted recently.

Table1. Countermeasures for Eastern Lake in Central Lowland (Source: HEC-23)

<table>
<tr><th>Physiographic region</th><th>State</th><th>Functional application</th><th>Structures</th><th>Type</th></tr>
<tr><td rowspan="11">Central Lowland (province)

Note: block lettered states are in Eastern Lake within Central Lowland</td><td>**IL**, MO</td><td>Primary use: stream stability (lateral)
Secondary use: local scour (abutments/piers)</td><td>Bendway weirs/ stream barbs</td><td rowspan="3">Transverse structures</td></tr>
<tr><td>ND, SD, NE</td><td>Primary use: stream stability (lateral)</td><td>Hardpoint</td></tr>
<tr><td>OK</td><td>Secondary use: Local scour (Abutments), contraction scour (floodplain)</td><td>Embankment spurs</td></tr>
<tr><td>OK</td><td>Primary use: stream stability (lateral)
Secondary use: local scour (abutments)</td><td>Longitudinal dikes</td><td>Longitudinal structures</td></tr>
<tr><td>IA</td><td>Primary use: stream stability (lateral)
Secondary use: local scour (piers)</td><td>Vanes</td><td rowspan="2">Areal structure/ treatments</td></tr>
<tr><td>MO, TX</td><td>Primary use: stream stability (lateral)
Secondary use: local scour (abutments/piers)</td><td>Channelization</td></tr>
<tr><td>SD</td><td>Primary use: stream stability (lateral)
Secondary use: local scour (abutments), contraction scour (floodplain and channel), stream stability (vertical), overtopping flow (approach embankments)</td><td>Rigid grout filled mattress/ concrete fabric mat</td><td rowspan="4">Revetments and bed armor</td></tr>
<tr><td>**MI**</td><td>Secondary use: stream stability (lateral)</td><td>Fully grouted riprap</td></tr>
<tr><td>**IL**</td><td>Secondary use: stream stability (lateral)</td><td>Self launching riprap (window)</td></tr>
<tr><td>IA, **IL**</td><td>Primary use: Local scour (abutments), stream stability (lateral)
Secondary use: Local scour (piers), overtopping flow (approach embankments), stream instability (vertical)</td><td>Concrete/grout mattress (fabric-formed)</td></tr>
<tr><td>TX</td><td>Primary use: Local scour (piers), contraction scour (floodplain and channel), stream stability (vertical)
Secondary use:
stream stability (lateral)</td><td>Crutch bents/ Underpinning</td><td>Foundation strengthening</td></tr>
</table>

Table2. Countermeasures for Till Plains in Central Lowland (Source: HEC-23)

Physiographic region	State	Functional application	Structures	Type
Appalachian Plateaus ***Note: block lettered states include both the Kanawha and Southern New York section within Central Lowland***	**NY**	Secondary use: local scour (pier, abutment)	Concrete armor units	Local scour armoring
	PA, VA	Secondary use: local scour (pier, abutment)	Concrete armor units (Toskanes, tetrapods, etc)	
	TN	Primary use: local scour (pier, abutment)	Gabions/gabion mattress	
	MD, GA	Primary use: stream stability (lateral) Secondary use: local scour (abutments), contraction scour (floodplain and channel), stream stability (vertical), overtopping flow (approach embankments)	Rigid grout filled mattress/ concrete fabric mat	Revetments and bed armor
	TN	Secondary use: stream stability (lateral)	Fully grouted riprap	
	PA, GA	Secondary use: stream stability (lateral)	Self launching riprap (window)	

Table3. Countermeasures for Till Plains in Central Lowland (Source: HEC-23)

Physiographic region	State	Functional application	Structures	Type
Central Lowland (province) ***Note: block lettered states are in Till Plains within Central Lowland***	**IL**, MO	Primary use: stream stability (lateral) Secondary use: local scour (abutments/piers)	Bendway weirs/ stream barbs	Transverse structures
	ND, SD, NE	Primary use: stream stability (lateral)	Hardpoint	
	OK	Secondary use: Local scour (Abutments), contraction scour (floodplain)	Embankment spurs	
	OK	Primary use: stream stability (lateral) Secondary use: local scour (abutments)	Longitudinal dikes	Longitudinal structures
	IA	Primary use: stream stability (lateral) Secondary use: local scour (piers)	Vanes	Areal structure/ treatments
	MO, TX	Primary use: stream stability (lateral) Secondary use: local scour (abutments/piers)	Channelization	
	SD	Primary use: stream stability (lateral) Secondary use: local scour (abutments), contraction scour (floodplain and channel), stream stability (vertical), overtopping flow (approach embankments)	Rigid grout filled mattress/ concrete fabric mat	Revetments and bed armor
	MI	Secondary use: stream stability (lateral)	Fully grouted riprap	
	IL	Secondary use: stream stability (lateral)	Self launching riprap (window)	
	IA, **IL**	Primary use: Local scour (abutments), stream stability (lateral) Secondary use: Local scour (piers), overtopping flow (approach embankments), stream instability (vertical)	Concrete/grout mattress (fabric-formed)	
	TX	Primary use: Local scour (piers), contraction scour (floodplain and channel), stream stability (vertical) Secondary use: stream stability (lateral)	Crutch bents/Underpinnin g	Foundation strengthening
	TX	Primary use: Local scour (piers and abutments), contraction scour (floodplain and channel), stream stability (vertical and lateral), overtopping flow (approach embankments)	Lower foundation	

Table 4. Widely used countermeasures (Source: HEC-23)

Type	Structure	Functional application
Transverse structures	Impermeable spurs	Primary use: lateral stream instability Secondary use: local scour (abutments, piers)
	Permeable spurs	Primary use: lateral stream instability Secondary use: local scour (abutments, piers)
	Drop structures (check dams, grade control)	Primary use: Vertical stream instability Secondary use: Local scour (abutments, piers), contraction scour (floodplain and channel)
Longitudinal structures	Retards	Primary use: lateral stream instability Secondary use: local scour (abutments, piers)
	Bulkheads	Primary use: lateral stream instability, local scour (abutments, piers)
	Guide banks	Primary use: local scour (abutments) Secondary use: local scour (pier), contraction scour (floodplain and channels), lateral stream instability, overtopping flow (approach embankments)
Areal structures	Jacks/tetrahedron jetty fields	Primary use: lateral stream instability
	Flow relief (overflow, relief bridge)	Primary use: overtopping flow (approach embankments), contraction scour (floodplain and channel) Secondary use: local scour (abutments, piers)
	Sediment detention basin	Primary use: Vertical stream instability
Revetments and bed armor	Roller compacted concrete	Primary use: local scour (abutments), contraction scour (floodplain and channel), lateral and vertical stream instability, overtopping flow (approach embankments) Secondary use: local scour (piers)
	Concrete pavement	Primary use: lateral stream instability, contraction scour (floodplain and channel) Secondary use: local scour (abutments), vertical stream instability, overtopping flow (approach embankments)
	Riprap	Primary use: local scour (abutments, piers), lateral stream instability Secondary use: vertical stream instability, contraction scour (floodplain and channel), overtopping flow (approach embankments)
	Riprap fill-trench	Primary use: lateral stream instability Secondary use: local scour (abutments)
	Gabions/ gabion mattress	Primary use: local scour (abutments, piers), lateral stream instability Secondary use: contraction scour (floodplain and channel), vertical stream instability, overtopping flow (approach embankments)
	Articulated blocks (interlocking and/or cable tied)	Primary use: local scour (abutments, piers), contraction scour (floodplain and channel), lateral

		stream instability, overtopping flow (approach embankments) Secondary use: vertical stream instability
Local scour armoring	Riprap (fill/apron)	Primary use: local scour (abutments, piers)
	Fully grouted riprap	Primary use: local scour (abutments)
	Grout filed bags/ sand cement bags	Primary use: local scour (abutments) Secondary use: local scour (piers)
	Articulated blocks (interlocking and/or cable tied)	Primary use: local scour (abutments, piers)
Structural countermeasures (foundation strengthening)	Pumped concrete/grout under footing	Primary use: local scour (abutments, piers) Secondary use: contraction scour (floodplain and channel), lateral and vertical stream instability
Pier geometry modification	Extended footings	Primary use: local scour (piers) Secondary use: overtopping flow (approach embankments)
Biotechnical engineering	Vegetated geosynthetic products	Primary use: lateral stream instability
	Fascines/woody mats	Primary use: lateral stream instability Secondary use: overtopping flow (approach embankments)
	Vegetated riprap	Primary use: lateral stream instability
	Root wads	Primary use: lateral stream instability
	Live staking	Primary use: lateral stream instability

SELECTION PROCEDURE

The procedure for selecting countermeasures will be based on HEC-23, the literature review provided in this report, limitations not included in HEC-23, such as right-of-way restrictions, and in-stream structures not included in HEC-23, such as rock vanes. Unlike HEC-23, the procedure will be specific to Ohio Districts 2 and 3 physiographic settings. Another goal of the procedure will be to have minimal data requirements, but increased dependence on level of confidence in the circumstances, ability to monitor, and other risk-related factors.

As discussed above, there are many techniques, measures, and practices available for countering scour at existing bridge piers and abutments. Armor is the most common treatment for protecting bridges from scour. Armoring countermeasures included in this study are riprap, precast concrete units, grout filled bags, and concrete aprons. Flow altering devices included in this study are submerged (Iowa vanes), bendway weirs, rock vanes, and cross vanes. Realignment of the existing stream channel upstream from the bridge is sometimes necessary to reduce scour and improve the conveyance capability of the bridge waterway opening. Such channel modifications are often followed by channel adjustments, including bed degradation and bank erosion, resulting in migration of the channel upstream of the bridge. The erosion of channel materials upstream frequently deposits at the downstream side of the bridge, forming a temporary or permanent bar in the channel. Thus, realignment is often followed by the use of scour countermeasures described above, including armor and flow diversion techniques (Johnson and Niezgoda, 2004).

The selection of the various countermeasures is dependent on the application and whether the problem is local scour at the pier or abutment, contraction scour across the bed at the bridge opening, reach-wide channel degradation, or lateral channel movement or widening. The feasibility of and confidence in each of the various countermeasures is a function of several factors, including effectiveness, cost, maintenance, and the ability to detect failure. Some countermeasures have been systematically tested, while others may have been laboratory tested, but not field tested. Still others are not trusted by highway agency personnel. There is a wide range of costs associated with the initial design and construction of the measures as well as the maintenance costs. The ability to detect failure or impending failure of scour countermeasures is important to assuring that the bridge will be protected during high flow events.

The selection procedure developed for this project will include functional applications, suitability specific to Ohio districts 2 and 3, expertise required for design and construction, maintenance requirements, right-of-way limitations, and confidence level.

- Applicability – includes the intented function, such as armoring, redirecting of flow, bed or bank stabilization, pier or abutment scour, contraction scour, protection of steep slopes under bridges especially with limited access.
- Suitability – includes planform type, stream width, velocity, bed material, bank slope
- Right-of-way limitations – based on the suitability of the intended countermeasure to be effective within a typical Ohio DOT right-of-way.
- Confidence level will be based on the amount and quality of evidence indicating successful application for the given environment, as well as agreement between the various studies or experts. Confidence level – this is a function of the amount and quality of evidence indicating successful application for the given environment, as well as agreement between the various studies or experts.
- Maintenance requirements – relative maintenance requirement
- Ease of monitoring and detection – relative ease given as high to low.
- In addition, pros and cons of each option will be given.

Table 5 provides an example of the possible selection summary.

Table 5. Summary of Applicability and Limitations of Stabilization Practices for Ohio DOT Districts 2 and 3.

	APPLICATIONS					MAINTENANCE AND MONITORING REQUIREMENTS	CONFIDENCE LEVEL
Stabilization Practice	**Bank Stabilization**	**Bed Stabilization**	**Redirecting Flow**	**Abutment Scour**	**Pier Scour**		
Rock Vanes	○	□	○	○	□	M	H
Cross vanes	○	○	○	○	□	M	H
W-weirs	○	○	○	○	□	H	L
Two-stage channels	□	□	□	□	□	L	M

○ = well suited; □ = moderately well suited; □ = not suitable; L = low; M = moderate; H = high

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Appendix E. Post-Construction Rapid Monitoring Protocol

Monitoring Countermeasures at Bridges: Post-Construction Rapid Monitoring Protocol

Background

Stream maintenance at bridge crossings is common, but systematic efforts to assess the effectiveness of different maintenance activities are less common. Although some guidelines for monitoring stream restoration projects are found in the literature, less than 10% of stream restoration projects included the monitoring actions (Petty, 2006). Roni (2005) provides resources for various experimental and statistical designs for restoration monitoring which are necessarily technical in nature and very difficult to implement without a strong background in statistics. Petty (2006) stated that the main problem of these well-designed monitoring programs is the inability to clearly identify the minimum standards for the monitoring projects. Another problem as mentioned by Petty (2006) is that the implementation of these monitoring designs requires significant time and resources.

A rapid restoration monitoring protocol recently developed by U.S. Fish and Wildlife Service (Davis et al., 2014) provides minimum standards for assessing the functional stability of a project in a structured format which requires less time and resources. The additional objectives of this protocol are to assess the benefits achieved from the project and to identify potential causes of impairment. In this monitoring protocol, parameters that describe the stream functions (Harman et al., 2012) are used to evaluate vertical stability, lateral stability and riparian conditions. Parameters are also used to evaluate the performance of in-stream structures. Recommended future actions can also be selected from this monitoring protocol unless an intensive survey monitoring is required to ensure the extent of the degradation of the functionality of the project. Qualifications of the evaluator are also discussed in detail in the monitoring protocol. The evaluator must be responsible for design and/or implementation; otherwise the evaluator should contact the designer and/or implementer to convey the information.

Rapid stream maintenance monitoring at bridge crossings

The framework of the monitoring protocol developed for the current project “Alternative Stream Channel Maintenance at Bridge Crossings” is based on the procedure and indicators developed by Davis et al. (2014). The modified evaluation parameters in this protocol reflect the indicators in the stream stability assessment method developed by Johnson, 2005; 2006) as well as appropriate indicators for various countermeasure and bank stability design approaches of stream channel maintenance at bridge crossings. The monitoring protocol is rapid as it involves visual observation which focuses on stability of channel and bank and the conditions of countermeasures and bridge structure. The flow condition during the monitoring time is also recorded. In addition, the monitoring protocol identifies the areas that are trending towards instability and threatening the safety of the bridge. The monitoring program is intended to assess the project success, failure, or level of functioning through documentation of conditions that identify changes from stable to unstable over time. Recommended corrective actions are also included in the monitoring protocol, which are selected considering the severity of the indicators and the possible causes of instability. As this protocol is primarily based on visual observations, a confidence level is introduced to qualify the level of subjectivity. A more detailed intensive survey may be required if the confidence level is low or if the rapid survey indicates potential functional failure.

This monitoring protocol is intended to provide a rapid assessment of the components of the project over time. The indicators combined with the corrective actions can be used to determine the degree of success and maintenance requirements for the project. This protocol addresses a series of key issues: (1) flow and channel bed conditions; (2) riparian and bank conditions; (3) conditions of bridge structure and countermeasures. Therefore, this protocol aids in the decision making process for determining the site conditions in a holistic approach that are conductive to each type of countermeasure. It is a very important tool for the research team to assess the effectiveness of the project design for the given site condition. For designers and funding agencies, this protocol could be used to ensure that time and money are being used effectively.

Protocol Objectives

The most significant objectives are listed below:

1. To provide a guidance for monitoring the channel maintenance projects at the bridge crossings
2. To assess project level of success and stability with limited resources and time
3. To ensure the effectiveness of the project by recommending corrective actions
4. Documentation of countermeasure disturbances or failures and the associated causes

Monitoring form

The monitoring form, summarized in Figure 1 and an example is provided in Figure 2. Detail on codes used to populate the form are provided in Tables 1-6. The form has five general sections: (1) project information and notes, (2) station identification, (3) problem description including indicators, severity, implications, and causes along with a qualitative estimate of confidence level in the observation or assessment, and (5) recommended corrective actions. Each are described below, and shown in Figures 1 and 2.

Project information

General information about the bridge crossing are recorded in this section, including bridge ID, road name, stream name and the crew that is involved in the surveying. Any particular description of the project related to the specific bridge crossing can also be included in this section.

Station identification

This section records the survey location with respect to the bridge structure. The location can be upstream or downstream of a bridge section. If there are multiple locations to be assessed upstream or downstream of a bridge section, then the evaluator may include the approximate distance of the location from the bridge section. If the evaluator is assessing one specific stream bank (left bank or right bank while facing downstream) then he or she may also identify the bank.

Problem description

In this section an evaluator will be able to describe a problem in terms of stability indicator, severity, implication and cause. The indicators are divided in four types: (1) channel and bank indicators which are used to assess vertical and lateral stability near the structure; (2) countermeasure and structure indicators which are used to evaluate structural integrity and performance; (3) severity and implications which indicate the intensity and persistence of the problem, which helps to determine the potential for project failure; and (4) apparent causes of the instability. The possible causes that are included in this monitoring protocol are based on relatively short time and spatial scales.

Corrective actions

The corrective actions included in this monitoring protocol are intended to provide the evaluator with a means of quickly indicating what he or she believes might correct the problem based on the observations made.

Confidence level

The confidence level associated with indicators and severity indicates the evaluator's confidence in understanding the observed physical processes and their effects. The confidence level associated with implications and corrective actions indicates the evaluator's confidence in predicting the physical processes and the corresponding remedy for any problems. Finally the confidence level associated with the causes indicates the evaluator's confidence in determining the causes of instability. The evaluator will enter an overall score that he/she thinks represents the overall confidence after filling out the second confidence table. The second confidence table helps to remind the evaluator where the confidence level is lower.

Figure 66 Field Sheet for Monitoring Bridge Sites (modified from Davis et al., 2014)

Date	
Road	
Stream	
Bridge ID	
lat long	
Crew	
Flow	Low flow

Notes:

Station	Type	Indicators	Severity	Implications	Causes	Corrective Actions

Observations (confidence)

Key Codes Type	Indicators	Severity	Implications	Causes	Actions
In Channel	IC	IC	All	IC	IC
Left Bank or RB-Right Bank	LB or RB	LB or RB		LB or RB	LB or RB
Countermeasure	C	C		C	C
At Bridge Structure	S	S		S	S

Figure 67 Example Field Sheet

Date	6/20/2014, 8/13/2015
Road	**WAY 604 Easton Rd**
Stream	**Chippewa Creek**
Bridge ID	**WAY 00604-1307**
lat long	40.9454,-81.8899
Crew	OSU, EMH&T, PS
Flow	Low flow

Notes: Upstream the channel had at one time been over widened. The meander pattern has a definite valley-right bend on the right bank upstream of the bridge that may be migrating down-valley. The over-widening and meander pattern have led to a bar forming off the left bank and bank erosion of the right bank. The alignment is poor and scouring at the right abutment/wing-wall.

Observations (confidence)

Station	Type	Indicators		Severity		Implications		Causes		Corrective Actions
US	IC	4 (lf)	very high	3	high	2	high	2	very high	1
US	RB	2 , 3, 8	very high	3	high	2	high	1	very high	9 (vane)
	S	1	very high							
DS	IC	1	very high							
DS	LB & RB	1	very high							

Table 1 Indicators for use in the monitoring protocol in Figure 1.

Indicator	In channel	Bank	Countermeasures
1	Stable or no change	Stable or no change	Stable or no change
2	Reach-wide degradation	Lateral scour/ undercut (left bank, right bank)	Unstable/displaced structure rocks
3	Reach-wide aggradation	Increased bank height/angle (left bank, right bank)	Undermining of the structures
4	Bar development (left bank, right bank, mid-channel)	Decreased bank height/angle (left bank, right bank)	Buried structure
5	Localized deposition in vicinity of bridge	Undercut roots (left bank, right bank)	Poor alignment of countermeasure to the flow
6	Localized degradation in vicinity of bridge	Exposed bank material (left bank, right bank)	End around erosion
7	Obstruction (Debris, logs etc)	Bank failure (left bank, right bank)	Others
8	Increase or change in sinuosity, affecting bridge	Trees leaning into stream (left bank, right bank)	
9	Channel widening	Sparse woody vegetation	
10	Irregular channel width developing	Steep banks (left bank, right bank)	
11	Poor alignment of flow in vicinity of bridge	Others	
12	Others		

Table 2 Severity for use in the monitoring protocol in Figure 1.

Level	In channel	Bank	Countermeasures
1	Insignificant	Insignificant	Insignificant
2	Limited scour or deposition formation; minor changes to bed/ limited effects	Localized bank erosion; minor loss of bank material	Minor stress; still functioning as intended
3	Moderate scour or bar formation; moderate changes to bed/ moderate effects	Localized, moderate bank erosion; moderate loss of bank material	Partial failure; minimally functioning as intended
4	Extensive changes to bed characteristics/ extensive effects	Widespread failure of entire bank, bank actively eroding, substantial loss of bank material	Complete failure; no longer functioning as intended
5		Minor riparian degradation	May fail if flood occurs
6		Localized riparian degradation	
7		Widespread riparian degradation	

Table 3 Implications for use in the monitoring protocol in Figure 1.

Level	Expected Effects
1	Not expected to worsen or cause further problems; may stabilize over time
2	Expected to worsen over time
3	Immediate concern; will cause further damage and contribute to other problems

Table 4 Causes for use in the monitoring protocol in Figure 1.

Cause	In channel	Bank	Countermeasures
1	Localized/regional sediment input from an immediate source/upstream source	Downstream migration of meander	Faulty design or improper construction or poor maintenance practices
2	Cross section w/y ratio is too high (section widened at bridge).	Vertical and lateral heterogeneity of the bank	Poor alignment of flow
3	Aggradation from in-stream vegetation, debris jam, or other channel obstruction	Non-cohesive bank material	Seepage
4	Scour from debris jam or other channel obstruction	Lack/loss of vegetation	Uplift pressure
5	Loss of floodplain connectivity	Loss of floodplain connectivity	High angle of attack
6	Other	Other	Back water effect
7			Other

Table 5 Corrective action for use in the monitoring protocol in Figure 1.

Action	In channel	Bank	Countermeasures
1	No action	No action	No action
2	Remove debris jam, bars, other obstruction and/or excessive sediment	Adjust or add proper countermeasure to stabilize the channel banks	Stabilize structure with rock
3	Adjust or add proper countermeasure to prevent scour	Reconnect channel to floodplain	Repair unstable portion of structure
4	Adjust or add proper countermeasure for grade control	Regrade banks, repair matting, replant vegetation	Relocate or rebuild entire structure
5	Adjust or add proper countermeasure to realign the flow	Armor bank	Others
6	Reconnect channel to floodplain	Modify channel dimensions	
7	Modify channel dimensions	Modify channel profile	
8	Modify channel profile	Modify channel planform	
9	Modify channel planform	Others	
10	Stabilize local sediment source		
11	Dissipate energy of the flow		
12	Others		

Table 6 Confidence for use in the monitoring protocol in Figure 1.

Confidence level	Scoring	Description
Very high	1	High confidence in assessment, sufficient measurements are performed, sufficient knowledge regarding the observed physical processes
High	2	High confidence in assessment, some measurements are performed, sufficient knowledge regarding the observed physical processes
Medium	3	Moderate confidence in assessment, some measurements are performed, moderate knowledge regarding the observed physical processes
Low	4	Moderate confidence in assessment, no measurements are performed, moderate knowledge regarding the observed physical processes
Very low	5	Low confidence in assessment, no measurements are performed, little or newly established knowledge regarding the observed physical processes

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Appendix F. Results of Post-Construction Monitoring

Date	5/8/2014, 8/13/2015	Notes:	Upstream the channel base had been over widened causing a right bank bar to form and further drive lateral migration of the channel to the left. Aggradation downstream from misalignment also reduces slope up through the bridge and may be increasing the lateral extent of channel migration upstream.
Road	**WAY 83 Millersburg Rd**		
Stream	**Savage Run**		
Bridge ID	**WAY 0083-0087**		
lat long	40.6785, -81.9514		
Crew	OSU, EMH&T, PS		
Flow	No flow		

Station	Type	**Observations** (confidence) Indicators		Severity		Implications		Causes		**Corrective Actions**
US	IC	4 (rt)	very high	4	very high	3	very high	6	very high	9
US	LB	2, 3, 6	very high	3	very high	2	very high	1, 6	very high	9 (vane)
	S	5	medium	2	medium	2	medium	2	high	1
DS	IC	9, 5	high	2	very high	1	very high	2	very high	1
DS	LB & RB	1	very high							

Date	4/22/2016, 6/27/2016	Notes:	Upstream flows are aligned with bridge. Deposition of fine material has occurred on left bank upstream from vane. No left bank scour. Some soil has scoured from lower portion of buried riprap but do instability evident. Downstream flows have narrowed the channel to a normal width and low mid-channel bar that had reduced slope through bridge has mostly been scoured way.
Road	**WAY 83 Millersburg Rd**		
Stream	**Savage Run**		
Bridge ID	**WAY 0083-0087**		
lat long	40.6785, -81.9514		
Crew	DEM of OSU		
Flow	No flow		

Station	Type	**Observations** (confidence) Indicators		Severity		Implications		Causes		**Corrective Actions**
US	IC	1	high							
US	LB	1	high							
DS	IC	1	high							
	S	1	high							
DS	LB & RB	1	high							
DS	IC	6	high	2	high	1	high	6	high	1

Date: 6/20/2014, 8/13/2015
Road: **WAY 604 Easton Rd**
Stream: **Chippewa Creek**
Bridge ID: **WAY 00604-1307**
lat long: 40.9454,-81.8899
Crew: OSU, EMH&T, PS
Flow: Low flow

Notes: Upstream the channel had at one time been over widened. The meander pattern has a definite valley-right bend on the right bank upstream of the bridge that may be migrating down-valley. The over-widening and meander pattern have led to a bar forming off the left bank and bank erosion of the right bank. The alignment is poor and scouring at the right abutment/wing-wall.

		Observations (confidence)								Corrective
Station	**Type**	**Indicators**		**Severity**		**Implications**		**Causes**		**Actions**
US	IC	4 (lf)	very high	3	high	2	high	2	very high	1
US	RB	2 , 3, 8	very high	3	high	2	high	1	very high	9 (vane)
	S	1	very high							
DS	IC	1	very high							
DS	LB & RB	1	very high							

Date: 4/22/2016, 6/27/2016
Road: **WAY 604 Easton Rd**
Stream: **Chippewa Creek**
Bridge ID: **WAY 00604-1307**
lat long: 40.9454,-81.8899
Crew: PJ, JW, DM
Flow: Low flow

Notes: A vane was installed along the right bank upstream of the bridge in an attempt to center and concentrate the flow away from the right bank and under the bridge. Rather than abutting the wing wall, riprap was placed at the bridge abutment and wing wall and the vane begins about 20 feet upstream. The vane is causing a pool to scour just upstream from the bridge near mid-span, reversed the bar progression with signs of scour rather than deposition on the bank of the bar.

		Observations (confidence)								Corrective
Station	**Type**	**Indicators**		**Severity**		**Implications**		**Causes**		**Actions**
US	IC	1								
US	RB	1								
	S	1								
DS	IC	1								
DS	LB & RB	1								
US	C	1								

Date 6/20/2014, 7/24/2015
Road **Hinckley Hills Road**
Stream **East Branch Rocky River**
Bridge ID **MED 00606-0386**
lat long
Crew OSU, EMH&T, PS
Flow Low flow

Notes: This stream and similar others in the area are known to have high bedload as is evident from the prevalence of active bars of coarse gravel and cobble and lateral channel migration. Channel alignment is poor as it has shifted into the right with bar developing from the left. There are three spans with the middle span adequate for bankfull flow however the abutment slopes stop short of the piers and permit low and intermediate flows around the right piers.

Station	Type	Indicators	(confidence)	Severity	(confidence)	Implications	(confidence)	Causes	(confidence)	Corrective Actions
US	IC	4 (lf)	very high	3	very high	2	high	2, 6	high	9, 5
US	RB	5, 6, 7, 8, 10	very high	3	very high	2	high	1	very high	8, 9 x-vane
	S	5, 6	very high	3	very high	2	high	1, 5	very high	2, 5 x-vane
	S	7	very high	3	very high	2	high	1, 5	very high	2, 5 x-vane
DS	IC	1	high							
DS	LB & RB	1	high							

Date 4/22/2016, 6/27/2016
Road **Hinckley Hills Road**
Stream **East Branch Rocky River**
Bridge ID **MED 00606-0386**
lat long
Crew DEM
Flow Low flow

Notes: Work occurred in two phases, the first in 2014 when a remote control excavator was used under the bridge deck to remove sediment accumulations and place rip rap under both side spans. The second phase in 2015 realigned the channel upstream and constructed a cross vane to concentrate and accelerate flow through the middle span. The countermeasure has not performed. Recommend adding a layer of block and narrowing channel from right bank.

Station	Type	Indicators	(confidence)	Severity	(confidence)	Implications	(confidence)	Causes	(confidence)	Corrective Actions
US	IC	5 (mid, lf)	very high	3						7
US	RB	1	high							
	S	5	very high	3						6
	S	7	very high	2						1
DS	IC	1	high							
DS	LB & RB	1	high							
US	C	4	very high	4	high	3	high	1	high	5 (add block)

Date	6/20/2014
Road	**SR 603**
Stream	**Tributary to Black Fork Mohican River**
Bridge ID	**ASD 00603-0614**
lat long	40.7981, -82.3852
Crew	OSU, EMH&T, PS
Flow	Low flow

Notes: The stream has naturally high bedload increased further by years of channel instability in the watershed. The stream has adequate competence until it meets the broad flat floodplain of Black Fork Mohican River; made even flatter by backwater from the Charles Mill Lake dam. Rt 603 is at the natural transition from single thread channel to alluvial fan. Channelization through the alluvial fan has aggraded to the point that flows have been developing new courses. The bridge has little capacity, frequent flooding and perpetual maintenance.

		Observations (confidence)								Corrective
Station	**Type**	**Indicators**		**Severity**		**Implications**		**Causes**		**Actions**
US	IC	1, 3	high	2	high	3	high	1, 3	very high	2, 8, 9, 12 x-vane
US	LB & RB	1	high							
	S	11 (agg), 7	very high	4	very high	3	very high	6	very high	5 (outlet, x-vane)
DS	IC	3	very high	4	very high	3	very high	1, 6 (natural)	very high	8, 7, 9

Date	10/12/2016
Road	**SR 603**
Stream	**Tributary to Black Fork Mohican River**
Bridge ID	**ASD 00603-0614**
lat long	40.7981, -82.3852
Crew	DEM
Flow	Low flow

Notes: Construction was completed in August 2016 with no significant flows prior to this report. The design objectives were 1) to maximize sediment transport downstream, 2) lower the grade under the bridge for capacity, and 3) prevent degradation upstream where the first two objectives required the channel to be steepened. In addition altering the profile to meet the objectives the plan also employed plan form, dimension and bed form with the principal structure being a block cross vane abutting the bridge to concentrate and accelerate flows through the bridge.

		Observations (confidence)					Corrective
Station	**Type**	**Indicators**		**Severity**	**Implications**	**Causes**	**Actions**
US	IC	1	medium				
US	LB & RB	1	medium				
	S	1	low				
DS	IC	1	low				
US	S	1	low				

Date	6/20/2014, 11/10/2015
Road	**FUL 20**
Stream	**Bean Creek**
Bridge ID	**FUL 0020-0914**
lat long	41.6778,-84.2319
Crew	OSU, EMH&T, PS
Flow	Low flow

Notes: Historic channilization (straightening and lowering) of this large (206 sq.mi.) river have made it prone to adjustments. Abandon bridge abutments near-upstream and this bridge have been sufficent to initiate some lateral migration. The three span bridge is about 2x the natural channel width, with one span self-adjusted to flood stage while intermediate flows now use 2 stages leading to repeated debris removal from one pier. A w-weir should direct flow (and debris) around the peir and away from the eroding bank however as this is a sand bed river with low w-d ratio it will be difficult.

		Observations (confidence)								Corrective
Station	Type	Indicators		Severity		Implications		Causes		Actions
US	IC	1	high							
US	LB	1	high							
US	RB	3, 6	very high	3	high	2	high	1, 5	medium	4, 9 (w-weir)
	S	7	high	3	high	2	high	7 (it happens)	high	5 (w-weir)
DS	IC	1	high							
DS	LB & RB	1	high							

Date	4/14/2016, 6/27/2016
Road	**FUL 20**
Stream	**Bean Creek**
Bridge ID	**FUL 0020-0914**
lat long	41.6778,-84.2319
Crew	DEM
Flow	Low flow

Notes: Construction was November 2015 included a modified w-weir, regrading the floodplain bench through the right span and bank stabilization. Construction in sand was difficult.

		Observations (confidence)								Corrective
Station	Type	Indicators		Severity		Implications		Causes		Actions
US	IC	1								
US	LB	1								
US	RB	1								
	S	1								
DS	IC	1								
DS	LB & RB	1								
US	C	2	very high	2	medium	2	medium	1	high	3, 2

Date	6/2/2016, 6/27/2016
Road	**Castalia Rd, St Rt 412**
Stream	**Fuller Creek**
Bridge ID	**SAN 0412-7.12**
lat long	41.3717,-82.9465
Crew	DEM,
Flow	Low flow

Notes: Construction in October 2015 took three days and consisted of earthwork, just lowering and widening the bars. After one high flow season the deposition is evident on what was the eroding bank and depositionis not yet accumulating on the floodplain bars although we expect it will, just at a slow enough rate to require less maintenance than if the entire channel was over widened to the stream bed elevation and without poor alignment developming.

Station	Type	Indicators		Severity		Implications		Causes		Corrective Actions
		Observations (confidence)								
US	IC	1								
US	LB & RB	1								
	S	1								
DS	IC	1								
DS	LB	1								

Date	5/22/2014, 6/24/2015
Road	**Castalia Rd, St Rt 412**
Stream	**Fuller Creek**
Bridge ID	**SAN 0412-7.12**
lat long	41.3717,-82.9465
Crew	OSU, EMH&T, PS
Flow	Low flow

Notes: The channel cross sectional originally constructed was uniform and overwide, upstream, through the bridge and downstream. It was more than twice the width of the naturally forming channel. It remains stable and overwide under the bridge but with the influence of vegitation upstream and down it has developed floodplain bars, on the left upstream and right downstream. Reduced maintenance is anticipated by aligning the channel and lowering the bars to a compound form with low floodplain.

Station	Type	Indicators		Severity		Implications		Causes		Corrective Actions
		Observations (confidence)								
US	IC	4(lf)	very high	3	very high	2	very high	2	very high	6
US	LB & RB	1	high							
	S	1	very high							
DS	IC	4(rt)	very high	3	very high	3	very high	2	very high	6
DS	LB	3, 6	very high	2	very high	2	very high	6 (meander)	very high	3

Date 5/21/2014, 6/24/2015
Road **Williston Rd, St Rt 579**
Stream **Crane Creek**
Bridge ID **OTT 0579-1-86**
lat long 41.6025,-83.3803
Crew OSU, EMH&T, PS
Flow Low flow

Notes: The bridge piers are corroded, they will have significant maintenance then the abutment slopes will be restabilized. Concrete cloth will be used as alternative to the traditional technique of placing rock. A benefit is anticipated do in particular to the limited access and clearence.

		Observations (confidence)								Corrective Actions
Station	Type	Indicators		Severity		Implications		Causes		
US	IC	1	very high							
US	LB & RB	1	high							
Br	IC	1	high							
Br	LB & RB	6	high	2	high	1		6 (no sun)	high	5
DS	IC	1	very high							
DS	LB & RB	1	very high							

Date 6/2/2016
Road **Williston Rd, St Rt 579**
Stream **Crane Creek**
Bridge ID **OTT 0579-1-86**
lat long 41.6025,-83.3803
Crew DEM
Flow Low flow

Notes: Construction was in October of 2015 and proceeded as anticipated, with hand labor and no machine access needed. After one season of high flows (winter spring 2016) the material appears as it did when installed.

		Observations (confidence)								Corrective Actions
Station	Type	Indicators		Severity		Implications		Causes		
US	IC	1	very high							
US	LB & RB	1	high							
Br	IC	1	high							
Br	LB & RB	1	very high							
DS	IC	1	very high							
DS	LB & RB	1	very high							

Date 8/10/2016
Road **St Rt 224**
Stream **Tributary to Chippewa Creek**
Bridge ID **MED 0224**
lat long 41.0305,-81.9033
Crew DEM
Flow Low flow

Notes: The CMP is corroded along the wetted edge, at and just above the normal flow surface. Sevier corrosion exists at the inlet end of the pipe and diminishes rapidly but to some extent continues through the entire length. Large holes exist in the first 5 feet with piping flow outside the pipe. No piping is observed after 10 feet. By 50 feet from the entrance small holes (<1 inch) are observed sporadically for the remainder of the length. Deposition covering the bottom of the CMP from 35 feet on seems to have protected the pipe, the original coating is still present under the gravel.

		Observations (confidence)								Corrective
Station	Type	Indicators		Severity		Implications		Causes		Actions
US	IC	1	very high							
Br	S	11 (corrosion)	very high	3	high	2	high	7 (age)	medium	5 (cloth)
DS	IC	1	very high							

Date 9/1/2016
Road **St Rt 224**
Stream **Tributary to Chippewa Creek**
Bridge ID **MED 0224**
lat long 41.0305,-81.9033
Crew DEM
Flow Low flow

Notes: October 13, 2016 the most corroded section of CMP was covered with concrete cloth (50 feet). This appears adequate to stop existing piping and abrasion and perhaps reduce or slow further corrosion. Under the concrete cloth the wetted edge, the water/air surface, will still experience wetting but perhaps with less oxidation. Sealing the edge of the top edge of the concrete cloth to the inside surface of the CMP has been discussed as a strategy to reduce oxidation further but was not performed. A procedure for monitoring of the CMP's integrity that is now covered by the concrete cloth will need to be developed. The cloth was installed longitudinally by using an excavator to suspending the concrete cloth roll outside the entrance to the pipe and pulling into the pipe by hand. This method worked well, maximized material strength and minimized the length of seams required over installing the material transversely. For lengths over 50 feet the weight of each piece of concrete cloth might become problematic.

		Observations (confidence)					Corrective
Station	Type	Indicators		Severity	Implications	Causes	Actions
US	IC	1	very high				
Br	S	1	low				
DS	IC	1	very high				

Date	11/10/2016
Road	**Sample Rd**
Stream	**Tributary Little Indian Creek**
Bridge ID	**BUT 732**
lat long	39.4272,-84.7613
Crew	DEM
Flow	Low flow

Notes: These two reports are based on photos and discussion with people present during construction and on one post construction inspection. The CMP was reportedly corroded along the bottom of the pipe. Concrete cloth was placed in transverse lengths starting at the downstream. , abrasion on protruding bolts

Station	Type	Indicators		Severity		Implications		Causes		Corrective Actions
		Observations (confidence)								
US		1	very high							
Br		11 (corrosion)	high	3	high	2	high	7 (age)	medium	5 (cloth)
DS		1	very high							

Date	11/10/2016
Road	**Sample Rd**
Stream	**Tributary Little Indian Creek**
Bridge ID	**BUT 732**
lat long	39.4272,-84.7613
Crew	DEM
Flow	Low flow

Notes: The pipe and concrete cloth appeared to be stable and functioning as intended. Some minor abrasion of the surface fabric of the concrete cloth was evident where the bolts that fasten together sections of the CMP protrude and cause a bump in the concrete cloth. The concrete interior of the cloth was not showing ware. A procedure for monitoring of the integrity of the CMP covered by the concrete cloth will need to be developed.

Station	Type	Indicators		Severity		Implications		Causes		Corrective Actions
		Observations (confidence)								
US		1	very high							
Br		1	low							
DS		1	very high							

Date: 5-21-2014, 6/26/2016

Road: **Middleton Pike**

Stream: **Toussaint Creek**

Bridge ID: **WOO-0582**

lat long: 41.4567, -83.5149

Crew: OSU, EMH&T, PS

Flow: Low flow

Notes: The channel is poorly aligned with the bridge due to lateral migration of the channel. Past over widening of the channel in the vicinity of the bridge has aggravated the alignment problem. Within the widened sections upstream and down a floodplain bar formed, re-narrowing the channel against the opposite bank. Once indicated meander pattern development as continued to worsen the alignment. The right piers are now mid channel, obstructing intermediate flows. It has been suggested that the channel and bars be reconstructed with a proper alignment and with a compound cross sectional shape that will be less prone to rapid bar deposition and lateral migration.

		Observations (confidence)								**Corrective Actions**
Station	**Type**	**Indicators**		**Severity**		**Implications**		**Causes**		
US	IC	9, 4(lf), 5, 11	very high	3	high	2	high	2, 6 (lat migr)	high	2, 3, 5, 6, 7 ,9
US	LB	1	high							
US	RB	3, 6	high	3	high	2	high	1	high	3, 6, 8
Br	S	5, 7	high	3	high	2	medium	2	high	5 (align)
DS	IC	1	medium							
DS	LB & RB	1	medium							

Date: 6/26/2016

Road: **Middleton Pike**

Stream: **Toussaint Creek**

Bridge ID: **WOO-0582**

lat long: 41.4567, -83.5149

Crew: DEM

Flow: Low flow

Notes: An alternative requiring significantly less disturbance is to construct a single vane upstream from the right pier. Vanes affect the flow provide bank protection well upstream of the structure itself to stop the bank erosion and align the dominant flow away from the right piers and through the middle span without additional earthwork except as required to install the structure.

		Observations (confidence)								**Corrective Actions**
Station	**Type**	**Indicators**		**Severity**		**Implications**		**Causes**		
US	IC	9, 4(lf), 5, 11	very high	3	high	2	high	2, 6 (lat migr)	high	1
US	LB	1	high							
US	RB	3, 6	high	3	high	2	high	1	high	1
Br	S	5, 7	high	3	high	2	medium	2	high	5 (vane)
DS	IC	1	medium							
DS	LB & RB	1	medium							

Date	5/7/2014, 7/8/2015
Road	**Lafayette Rd**
Stream	**East Fork Black River**
Bridge ID	**MED 0042**
lat long	41.0456,-82.0147
Crew	OSU, EMH&T, PS
Flow	Low flow

Notes: Downstream migration of the meander pattern is very evident as the meander upstream on the right side of the valley moved down valley and is now eroding the road embankment right of the right abutment. The alignment is very poor and there is woody debris in the channel other than the immediate threat of further damage and instabilities of the road embankment the channel under the bridge appears to be functioning. Realigning the channel with the bridge and installing a block vane to protect the bridge abutment and affect the right bank farther upstream to control future downstream migration of bend is suggested.

		Observations (confidence)								Corrective
Station	Type	Indicators		Severity		Implications		Causes		Actions
US	IC	11	very high	3	high	3	high	6 (lat migr)	very high	9
US	LB	1								
US	RB	3, 6		3	medium	3	high	1	very high	8, 5
Br	S	1								
DS	IC	1								
DS	LB & RB	1								

Date	
Road	**Lafayette Rd**
Stream	**East Fork Black River**
Bridge ID	**MED 0042**
lat long	41.0456,-82.0147
Crew	
Flow	Low flow

Notes:

		Observations (confidence)				Corrective
Station	Type	Indicators	Severity	Implications	Causes	Actions

Date	7/22/2014, 7/16/2015
Road	**St Rt 53 / 6**
Stream	**Muskellunge Creek**
Bridge ID	**SAN-0006-14-03**
lat long	41.3571,-83.1654
Crew	OSU, EMH&T, PS
Flow	Moderate flow

Notes: The existing bridge is a 133-foot, 2-span steel beam bridge proposed to have structural maintenance to the deck. At the conclusion of the deck maintenance additional armoring is proposed to address the exposed slope material under the deck. This will be achieved by armoring the slopes with Flexamat. In addition the central pier is mid-channel, exposed to low and intermediate flows and prone to accumulating debris. This has reportedly not been a significant enough maintenance burden or structural thread to warrant construction of a w-weir to divert flow around the pier.

		Observations (confidence)								Corrective
Station	Type	Indicators		Severity		Implications		Causes		Actions
US	IC	1	high							
US	LB & RB	1	high							
Br	S	5	high	2	high	1	high	1	very high	1
Br	LB & RB	6	very high	1	high	1	high	6 (no sun)	very high	5
DS	IC	1	high							
DS	LB & RB	1	high							

Date	12/9/2015
Road	**St Rt 53 / 6**
Stream	**Muskellunge Creek**
Bridge ID	**SAN-0006-14-03**
lat long	41.3571,-83.1654
Crew	DEM
Flow	Moderate flow

Notes: Concrete rubble made available from the bridge deck maintenance was placed on the most exposed areas negating the need for placing Flexamat.

		Observations (confidence)								Corrective
Station	Type	Indicators		Severity		Implications		Causes		Actions
US	IC	1	high							
US	LB & RB	1	high							
Br	S	5	high	2	high	1	high	1	very high	1
Br	LB & RB	1	very high							
DS	IC	1	high							
DS	LB & RB	1	high							

Appendix G. Concrete Cloth for Culvert Lining Documentation

MED 224 - State Route 224 and Trib to Chippewa Cr in Medina County, Ohio

The corrugated metal pipe (CMP) is corroded along the wetted edge, at and just above the normal flow surface. Severe corrosion exists at the upstream end of the pipe and diminishes rapidly downstream. Large holes exist in the first five feet with piping flow outside the CMP. No piping is observed after 10 feet. By 50 feet from the entrance, small holes (<1 inch) are observed infrequently for the remainder of the length. Deposition covering the bottom of the CMP, from 35 feet on has protected the pipe from corrosion. The original coating is still present under the gravel.

Figure 1. Severe corrosion at the upstream end of the CMP.

Figure 68 Corrosion 8 feet from the upstream end.

Figure 69 Beyond 50 feet the CMP is less corroded.

Concrete cloth was used to cover the most corroded section of the CMP, 50 feet of length from the upstream end and about 8.5 feet of the bottom and up the sides. It was also used to repair the transition from the headwall to the CMP.

Figure 70 Concrete cloth pulled from the roll suspended from an excavator.

Figure 5 The last of three 55 foot lengths of material installed longitudinally.

The concrete cloth can be oriented longitudinally or transversely. Both methods have been used in culvert lining applications. For this project, the concrete cloth was installed longitudinally. Transverse installation has the advantage of using short sections that can be carried by hand and can be cut to the width of coverage needed. Longitudinal installation requires fewer seams and relies not on each joint for strength but on the tensile strength of the material.

The concrete cloth was moved into place by suspending the entire roll at one end of the culvert and pulling the material into the CMP. Three people were able to pull the 50 foot lengths quickly and without difficulty; however, much longer and heavier sections might be challenging.

Figure 6 Fastening with self-tapping screws thru the CMP.

Additional layers of cloth were placed at the inlet and around to the upstream face of the headwall.

Figure 7 Concrete cloth wrapped around and fastened to the headwall.

This project is expected to stop piping around the CMP and abrasion from sediment. Hopefully, it will also reduce, or at least slow, further corrosion. Under the concrete cloth the CMP will still experience wetting but perhaps with less oxidation. Sealing the top edge of the concrete cloth against the CMP, has been discussed as a strategy to reduce oxidation further. However, sealing the top edge has not been done. A procedure for monitoring the CMP's integrity, where it is now covered by the concrete cloth, will need to be developed.

Figure 8 The completed project.

Figure 9 The completed project.

BUT 732 - State Route 732 and Trib to Indian Creek in Butler County, Ohio

The CMP is corroded along the bottom of the pipe. Concrete cloth was placed in transverse lengths starting at the downstream.

Figure 710 Concrete cloth installed.

Figure 11 The cloth fastened to the headwall.

The concrete cloth can be oriented longitudinally or transversely. Both methods have been used in different culvert lining applications. For this project, the concrete cloth was installed transversely. Advantages of longitudinal installation are that it requires fewer seams and relies, not on each joint for strength, but on the tensile strength of the material. Transverse installation has the advantage of using short sections that can be carried by hand and the material can be cut to the width of coverage needed. The shorter sections are also easier to work into the pipe corrugations and create seal along the edges.

Figure 12 The edges of the concrete cloth sealed to the CMP.

The pipe and concrete cloth appeared to be stable and functioning as intended. Some minor abrasion of the surface fabric of the concrete cloth was evident where the bolts that fasten together sections of the CMP protrude and cause a bump in the concrete cloth. The cloth's concrete interior was not perceptibly worn.

Figure 13 Abrasion over the CMP's bolts.

A procedure for monitoring of the integrity of the CMP, covered by the concrete cloth, will need to be developed.

Figure 14 Completed project viewed looking upstream.

Figure 15 Downstream.

Appendix H. Considerations for Integrating NCD Practices in Bridge Replacement Projects

Can implementation of innovative channel design practices at bridge crossings lead to more sustainable transportation infrastructure?

Introduction and Problem Statement

Streams are dynamic systems. Flowing water erodes banks and beds and sediments are deposited within the channel and on floodplains to constantly shape and reshape stream channel pattern (planform), profile (longitudinal slope), and dimension (cross sectional geometry). In watersheds disturbed by land use change, streams often respond to altered flow and sediment regimes through channel incision, bed aggradation, and/or rapid failure on banks. Even in undisturbed or stabilized watersheds lateral migration of meander bends is a naturally occurring process. Unfortunately, the natural movements of streams are problematic for designers that must engineer bridge structures that remain in fixed locations.

Historically, design of bridge openings has been driven largely by the goal to convey a specified design discharge rate without flooding the roadway or impacting the structural integrity of the bridge. However, streams also convey sediment and debris that if not adequately considered in the design process can have negative impacts on the bridge structure and may require frequent and costly maintenance to remedy. For example, bridge openings that are designed too narrow can constrict flows causing a rise in the water surface elevation upstream of the bridge. Elevated flow levels may result in increased flow velocities and shear stresses through the bridge opening and backwater conditions upstream of the bridge. This condition can cause local scour of the bridge foundation, abutments, wing walls, and piers. Similar conditions may occur when debris jams constrict the bridge opening.

Another common problem occurs when a bridge opening is constructed too wide to maintain effective sediment transport through the reach. The typical response in this scenario is sediment deposition at the upstream opening that leads to the formation of a bar. The development of a sediment bar can then redirect flow towards the opposing channel bank and cause erosion of the bridge embankment (e.g. Figure 1). Another potential negative consequence of sediment deposition at the bridge opening is increased backwater effects upstream, which can further exacerbate sediment deposition and aggradation of the channel bed and further reduce hydraulic conveyance.

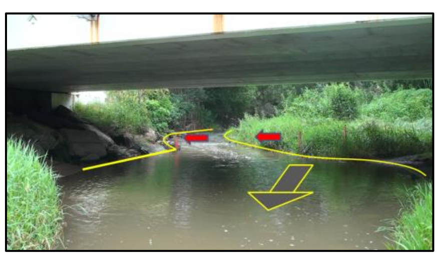

Figure 72. During initial construction of this bridge, flow was well-aligned with the bridge opening (approximated by the yellow arrow). However, the bridge opening that was constructed to pass the design discharge rate was much wider than the bankfull channel dimensions of the stream. This created a disruption in sediment transport through the 'over-wide' section of the reach. In response, gravel and sediments were deposited forming the bar (located at the red arrow on the right of the figure) which vegetated and narrowed the flow to regain sediment transport capacity. As the bar developed, flow was redirected to the channel banks (red arrow on the left) causing erosion, which now threatens the embankment.

Throughout Ohio the scenarios described above are common. Many bridges and the stream channels they cross require frequent and costly maintenance to function properly. Maintenance activities are carried out at the local-level by ODOT county garage crews. These maintenance activities typically fall into the following categories: 1) dredging of deposited sediments, 2) removal of debris accumulations, 3) hardening of stream banks, and 4) placement of materials to protect bridge structural components (e.g. piers, abutments, etc.) from local scour. A more detailed discussion of these maintenance activities is provided in the following paragraphs.

Dredging of Sediments: Sediment removal typically occurs upstream of a bridge structure where: 1) the bridge opening is designed and built too wide and natural stream processes function to develop point bars that narrow the bankfull channel or 2) the bridge opening constricts flow causing backwater conditions which promote sediment deposition upstream of the bridge opening. Accumulated sediments reduce the channel conveyance capacity increasing the likelihood of flooding onto the roadway or redirecting flows leading to poor alignment with the bridge opening. The typical solution to this problem is to utilize excavators to "dip" or "clean" the deposited sediments from the bridge opening. Unfortunately, this remedy only provides a temporary resolution as the same natural processes of sediment transport and deposition ensue causing a recurring problem for county maintenance forces.

Removal of Debris Accumulations: Narrow bridge openings or bridges with piers are susceptible to debris accumulations, particularly in steep, forested watersheds. Log jams and other debris accumulations effectively decrease the size of the bridge opening, increase channel roughness or resistance to flow, and increase turbulence around bridge structural components. All of these factors can increase potential for flooding and result in higher stresses to the bridge structure. The typical solution to this problem is to use county forces to cut logs into smaller pieces that will be conveyed downstream during the next high flow event or removed with excavators. This solution is also likely temporary as more fallen trees and other debris are likely to accumulate during future flow events.

Hardening Stream Banks: Stream banks are often hardened or "armored" where eroding banks result in flow misalignment with the bridge opening or erosion of the embankment that leads to undermining of the abutment, which threatens the integrity of the bridge structure. In streams, bank erosion is a natural process, called lateral migration that is often balanced by deposition on the opposite bank leading to the development of a point bar. Together these processes maintain the size and geometry of a channel over time. However, the process of lateral migration is unacceptable when the bridge opening remains stationary. To lock the channel alignment into place, crews often rely on rip rap rock channel protection to reinforce the eroding bank against the erosive forces of flowing water. This type of solution is often effective, but can be costly and degrade the quality of the site relative to a more natural, vegetated condition.

Local Scour Protection: In order to build bridges economically, narrow openings are often designed to pass a specified design discharge. These openings often are not as wide as the channel and floodplain flows that would normally occur during a high flow event. This constriction can lead to higher flood flows and flow velocities resulting in local scour around bridge structural components. Local scour issues are typically identified during annual bridge inspections from district staff and work plans are developed for county crews to remediate issues. The typical solution to this problem is to place concrete or large rip rap rock protection around the affected area to ameliorate scour.

Expanding the ODOT Toolbox with More Sustainable Management Solutions

In an effort to expand the number and type of options available to county crews and district staff to solve channel maintenance issues the ODOT Research Section sponsored a project (ODOT Research Project #25959; Alternative Stream Channel Maintenance at Bridge Crossings) to evaluate alternative management practices. This research project has evaluated numerous natural channel design structures (e.g. vanes, cross vanes, and w-weirs) to alter and align flows and solve maintenance issues with more natural approaches and 'softer' construction materials (e.g. vegetated surfaces, Flexamat tied concrete matting, etc.). The research project team worked with county and district forces to: 1) assess skills and capabilities of county crews to install alternative maintenance practices and materials, 2) develop design solutions that were implementable within budget limits and time constraints, 3) undertake the environmental permitting processes, 4) provide on-site technical assistance during the construction phase of pilot projects, 5) conduct post-construction monitoring of pilot projects, and 6) document project outcomes for education and training purposes.

As a result of the research, numerous pilot projects have been implemented successfully (examples provided in Figure 2; see links to project videos provided in Reference Section) and preliminary monitoring suggests that performance goals are being met and future maintenance requirements at these sites will be less frequent or unnecessary. While experience with this research has shown that ODOT local forces are quite skilled and highly capable of implementing these practices for maintenance purposes the selection and design of these practices and subsequent environmental permitting present challenges that are barriers to widespread implementation.

Figure 2. Left: A single-arm vane installed in Wayne County (SR 604) to better align flow and redirect it to the center span of the bridge, which will protect the embankment along the outer bend of the stream channel. Right: Construction of a cross-vane structure through a bridge opening in Ashland County (SR 603) to promote scour in the center of the channel and mitigate deposition of sediment, which had severely reduced conveyance through the bridge opening and led to frequent flooding and closure of the roadway.

New research is currently underway to address barriers impacting the use of natural channel design practices (i.e. w-weirs, vanes, cross-vanes, etc.) to solve maintenance problems. To date, the biggest challenges that have been identified include: 1) time and effort to mobilize equipment can be a significant cost to the overall project, 2) the environmental permitting process can be challenging, costly, and time consuming, and 3) most ODOT engineers are unfamiliar with these practices and not trained in the methods to design them. While these challenges can be addressed, it may be beneficial to consider integration of these practices into new bridge construction, replacement, or rehabilitation projects for a number of reasons. First, most engineering firms that design bridges would have in house expertise or could partner with firms with the appropriate experience to design and integrate these natural channel design practices into bridge construction projects. Secondly, environmental permitting required for bridge construction could include these practices with little additional effort and cost to the overall project. Furthermore, these practices are commonly viewed as more environmentally sensitive and may make the environmental permitting process easier compared to projects that propose extensive armoring or other hard engineering approaches to protect the bridge structure. Additionally, the equipment utilized in bridge construction should be adequate for installing natural channel design practices around bridges and that equipment has already been mobilized for the bridge project leading to greater efficiency and further cost savings. Lastly, well-designed projects that properly align flow and effectively route debris through the opening should improve performance (e.g. reduce flooding, reduce scour, reduce deposition), which should lead to increased service life for the structure.

It should be noted that only a fraction of bridge projects might consider inclusion of natural channel design practices. Projects that would be likely candidates include 1) sites where there has been an extensive history of problems requiring regular maintenance activity or 2) locations where designs call for armoring (e.g. rip rap, gabion baskets, etc.) of the channel to protect the bridge. Sites with problems can be easily identified from bridge inspection reports and sites requiring frequent maintenance are well known by the local forces that regularly maintain them. A review of historical aerial imagery, obtained from ODOT Aerial Engineering or even a quick review of historical images from Google Earth, may help to identify streams with high rates of meander migration would potentially cause problems during the design life of a bridge.

Additionally, it is important to determine if the upfront costs of including natural channel design practices into a bridge construction project would outweigh the long-term costs of maintenance. BridgeLCC Version 2.0 (Ehlen, 2003) is a life-cycle costing software for planners and engineers to assess the long-term costs of various project alternatives and fairly compare their costs over the design life of the structure considering operation and maintenance costs and frequency, inflation, and real discount rates. The software can evaluate costs to the agency (e.g. ODOT), users (e.g. motorists), or third parties (e.g. impacted businesses).

For example, consider the following scenario. A $250,000 bridge project is constructed and based on past history at the site it is likely that the county maintenance crew will spend one day annually at a present cost of $1500/year to remove sediment that accumulates at the bridge opening. An alternative design that incorporates a cross vane structure and minor reshaping of the channel would cost $30,000 (total project cost of $250,000+$30,000=$280,000), but eliminate or greatly reduce long-term maintenance needs. Given an estimated current inflation rate of 1.6% and a real discount rate of 1.0% the present cost of each alternative can be compared for a specified design life (here assumed to be 100-yrs). Results of the analysis for the cost to the agency (i.e. ODOT) are provided in Figure 2. In this scenario, the present cost of the structure that will require annual maintenance is $345,489 over the design life. In comparison, the present value of the bridge with vane structure which requires no additional maintenance is $280,000 and results in an overall cost savings.

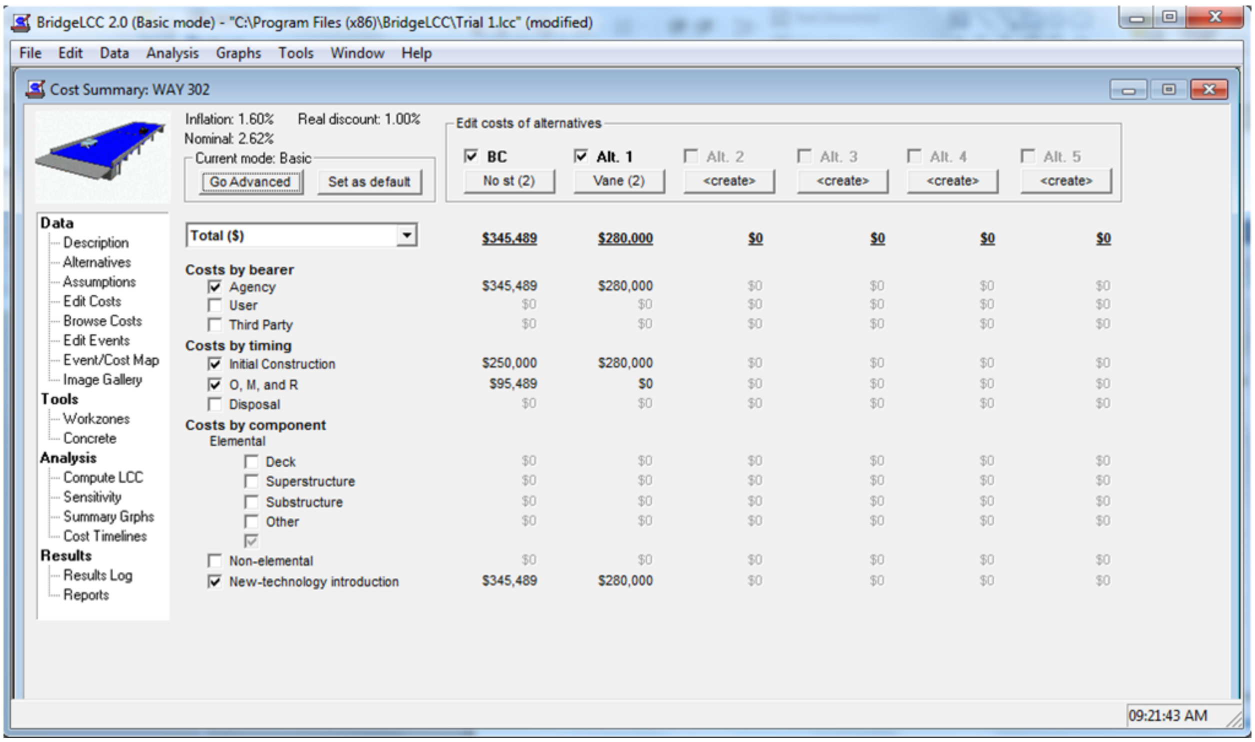

Figure 3. A screenshot of the BridgeLCC 2.0 software showing a comparison of the present costs for a bridge construction project that requires annual maintenance compared to the same bridge that incorporates a natural channel design practice that eliminates maintenance. Note that the analysis does not include costs to the user; however, ODOT currently has a spreadsheet tool (RoadUserCosts.xls) to determine costs related to detours and reduced speeds through work zones that would impact roadway users.

Summary

The integration of practices into bridge construction projects that properly align flow, safely transport sediment and debris, and protect the bridge structure provide an opportunity to improve the sustainability on some projects, if implemented responsibly. Natural channel design practices are often utilized in the field of stream restoration, but have seen little application at bridge crossings. Preliminary research in Ohio and elsewhere suggests that these practices can enhance channel stability in the vicinity of bridges and reduce maintenance requirements. Additionally, tools are available to evaluate life-cycle cost including initial construction costs, operation and maintenance costs, and costs to users and third parties. Consideration of these practices in bridge construction projects could lead to overall cost savings and reduction in maintenance needs.

REFERENCES

Ehlan, Mark. 2003. BridgeLCC 2.0 Users Manual – Life-Cycle Costing for the Preliminary Design of Bridges. National Institute of Standards and Technology. NIST GCR 03-853. 99pp.

Draft project videos of natural channel design projects

WAY 604 Vane at a bridge https://youtu.be/04OoEQB7YNU

WAY 83 Vane - https://youtu.be/lge8OSRWjyk

FUL 20 W-weir - https://youtu.be/ukJqKsV5OSw

MED 606 Cross vane - https://youtu.be/ZQh5Qh1hqsg

SAN 412 Floodplain bench - https://youtu.be/2V_TfJaM1iU