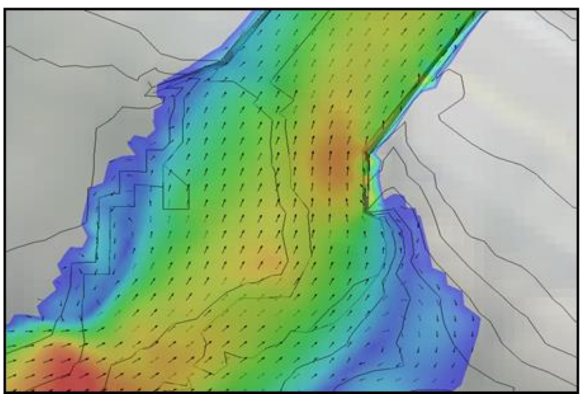
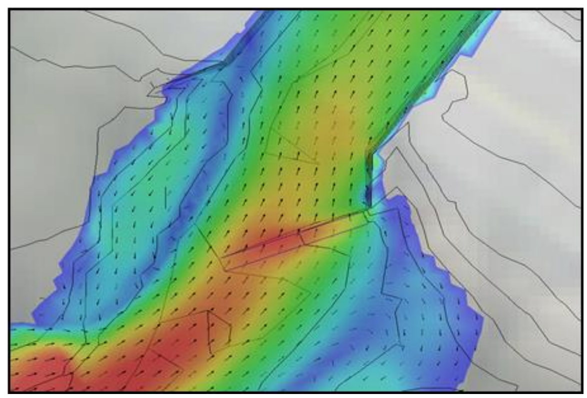
Streamlining Implementation of Sustainable Channel Maintenance Practices



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16. Abstract

Projects were implemented at seven sites to determine if implementation of natural channel design-based maintenance practices could be streamlined when completed with state sources of funding. Projects that could be completed under Section 404 general permits without project-specific authorization from the ACOE (e.g., non-notifying) were identified and installed without much difficulty. Clear guidance was developed by ODOT OES to help District and County staff determine which types of projects met criteria for non-notifying permits.

Additionally, two-dimensional hydraulic modeling was completed for six projects including three single arm vanes and three culvert weirs. Model results indicated that the single arm vanes reduced shear stresses and shifted them away from the stream bank and embankment towards the center of the channel for the most frequent events. Modeling for the culvert weir projects indicated that concentrating the low and intermediate flows by partially blocking one culvert in a twin culvert arrangement resulted in shear stresses that were more consistent with the natural channel upstream and downstream of culvert for the bankfull discharge. Modeling results also revealed that the water surface elevations for the post-maintenance conditions were improved relative to the pre-maintenance conditions; however, capacity post-maintenance was less than originally designed and constructed. The findings of the research could also be used to improve new and replacement bridge designs. We recommend that an evaluation of sediment transport from the natural channel upstream through the opening and to the downstream natural channel be completed during the design process.

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June 2019

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Table of Contents

1.0 Executive Summary

Projects were implemented at seven sites to determine if implementation of natural channel design-based maintenance practices could be streamlined when completed with state sources of funding. The research team worked with ODOT staff to identify potential projects in Districts 10 and 12. A joint meeting with ODOT Office of Environmental Services (OES) and the Army Corps of Engineers (ACOE) helped to identify the types of projects that could be completed more quickly and easily under existing Section 404 general permits without project-specific authorization from the ACOE (e.g., non-notifying). The seven projects met these permitting criteria and were authorized and installed without much difficulty. Clear guidance was developed by ODOT OES to help County staff and District Environmental Coordinators determine which types of projects and circumstances met the requirements for non-notifying permits.

Additionally, two-dimensional hydraulic modeling was completed for six projects including three single arm vanes and three culvert weirs. Model results indicated that the single arm vanes reduced shear stresses and shifted them away from the stream bank and embankment towards the center of the channel for the most frequent events. Modeling for the culvert weir projects indicated that concentrating the low and intermediate flows by partially blocking one culvert in a twin culvert arrangement resulted in shear stresses that were more consistent with the natural channel upstream and downstream of culvert for the bankfull discharge. Modeling results also revealed that the water surface elevations for the post-maintenance conditions were improved relative to the pre-maintenance conditions; however, capacity post-maintenance was less than originally designed and constructed. Therefore, if capacity is a concern any potential design should be modeled as part of the process to select a maintenance solution.

The findings of the research could also be used to improve new and replacement bridge designs. We recommend that an evaluation of sediment transport from the natural channel upstream through the opening and to the downstream natural channel be completed to evaluate continuity during the design process. Furthermore, at sites with dynamic channels, we recommend that meander migration rates be evaluated with historical aerial imagery and sites were lateral migration is likely to impact the structure that natural channel design based practices, such as vanes, cross vanes, or w-weirs, are implemented when a new or replacement bridge is constructed.

2.0 Project Background

Ohio Department of Transportation (ODOT) county crews and district staff are continually faced with the difficult task of implementing effective channel maintenance programs to ensure safe operation of roadways. These maintenance activities typically fall into the following categories: 1) dredging of deposited sediments from the bridge or culvert opening, 2) removal of debris accumulations from stream banks and bridge piers, 3) armoring of stream banks to mitigate erosion, or 4) placement of materials to protect bridge structural components (e.g. piers, abutments) from scour.

Dredging of Sediments

Sediment dredging typically occurs where: 1) the bridge opening is designed and built too wide relative to the natural channel and stream processes function to deposit point bars to reestablish a bankfull channel or 2) the bridge opening constricts flow causing backwater conditions which promotes sediment deposition upstream of the bridge. Accumulated sediments can reduce conveyance capacity increasing the likelihood of flooding onto the roadway or redirecting flows that lead to poor alignment with the bridge opening. The typical solution to this problem is to excavate or dredge deposited sediments. This remedy usually provides a temporary solution as the natural processes of sediment transport and deposition ensue causing a recurring problem for county maintenance crews.

Removal of Debris Accumulations

Bridges with narrow spans or piers that are misaligned with high flows are susceptible to debris accumulations, particularly in 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. These factors may increase potential for flooding and result in higher stresses to the bridge structure. The typical solution is to cut logs into smaller pieces that will float downstream during the next high flow event or remove debris with excavators or cable winch systems. This solution is also likely temporary as more fallen trees and other debris are likely to accumulate during future flow events.

Stream Bank Armoring

Stream banks are often armored or hardened where eroding banks result in misalignment of flow with the bridge opening and erosion of the embankment leads to undermining or outflanking of the abutment. In streams, lateral migration of the bank is a natural process balanced by deposition in the channel on the opposite bank leading to the development of a point bar. However, excessive lateral migration is unacceptable because the bridge opening remains stationary. To realign flow through the opening, crews often place rip rap rock channel protection to rebuild or reinforce the eroding bank. This type of solution is often effective but can degrade the quality of the site relative to a more natural, vegetated condition.

Local Scour

In order to build bridges economically, openings that are narrower than the river floodplain are often designed to pass a specified design discharge rate. Constriction of flow can lead to higher flood elevations and increased flow velocities resulting in local scour around bridge structural components. Local scour is typically identified during annual bridge inspections by district staff and work plans are developed for county crews to remediate issues. The typical solution is to place concrete slabs or large rip rap rock protection around the affected area to reduce or eliminate scour.

Expanding Maintenance Options with More Sustainable Practices

To expand the number and type of maintenance options available to ODOT county crews and district staff, an ODOT sponsored research project (ODOT Research Project #25959; Alternative Stream Channel Maintenance at Bridge Crossings) was undertaken to identify and test potential alternatives. The research project implemented numerous instream structures (e.g. vanes, cross vanes, and w-weirs) to alter and align flows, bioengineering practices (e.g. live stakes, vegetated rip rap, etc.) to stabilize eroding banks with more natural materials, and assessed other construction materials (e.g. concrete cloth, Flexamat tied concrete matting, etc.) to stabilize slopes where vegetative practices were impractical or impossible (i.e. under bridge decks). The research team worked with county and district forces to: 1) assess skills and capabilities of crews to install alternative maintenance practices and materials, 2) develop solutions that were implementable within budgetary constraints and time limitations, 3) aid in the environmental permitting processes, 4) provide technical assistance during the pilot project implementation phase, and 5) document project outcomes to disseminate knowledge and share lessons learned.

Implementation Challenges for Alternative Stream Channel Maintenance Projects

As an outcome of the research described above, eight pilot projects were implemented in collaboration with ODOT district and county forces. Conclusions from the research suggested: 1) that ODOT county crews have the necessary skills and equipment to effectively and efficiently install natural channel design practices, 2) projects can be completed at a reasonable cost and within timeframes that are acceptable to county transportation administrators, 3) some alternative practices and materials were preferable to standard practices, and 4) technical assistance from the research project team was necessary in some instances to help overcome technical challenges. Our primary goal for this project was to determine if the environmental permitting process might be streamlined when conducted with state sources of funding typically associated with maintenance activities rather than federal funding, which supported the previous research effort and implementation of pilot projects. The purpose of the research was to better understand any challenges county crews and district staff might encounter using the standard maintenance process, identify ways to eliminate barriers associated with implementing the alternative practices, and develop a process that streamlined environmental permitting, if possible, to further facilitate adoption of a more sustainable channel maintenance paradigm utilizing natural channel design-based practices.

3.0 Research Context

3.1 Goals and Objects of the Original Proposal

The primary goal of the research was to explore means to simplify implementation of Natural Channel Design (NCD) based practices and use of alternative construction materials for maintenance projects. This overarching goal is critical to the future adoption of natural channel design-based practices as ODOT county forces are unlikely to willingly choose maintenance practices that are appreciably more difficult to implement than standard approaches. To address this goal, we set forth the following objectives:

1. Identify potential pilot projects and evaluate the implementation process by county forces at two sites with maintenance problems.
2. Identify steps necessary to streamline implementation of alternative stream channel maintenance for future projects.
3. Test the new process through implementation of three additional pilot projects.
4. Summarize findings and recommendations in a final report.

3.2 Goals and Objectives of Addendum A

Our work on the original proposal began with the assumption that implementation of natural channel design-based practices would be easier when only state sources of funding were involved. However, the assumption was proven to be untrue initially and an alternative approach was needed. The long-term strategy was to continue to educate ODOT Districts on the practices, continue to work with ODOT to implement projects, and monitor the performance of existing projects to determine if ODOT would attempt to include natural channel design practices into future RGPs. To address this goal, we outlined the following objectives:

1. Educate ODOT staff on alternative stream channel maintenance practices and implement additional projects.
2. Document and monitor pilot projects and utilize research findings in deliberations with the ACOE regarding coverage of these practices by the Regional General Permit.
3. Summarize project findings and recommendations in a final report.

3.3 Goals and Objectives of Addendum B

During previous phases of research, numerous field days and research results presentations were made in Districts and throughout the state. A recurring question that arose at these meetings focused on the impacts of implementing these structures on channel hydraulics and the capacity of the bridge opening. While one-dimensional hydraulic models were developed to support design of the original pilot projects, these tools are not well-suited for representing the effects of natural channel design structures on channel hydraulics at the bridge opening. Following discussion with ODOT Technical Liaisons, the research team outlined the following research objectives to address this gap in knowledge:

1. Develop a series of two-dimensional hydraulic models to simulate a range of intermediate and high events to assess hydraulics associated with implementation of alternative stream channel maintenance practices.
2. Develop models for two sites where alternative stream channel maintenance projects have been implemented and compare channel hydraulics to pre-maintenance and as-designed conditions.
3. Summarize findings and recommendations in a final report.

4.0 Research Approach

4.1 Implementation of Pilot Projects Using State Funding for Maintenance

The ODOT research project manager coordinated interactions between researchers and ODOT staff in multiple districts to assess sites with maintenance problems as potential candidates for alternative maintenance practices. In each case, the researchers communicated with staff to educate them about the alternatives and ODOT worked to identify a short list of potential problem sites in each county or district. Once candidate sites were identified, a combination of desktop analysis with GIS databases and hydrology and hydraulics models were constructed. Field visits were made to support the development of conceptual solutions. The proposed concepts were then provided to the District for consideration. In each case, it was requested that the information be shared with appropriate district engineering staff members (e.g. bridge engineer, hydraulics engineer, roadway services engineer, etc.) for evaluation and provided to District Environmental Coordinators (DECs) to begin the permitting process. Once approvals and any necessary permits were obtained, district and county staff coordinated implementation of the projects and informed the research team of the construction dates. The research team documented the construction process at each of the sites and edited footage into project videos.

4.2 Monitoring Project Outcomes and Conducting Outreach Education

Following construction, sites were visited periodically to assess site evolution, performance of the maintenance practice, and document project outcomes. Photographs were used to develop PowerPoint presentations and video for educational purposes and to provide guidance to Districts on which instream maintenance structures (e.g. weir, vane, etc.)) should be selected, designed (e.g. length, deflection angle, etc.), and installed.

4.3 Two-Dimensional Modeling of Channel Hydraulics

Hydraulic models were developed for six projects and used to simulate a range of as-designed, pre-maintenance, post-maintenance, and hypothetical scenarios to assess the impact of natural channel design-based structures on channel hydraulics. LiDAR data (https://ogrip.oit.ohio.gov/projectsinitiatives/osipdatadownloads.aspx) and topographic survey data were combined using the Riverine Pro package of the Surface Water Modeling System v12.2 (Aquaveo, LLC.) to develop physical models of the stream systems and any structures. Hydrology estimates were made for a range of recurrence interval events using the USGS StreamStats program. The SRH-2D model was used to predict water surface elevations, flow velocities, and shear stresses for each project. Results were stored, summarized, and graphed using MS Excel.

Two maintenance practices were simulated including single-arm vanes (Figure 1A) and culvert weirs (Figure 1B). Single-arm vane structures were used at bridge embankments to reduce flow velocities along eroding banks. Single arm vanes typically diverge from the bank at 20°-30° angle and are installed at a 3°-7° decline starting at the bankfull channel elevation and extending upstream until intersecting with the stream bed. This configuration causes flow and energy to be redirected towards the channel centerline and away from the streambank thus protecting it from erosion. Culvert-weirs were implemented at sites with double box culverts where the bankfull channel width was much smaller than the aggregate width of both culverts. This overly wide condition at the opening typically results in aggradation. A weir was built in front of one culvert to concentrate the low and intermediate flows into the other culvert to enhance sediment transport while retaining the capacity of the second culvert for high flow events.

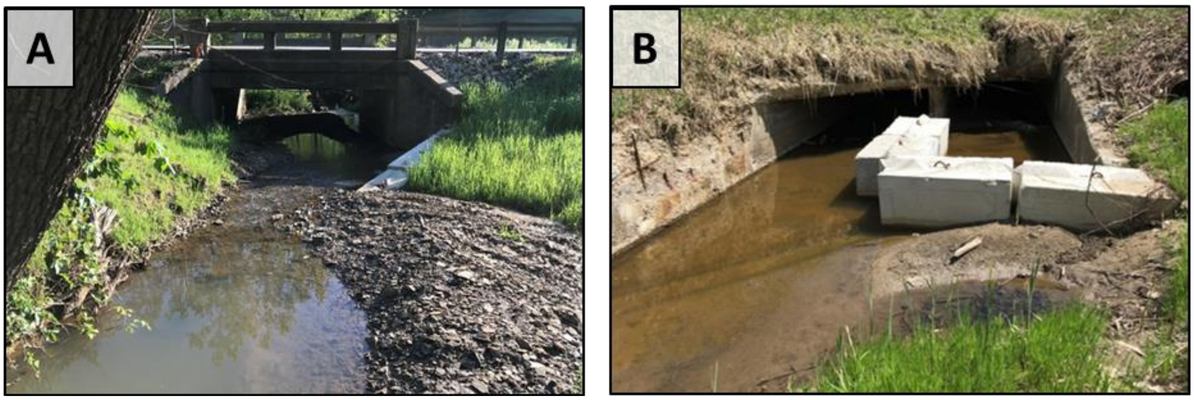

Figure 1. A) Single-arm vane at Meigs County on State Route 143, and 2) level-weir at Geauga County on State Route 528.

5.0 Research Findings and Conclusions

5.1 Outreach Education and Field Site Visits

Outreach education presentations and field site visits were made in Districts 3, 5, 6, 7, 8, 10, and 12. Field visits or desktop evaluations of specific sites were made at more than 30 locations in 18 counties including Ashland County (ASH 003), Coshocton County (COS 16), Geauga County (GEA 528 (2 sites), GEA 044 (2 sites)), Guernsey County (GUE 22), Hocking County (HOC 056(2 sites), HOC 093, HOC 664), Knox County (KNO 3, KNO 586), Licking County (LIC 79), Madison County (MAD 187), Meigs County (MEI 143 (2 sites)),Monroe County (MOE 7), Noble County (NOB 821), Perry County (PER 13, PER 93 (2 sites), PER 155 (2 sites), PER 204, PER 668), Pickaway County (PIC 022), Summit County (SUM 303, SUM 271), Union County (UNI 161), Wayne County (WAY 302), Williams County (WIL 20), and Wood County (WOO 582). Additional meetings and presentations were made at the Ohio Transportation Engineering Conference, District Bridge Engineers Meeting, District Environmental Coordinators Meeting, Bridge Inspectors Meeting, 2018 National Hydraulic Engineering Conference, and the 2018 Transportation Research Board Annual Meeting. One additional meeting and field site visits were coordinated by ODOT – Office of Environmental Services with ACOE and the research team to discuss permitting issues related to natural channel design-based maintenance practices.

5.2 Project Implementation

Seven total projects were constructed in Districts 10 and 12 (Table 1; Appendix A). Two sites in Geauga County (Figure 1A and 1D) were single box culverts that were wider than the upstream channel. Partial dredging to form a compound channel with dimensions consistent with the natural stream was completed at GEA 044 1469 (Figure 1A). A partition made of drainage pipe was installed at GEA 044 0667(Figure 1D) to guide low and intermediate flows to one side of the pipe, which coincided with dimensions of the natural stream channel.

Two sites in Geauga County and the Noble County site were double box culverts impacted by aggrading sediment that reduced capacity. A weir was placed across the entire inlet at GEA 528 1931 (Figure 1C) to increase the slope at the apron, which reduced the severity of sedimentation that frequently became vegetated and blocked flow. Sedimentation inside the box culvert was not an issue at this site. At GEA 528 1526 and NOB 821 0018, culvert-weirs were placed in front of one box culvert as the natural channel upstream had dimensions roughly equivalent to a single culvert width. Both sites had sedimentation within one or both culverts, which appeared to be mitigated in post-construction site evaluations.

Single-arm vane structures were installed at MEI 143 0691 and MEI 143 0716 (Figures 1B and 1C, respectively) to realign the channel with the opening. At the former site (1B), progressive lateral migration had eroded into the roadway embankment and multiple attempts to protect the structure were unsuccessful or failing. Additional details on each of the projects is provided in Appendix A.

Figure 2. A) Compound channel created on single box culvert at GEA 044 1469, B) single-arm vane installed at MEI 143 0716, C) weir installed at GEA 528 1526, and D) partition installed at GEA 044 0667.

Table 1. List of project sites, maintenance problem, and implemented solution.

Site (County/Route/SLM[1])	Problem	Solution
GEA[2] 44 667	Sedimentation	Channel Partition
GEA[2] 44 1469	Sedimentation	Compound Channel
GEA[2] 528 1526	Sedimentation	Level-Weir
GEA[2] 528 1931	Sedimentation	Level-Weir
MEI[3] 143 0691	Lateral Migration	Single-Arm Vane
MEI[3] 143 0716	Lateral Migration	Single-Arm Vane
NOB[4] 821 0018	Sedimentation	Level-Weir

1-Straight Line Mileage; 2-Geauga County; 3-Meigs County; 4-Noble County

5.3 Channel Hydraulics

5.3.1 Single-Arm Vanes to Improve Alignment

SRH-2D model results for three single-arm vane projects, WAY 083 0087, WAY 604 1307, and MEI 143 0716, showed a consistent shift in shear stresses away from the bank and abutment towards the center of the opening at the bankfull discharge (approximated as 50% of the 2-year peak discharge rate) and the 2-year recurrence interval events (Figure 3G). In general, the shift in peak shear away from the abutment diminished for the larger, less frequent events (≥5-year recurrence interval; Figure 3G). All sites had at least one discharge rate in which the modeled shear stress was shifted towards the abutment compared to the pre-maintenance condition. However, the bankfull discharge event is the most influential flow in terms of erosion and sediment transport over the long-term and the vanes at these sites effectively protected the bank and abutment during these important flow conditions. Furthermore, the peak shear stress modeled in cross sections just upstream of the openings was much less with the vane in place compared to the misaligned, pre-maintenance condition. In fact, shear stresses for the bankfull and 2-year discharge events with the vane in place were <40% of the peak shear stress values for the corresponding discharge rates modeled for the pre-maintenance condition (Figure 3H). All peak shear stresses were reduced with the vane in place except for WAY 604 1307, which had a minor increase in shear stress for the 50- and 100-year recurrence interval events.

As an example, pre-maintenance conditions at WAY 083 0087 are shown in Figure 3A. Lateral migration along the left bank (Figure 3A and 3C; red arrows) required multiple maintenance activities by the ODOT county crew. Bars formed across most of the width of the channel decreasing hydraulic capacity and velocity of flow through the opening leading to the formation of a bar downstream. Installation of the single-arm vane (Figure 3B and 3D; purple arrows) aligned the flow, halted development of the point bar, transported sediment that had accumulated downstream, and decreased and shifted shear stress away from the abutment (Figure 3E and 3F; high shear stresses are indicated by orange and yellow shading) towards the center of the span (Appendix B).

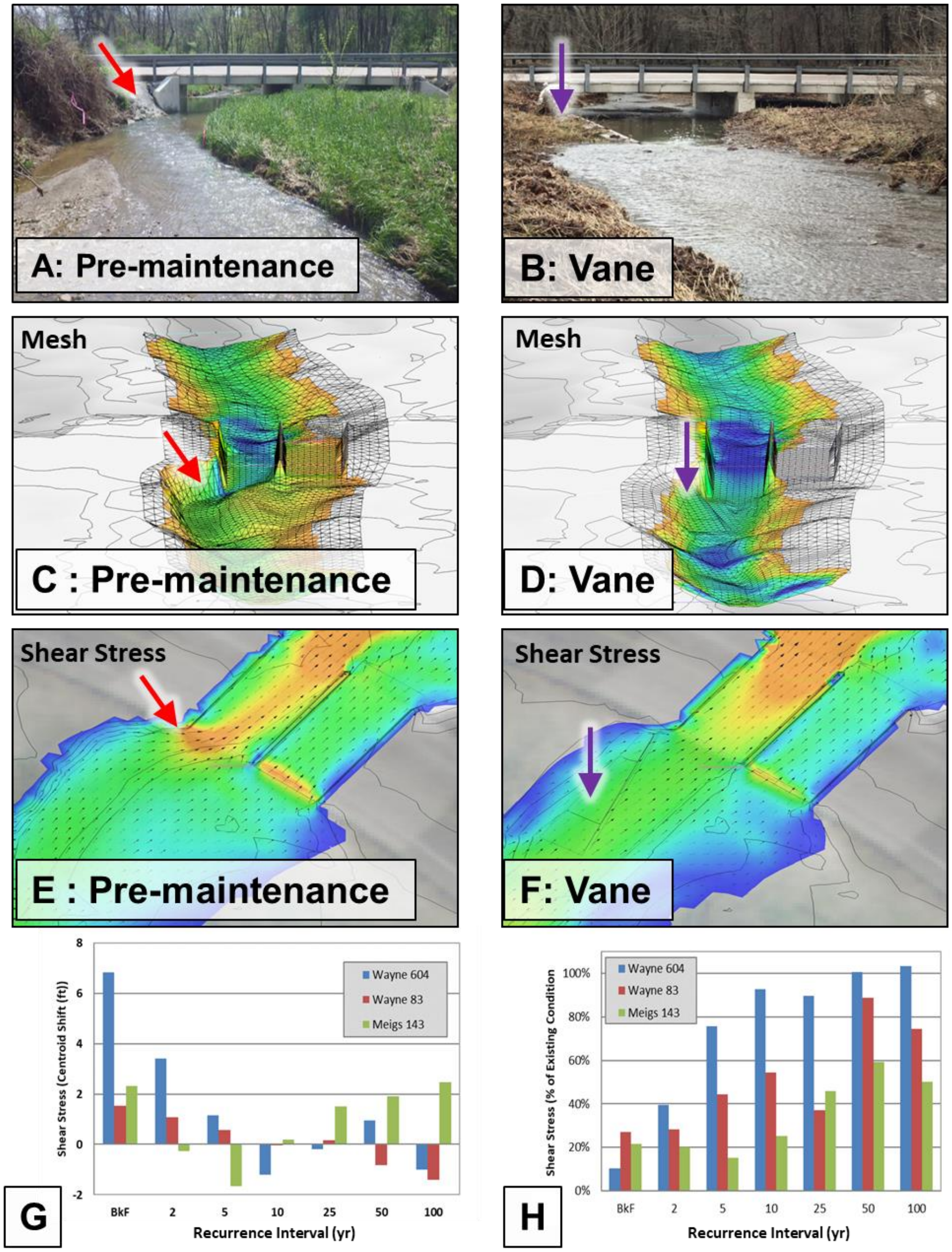

Figure 3. A) Lateral migration and bar formation at WAY 83 0087. Grouted rip rap was installed to protect against lateral migration along the left bank is failing. A point bar that formed in the channel is partially blocking ~75% of the opening, B) a single-arm vane installed on the left bank at the site, C) SMS mesh for the pre-maintenance condition (corresponds to Figure 3A), D) SMS mesh for the post-construction condition (corresponds to Figure 3B), E) SRH-2D model output for the pre-maintenance condition (corresponds to Figure 3A and 3C), F) SRH-2D model output for the post-construction condition (corresponds to Figure 3B and 3D), G) the shift in the calculated centroid of the shear stress distribution (positive values indicate a shift away from the abutment; negative values indicate a shift in shear stresses towards the abutment) for WAY 604 1307, WAY 83 0087, and MEI 143 0716, and H) peak shear stress at the abutment with vanes installed expressed as a percentage of the pre-maintenance peak shear stress values.

5.3.2 Culvert-Weirs to Resolve Sediment Aggradation

Blocking a portion of the hydraulic opening of a bridge or culvert with a weir has consequences for conveyance capacity and sediment transport through the structure. Models comparing the original design (i.e. "as-built"), pre-maintenance (i.e. "sediment bar" or aggraded; Figure 4A), and post-construction (i.e. "inlet weir"; Figure 4B) conditions were evaluated to determine the impact of the culvert-weir retrofit maintenance practice. For the GEA 528 1526 project, the original "as-built" design had the lowest water surface elevation for all discharge events from the bankfull (i.e. 50% of the 2-year event) through the 100-year discharge rate (Figure 4C). Models for the aggraded or pre-maintenance condition consistently predicted the highest water surface elevations across all recurrence intervals (Figure 4C). Installation of the inlet weir led to a reduced water surface elevation compared to the pre-maintenance condition but was not able to fully restore the capacity of the original "as-built" condition (Figure 4C).

Another important result from modeling the as-built and post-construction (i.e. with level-weir installed) conditions is the stark difference in the distribution of shear stresses (Figure 4D) for the two geometries. For the as-built condition (2 fully open, sediment free culverts), predicted shear stresses in the left box culvert (green bars in left graph of Figure 4D) were 24% and 54% of the predicted values for the natural channel (values reported in background blue bar graph) just upstream of the opening for the bankfull and 2-year discharge events, respectively. Shear stresses in the right culvert were 20% and 36% (red bars in left graph of Figure 4D) of the natural channel just upstream of the opening for the bankfull and 2-year discharge events, respectively. Low shear stresses through the opening relative to the natural stream provide an ideal environment for sedimentation, which often requires periodic dredging to restore capacity. While the project was certainly designed to pass a design discharge rate, it most likely did not account for impacts of the design on sediment transport competence, essentially building a sediment trap through the opening by making it too wide relative to the natural channel.

Conversely, the inlet weir design (graph on right in Figure 4D) concentrated the bankfull and 2-year discharge events into the left box culvert, thus increasing shear stress to levels more consistent with the natural channel upstream (blue background bar on graph). This increase in shear stress was able to transport sediment that had aggraded in the left culvert without any further maintenance. Furthermore, the culvert with the weir in front was also able to clear itself during high flow events that overtopped the weir. The combination of increased slope through the drop over the weir and the lack of bedload sediment moving through the right culvert (due to being blocked at the bed elevation) cleared the sediment in the culvert without a maintenance activity. Additional model results for other sites are included in Appendix B.

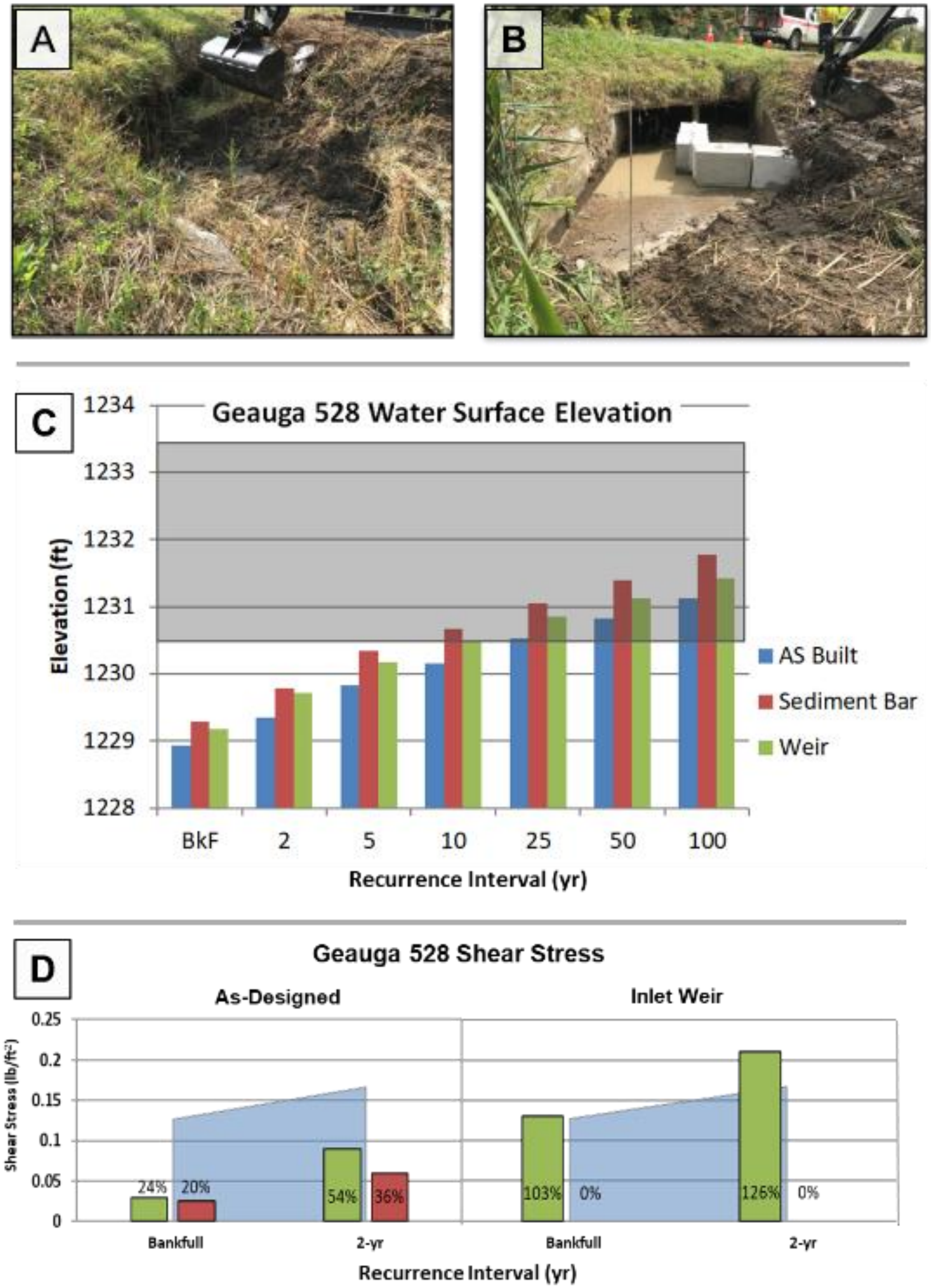

Figure 4. A) Pre-maintenance condition at GEA 528 1526, B) construction of culvert-weir retrofit project, C) predicted water surface elevations for the bankfull through 100-year discharge rates, and D) shear stresses in the left (green bars) and right (red bars) culverts relative to the natural channel for the as-built and inlet weir geometries at Geauga County 528.

5.4 Environmental Permitting

During early stages of the research, ODOT OES staff coordinated a meeting with ACOE to review projects completed during the prior research project, Alternative Stream Channel Maintenance at Bridge Crossings (State Job #134821), and make a determination as to how permitting requirements might vary based on different sources of funding to undertake maintenance activities. Hypothetical scenarios describing a range of potential project types or actions were laid out to ACOE and responses were used to gauge their views on permitting requirements. Subsequent field visits to assess previously implemented and several potential projects were made to further understand their thought process on these novel maintenance approaches and identify permitting requirements. The meetings and field visits also served as an educational opportunity for ACOE staff to better understand the methods that were being implemented.

A primary outcome of the interactions with ACOE, indicated that smaller projects implemented in proximity of the bridge for the purpose of protecting the structure could be permitted under Nationwide Permit #3 or through the current Regional General Permit Section B. The seven subsequent pilot projects that were implemented through this research all fell within this categories and effort and cost related to permitting these projects was greatly reduced relative to previous projects.

Actual permitting of the projects was undertaken by the District Environmental Coordinators in District 10 and 12 in coordination with ODOT OES. Beyond initial meetings at project sites with District staff, including the DEC, the permitting process was completed efficiently by ODOT staff without aid from the research team. Furthermore, District staff were present throughout the installations to ensure compliance during the implementation phase.

After completing the permitting process for the seven projects implemented through this research, ODOT OES was able to write specific guidance to help DEC's determine which types of natural channel design projects will meet requirements of a non-notifying RPG B. According to the guidance, allowable activities include: 1) debris removal, 2) structures (e.g. vanes, cross vanes, weirs) adjacent to the structure for the purpose of protecting the structure, 3) practices for channel stability when the instability directly impacts the structure, 4) rock channel protection to protect the structure, and 5) temporary activities with a duration shorter than two years. Additional details on Section 404 Regulation principles, allowable and non-allowable activities, and characteristics of sites where natural channel design-based practices should be avoided are provided in Section K of the Highway Operations Environmental Checklist (included here in Appendix C). An additional benefit of the research were the additional experiences that, in part, guided revisions to the proposed 2019 Regional General Permit that included revisions to Section RGP B (Maintenance) and inclusion of a new Section RGP C (Bank Stabilization), which could further streamline implementation of alternative channel maintenance practices at bridges.

6.0 Recommendations for Implementation of Research Findings

Maintenance practices based on natural channel design concepts appear to provide some potential benefits over traditional maintenance practices; however, monitoring of the projects is in the early stages and longer-term monitoring is needed to draw definitive conclusions. Based on our experience thus far, it appears that single-arm vanes are effective countermeasures for streambank lateral migration that threatens the bridge abutment and embankment. Moreover, when attached to the bridge and built for the purposes of protecting the structure the practice can be permitted under Nationwide Permit 3 (Maintenance) or the Regional General Permit with a reasonable level of effort and in a timely manner. At sites on small watersheds, our experience suggests single-arm vanes can be built in less than one day at a cost that is acceptable to county transportation administrators. Therefore, early indications are that single-arm vanes are a viable practice and we recommend:

1) Existing sites continue to be monitored for changes to stream morphology and for other environmental indicators of success or failure.
2) Additional single-arm vane projects are constructed at new sites to further test the utility and limits of the practice.

Preliminary evaluation of level-weir, culvert inlet weir, and flow partitioning approaches to smoothly transition the bankfull channel through the bridge or culvert opening suggests another potentially viable approach to maintenance. Our findings indicate that concentrating the low and intermediate flows to a portion of a single culvert or one culvert in a double barrel arrangement improves sediment transport through the reach. Furthermore, the projects have addressed issues of existing sedimentation within the culverts without any additional human intervention. These projects were also quick, simple, and economical to build and had permit requirements consistent with the single-arm vane projects described previously. If additional weirs and partitions are implemented to more closely approximate bankfull channel conditions at a site, we recommend:

1) Further monitoring of existing and any future projects to track performance due to relatively short time since installation and subsequent implementation of adaptive management as needed.
2) Hydraulics should be evaluated a priori if capacity of the structure is of concern to the District Bridge Engineer, Hydraulics Engineer, or Roadway Services Manager.

We, also, recommend that the findings of this research are evaluated by ODOT OHE and used to consider revisions to the “Location and Design Manual - Volume Two: Drainage Design” for new bridge and bridge replacement projects. While the manual already requires consideration of geomorphic conditions of channel and bankfull channel hydraulics and references “Stream Corridor Restoration: Principles, Processes, and Practices” (Federal Interagency Stream Restoration Working Group (FISWRG), 2001), we suggest adding specific language to the “Location and Design Manual” that requires an analysis of sediment transport from the upstream existing channel to the bridge opening through to the downstream channel for more frequent flow events (e.g. bankfull flow or channel forming discharge rates) than typically used to analyze flood capacity of bridges (i.e. ≥10-year discharge event). Stream power or bed shear stresses are related to sediment transport and are potentially useful indicators of channel stability (FISRWG, 2001).

Furthermore, for sites with dynamic channels with potential alignment issues, we recommend that an analysis of historical aerial imagery be undertaken in the vicinity of the bridge in order to estimate meander migration rates and determine if alignment issues are likely during the anticipated design life of a proposed structure. Where misalignment of the channel and potential for lateral migration to impact the embankment leading to hydraulic inefficiency through the opening, the incorporation of vane structures to smoothly transition flow should be considered when new or replacement bridges are designed. Design, permitting, and installation of instream structures for new or replacement bridges could be included into the design and permit requirements for a new or replacement bridge. Integrating instream structures at the beginning of a project could lead to cost and time efficiencies and reduce needs for reactive maintenance in the future.

In general, we also recommend that:

1) All projects should be reviewed and approved by a licensed ODOT engineer or other qualified individual, undertaking any analysis deemed necessary to ensure safety of the bridge and proper design of instream structures along with any ancillary practices associated with its installation.
2) ODOT identifies an engineer and environmental scientist from within the organization to learn the design process and permitting strategies associated with natural channel design-based practices and these individuals serve as guides to other Districts interested in undertaking implementation of natural channel design-based maintenance practices.
3) Annual bridge inspection reports for pilot project sites across all districts are evaluated by a central office staff person to ensure that any potential issues that may surface through time are identified across projects in multiple Districts.
4) The ODOT Bridge Maintenance Manual should be updated to include the practices developed and tested through this and previous research. Recommended draft language for the maintenance manual is provided in Appendix D.

Appendix A. Descriptions of Pilot Projects

Geauga County State Route 44

This crossing exhibited the most common problem encountered with the simplest solution. The channel approach was converted from a uniform overly wide cross section to a compound channel form. Aggradation caused loss of flow capacity. Recurring maintenance involved excavating the approach to the culvert and wing walls, which was more than double the width of the natural stable channel upstream. The alternative approach involved excavation of only the width of the upstream channel at the opening. The low bench that was left in place was vegetated and compound channel that resulted has hydraulics with adequate shear to maintain the channel depth at the approach and through the culvert.

Figure A1. Excavation of a portion of the width of the channel to form a compound channel geometry more consistent with the natural channel upstream.

Figure A2. The compound channel form after the "partial" maintenance activity. Vegetation of the bar stabilizes the compound channel form.

Meigs County State Route 143 Project #1

The channel migrated laterally into the embankment from the as-designed alignment. Recurring problems caused from lateral channel migration continued to threaten the structure despite past realignment and armoring of the embankment. The alternative maintenance approach implemented was a single-arm concrete block vane to reestablish and maintain flow alignment and protect the embankment.

Figure A3. Scour behind the wing wall requiring recurring maintenance with grouted rip rap to protect the embankment.

Figure A4. Approximate flow pathway (indicated by the red arrow) prior to installation of the vane.

Figure A5. Oblique view of approximate flow pathway (red arrow) prior to installation of the vane.

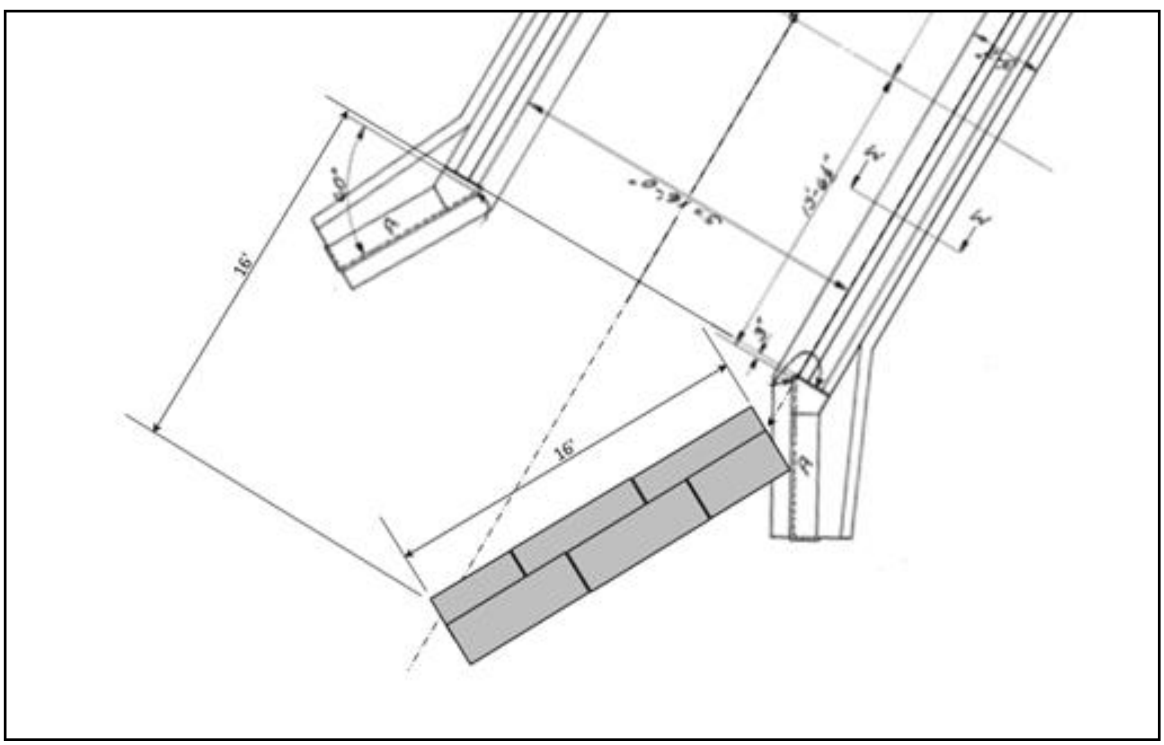

Figure A6. Conceptual diagram of vane structure (shown in gray) overlain on original construction drawings.

Figure A7. Post-construction condition months later exhibiting good alignment with the opening.

Meigs County State Route 143 Project #2

Sediment repeatedly accumulated, limiting flow capacity, and required removal at this twin box culvert. A weir was constructed to concentrate the low and intermediate flows that generally transport about half the total sediment load. Forcing low and intermediate flows to be concentrated into a single culvert improved sediment transport through the opening. A brief video of the project in provided at: https://youtu.be/EobQEZPDwPE

Figure A8. Sediment accumulation and subsequent vegetation of the deposits on the approach apron.

Figure A9. Looking upstream at the project with the level-weir in place. Dimensions of the natural channel upstream are approximated by the yellow lines.

Figure A10. Looking downstream at the project several months post-construction. Both boxes are free of sediment beneath the roadway.

Noble County State Route 821

The crossing had been designed to be about twice the width of the stable channel in the vicinity of the bridge. Sediment bars formed repeatedly, and sediment aggraded in both box culverts limiting flow capacity. A culvert-weir was constructed to enhance sediment transport competence and improve high flow capacity by scouring sediments that had deposited inside the culvert. The weir concentrates low and intermediate flows while allowing high flows access to both culverts. In addition, most of the coarse bed load sediment travels through the culvert open to the streambed. The second “overflow” culvert then carries a relatively small sediment load. A brief video of the project in provided at: https://youtu.be/Gxfcj__ElCs

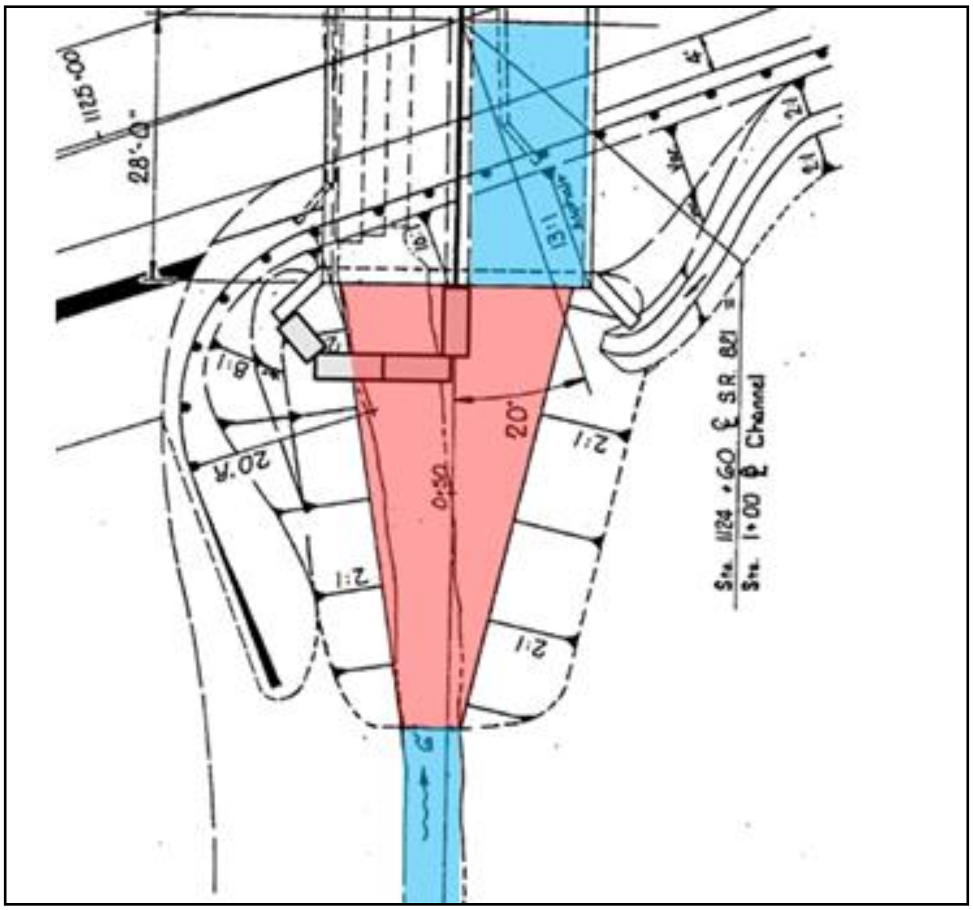

Figure A11. Conceptual diagram of the culvert weir structure in front of the left culvert overlain on original construction drawings. The approximate width of the natural channel is highlighted in blue. The width of the designed approach is highlighted in red. Width at the opening is 2-3 times wider than the natural stream.

Figure A12. Placement of the last interlocking block to complete the culvert weir at NOB 821.

Figure A13. Left Panel) Accumulated sediment in the culvert prior to installation with a culvert weir. Right Panel) Remaining sediment in the culvert after installation and a few high flow events. Approximate level of sediment for the pre-maintenance condition is highlighted by red and yellow dashed lines.

Figure A14. Debris accumulation on the culvert weir. Minor modification of the practice may alleviate some of the debris, but accumulations on this site have historically been a problem.

Geauga County State Route 44

A culvert more than twice the width of the stable channel upstream had sediment accumulation under the deck that reduced capacity. To maintain sediment transport competence similar to the upstream compound channel form, a partition was constructed and secured under the deck. Similar to the culvert weir concept, this design concentrates low and intermediate flows on one side of the partition and allows high flow access to the entire width of the culvert. The partition was tied into a floodplain bench, alternatively a weir could have been constructed across the floodplain side of the entrance further increasing high flow capacity. A project video is available at: https://youtu.be/ZBZkN5CLO_w

Figure A15. The narrow, natural stream channel leading up to the culvert which is more than twice as wide as the channel upstream.

Figure A16. Looking downstream through the culvert at sediment that was deposited at the site prior to construction of the bankfull partition.

Figure A17. Site following construction with the partition installed to more closely establish the compound geometry consistent with the upstream channel.

Figure A18. Flow capacity might be further enhanced by integrating the culvert weir design to increase velocities in addition to the channel partition.

Figure A19. View from downstream looking at addition depth that was gained along the dominant flow path.

Geauga County State Route 528

This crossing utilizes a low weir to prevent sediment deposits from accumulating on the approach apron of a twin box culvert crossing. Sediment accumulation had not been a problem within the culverts, so a culvert weir was not necessary; however, a recurring sediment bar on the apron was of concern. A low weir was installed to increase the slope and flow velocity through the apron and enhancing sediment transport to keep deposits from accumulating.

Figure A20. Oblique view of the approach apron where sediment deposits vegetated and stabilized along the right side blocking the opening.


Figure A21. Same view as Figure A20 months later with no sediment deposits accumulating since installation of the low weir.


Figure A22. Stream-level view months after construction with clear apron and box culverts.

Appendix B. Hydraulic Modeling Results

Table B1. Modeled shear stress and velocity values for the "as-designed" condition at Noble County 821.

		Discharge Interval Event (years)						
	Variable	Bankfull	2	5	10	25	50	100
Natural Channel	Shear (lb ft^{-2})	0.2	0.32	0.4	0.2	0.19		
Left Culvert	Shear (lb ft^{-2})	0.04	0.05	0.19	0.22	0.33		
Right Culvert	Shear (lb ft^{-2})	0.08	0.12	0.16	0.24	0.34		
Natural Channel	Velocity (ft sec^{-1})	5	5	7.3	5.6	4.6		
Left Culvert	Velocity (ft sec^{-1})	2	2.6	3.8	5.7	6.7		
Right Culvert	Velocity (ft sec^{-1})	3	3.8	4.8	5.5	6.8		

Table B2. Modeled shear stress and velocity values for the "pre-maintenance" condition at Noble County 821.

		Discharge Interval Event (years)						
	Variable	Bankfull	2	5	10	25	50	100
Natural Channel	Shear (lb ft^{-2})	0.2	0.3	0.35	0.22	0.15		
Left Culvert	Shear (lb ft^{-2})	0.02	0.1	0.19	0.28	0.35		
Right Culvert	Shear (lb ft^{-2})	0.065	0.05	0.07	0.15	0.24		
Natural Channel	Velocity (ft sec^{-1})	4.8	6.2	7	5.5	4.5		
Left Culvert	Velocity (ft sec^{-1})	1.8	3.4	4.7	6.2	7		
Right Culvert	Velocity (ft sec^{-1})	2.8	2.2	3.3	4.8	5.7		

Table B3. Modeled shear stress and velocity values for the "post-construction" condition at Noble County 821.

		Discharge Interval Event (years)						
	Variable	Bankfull	2	5	10	25	50	100
Natural Channel	Shear (lb ft^{-2})	0.2	0.3	0.38	0.25	0.17		
Left Culvert	Shear (lb ft^{-2})	0	0	0.04	0.17	0.33		
Right Culvert	Shear (lb ft^{-2})	0.12	0.23	0.24	0.27	0.33		
Natural Channel	Velocity (ft sec^{-1})	5.2	6.3	7	5.8	4.5		
Left Culvert	Velocity (ft sec^{-1})	0	0.4	2.5	4.9	6.75		
Right Culvert	Velocity (ft sec^{-1})	3.7	5.4	5.7	6.2	6.75		

Table B4. Modeled shear stress values for the "as-designed" condition at Geauga County 528.

		Discharge Interval Event (years)						
	Variable	Bankfull	2	5	10	25	50	100
Natural Channel	Shear (lb ft^{-2})	0.12	0.17	0.2	0.2	0.23	0.24	0.25
Left Culvert	Shear (lb ft^{-2})	0.03	0.09	0.17	0.22	0.27	0.33	0.44
Right Culvert	Shear (lb ft^{-2})	0.025	0.06	0.1	0.15	0.22	0.26	0.35

Table B5. Modeled shear stress values for the "pre-maintenance" condition at Geauga County 528.

		Discharge Interval Event (years)						
	Variable	Bankfull	2	5	10	25	50	100
Natural Channel	Shear (lb ft^{-2})	0.13	0.15	0.18	0.2	0.2	0.2	0.2
Left Culvert	Shear (lb ft^{-2})	0.15	0.25	0.35	0.4	0.5	0.55	0.7
Right Culvert	Shear (lb ft^{-2})	0	0.02	0.06	0.1	0.14	0.18	0.3

Table B6. Modeled shear stress and velocity values for the "post-construction" condition at Geauga County 528.

		Discharge Interval Event (years)						
	Variable	Bankfull	2	5	10	25	50	100
Natural Channel	Shear (lb ft^{-2})	0.13	0.18	0.2	0.2	0.2	0.2	0.2
Left Culvert	Shear (lb ft^{-2})	0.13	0.21	0.25	0.3	0.35	0.45	0.55
Right Culvert	Shear (lb ft^{-2})	0	0	0.05	0.1	0.15	0.18	0.26

Table B7. Modeled shear stress and velocity values for the "as-designed" condition at Wayne County 83.

		Discharge Interval Event (years)						
	Variable	Bankfull	2	5	10	25	50	100
Natural Channel	Shear (lb ft^{-2})	0.2	0.4	0.6	0.7	0.8	0.8	0.86
Left Culvert	Shear (lb ft^{-2})	0.08	0.2	0.2	0.35	0.48	0.55	0.66
Right Culvert	Shear (lb ft^{-2})	0.2	0.4	0.5	0.6	0.75	0.76	0.85
Natural Channel	Velocity (ft sec^{-1})	3.5	4.5	6	6.7	7.4	7.5	7.8
Left Culvert	Velocity (ft sec^{-1})	1.4	2.4	3.4	4.5	5.5	6.4	7
Right Culvert	Velocity (ft sec^{-1})	3.7	5	5.5	6	6.8	7	7.5

Table B8. Modeled shear stress and velocity values for the "pre-maintenance" condition at Wayne County 83.

		Discharge Interval Event (years)						
	Variable	Bankfull	2	5	10	25	50	100
Natural Channel	Shear (lb ft^{-2})	0.4	0.4	0.5	0.7	0.8	0.8	0.8
Left Culvert	Shear (lb ft^{-2})	0.03	0.4	0.8	1.1	1.2	2	2.4
Right Culvert	Shear (lb ft^{-2})	0.55	0.7	0.9	1.2	1.4	2	2.4
Natural Channel	Velocity (ft sec^{-1})	3.5	4.4	5.6	6	7	6.5	7
Left Culvert	Velocity (ft sec^{-1})	0.8	4	6.6	8	9	10.2	11
Right Culvert	Velocity (ft sec^{-1})	5.3	7.5	9	9.5	10.5	11.5	12.3

Table B9. Modeled shear stress and velocity values for the "post-construction" condition at Wayne County 83.

		Discharge Interval Event (years)						
	Variable	Bankfull	2	5	10	25	50	100
Natural Channel	Shear (lb ft^{-2})	0.3	0.4	0.6	0.8	0.9	0.9	1
Left Culvert	Shear (lb ft^{-2})	0	0.08	0.2	0.4	0.7	1	1.2
Right Culvert	Shear (lb ft^{-2})	0.3	0.7	1	1.5	2	2	2.4
Natural Channel	Velocity (ft sec^{-1})	4.5	5	6.5	7.2	7.8	8	8.2
Left Culvert	Velocity (ft sec^{-1})	0.2	2.5	4.5	6	8	8.8	10
Right Culvert	Velocity (ft sec^{-1})	5	7	8.2	9	11	11.5	12.5

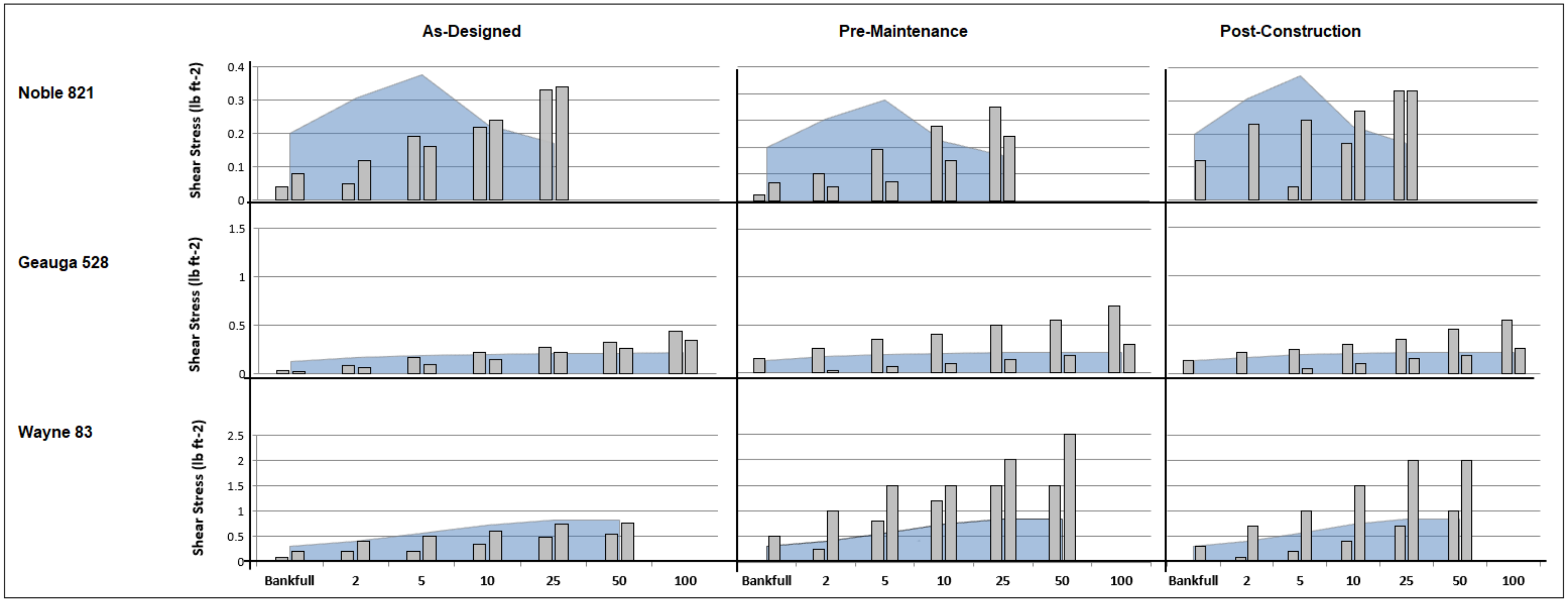

Figure B1. Graphs of shear stress at the culvert opening for the as-designed, pre-maintenance, and post-construction conditions at bankfull flow conditions through the 100-year recurrence interval events. Modeled shear stress values for the natural channel upstream of the opening are presented as the blue background.

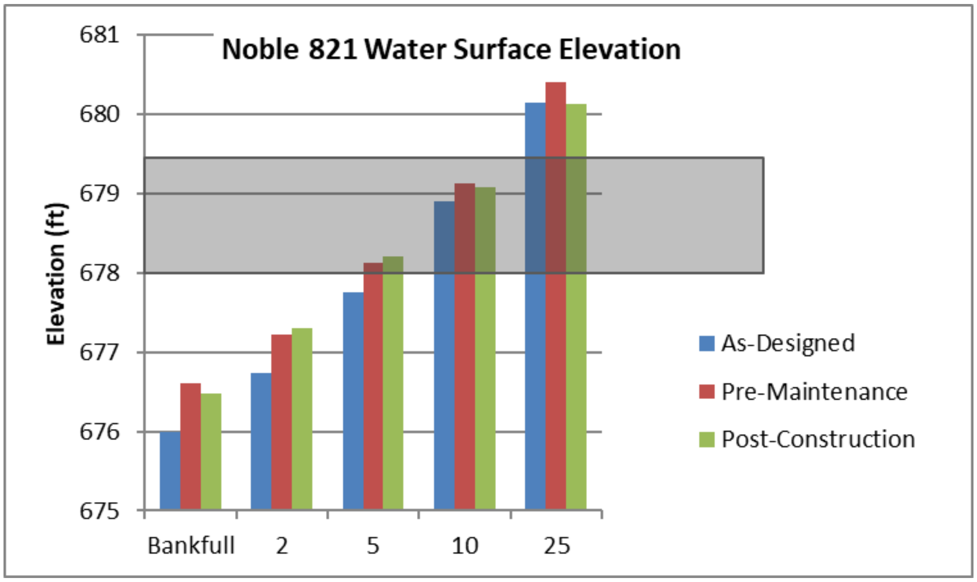

Figure B2. Predicted water surface elevations for the bankfull through 25-year recurrence interval events at Noble County State Route 821.

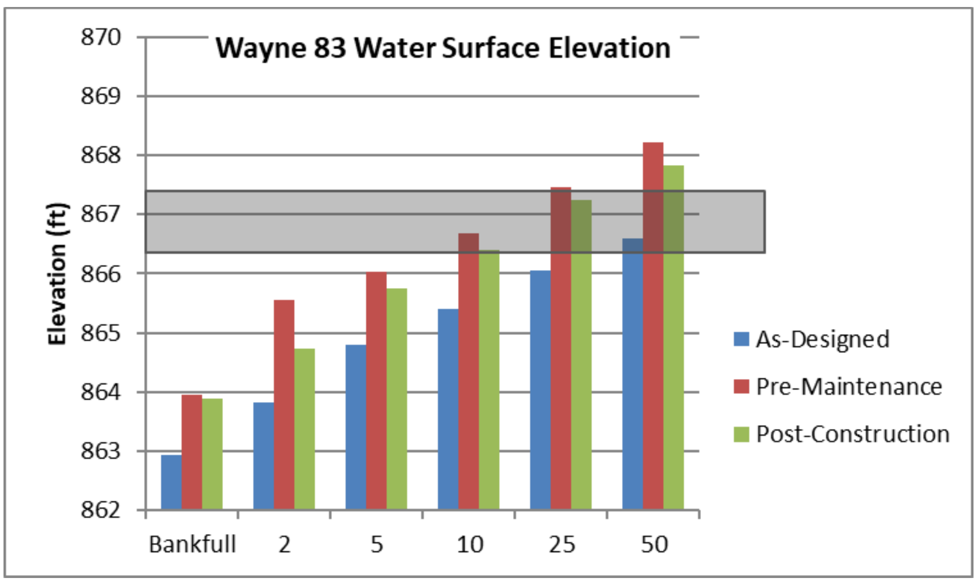

Figure B3. Predicted water surface elevations for the bankfull through 50-year recurrence interval events at Wayne County State Route 83.

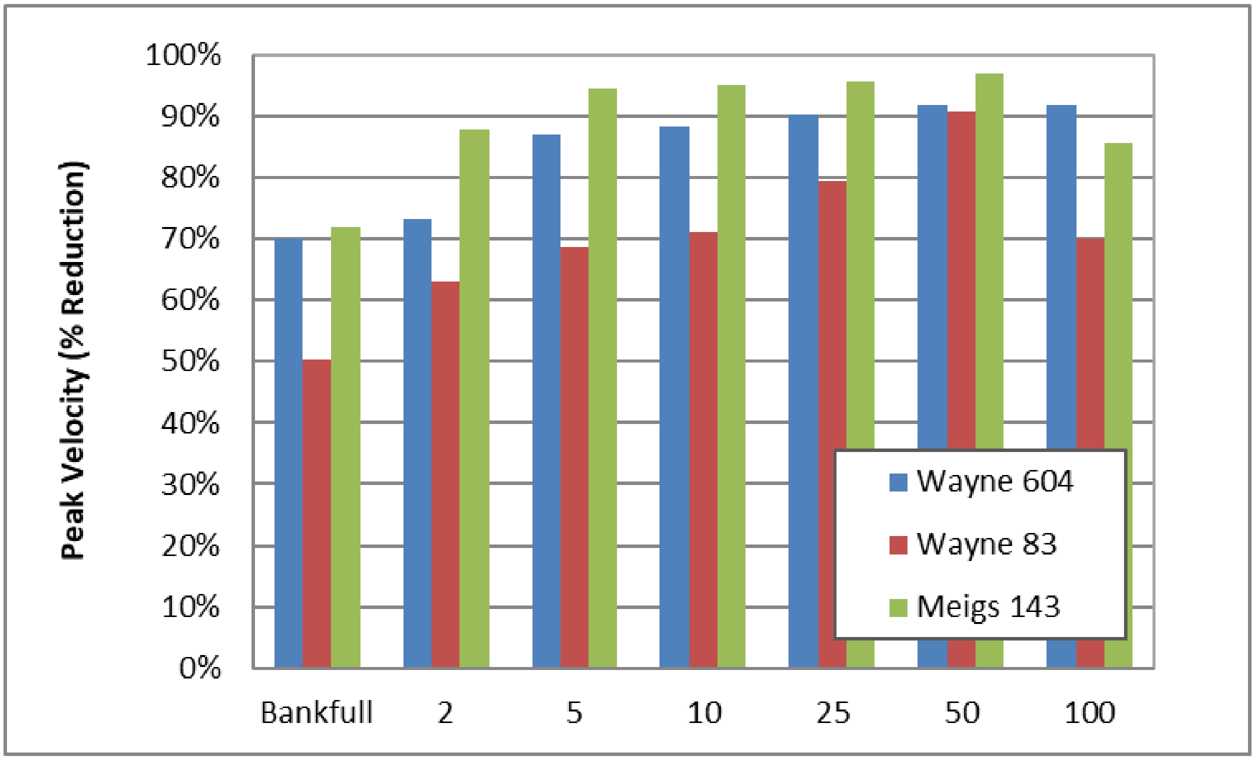

Figure B4. Reduction in peak velocity values for post-construction vane sites relative to the pre-maintenance condition.

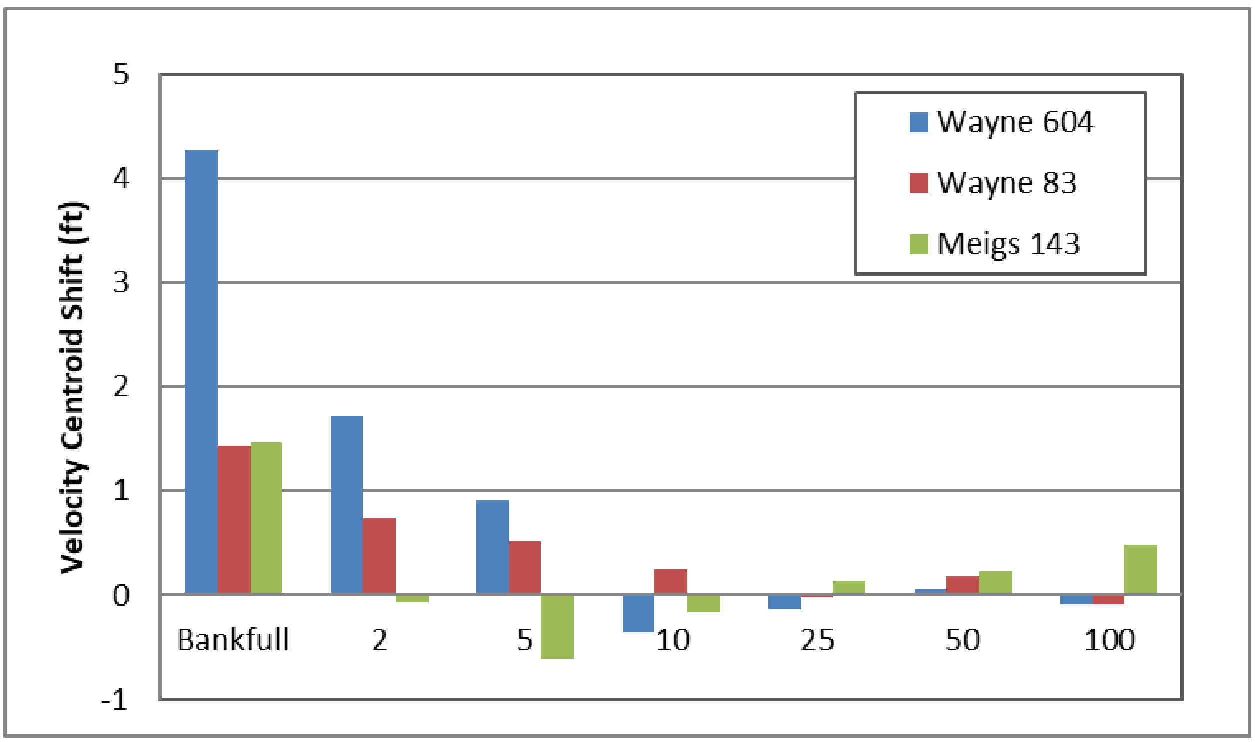

Figure B5. Shift in the centroid of peak velocity values for post-construction vane sites relative to the pre-maintenance condition.

Appendix C. ODOT Highway Operations Environmental Checklist

K. Section 404 Regulation: Natural Channel Design Criteria for Regional General Permit B (Maintenance)

Natural Channel Design is becoming a more common method for maintaining structures where streams deposit a high amount of sediment, causing maintenance crews to clean out the streams more frequently. This guidance is meant to help DECs determine which types of natural channel design projects will meet a non-notifying RGP B. DECs must submit a PDR to OES WPU for all natural channel design projects.

General Section 404 Principles:

1. Removing fill is not regulated under Section 404.
2. Placing any amount of fill into streams and wetlands is regulated under Section 404 and requires a permit.
3. Removing fill, but replacing fill back into the same water, or any other waters, is a regulated activity under Section 404 and requires a permit.
   a. This includes removing and replacing fill with a net amount of zero.
4. Dewatering a stream does not count as fill within the dewatered area (unless other impacts will occur). However, the device used to dewater (cofferdam, pump, etc.) does count as fill and is considered an impact requiring a permit.
5. Regional General Permit (RGP) B (Maintenance) is authorized for projects associated with the repair, rehabilitation, or replacement of an existing and currently serviceable structure.
   a. Stream channel modification is limited to the minimum necessary for the repair, rehabilitation, or replacement of the structure or fill.
      i. Modifications, like removing material from the stream channel, must be immediately adjacent to the project or within project boundaries of the structure or fill.
   b. Temporary fills must consist of materials, and be placed in a manner, that will not be eroded by expected high flows.
   c. Following completion, temporary fills must be removed in their entirety and affected areas must be revegetated, as appropriate.

Activities permitted under RGP B:

1. Debris removal
2. Cross vanes, rock vanes, j-hook vanes, etc. shall be directly adjacent to the structure with the purpose of protecting the structure
   a. Ex: directing flow to the center of the structure, away from abutments, piers, etc. and reducing stream bank erosion that directly affects the structure
3. Channel stability when the instability is directly affecting the structure
   a. Ex: bank erosion threatens an abutment or pier
   b. Ex: stream migration due to sediment deposition is undermining a wing wall, pier, abutments
   c. Ex: material deposition is creating a floodplain bench that is stressing the bank, and impacting hydraulic capacity and flow the stream, leading to the stream no longer flowing under the bridge as designed
4. Rock channel protection to protect the structure (not solely to protect a bank)
   a. Must be the minimum necessary to protect the structure, and cannot exceed 300 feet from the structure in either direction
5. Temporary activities
   a. Maximum of 2-year duration per single and complete project

Activities *not* permitted under RGP B:

1. Stream realignment/relocation

   a. Does not include removing accumulated sediment
2. Stream channelization
   a. Includes: the manipulation of a stream's course, condition, capacity, or location causing more than a minimal interruption of normal stream processes
      i. Increasing the capacity adjacent to the existing structure in order to protect it from sediment deposition will typically be permitted. Increasing capacity upstream and not adjacent to the structure is not permitted.
   b. Ex: channelization to reduce or negatively impact the capacity of the stream.
3. Stream stabilization
   a. Re-grading and reinforcing stream bank
      i. ex: rock toe, biodegradable coir rolls, and live stake vegetation
   b. Channel maintenance that affects channel characteristics
      i. ex: riffles upstream of a structure; significantly negatively lowering the flow line
   c. Slope protection not directly associated with an existing structure (includes rock channel protection)
4. Stream restoration
   a. Installing riffles
   b. Creating pools
   c. Re-contouring stream bank
   d. Exposing existing riffles (if fill is involved – excavation is not regulated)

Avoid:

1. Projects in Section 10 waters
2. Projects in streams and/or townships with federally endangered species/habitat
3. Projects in a flowage easement of a flood control facility
4. Projects in National or State Wild and Scenic Rivers
5. Projects in Critical Resource Waters or within the Oak Openings
6. Projects that will impact fens, bogs, or other Category 3 wetlands
7. Temporary fill exceeding 300 feet upstream to downstream in perennial and intermittent streams
8. Wetland impacts greater than 0.1 acre
9. Wetland impacts greater than 0.5 acre

Appendix D. Draft Language for ODOT Bridge Maintenance Manual

Twin box Culvert Weir

Purpose:

To increase flow capacity at a twin box culvert crossing by scouring accumulated sediment and controlling aggradation.

Planning Considerations:

- Application where:
  - Flow capacity has been limited by sediment deposition
  - Aggradation was caused by relatively wide shallow flows through the culverts
  - The width of one culvert is similar to the natural stable channel in the vicinity
- This practice can be adapted to crossings with more than 2 culverts and to multi-span bridges.

Design Considerations:

- The open culvert or span without the weir must have a width that is similar to the width of the natural stable channel in the vicinity. It may be preferable if the culvert or span width is somewhat less than the channel.
- The height of the weir is generally similar to the height of the sediment bars and floodplain and/or other indicators of the naturally stable bankfull channel. Consideration should be given to constructability and limits of the materials used. The structures effect diminishes with reduced height.
- Footers of adequate depth are necessary for the stability. Ridged structures set on erodible material must be constructed below the maximum depth of scour. A common cause of failure is the scour hole undermining the weir. With adequate footer depth no additional footer material should be necessary. Geotextile on the upstream surface of the block may be desirable to prevent piping between blocks.
- Twin-box culvert weirs by themselves do not manage channel alignment. If necessary, this practice could be combined with a vane, cross vane or even w-weir.

Channel Partition

Purpose:

To increase flow capacity at a crossing where sediment aggradation has resulted from relatively wide shallow flows under the deck. The partition narrows low and intermediate flows to induce scour under the deck while allowing high flows to access the entire width of the opening.

Planning Considerations:

- This practice may be useful where the channel under the deck is much wider than the channel width in the vicinity of the crossing; where small streams enter wide culverts.
- The over wide channel under the deck is often the result of shade preventing vegetation that generally causes channels to narrow.

Design Considerations:

- Types of material used may be constrained by access under the deck. Options include various types of precast concrete such as Vee-lock block or Jersey barriers, or if adequately anchored logs or plastic pipe.
- Prevent undermining failure of the partition by planning for scour to lower the channel bed. Plastic pipe has the benefit of not requiring footers.
- The partition should be positioned to restrict low and intermediate flows to a width that approximates the natural stable stream in the vicinity of the crossing.
- The height of the partition should be similar to the height of the sediment bars and floodplain and/or other indicators of the naturally stable bankfull channel.
- The upstream end of the partition may be keyed into the bank or bar or a weir.

Vane

Purpose:

Align stream flow with crossing structure. The vane creates a gradual transition from the dynamic natural channel to the fixed location of the crossing.

Planning Considerations:

- Use to maintain channel alignment with the bridge abutments and/or piers:
  - If the channel can be realigned with the crossing structure and the vane is used to prevent the channel from redeveloping poor alignment.
  - If the channel cannot be realigned as it approaches the structure, then the vane can be used to make the change in flow direction less abrupt.
  - If actively realigning the channel is not feasible a vane may be used to redirect the current, having the flow gradually do the work of realigning the channel with the crossing structure.
- Vanes affect flow upstream by reducing the water surface slope along the bank, reducing near-bank shear stress, bank erosion and gradually shifting the current's direction. This influence extends upstream beyond the vane structure itself, which is particularly beneficial when dealing with right-of-way constraints.

Design Considerations:

- A variety of materials are commonly used in construction including large rock, logs, or Vee-lock concrete blocks. Block may not be desirable if aesthetics is a primary issue;

however, they have superior constructability and performance relative to irregularly shaped, quarried boulders commonly used in construction of instream structures.

- Vanes can be placed up against the abutment or wing wall.
- The layout has two design targets, 1) angle and 2) slope with the principal design variable being the vane length. A design spreadsheet, Vane Layout, is available to help determine vane geometry and design targets.
    - Angle of the vane should be 20-30 degrees off the bank, as measured from a line projected upstream parallel the angle under the crossing of the abutment and/or piers Steeper angles are more likely to create turbulence and back eddies. If a poor stream approach angle cannot be corrected, the angle of the vane might be a compromise between the channel approach and the abutment.
    - The upstream end of the vane extends out into the channel, between 1/3 of the channel width to the midpoint or ½ of the channel width.
    - Slope 2 to 7% from the abutment to the upstream end of the vane.
        - The upstream end is generally flush with the stream bed but might be slightly higher if necessary, such as for grade control.
        - The height of the downstream end is generally similar to the height of the sediment bars and floodplain and/or other indicators of the naturally stable bankfull channel. Consideration of cross vane height should be given to constructability and limits of the materials used. The structures effect diminishes with reduced height.
    - All design targets cannot always be met such as if the channel is narrow and deep or if the crossing is at a steep skew. The design process becomes a process of compromise, minimizing deviation from design targets.
- Footers of adequate depth are necessary for the stability of vanes. Ridged structures set on erodible material must be constructed below the maximum depth of scour. A common cause of failure is the scour hole undermining the vane. Maximum scour depths typically develop near the midpoint of the cross vane. With adequate footer depth no additional footer material should be necessary. Geotextile on the upstream surface of the block may be desirable to prevent piping between blocks.

Cross Vane

Purpose:
Increase flow capacity by controlling sediment accumulation, grade control, and/or align stream flow with crossing structure.

Planning Considerations:
- Cross vanes concentrate and accelerate flow and so may be used where sediment accumulation at the approach to a crossing requires recurring maintenance.
- Use to maintain channel alignment with the bridge abutments and/or piers particularly if poor alignment may develop from one side or the other.
    - If the channel can be realigned with the crossing structure and the vane is used to prevent the channel from redeveloping poor alignment.
    - If the channel cannot be realigned as it approaches the structure then the vane can be used to make the change in flow direction less abrupt.
    - If actively realigning the channel is not feasible a vane may be used to redirect the current, having the flow gradually do the work of realigning the channel with the crossing structure.
- Use for grade control. Cross vanes may be used downstream from crossings as well as upstream and used in series minimizing the drop at any one structure. Similarly the stepped version of cross vane design reduces the height of any one drop.
- Cross vanes affect flow upstream by reducing the water surface slope along the bank, reducing near-bank shear stress, bank erosion and gradually shifting the current's direction. This influence extends upstream beyond the cross vane structure itself (particularly beneficial when dealing with right-of-way constraints.)

Design Considerations:
- A variety of materials are commonly used, large rock, logs, or Vee-lock concrete block. Block may not be desirable if aesthetics is a primary issue; however, they have superior constructability and performance relative to irregularly shaped quarried boulders.
- On single span structures the cross vanes can be placed up against each abutment or wingwall.

- The layout has three design targets, 1) angle, 2) slope and 3) width. The principal design variable is the length of the cross vane. The spreadsheet, Vane Layout, is available to help determine cross vane geometry and design targets.
    - Angle from each leg of the vane should be 20-30 degrees off the bank as measured from a line projected upstream parallel the angle under the crossing of the abutment and/or piers Steeper angles are more likely to create turbulence and back eddies. If a poor stream approach angle is expected to persist the angle of the vane might be a compromise between the channel approach and the abutment.
    - Slope 2 to 7% from the abutment to the upstream end of the vane.
        - The upstream end is generally flush with the stream bed but might be slightly higher if necessary, such as for grade control.
        - The height of the downstream end is generally similar to the height of the sediment bars and floodplain and/or other indicators of the naturally stable bankfull channel. Consideration of cross vane height should be given to constructability and limits of the materials used. The structures effect diminishes with reduced height.
    - Width proportions are based on thirds of the channel width, 1/3 for each leg and 1/3 in the middle for the crest.
    - All of the design targets cannot always be met such as if the channel is narrow and deep or if the crossing is at a steep skew. The design process becomes a process of compromise, minimizing deviation from design targets.

- Footers of adequate depth are necessary for the stability of cross vanes. Ridged structures set on erodible material must be constructed below the maximum depth of scour. A common cause of failure is the scour hole undermining the cross vane. Maximum scour depths typically develop near the midpoint of the cross vane. With adequate footer depth no additional footer material should be necessary. Geotextile on the upstream surface of the block may be desirable to prevent piping between blocks, especially if the crest of the cross vane is higher than the channel bed and creates sustained pressure head.

W-Weir

Purpose:

Decrease debris accumulation on mid-channel piers, grade control, and/or align stream flow with crossing structure.

Planning Considerations:

- Use at crossings with mid channel piers, prone to accumulating debris. W-weirs divide the current well upstream of the piers, gradually shifting the current and debris off to either side and through the open spans.
- While not always possible, it is preferable to avoid mid-channel piers by aligning the channel with one span allowing high flow to use additional spans.
- Use to maintain channel alignment with the bridge abutments and/or piers.
- Use for grade control. W-weirs may be used downstream from crossings as well as upstream and used in series minimizing the drop at any one structure. Similarly, the stepped version of design reduces the height of any one drop.

Design Considerations:

- A variety of materials are commonly used including large rock, logs, or Vee-lock concrete block. Block may not be desirable if aesthetics is a primary issue; however, they have superior constructability and performance.
- The outside legs can be placed up against each abutment or wing wall while the middle legs join upstream of the mid-channel pier.
- The layout has three design targets, 1) angle, 2) slope and 3) width. The principal design variable is the length of the legs. A design spreadsheet, Vane Layout, is available to help determine w-weir geometry and design targets.

- Angle from each leg of the leg should be 20-30° as measured from a line projected upstream parallel the angle under the crossing of the abutment and/or piers Steeper angles are more likely to create turbulence and back eddies. If a poor stream approach angle is expected to persist the angle of the vane might be a compromise between the channel approach and the abutment.
- Slope should decline 2-7% from the abutment to the channel bed upstream.
    - The upstream end is generally flush with the stream bed, but might be slightly higher if necessary, such as for grade control.
    - The height of the downstream end is generally similar to the height of the sediment bars and floodplain and/or other indicators of the naturally stable bankfull channel. Consideration of w-weir height should be given to constructability and limits of the materials used. The structures effect diminishes with reduced height.
- Width proportions are based on thirds of each span width, 1/3 for each leg and 1/3 in the middle for the crest.
- All design targets cannot always be met such as if the spans are narrow, or if the crossing is at a steep skew. The design process becomes a process of compromise, minimizing deviation from design targets.

- Footers of adequate depth are necessary for the stability of cross vanes. Ridged structures set on erodible material must be constructed below the maximum depth of scour. A common cause of failure is the scour hole undermining the w-weir. Maximum scour depths a typically develop near the midpoint of the legs. With adequate footer depth no additional footer material should be necessary. Geotextile on the upstream surface of the block may be desirable to prevent piping between blocks, especially if the crest of the w-weir is higher than the channel bed and creates sustained pressure head.