Iowa STIC

Final Report ST-001

State Transportation Innovation Councils (STIC) Incentive Funds

Implementation of Sedimentation Mitigation Using Streamlined Culvert Geometry

Submitted by

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to:
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Iowa Department of Transportation
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16. Abstract
The present STIC effort takes advantage of new innovative solutions developed through extensive research at IIHR-Hydroscience and Engineering (IIHR), at the University of Iowa. Implementation of the one of the developed self-cleaning designs at one of the existing culvert sites (through retrofitting) has demonstrated its operational capabilities as well as robustness and efficiency in mitigating sedimentation over a range of flows occurring over extended time periods. The major activities of this STIC incentive funded project entail a series of workshops organized by Iowa's Local Technical Assistance Program (LTAP) to disseminate the innovative designs. Four workshops were delivered at strategically chosen locations in Iowa with the participation of the State, County, City and other public stakeholders.

17. Key Words
Culvert sedimentation, multi-barrel culverts, decision support, self-cleaning culvert design, design specification.

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Executive Summary

The present State Transportation Innovation Council (STIC) Incentive funded Project focuses on the dissemination of innovative solutions for the mitigation of sedimentation at culverts, an issue frequently occurring at Midwestern multi-box culvert sites. The chronicity of the sedimentation problem, as well as the intensification of the activities on hillslopes, floodplains, and in-stream raised considerable concerns in Iowa as well as other United States territories. The socio-economic damages associated with culvert sedimentation are unlikely to diminish, as recent studies predict that the frequency and intensity of storms will continue to increase throughout the contiguous United States.

The present STIC effort takes advantage of new innovative solutions developed through extensive research at IIHR-Hydroscience & Engineering (IIHR), at The University of Iowa. Implementation of one of the developed self-cleaning designs at one of the existing culvert sites (through retrofitting) has demonstrated its operational capabilities as well as robustness and efficiency in mitigating sedimentation over a range of flows occurring over extended time periods. The proposed and tested self-cleaning solutions can be implemented before or after culvert construction and are intended to be functional for the entire duration of the structure's lifetime. Moreover, these solutions will keep culverts operational without additional interventions. This is in contrast with the current practice of repeated cleaning required for culverts located in areas prone to sedimentation.

The major activities of this STIC Incentive Project entail a series of workshops organized by the Iowa Institute of Transportation's Local Technical Assistance Program (LTAP) to disseminate the innovative designs. We delivered five workshops at strategically chosen Iowa locations with the participation of the Iowa Department of Transportation, counties, cities, and other public stakeholders. LTAP conducted post-delivery evaluations of the workshops to assess their effectiveness and contributions to the standard practice. The workshop participants offered positive comments on the usefulness of the sedimentation-at-culvert subject and on the overall quality of the delivered program. The discussions triggered by the materials presented in the workshop have brought in new perspectives on the implementation of the proposed solutions and advanced ideas for new concepts for mitigating the sedimentation at culverts. The activities funded by STIC have promoted a new systems approach for planning, designing, and maintaining culverts that are compatible and sustainable with the stream environment.

Table of Content

1. Background

Development of sedimentation at culverts has become a chronic issue in Iowa and neighboring states due to the accelerated pace of natural and anthropogenic activities occurring in drainage areas associated with the culverts. Sedimentation blockage at culverts can produce severe damage to both the transportation structure (e.g. from overtopping of road and culvert) and upstream headwater areas (e.g. from flooding) during storm events. Sedimentation at culverts is a complex multi-domain process involving coupled hydrological (non-uniform, unsteady channel flows carrying sediment loads) and geomorphological aspects (hillslope and in-stream erosion) that are further dependent on internal (hydro-meteorological) and external drivers (socio-economic aspects of the land and river use), making the experimental, analytical, or numerical simulation-based investigation difficult and inefficient for practical purposes. Consequently, there are no system-based culvert mitigation solutions nor design guidelines to address culvert siltation.

An innovative solution for mitigation of sedimentation at multi-barrel culverts was developed at IIHR-Hydroscience & Engineering (IIHR), The University of Iowa with Iowa Highway Research Board (IHRB) funding during 2007-2013. The self-cleaning culvert concept, labeled herein as Design A, relies on the use of the stream's hydraulic power for passing downstream suspended and bed loads of the culvert carried by the stream during storms. The solution does not affect current culvert design protocols; rather, it streamlines the areas adjacent to the culvert to enhance flow and sediment transport. We designed and extensively tested the self-cleaning culvert concept in laboratory conditions at IIHR between 2007 and 2010 and then implemented the concept at a culvert located on HWY 1 in Iowa City, Iowa. Since its implementation in January 2013, the self-cleaning culvert has operated efficiently in high and low flows, as illustrated in the post-construction photos provided in Figure 1.

a) April 17, 2013 (high flow) b) May 21, 2015 (low flow)

Figure 1. Views of the self-cleaning culvert operation during various conditions.

Iowa Department of Transportation (IDOT) highlighted the new self-cleaning culvert concept in various outreach activities (national and local, and conferences, press releases, newsletters), attracting), attracting interest from the Iowa DOT District and County engineers. Consequently, there have been requests for guidance to translate this innovation into practice for new or existing culvert sites throughout the state.

2. Project Goals and Objectives

The overall goal of this project is to implement the innovative self-cleaning culvert technology described above as standard practice throughout the state of Iowa through a comprehensive implementation plan. The implementation of this research-to-practice effort will have a significant economic impact, as the sedimentation problem is chronic for the majority of Iowa culverts due to the high soil erodibility in the state. The socio-economic damages associated with culvert sedimentation are unlikely to diminish soon, as recent studies predict that the frequency and intensity of storms will continue to increase throughout the United States Midwest region in the near future.

We accomplished the overall goal of the project through a phased, coordinated effort carried out through collaborative work between IIHR-Hydroscience & Engineering and the IDOT. The original objectives of the project are as follows:

- Formulation of the need for translating the self-cleaning culvert innovation to standards and specifications applicable to the entire range of culvert configurations and sites in Iowa (workshop organized by IDOT).
- Refining the current specifications to include sedimentation mitigation provisions based on the self-cleaning culvert innovation (IIHR).
- Preparation of technical guidance (IIHR and IDOT) and delivery of training for implementing those standards at culvert sites (IIHR and Iowa LTAP).

3. Project Activities

3.1. Assemblage of the Project Team

We assembled a diverse team of experts for designing and establishing the practical steps for the project implementation. More than half of the expert team has been involved (in various roles, such as IHRB board members, case studies presentations, organizers of site visits, etc.) with the series of culvert projects conducted since 2004. This meant that they were familiar with the innovative aspect of the research. The team included the following members:

Paul Assman – Crawford County

J.D. King – Page County

Ron Knoche – City of Iowa City

Greg Parker – Johnson County

Keith Knapp – Iowa LTAP

Andrew Wilson – FHWA, Iowa Division

Vanessa Goetz – Iowa DOT

Ahmad Abu-Hawash – Iowa DOT

Dave Claman – Iowa DOT

Nicole Fox – Iowa DOT

3.2. Development of the Implementation Plan

The project team first developed a plan to implement research results regarding the mitigation of sedimentation at culverts into actual practice. For this purpose, the expert team reached out to stakeholders in Iowa and involved them in the project process from planning to full development. The extended project team held their first meeting on December 4th, 2015 at the Johnson County office in Iowa City where they garnered input for defining various aspects of the project, including:

- Development of the road map for the project implementation.
- Identification of the need for translating the self-cleaning culvert innovation to standards and specifications applicable to the entire range of culvert configuration and sites in Iowa.
- Refinement of the current specifications to include sedimentation mitigation provisions based on the self-cleaning culvert innovation.
- Development of an evaluation matrix for assessing the use of the self-cleaning culvert details.

In addition to the expert team listed above, a diverse range of stakeholders attended this first whole-day workshop. Internal stakeholders/customers included IDOT staff from various offices in the Central Complex and field staff in the six districts. External stakeholders/customers included local public agencies, consultants, contractors, and fabricators.

During the first STIC workshop, participants visited the site of a culvert retrofitted with the investigated design and evaluated the structure’s appearance and functionality after two years’ use. They responded positively, although some members of the STIC group raised questions regarding the deposit of sediment created downstream of the culvert since the retrofitting in the upstream area was applied. Before retrofitting, removal of the sediment upstream and downstream, as well as throughout the culvert length, was conducted. Suggestions were made to extend the culvert retrofitting at the downstream end of the structure. During the same visit, they also observed that about 1 mile downstream from the retrofitted culvert there is another 3-box culvert built around 2006 that experienced significant sedimentation during the 3 years of observation of the Hwy 1 culvert. Given the proximity of the two structures and their similar geometry, this pair of culverts provides a unique opportunity to compare the efficiency of the prototype self-cleaning culvert design against a typical culvert structure, one not amended by any improvement. Currently, we are researching the suggestions made during the visit in an on-going IHRB project.

3.3 Development of Technology Transfer Guidance and Documentation

For a seamless transfer of the research results to the field, the project team prepared a set of documents for supporting the dissemination training workshops. These documents describe design and operational aspects of the self-cleaning culverts along with all the relevant information to make the materials self-explanatory. The set of documents entails:

a) Design specifications for self-cleaning culverts.

b) Lectures for the dissemination workshops.

The IDOT's specialized personnel (i.e., D. Claman and D. Mulholland) collaborated closely with us to develop detailed design specifications, (provided in Appendix A). They were an integral part of the lectures delivered in the dissemination workshops. The newly created specifications do not interfere with the current guidelines for sizing the culvert according to the hydraulic requirements. Instead, they add specific guidelines for amending the area upstream and downstream from the culverts so that they are less prone to retain sediment than in the current culvert construction practice.

The workshop lecture covered three topics: a) sedimentation process; b) description of the self-cleaning culvert research and the identified mitigation solutions; and c) presentation of the IDOT portal for supporting the design of culverts with consideration of sedimentation. More details about the workshop planning, content, delivery, and evaluations are provided in the next section.

3.4. Content of the Dissemination and Training Workshop Series

3.4.1 *Workshop Planning*

An inter-institutional group formed by the members listed below developed the strategy and delivery mechanics for the series of dissemination and training workshops:

Vanessa Goetz	Iowa Department of Transportation (IDOT)
David Claman	Iowa Department of Transportation (IDOT)
Ahmad Abu-Hawash	Iowa Department of Transportation (IDOT)
Jeffrey Tjaden	Iowa Department of Transportation (IDOT)
Danny Waid	Iowa County Engineers Association Service Bureau (ICEASB)
Keith Knapp	Iowa Local Technical Assistance Program (Iowa LTAP)
Ron Knoche	City of Iowa City

The meeting for planning the workshops involved all the STIC project members. The IIHR-Hydroscience & Engineering's (IIHR) responsibilities supported the STIC project activities and relied on the expertise of M. Muste, the Self-Cleaning Project Principal Investigator, and Haowen Xu, an IIHR PhD graduate student. The IIHR team carried out the following activities:

A. Development of guidelines for the design and retrofitting of culverts based on the self-cleaning concept and implementation for the 3-box culverts. The inter-institutional group listed above reviewed the prepared workshop materials.
B. Delivery of workshops using a strategy established by IDOT. Five workshops were originally planned to be delivered at sites throughout Iowa. The workshop information was delivered through presentation materials and handouts.
C. Preparation of surveys for adjustment of the self-cleaning culvert design to 2-box culverts (according to IDOT experts, these types of culverts are mostly located on the secondary roads and are more exposed to sedimentation compared to 3-box culverts).
D. Demonstration of the use of IDOT Culvert Portal for assessment of the sedimentation potential at existing and new culvert construction sites.
E. Preparation of User Guidelines for the IODT Culvert Portal and Design Guidance for side wedges for implementation of the self-cleaning solution to 3-box culverts.
F. Final report documenting the project activities.

3.4.2 *Workshop Delivery*

Iowa LTAP carried out participant recruitment as well as the logistics and delivery of the workshop using conventional institutional protocols (http://www.iowaltap.iastate.edu/workshops/ltap-workshops). There were no fees for attending the workshop but registration was mandatory for workshop planning and delivery purposes. The spatial distribution of the workshop was chosen to uniformly cover the State of Iowa and to deliver the workshop information in areas with culvert sites where the sedimentation is a hazard issue (see Figure 2).

Figure 2. Location and dates of the dissemination and training workshops.

Iowa LTAP posted the workshop announcement in advance on the Iowa LTAP website (see Appendix B). The dates and locations for the workshops were as follows:

May 31, 2017
Ames, Institute for Transportation

June 6, 2017
Ottumwa, Bridgeview Center, Ottumwa

June 7, 2017
Cedar Rapids, Kirkwood Community College

June 13, 2017
Storm Lake, King’s Pointe Waterpark Resort

June 14, 2017
Red Oak, Red Coach Inn & Restaurant

Participants received a set of preliminary documents via email and direct distribution at the workshop times (i.e., agenda, workshop flyer, surveys, and essential illustrations). The workshop flyer is provided in Appendix C. The detailed agenda for all the workshops is provided below:

7:45 a.m.	Registration
8:00 a.m.	Introduction
	Sedimentation at Culverts (Part I)
10:00 a.m.	Break
	Solutions for Culvert Sedimentation (Part II)
12:00 p.m.	Lunch
	Demonstration of the IDOT Web Tool
1:50 p.m.	Break
	One-to-one Training Session for IDOT Web Tool (Part III)
	Survey on Sedimentation at 2-box Culverts
3:00 p.m.	Course closure

Prior to the delivery of the five workshops, there were 84 registered people. Due to job-related emergencies, however, on the date of the workshops' delivery some registered people did not attend. The actual number of participants in the five workshops was 70. Table 1 illustrates the distribution of the registered and actual participants. Participants in the workshops came from the technical, managerial, and governance offices of IDOT Districts, cities, and counties, and also included contractors and consultants.

Table 1. Distribution of the workshop attendance per location

Location/date	Registered	Actual participants
Ames May 31, 2017	**28**	**24**
Ottumwa June 6, 2017	**12**	**8**
Cedar Rapids June 7, 2017	**26**	**24**
Storm Lake June 13, 2017	**8**	**7**
Red Oak June 14, 2017	**10**	**7**
Total	**84**	**70**

We delivered the workshops as an open, interactive dialogue on solutions and tools for mitigating sedimentation at culverts in Iowa (see Figure 3). A Question & Answer (Q&A) session followed each lecture part. The Q&A sessions were valuable both for providing more details on various aspects of sedimentation at culverts as well as completing the presented materials with new evidence brought up in discussions by participants. Besides the culvert sedimentation mechanics and descriptions of the self-cleaning mitigation solutions, we also demonstrated a new web-based program for evaluating the potential of sedimentation at Iowa's multi-box culverts through group and one-to-one training sessions.

a)

b)

c)

Figure 3. Photos from the dissemination workshops: a) Ames, b) Ottumwa, and c) Cedar Rapids.

3.4.3 *Workshop Content*

We transferred our knowledge of sedimentation at culverts through a three-part lecture that summarized the results of more than 10 years of research. The research started with the investigation of the origin of sedimentation and clarified the processes involved, along with their dependencies (Muste et al., 2010). Physical and numerical modeling resulted in the formulation of design specifications for one of the self-cleaning solutions (Muste and Ho, 2013). The lecture entailed 145 Power Point slides. Online and recorded tutorials were used during the workshops to demonstrate the IDOT Culvert web tools. The lecture is available on the IDOT Culverts site: iowawatersheds.org/idotculverts (see Figure 4).

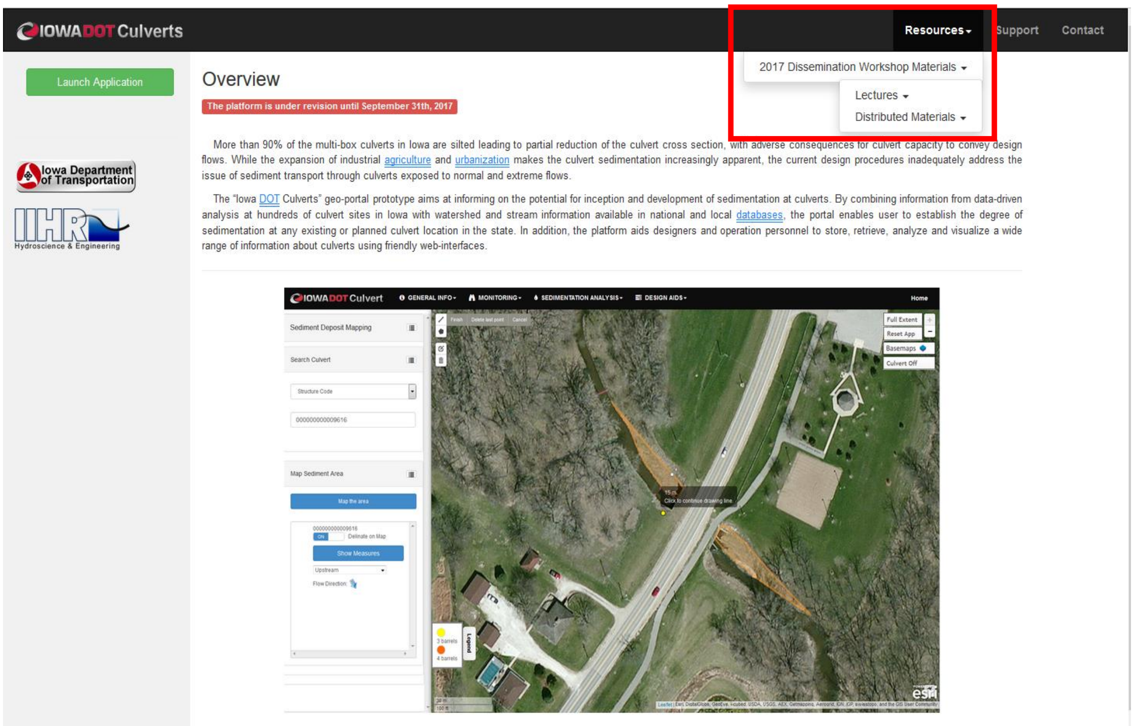


Figure 4. The landing page of the IDOT Culverts website containing the tools for aiding culvert design (iowawatersheds.org/idotculverts). The three-part lecture is available online under the "Resources" tab of the platform (see the area enclosed in red).

The Table of Contents for the three-part lecture is provided in Figure 5. The first part of the presentation describes the extent of the sedimentation problem in Iowa as documented by literature reviews, site visits, analysis of aerial images, and discussions in various contexts with specialized culvert-related technical personnel and surveys. We subsequently reviewed the essential elements of the watershed hydrology and instream hydraulics that are responsible for sedimentation at culverts to highlight the origin of the sediment deposits and the processes resulting in the entrainment-transport-siltation cycle.

The second part of the presentation reviews self-cleaning solutions thoroughly investigated through laboratory and field studies or critically reviewed based on field evidence. It is essential to emphasize that the self-cleaning designs presented in this lecture are innovative approaches to keep the culverts clean using the streamflow power to continuously move the sediment downstream as if the culvert does not exist. The self-cleaning solutions can be implemented in the design stage or during culvert operation. These solutions are safer, easier, more time-efficient, and cheaper that the current culvert cleanups. They are smart solutions that improve efficiency and effectiveness for the culvert lifetime.

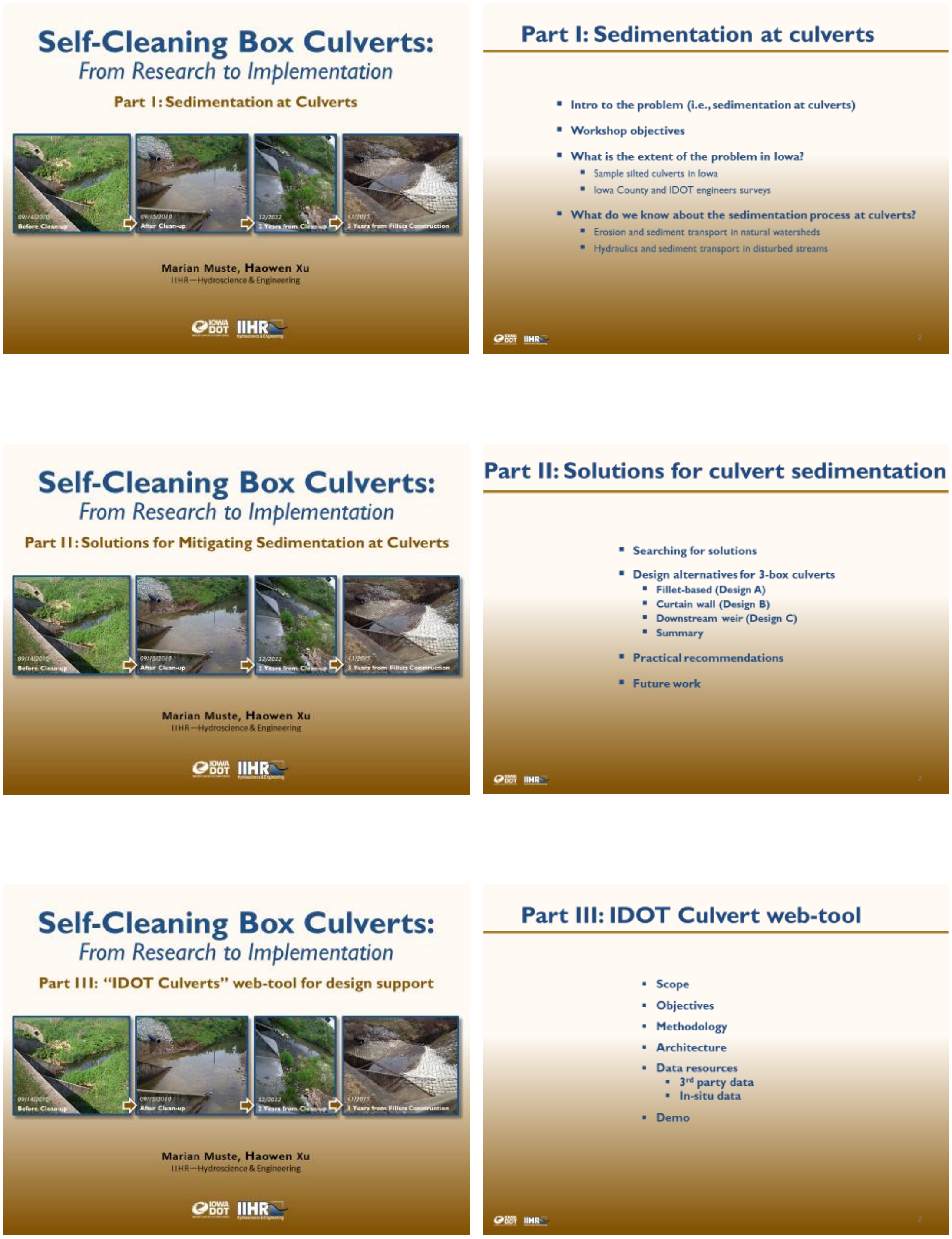


Figure 5. The cover page and Table of Contents for the three parts of the lecture delivered in the five Iowa dissemination workshops.

The three designs presented in the lecture are labeled as Designs A, B, and C. Design A is based on shaping the streambed at the culvert inlet and outlet. Design B is based on a conceptual approach that aims at blocking the entrance of sediment in the culvert by placing a low-height curtain wall upstream from the culvert that spans one or more culvert barrels. Design C consists of a submerged weir located downstream from the culvert that produces a pooling area (i.e., backwater) over the entire culvert vicinity. Designs B and C were brought to our attention during field campaigns at 250 culverts in Iowa. Design B is in use quite extensively for new culverts constructed in some Iowa counties (i.e., Washington, Dubuque, Ida). Design C results from ad-hoc field observations made by the IIHR research team that were subsequently reviewed for potential mitigating effects. Despite the very different principles involved in Designs A and B (i.e., concentrating the flows on the central barrel for more efficient flushing of the sediment), the handful of culverts associated with Design C is performing relatively well in practice over extended time intervals.

Appendix A provides detailed descriptions of the principle of operation, geometry of the structures, and examples for each of the three self-cleaning culvert designs. Only Design A, however, is associated with detailed design specifications as this alternative was thoroughly documented through a complete research cycle, from laboratory investigations at IIHR to site implementation for a culvert site located in Iowa City. Designs A and C are currently being investigated through an in-situ investigation by our research team. An important aspect for assessing sedimentation at culverts is the presence of vegetation in the culvert vicinity. Part 2 of the lecture also provides field evidence on the effect of vegetation on sediment deposit formation and its role in accelerating the rates of sediment accumulation by trapping suspended sediment.

The third part of the lecture is focused on the IDOT Culvert web-tool. The website provides assistance regarding the potential of sedimentation at any culvert location and hosts relevant information regarding the mitigation of sedimentation. The third portion of the lecture also describes first its architecture, technologies, and data resources stored or accessed by the tool. During the workshops, instructors carried out online demonstrations of the platform to familiarize the users with the tool operation and shorten the learning curve associated with using the platform. The third part of the lecture also contains embedded tutorials.

Following the lectures at each workshop location, participants were surveyed on their experience with sedimentation at two-box culverts. Figure 6 provides the survey questions. The results of the participant survey (provided in Appendix D) guided the extension of the self-cleaning solutions to this important category of culverts and will eventually lead to standards and specifications applicable to the entire range of culvert configurations and sites in Iowa.

	Question	Answer			
1	**Please provide the number of multi-box culverts in your area of operation (an estimation suffices)?**	1-box			
		2-box			
		3-box			
		4- box			
2	**What is the $ amount spent for cleaning culverts in your area of operation?**	Per culvert			
		Annually			
3	**Have you had situations of overtopping at culverts? If yes, what type of culverts are most often overtopped?**	1-box			
		2-box			
		3-box			
		4-box			
Do you experience sedimentation problems at multi-box culverts in your area of operation? If yes, please answer the following related questions:		YES	NO		
4	What is the approximate percentage (i.e., 25%, 40%, 50%, 60, 70%) of area covered by sediment for each type of culvert?	2-box			
		3-box			
		4-box			
5	How often do you clean the culvert?		2-box	3-box	4-box
		every 5 years			
		every 10 years			
		once in a while			
6	Please rank the potential causes leading to sedimentation at multi-box culverts (listed on the right)?	runoff			
		debris			
		vegetation			
		other (specify)			
7	How do you track sediment deposition growth?	visually			
		other (specify)			
8	Have you observed a seasonal pattern in the sedimentation growth?				
9	Could you list successful solutions for mitigating sedimentation at culverts?				
10	List issues/problems associated with sedimentation at culverts that you consider that need further attention/research				

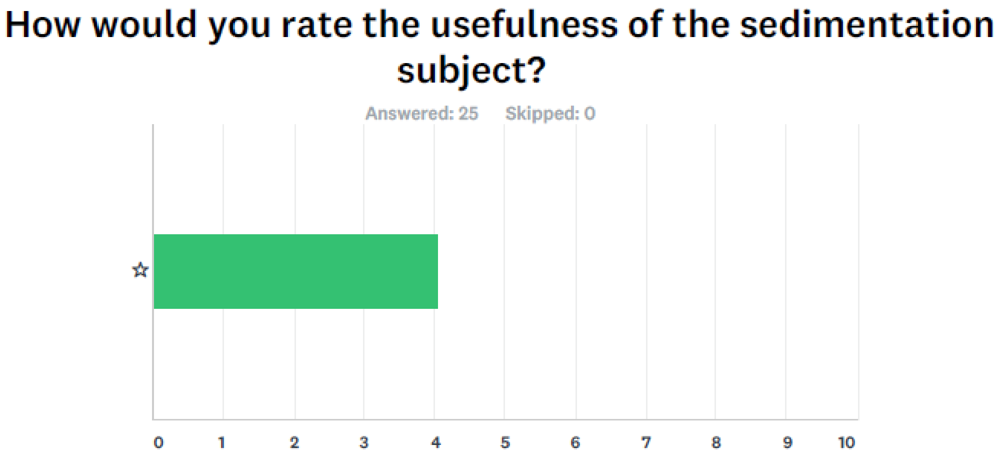
Figure 6. The survey questions regarding sedimentation at 2-box culverts released during the workshop series.

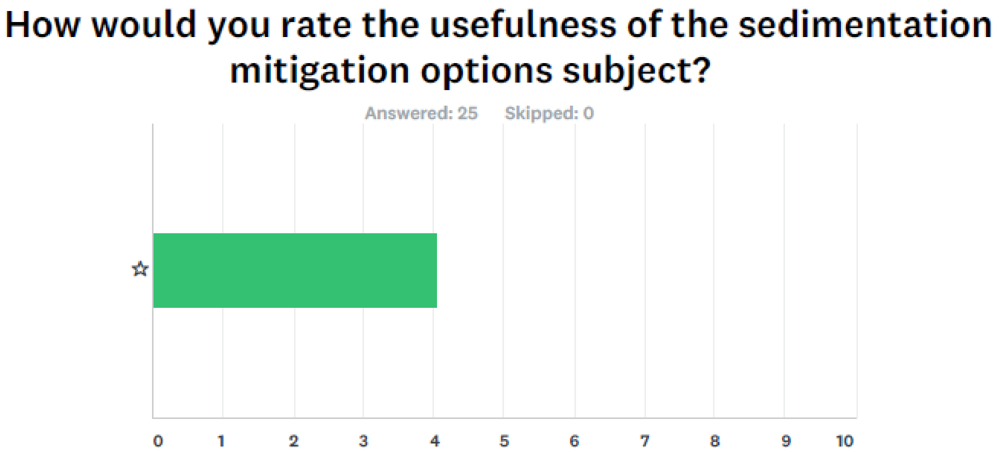
3.4.4 *Workshop Evaluation*

Following the workshop delivery, Iowa LTAP conducted an evaluation of the Self-Cleaning Multi-Barrel Culvert workshop series. We synthesized the results of the evaluation survey in Table 2. Overall, the survey results are positive, indicating the appropriateness of the workshop subject, scope, content, and presentation means. As a result of these positive outcomes, the MINK Local Roads Meeting held in St. Joseph, Missouri on September 20-21, 2017, included discussions of self-cleaning culverts. The MINK Local Roads Annual Meeting brings together officials from local road agencies, state DOTs, and FHWA divisions in Missouri, Iowa, Nebraska, and Kansas to share information, learn, and talk about practical topics on maintenance, administration, innovative ideas, safety, and funding.

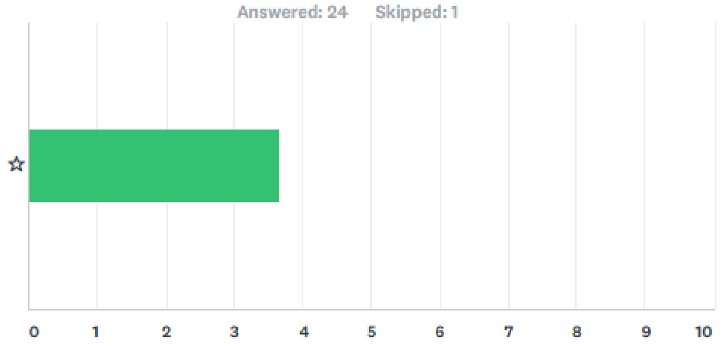
Table 2. Evaluation survey results following the delivery of the Self-Cleaning Culvert workshops. Graphs display the "Weighted Average" of the 1-5 scale illustrated below..

1 - Needs Improvement	2	3 - Okay	4	5 - Very Good	Total	Weighted Average

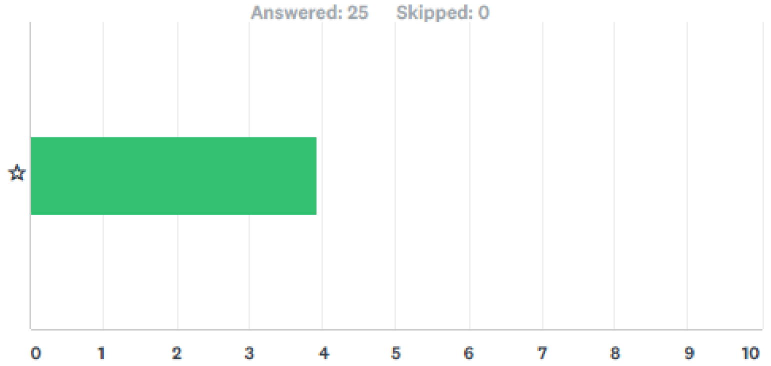




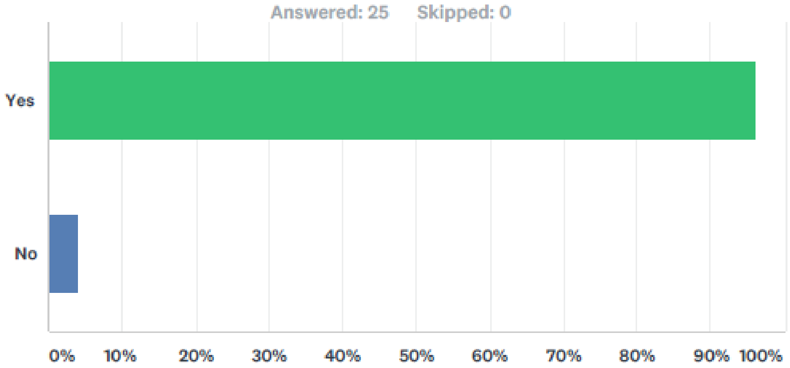
How would you rate the usefulness of the IDOT culvert portal demonstration subject?

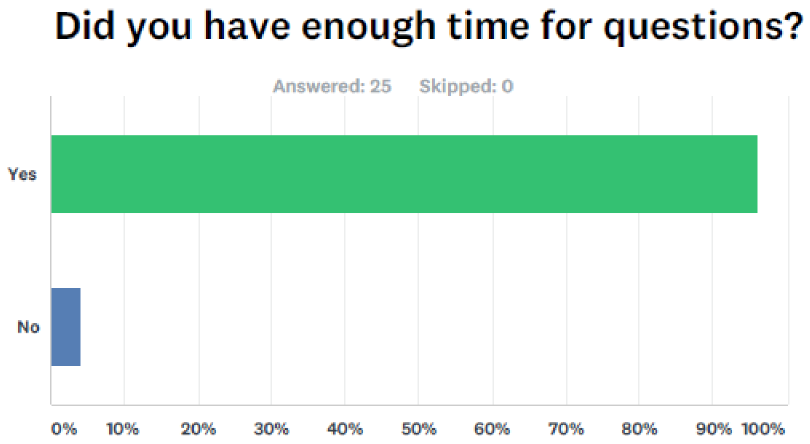


What is your overall rating of the workshop subjects?



Were the handouts clear?





Answered: 17 Skipped: 8

#	Responses	Date
1	The innovate design that seems to work under the trials that have been completed.	6/30/2017 11:08 AM
2	the discussion that took place about ones real life problems on the subject	6/29/2017 4:07 PM
3	Practical knowledge presented that can be used in the field.	6/28/2017 2:16 PM
4	It was good to learn about all the research to date on sedimentation issues in multi barrel culverts	6/27/2017 9:45 AM
5	Great to see research into a topic that can used right away by engineers in the state. I was glad to see an example plan and cost estimate available for use as well. This is a great tool that I will keep for the next time I have to work on a large box culvert.	6/26/2017 4:25 PM
6	The speaker was interested in the subject.	6/26/2017 3:28 PM
7	mitigation options	6/26/2017 10:06 AM
8	I like how multiple options were discussed along with the primary design.	6/26/2017 10:05 AM
9	This topic has been of interest to me for many years. It was very satisfying to see the results of IHRB research and field implementation.	6/26/2017 8:39 AM
10	Designs A,B & C	6/26/2017 8:33 AM
11	the different methods for reducing silt in box culverts and what one imperfection on a project can cause silting problems	6/26/2017 8:22 AM
12	IDOT Protal Demonstration. However the demonstration could have been more hands on and more organized.	6/26/2017 8:22 AM
13	The presenter was very knowledgeable on the subject. He held my attention throughout most of the presentation.	6/26/2017 8:00 AM
14	The information is interesting and applicable, I just question whether it is actually cost effective. The number given for cleaning a culvert is probably high. More data should be collected (survey) on what other spend on cleaning a culvert.	6/26/2017 7:45 AM
15	I think the topic was good and the discussion on sedimentation and the challenges associated with it sound. I find the concept of the box culvert modifications potentially useful, but have some concerns as there is limited realworld experience with the improvements on both ends of the a culvert. Also, the cost of retrofitting may not provide a signification benefit vs. clearing routinely if there is suitable access.	6/26/2017 7:39 AM
16	The explanation regarding the logic\science behind the proposed sedimentation reduction methods was good. Also the real world applications were well done too.	6/26/2017 7:38 AM
17	New designs to keep culverts clean.	6/26/2017 7:35 AM

4. Conclusions and Practical Considerations

The presence of sediment deposits near multi-barrel culverts has become ubiquitous at these stream-crossing sites and there are no efficient solutions to this this hazard. A multi-year research study conducted at IIHR-Hydroscience & Engineering, followed by the implementation of the research results in practice, promises to change this status-quo. The developed solution is an innovative approach that changes the geometry of the culvert vicinity without affecting the operational parameters of the culvert. The field implementation has proven that the solution is efficient in eliminating or limiting the growth of sediment deposits at these structures. Taking advantage of this STIC project, the innovation deployment has been considerably accelerated by sharing the newly acquired technological experience within the state of Iowa and beyond. Specifically, a series of statewide workshops have been organized and delivered to disseminate principles of the solution and train personnel in field implementation. One of the designs (i.e., Design A) was thoroughly investigated through laboratory studies and has already been performing successfully in the field for five years. Two other self-cleaning designs (i.e., B and C) observed during site visits are potentially capable of mitigating sedimentation; they are currently under investigation through an IHRB study.

Based on the expertise developed during the research conducted for the self-cleaning solutions and on extensive field observations, some preliminary evaluation of the three designs can be formulated, as illustrated in Table 2. Despite the minimal assessment associated with Designs B and C, they were presented and discussed in the series of STIC workshops. We garnered many other new insights through this multi-year research on the broader subject of sedimentation at culverts. Given that literature is scarce in this area, we share some of the practical findings below.

Table 2. Comparison of the three self-cleaning culvert designs.

Design concept	Hydraulic principle	Protected area	Sensitivity to approach angle	Relative cost*	Relative efficiency**	Applicable
Fillet-based (Design A)	sediment transfer	Upstream, downstream	yes	highest cost	-	anytime
Upstream curtain wall (Design A)	sediment transfer	Upstream	yes	relatively high	relatively limited	anytime
Downstream submerged weir (Design C)	sediment trapping	Upstream, downstream	no	-	Similar (unknown lifetime)	anytime

* Reference: Design C
** Reference: Design A

It is well known that streams carry sediment loads that tend to deposit whenever/wherever their velocities decrease. What is less well known and difficult to establish is the origin of the sediment deposited at the culvert, the quantification of that amount, and the actual times when sedimentation occurs during water recession. The stream and watershed characteristics (i.e., magnitude of the design discharge, soil, land-use, and practices in the channel and watershed), along with the culvert design specifications (orientation with respect to stream, width, slope, roughness, offsets, if applied) all play key roles in the quantification of these critical details about sedimentation at culvert sites. The investigations conducted so far lead to the following practical considerations:

- Cautiously approach the culvert design with a thorough knowledge of the stream flow regime (i.e., high & low flows) and bed-bank and watershed characteristics (sedimentation likely occurs at low flow while culvert sizing is based on high flows, leading to a tendency of oversizing).
- Align the culvert with the direction of the upstream channel (oblique stream entering the culvert affects sedimentation processes, regardless of its type: scouring or deposition).
- Setting culvert width to less than or equal to the channel bankfull width is not expected to inhibit sedimentation at the culvert. (This rule was developed for minimizing obstructions for fish and aquatic organism passage at culverts and bridges.)
- Erosion and sedimentation does not balance over time at culverts located in Iowa streams, even if the channel is stable (i.e., increased velocities during storm events do not cleanse culverts).

The knowledge base for designing sedimentation mitigation measures is in its infancy as the involved processes are difficult to anticipate because they depend on multiple stream and watershed characteristics in addition to culvert design specifications. The investigations conducted so far corroborated with similar studies (although few are available) and lead to the following inferences:

- Vegetation plays a critical role in sedimentation (i.e., as flows recede, vegetation starts growing, leading to increased roughness, thus enhancing sedimentation during the next flood event).
- While solving the hydraulics and sedimentation problems, do not overlook environmental aspects (i.e., maintain the natural-stream capabilities to pass fish and other aquatic organisms).
- Sediment mitigation designs introduce additional head losses (checks should be in place during the design to verify if damaging backwater levels upstream from the culvert are formed by the proposed solutions).

5. References

Muste, M. and Ho, H-C. (2013). "Development of Self-cleaning Box Culvert Design – Phase II," Iowa Highway Research Board, Ames, Iowa.

Muste, M., H-C. Ho, Mehl, D. (2010). "Insights into the Origin and Characteristics of the Sedimentation Process at Multi-Barrel Culverts in Iowa" IIHR-Hydroscience & Engineering Technical Report No., Iowa City, Iowa.

APPENDIX A:
GUIDELINES FOR DESIGN OF SELF-CLEANING CULVERTS

A.1 SELF-CLEANING CULVERT DESIGN A: FILLETS

1. Identify\locate triple-box culvert at which sedimentation has been problematic.
2. Use IDOT web portal to perform sedimentation analysis (optional). The portal can be found at: http://iowawatersheds.org/idotculverts. Using this portal, one can forecast the potential for sedimentation at existing and new culvert sites with the "Sedimentation Potential Warning" tool under the "Design Aids" menu. A video tutorial on the use of the tool is available under the "Support" menu.
3. Obtain topographic survey data of the site. The survey should, at a minimum, include the following elements (see Figure 1A):

a) b) c) d)

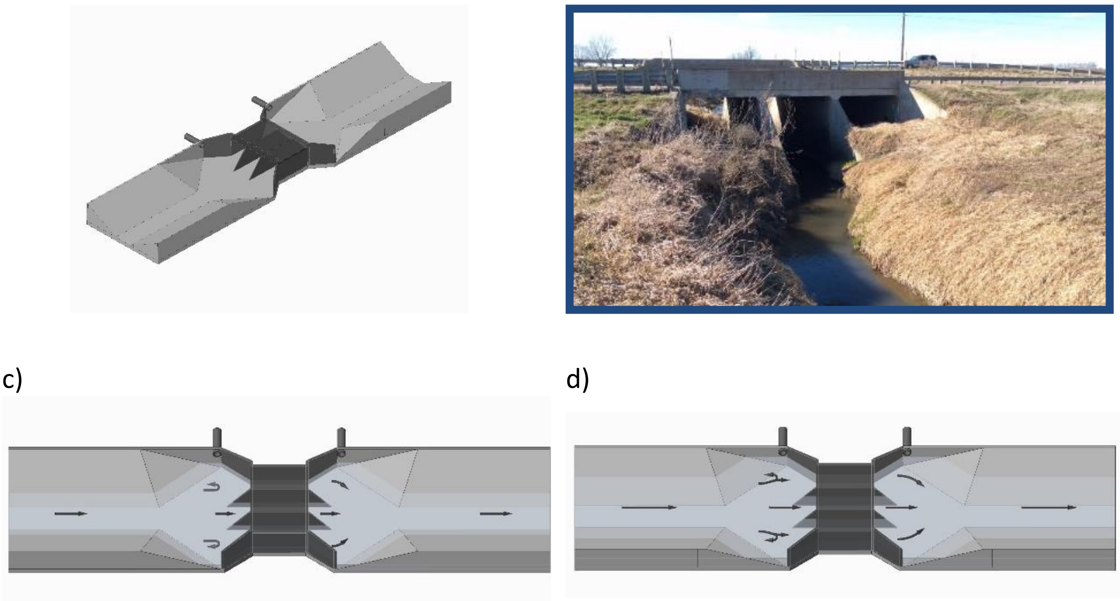


Figure 1A: Conceptual sketches for a cast-in-place triple-box culvert with flared wingwalls: a) setting of the structure in the stream; b) sample silted culvert; c) flowlines for low flows; d) flowlines for high flows.

a) Apron\headwall structure.
b) Sedimentation area\volume adjacent to headwall.
c) Stream flowlines, channel bank, and adjacent top of bank.
d) Observe the change in the flow patterns at culvert inlet and outlet with special emphasis on the areas with flow recirculation or very low flows (these areas are prone to sedimentation during flow recession).
e) The adjacent roadway shoulder and edge of pavement\roadway.
f) Existing utilities.
g) Right of way markers\monuments.
h) Existing ground topography adjacent to headwall and sedimentation area.

i) All major trees and shrubs.
j) All adjacent culverts or other drainage facilities (i.e., road-side ditches).
k) The topographic survey to show the transition from typical stream channel to sedimentation area.
l) Photographs of the site.

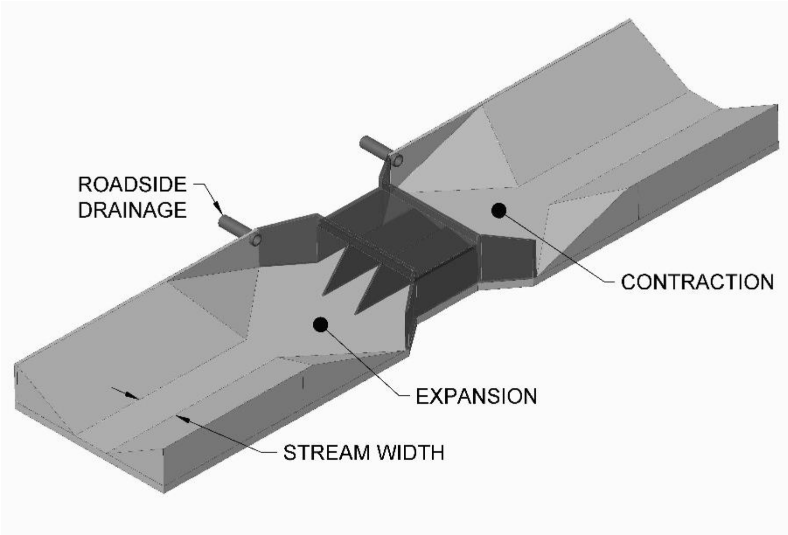
4. The self-cleaning culvert design using fillets is driven by the following principles:

   a) Modify the entrance and exit of the culvert structure to emulate as closely as possible the shape and functionality of the original stream.
   b) Convey the low flows through the central barrel (side barrels become operational at higher flows).
   c) Intercept the flow incoming from the roadside ditches/pipes on the fillet surface sloping toward the channel entrance (not on the surface sloping toward the stream).
   d) Shape the fillets' slopes and positioning to eliminate as much as possible the area of flow recirculation and low flows.
   e) Extend the fillets upstream and downstream to fully cover the stream reach that was modified due to culvert construction. If the stream bank lines are poorly defined, extend the fillets 4-8 side-barrel-widths upstream and downstream from the culvert.

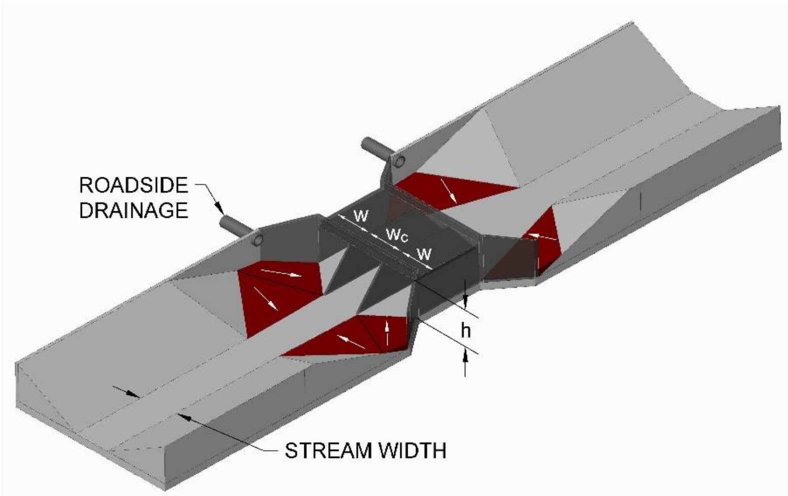
   We recommend covering the stream area between the fillets with the same surface as the fillet material to avoid scouring in between the surface transition due to possible settling of the fillets. Covering this surface will also avoid growth of vegetation near the inlet that can produce unexpected sediment deposits that affect the functionality of the fillet system.

5. Each culvert has specific conditions for connecting the undisturbed stream geometry with the culvert structure. Refer to Figure 2 for typical fillet shape and positioning. Typical upstream and downstream connections are made with straightforward expansions and contractions transitioning the natural stream geometry with the lateral walls of the culvert as illustrated in Figure 2Aa. The fillet geometry used for mitigating the sedimentation illustrated in this figure is based on an extensive experimental study followed by testing the solution's performance at an existing culvert site. The fillets upstream from the culvert consist of two triangular facets (see Figure 2Ab): one sloping toward the entrance of the side barrel, the other toward the channel. Downstream from the culvert the fillet has one slope toward the central barrel.

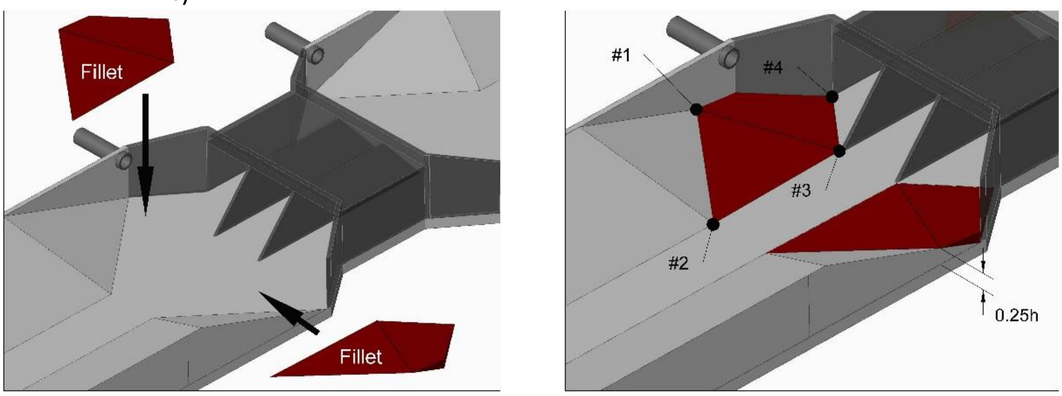
a)


ROADSIDE
DRAINAGE
CONTRACTION
EXPANSION
STREAM WIDTH

b)


ROADSIDE
DRAINAGE
W
Wc
W
h
STREAM WIDTH

c)


Fillet
Fillet
#1
#4
#3
#2
0.25h

d)

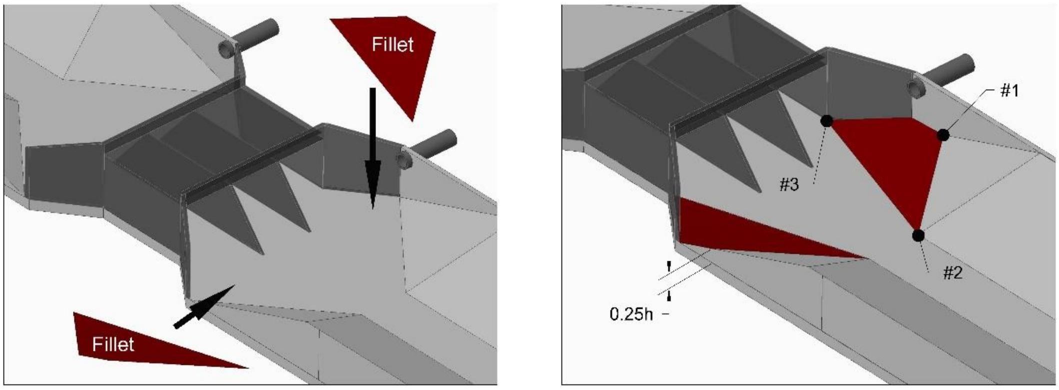


Figure 2A: Self-cleaning culvert design based on fillets*: a) typical triple-box culvert setting; b) culvert retrofitted with upstream and downstream fillets; c) view of the fillets at the culvert inlet; d) view of the fillets at the culvert outlet.

*conceptual sketches are provided for a cast-in-place triple-box culvert with flared wingwalls.

Refer to Figures 2Ac and 2Ad for the strategy of defining the fillet dimensions in the upstream and downstream area, respectively. Irrespective of the site characteristics, the phasing for establishing the fillet dimensions for each new culvert location is as follows:

Culvert inlet (see Figure 2Ac)

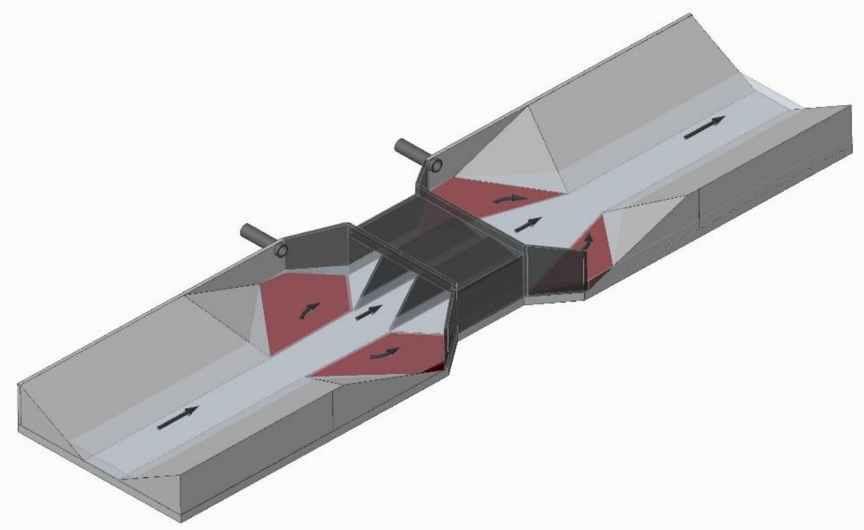
a) Select location of the fillet vertex (highest point of the fillets denoted with #1 in figure 2Ac) at a point that is immediately upstream from the roadside ditch incoming to the stream.
b) Identify the connecting point on the river bank upstream from the culvert (denoted with #2 in Figure 2Ac) where the stream geometry is not disturbed by the culvert construction.
c) Create the fillet surface sloping toward the stream by connecting the vertex with the stream determined at b) (i.e., connect points #1 and #2 in Figure 2Ac). Close the surface by connecting point #2 with the toe of the dividing wall of the side barrel (point #3).
d) Create the fillet surface sloping toward the barrel by connecting the vertex (point #1 or a downstream point on the same horizontal) with the dividing wall's toe (point #3). Close the surface by connecting point #3 with the origin of the wingwall at the invert level (point #4 in figure 2Ac).

Culvert outlet (see Figure 2Ad)

a) Establish the vertex (point #1 in Figure 2Ad) at a location downstream from the outlet of the ditch on this side of the road. Connect the vertex with the downstream point on that stream side where the channel is undisturbed (point #2 in Figure 2Ad). Connect point #2 with the origin of the wingwall at the invert level (point #3 in Figure 2ad) to close the surface.

The results of positioning the fillet upstream and downstream from the culvert is a better streamlining of the flow for both low flows passing the culvert as well as for high flows (as illustrated in Figure 3Aa and 3Ab).

a)



b)

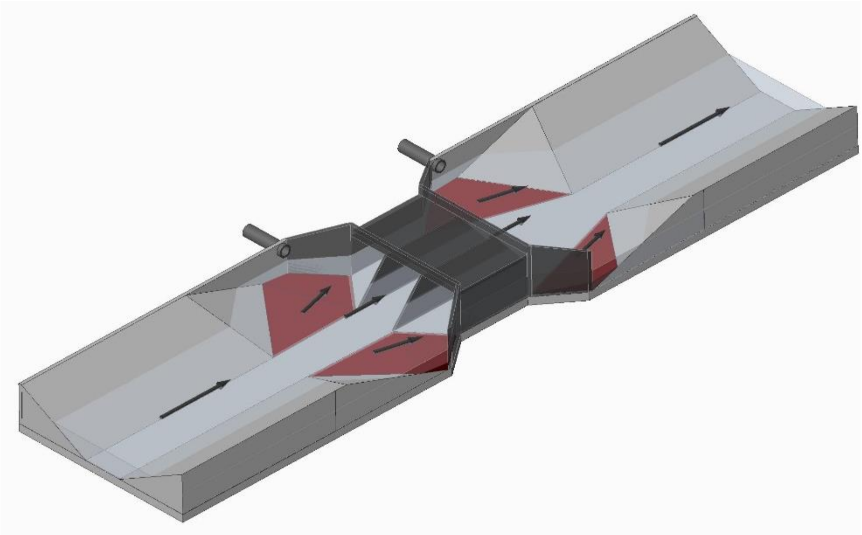


Figure 3A: Flow lines for self-cleaning culvert design based on fillets*: a) low flow situation; b) high flow situation.

*conceptual sketches are provided for a cast-in-place triple-box culvert with flared wingwalls.

The fillet design needs to be adjusted for slightly different site conditions (e.g., angle of the stream to culvert less than 30 degrees, stream entering the culvert on a side barrel or other type of culvert apron/headwall designs (e.g., precast, straight walls) following the above described criteria. Moreover, if the culvert structure is different, such as in the case of the pre-cast box culvert (where the dividing walls are not extended at the box edges), the fillets are adjusted following the guiding principles described above. Figure 4A illustrates the configuration of the fillets for this case.

a)

b)

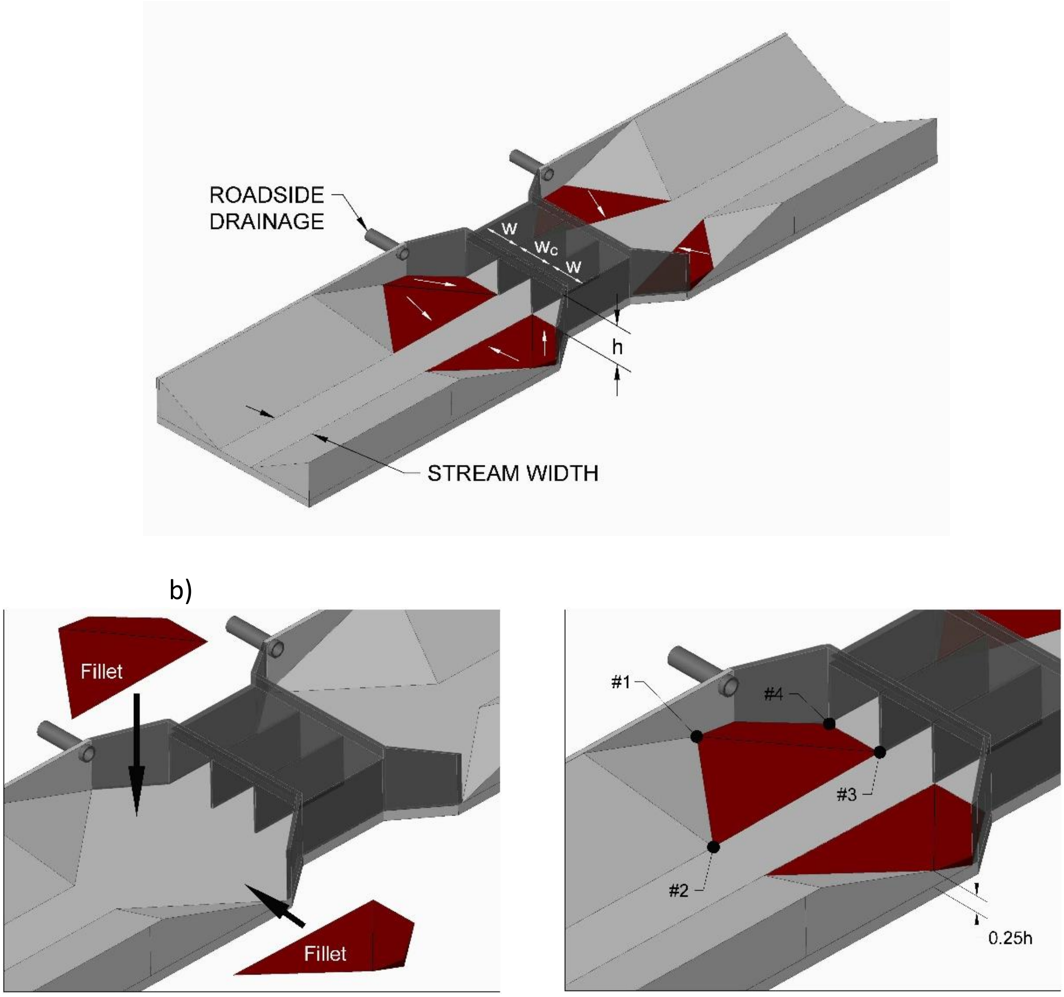


Figure 4A: Self-cleaning culvert design based on fillets**: a) culvert retrofitted with upstream and downstream fillets; b) view of the fillets at the culvert inlet

**conceptual sketches are provided for a precast triple-box culvert with flared wingwalls.

6. Fillets can be comprised of a variety of material including erosion stone and fabric formed revetment mats.
7. Erosion stone is used to form the wedge shape using the nominal dimensions shown in Figures 2A.
8. The erosion stone is capped with fabric formed revetment mats. A minimum 4-inch-thick fabric formed revetment mat should be used.
9. All accumulated siltation within the culvert apron and barrels should be removed to the greatest extent practical prior to the installation of fillets.

10. Installation of fillets during low flow periods is recommended. If flow will hamper the installation of fillets, temporary upstream dams or stream checks may be considered.
11. Fillets may cause an increase in water surface elevations upstream of the installation. This may be problematic if upstream structures are impacted or the project is located within a detailed Flood Insurance Study (FIS) zone. However, the blockage is usually minor if there is not across-the-stream blockage or blockage of the culvert cross section.
12. Fillets may have an impact on protected streams, wetlands, or aquatic species. An assessment of these impacts should be made prior to fillet installation.
13. Manufacturer's recommendations regarding mat material, placement, and filling with grout should be followed.
14. Anchorage of the fabric formed revetment to the stream bed is critical, especially at the upstream end. A common means of anchorage is via the use of an "anchor trench" that embeds the fabric mat at least 3 feet into the ground. A cap of rip rap is often placed against the anchor trench as an additional erosion control measure. Refer to example plan sheets (Appendix AA) for details regarding this connection.
15. Anchorage of the fabric formed revetment may also be accomplished using deformed steel reinforcing bars. This type of anchorage is used to anchor the mats to a concrete surface such as a headwall apron. An epoxy coating of the bars is recommended to reduce corrosional effects. Refer to example plan sheets (Appendix AA) for details regarding this connection.
16. Mat-to-mat transitions can be accomplished by several means. It is customary to overlap the ends of the mats by at least 18 inches; in some cases 36 inches is used. Upstream mats should overlap downstream mats. Refer to example plan sheets (Appendix AA) for details regarding this connection. Mats may also be directly connected to each other using deformed steel reinforcing bars. In this application, a steel bar is inserted into a mat by core drilling into the mat toto a depth of 75%. The bar is placed in the cored hole and the void is filled with a non-shrink grout. The end of the exposed bar is placed into the adjacent mat. Refer to example plan sheets (Appendix AA) for details regarding this connection.
17. Mats may also be installed along the stream bed directly upstream or downstream from the headwall apron. The intent of these mats is to provide a uniform transition from the stream channel cross section to the inlet, or from the outlet to the stream cross section, and to prevent scouring of the mat edges at the connection with the natural streambed.
18. The mats can be manufactured to meet custom dimensions. If possible, customary dimensions should be used. A common dimension used by manufacturers is the mill width. The mill width dimension is the direction that is parallel to the longest cell block length. In the case of 4-inch-thick mats

this dimension is 20 inches. The nominal length perpendicular to the mill width is 14 inches for 4-inch-thick mats.
19. Mats should be dimensioned to finished block size, including trench lengths.
20. Mats will deform more readily perpendicular to the mill width direction. In general, mats should be shown such that the mill width is perpendicular to the slope of the mat plane.
21. Depressions in mats or fillet surfaces should be avoided. Depressions may allow the deposition of silt which can lead to vegetative growth which is one of the factors that increases the likelihood of siltation occurring.
22. Monitoring of the fillets is recommended after installation is complete. Monitoring, at a minimum, should include photographs as well as sketches or drawings of the extent of additional siltation. The frequency of monitoring can vary but, at a minimum, two site visits per calendar year are recommended.
23. Typical construction costs in 2017 dollars are as follows:
    a. 4-inch fabric formed revetment mats $60/sy
    b. concrete grout for mats $350/cy
    c. erosion stone $50/ton
    d. rip rap $50/ton

Appendix AA provides photographs, example plan sheets, and specifications for construction of the self-cleaning culvert design type A.

APPENDIX AA: Additional Information for Constructing the Self-Cleaning Solution Design A

Figure 5A. Views of the mat-covered fillets as applied at the inlet of a 15’-18”-15” x 12 RCB on Hwy 1 W, Iowa City. Note: there is a slight difference in the fillet geometry compared to the specifications provided in Appendix A. The geometry has been updated based on observations during the monitoring of the implemented design.

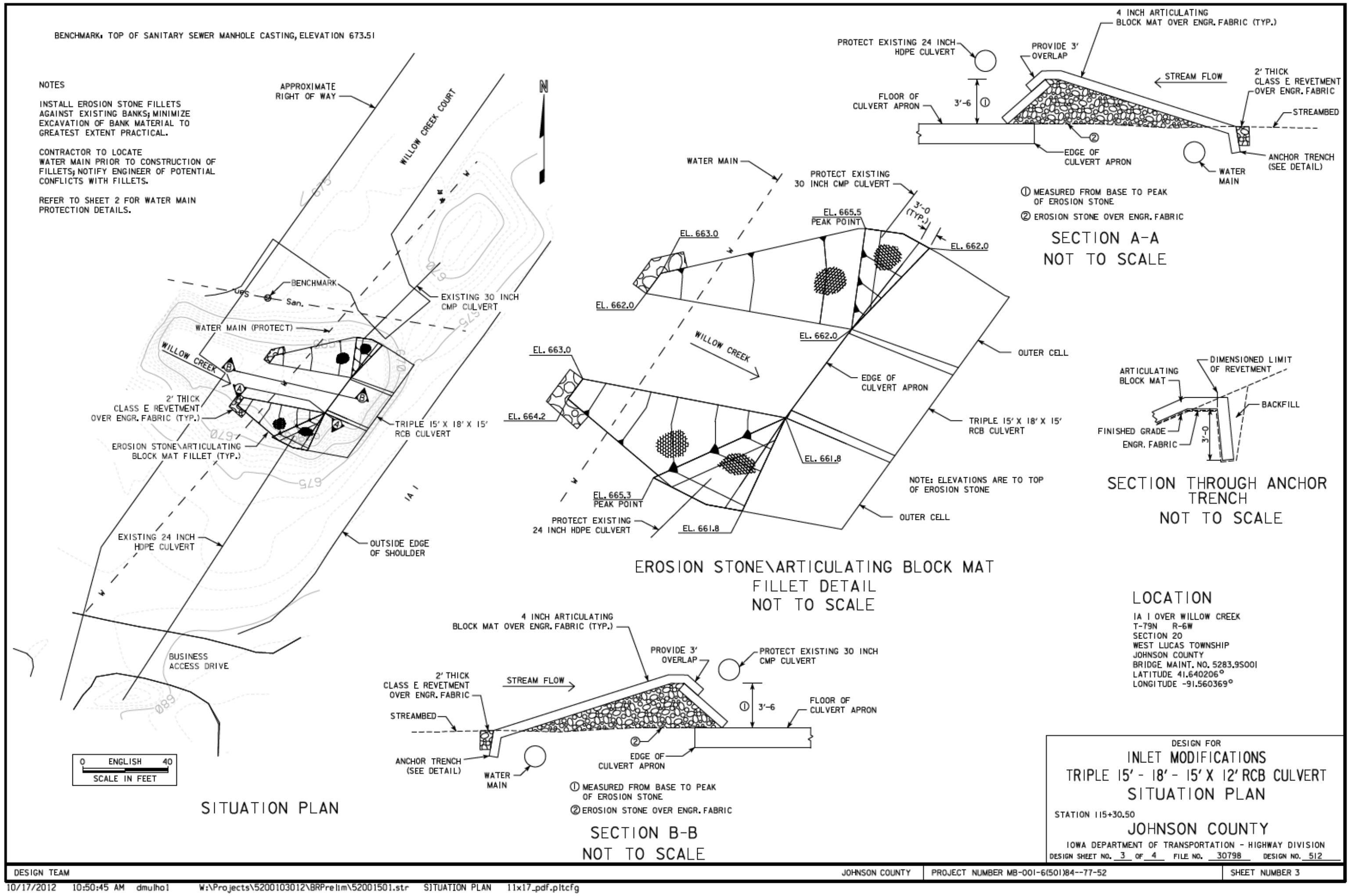


Figure 6A. Plan sheet for the self-cleaning design applied at the culvert inlet illustrated in Figure 5A.

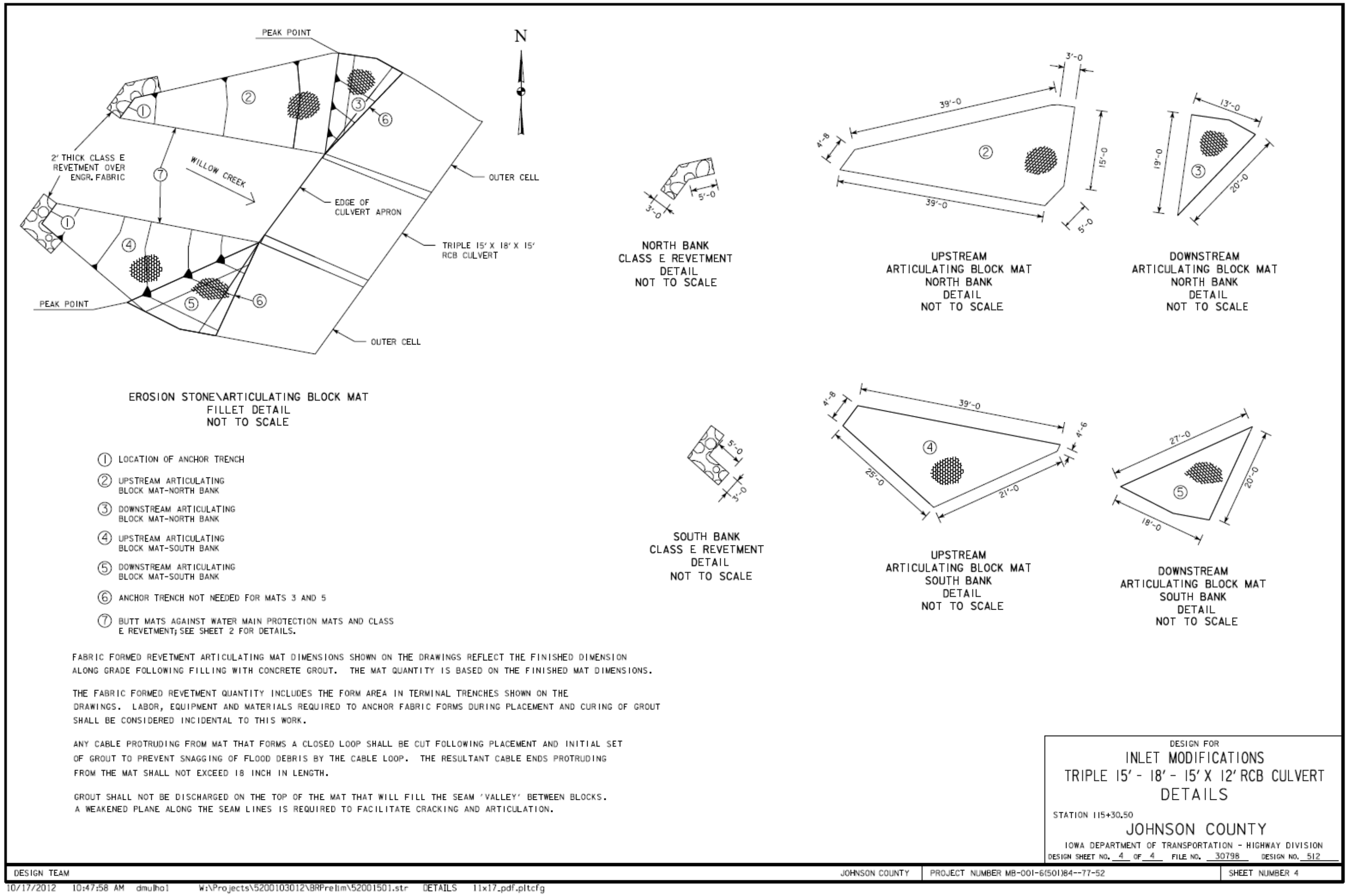


Figure 7A. Details for the plan sheet for the self-cleaning design applied at the culvert inlet illustrated in Figure 6A.

DS-15008
(New)

IOWA DOT

DEVELOPMENTAL SPECIFICATIONS
FOR
FABRIC FORMED CONCRETE STRUCTURE REVETMENT

Effective Date
October 20, 2015

THE STANDARD SPECIFICATIONS, SERIES 2015, ARE AMENDED BY THE FOLLOWING MODIFICATIONS AND ADDITIONS. THESE ARE DEVELOPMENTAL SPECIFICATIONS AND THEY SHALL PREVAIL OVER THOSE PUBLISHED IN THE STANDARD SPECIFICATIONS.

15008.01 DESCRIPTION.

A. Construct fabric formed concrete revetment as shown on the plans. The revetment is normally used adjacent to bridge substructure units to protect the substructure from excessive scour.

B. Use fabric formed revetment consisting of specially woven, double-layer synthetic forms filled with a pumpable, fine aggregate concrete grout in such a way as to form a stable revetment of required thickness, weight, and configuration.

C. Ensure the fabric formed revetment configuration is 'Articulating Block Mat' with reinforced polyester cable, and/or 'Armor Units' with or without reinforced polyester cable according to the contract documents.

15008.02 MATERIALS.

A. Fabric Forms.

1. Manufacturers and Products.

a. Acceptable manufacturers and products are shown in Materials I.M. 496.01, Appendix F.

b. Ensure the fabric forms supplied meet the details and specifications of the approved products as modified by this specification.

2. Fabric and Cables.

a. **General.**

1) Fabricate fabric forms to conform to the dimensions shown in the contract documents. Adjust the fabric form dimension to provide the finished dimension shown (following filling with concrete grout), including allowances for form material in anchor, terminal, or toe trenches as applicable. See Article 15008.02, C, for the requirements for concrete grout for the fabric formed concrete revetment.

2) Use fabric forms composed of synthetic yarns formed into a woven fabric. Ensure: Yarns used in the manufacture of the fabric are composed of nylon and/or polyester. Forms are woven with a minimum of 50% textured yarns by weight (mass) to improve adhesion to the concrete grout and to improve filtration.

Each layer of fabric conforms to the physical, mechanical, and hydraulic requirements referenced herein.

Fabric forms are free of defects or flaws that significantly affect their physical, mechanical, or hydraulic properties.

3) Ensure fabric used to fabricate the fabric forms meets or exceeds the values shown for the properties shown in Table DS-15008.02-1:

Table DS-15008.02-1: Fabric Form Minimum Property Requirements

Property	Test Method	Units	Armor Unit	Articulating Block Mat
Composition of Yarns			Nylon or Polyester	Nylon or Polyester
Mass Per Unit Area (double-layer)	ASTM D 5261	oz/yd^2	14	12
Thickness	ASTM D 5199	mils	28	25
Mill Width		in	76	76
Wide-Width Strip Tensile Strength - Machine - Cross	 ASTM D 4595 ASTM D 4595	 lbf/in lbf/in	 190 140	 140 110
Elongation at Break - Machine - Cross	 ASTM D 4595 ASTM D 4595	 % %	 20 30	 20 30
Trapezoidal Tear Strength - Machine - Cross	 ASTM D 4533 ASTM D 4533	 lbf lbf	 180 115	 150 100
Apparent Opening Size (AOS)	ASTM D 4751	US Std. Sieve	60	40
Flow Rate	ASTM D 4491	gal/min/ft^2	50	90

Notes:
1. Conformance of fabric to specification property requirements is based on ASTM D 4759.
2. All numerical values represent minimum average roll values (i.e., average of test results from any sample roll in a lot must meet or exceed the minimum values). Sample lots according to ASTM D 4354.

4) Ensure mill widths of fabric are a minimum of 76 inches. Reinforce each selvage edge of the top and bottom layers of fabric for a width of no less than 1.35 inches by adding a minimum of six warp yarns to each selvage construction. Cut mill width rolls to the length required. Separately join the double-layer fabric (bottom layer to bottom layer and top layer to top layer) by means of sewing thread to form multiple mill width panels with sewn seams on no less than 72 inch centers.

5) Ensure the following (field sewing will be permitted only to join the factory assembled fabric form panels together):

All factory-sewn seams face downward upon completion of the revetment.

All seams sewn in the factory are not less than 90 pound-force per inch when tested according to ASTM D 4884.

All sewn seams and zipper attachments are made using a double line of U.S. Federal Standard Type 401 stitch.

All stitches are sewn simultaneously and are parallel to each other, spaced between 0.25 inches to 0.75 inches apart.

Each row of stitching consists of four to seven stitches per inch.

Thread used for seaming is nylon or polyester, or both.

6) When cables are required, use cables constructed of high tenacity, low elongation, continuous filament polyester fibers. Ensure cables have a core construction consisting of parallel fibers contained within an outer jacket or cover. Ensure the weight of the parallel core is 65% to 75% of the total weight of the cable.

7) Use cable of nominal size and rated breaking strength specified in the following sections for the type and size of fabric formed revetment. Splice cables using aluminum compression fittings selected so that the resultant cable splice from use of a single fitting provides a minimum of 80% of the rated breaking strength of the cable.

At each splice, use a minimum of two fittings separated by a minimum of 6 inches of cable overlap. Upon completion of the revetment, encase all fittings by concrete grout within the fabric form.

b. Articulating Block Mat.

1) Use fabric forms consisting of double-layer woven fabric joined together by narrow perimeters of interwoven fabric into a matrix of rectangular compartments that form a concrete articulating block mat. Use cords to connect the two layers of fabric at the center of each compartment. Ensure the cords are interwoven in two sets of four cords each, one set for the upper layer and one set for the bottom layer. Ensure each cord has a minimum breaking strength of 160 pound-force when tested according to ASTM D 2256.
2) Offset fabric form compartments one-half a compartment length, in the mill width direction, to form a bonded concrete block pattern. The mill width direction for articulating block mat is the flow direction shown on the plans unless otherwise noted.
3) Ensure fabric form compartments each have four grout ducts, two on each side parallel to the mill width direction, to allow passage of the concrete grout between adjacent compartments. Two additional grout ducts, one on each side perpendicular to the mill width direction, is permissible. Ensure the concrete grout filled, cross sectional area of each grout duct is no more than 10% of the maximum filled cross sectional area of the block transverse to the duct.
4) Install grout stops at predetermined mill width intervals to regulate the distance of lateral flow of concrete grout. Use nonwoven filter fabric for the grout stop. Ensure the grab tensile strength of the filter fabric is no less than 90 pound-force when tested according to ASTM D 4632.
5) Install cables between the two layers of fabric and through the compartments in a manner that provides for longitudinal and lateral binding of the finished articulating block mat. Ensure two revetment cables perpendicular to mill width direction pass through each compartment. Ensure one revetment cable parallel to the mill width direction passes through the approximate center of each compartment.
6) Ensure the cables enter and exit the compartments through opposing grout ducts. As an alternate, cable ducts may be provided for insertion of revetment cables between compartments. Ensure the diameter of each cable duct is 1.0 inch maximum.
7) Completely embed in the concrete grout all cables within each compartment.
8) Ensure articulating block mat nominal finished dimensions and properties are those listed in Table DS-15008.02-2:

Table DS-15008.02-2 - Articulating Block Mat Properties

Size	4 inch	6 inch	8 inch	10 inch	12 inch
Average Thickness, inches	4.0	6.0	8.0	10.0	12.0
Mass Per Unit Area, lb/ft^2	45	68	90	113	135
Mass per Block, lb	88	188	325	563	844
Nominal Block Dimensions, inches[c]	20x14	20x20	20x26	30x24	30x30
Cable Nominal Diameter, inches	0.250	0.312	0.312[b]	0.375[d]	0.375[d]
Cable Average Breaking Strength, lbf	3700	4500	4500[b]	7000[d]	7000[d]
Concrete Coverage[a], ft^2/yd^3	75	50	38	30	25

[a] For information only.
[b] When the contract documents require 0.375 inches cable, the Average Breaking Strength is to be 7000 pound-force.
[c] Mill width direction x perpendicular to mill width direction.
[d] When the contract documents require 0.440 inches cable, the Average Breaking Strength shall be 10,000 pound-force.

c. Armor Units/Concrete Bags.

1) Use fabric forms consisting of two layers of woven fabric sewn together. Ensure when filled with concrete grout, they form a concrete Armor Unit (concrete bag).

2) Install self-sealing filling valves, suitable for use with an injection pipe at the end of a pump hose for concrete grout, at predetermined locations.

3) When Armor Units are specified, use fabric forms similar to the typical unreinforced bags produced by the manufacturers specified above.

4) When Armor Units Reinforced are specified, make the following modifications to the typical unreinforced bag:

- **a)** Use fabric form that is continuous along its length. The intent is to provide a continuous width and thickness of fabric formed concrete along the substructure unit being protected.
- **b)** Install grout stops as required to regulate the distance of flow of concrete grout. Use grout stop material consisting of nonwoven filter fabric. Ensure the grab tensile strength of the filter fabric is no less than 90 pound-force when tested according to ASTM D 4632.
- **c)** Space longitudinal cables evenly across the cross section of the Armor Unit. Splice them at joints. Ensure cables are a nominal 0.250 inches in diameter and their rated average breaking strength is no less than 3700 pound-force. Ensure cords connect the cables to the fabric form as required to position the cables near the center of the finished armor thickness. The number of longitudinal cables required and required nominal finished dimensions and properties are shown in Table DS-15008.02-3:

Table DS-15008.02-3: Armor Unit Properties

Size - Width Unfilled Fabric Form in	No. Longitudinal Cables[b]	Filled Thickness in / Volume of Concrete[a] ft^3/ft	Filled Thickness in / Volume of Concrete[a] ft^3/ft
24	2	6 / 0.8	9 / 1.1
36	2	6 / 1.3	9 / 1.8
48	3	9 / 2.6	12 / 3.2
60	4	9 / 3.3	12 / 4.2
72	5	9 / 4.1	12 / 5.2
84	6	9 / 4.8	12 / 6.5
96	7	12 / 7.2	15 / 8.8
108	8	12 / 8.2	15 / 10.0

(a) For information only.
(b) For Reinforced Armor Units

B. Delivery.

1. Keep fabric forms dry and wrapped such that they are protected from the elements during shipping and storage. If stored outdoors, ensure they are elevated and protected with a waterproof cover that is opaque to ultraviolet light. Ensure fabric forms are labeled as per ASTM D 4873.

2. Submit a manufacturer's certificate that the supplied fabric forms meet the criteria of this specification, as measured in full accordance with the referenced test methods and standards. Ensure the certificates include the following information about each fabric form delivered:
   - Manufacturer's name and current address;
   - Full product name;
   - Style and product code number;
   - Composition of yarns; and
   - Manufacturer's certification statement.

C. Concrete Grout for Fabric Formed Concrete Revetment.

1. Ensure materials for concrete grout for the fabric formed concrete revetment (concrete grout) meet the following requirements:

Item	Section (of the Standard Specifications)
Portland Cement	4101
Fine Aggregate	4110, 4111 or 4112
Water	4102
Admixtures	4103
Fly Ash	4108

2. Ensure the concrete grout consists of a mixture of Portland cement, fine aggregate, water, admixtures, and fly ash proportioned and mixed to provide a pumpable slurry. The Contractor has the option of using grout fluidizer.

3. Proportion and mix the concrete grout so that its consistency when delivered to the concrete pump has an efflux time of 8 to 12 seconds when passed through the 0.75 inch orifice of the standard flow cone that is described in ASTM C 939.

4. Ensure the concrete grout has an air content of no less than 5% or no more than 10% of the volume of the grout. Ensure the mix obtains a compressive strength of 2000 pounds per square inch at 28 days when tested in conformance with Materials I.M. 315.

5. Provide the Engineer with a mix design meeting the above requirements. Produce a 1 cubic yard test batch prior to utilizing the intended mix design. The Engineer will validate consistency and air content of the test batch. Previously approved mix designs with a history of strength and flow may be utilized without a test batch subject to approval of the Engineer. Once the mix has been designated, do not change without the Engineer's approval.

6. A mix utilizing at least 800 pounds of cementitious material with a required substitution of at least 25% but no more than 35% type C fly ash may be used without strength testing before placement. Efflux time and air content by unit weight determination will be measured by the project Engineer prior to placement and at least once every 4 hours until the placement is complete.

15008.03 CONSTRUCTION.

A. Equipment.
Obtain the Engineer's approval for mixing and pumping equipment used in preparation and handling of the concrete grout. Ensure proportioning and mixing equipment meets the requirements of Articles 2001.20 and 2001.21 of the Standard Specifications. Ensure the mixing capacity of mixers is sufficient to permit the intended pour to be placed without interruption. Before the mixers are used, remove all oil or other rust inhibitors from the mixing drums, stirring mechanisms, and other portions of the equipment in contact with the grout. Ensure pumping

equipment has a variable flow rate to provide enough pressure for pumping without breaking the fabric.

B. Site Preparation.

1. Construct areas on which fabric forms are to be placed to the lines, grades, contours, and dimensions shown on the plans. Remove all obstructions, such as roots and projecting stones. Bring areas below the allowable grades up to grade by placing compacted layers of select material. The Engineer will specify the thickness of layers and the amount of compaction. Where required by the contract documents, identity soft and otherwise unsuitable subgrade soils, excavate, and replace with select materials according to the Standard Specifications.

2. Excavate for and prepare aprons, anchors, terminal, and/or toe trenches according to the lines, grades, contours, and dimensions shown on the plans. Immediately prior to placing the fabric forms, the Engineer will inspect the prepared area. Do not place forms until the area has been approved.

C. Fabric Form Placement.

1. **General.**
   a. Place engineering fabric on the graded surface approved by the Engineer when required by the contract documents. Place fabric forms over the engineering fabric, when required, and within the limits shown on the plans. Anchor the fabric forms as required to prevent displacement during curing of grout. Anchorages requiring connection to the structure and not shown on the plans require approval by the Engineer prior to use.
   b. Where fabric formed concrete is placed adjacent to a substructure unit, place the fabric forms so that the filled fabric formed revetment is flush with the substructure unit. When placing fabric form, allow for contraction of the fabric form during filling.
   c. Make all field seams using two lines of U.S. Federal Standard Type 101 stitches. Use nylon and/or polyester thread. Sew all seams face down. Zipper seams are permitted unless noted otherwise in the contract documents. Ensure the finished strength of the field seams complies with the manufacturer's recommendations.
   d. Splice all cables crossing a field seam according to Article 15008.02, A, 2. Upon completion of the revetment, encase all splice fittings by concrete grout within the fabric form.
   e. Where fabric formed concrete units/mats lap on top of previously installed units, place 6 mils thick polyethylene sheeting on top of the underlying unit to prevent bonding prior to placement of the engineering fabric and fabric forms for the succeeding layer.
   f. Immediately prior to filling with the concrete grout, the Engineer will inspect the assembled fabric forms. Do not pump grout until the fabric seams have been approved. Do not allow unfilled fabric forms to be exposed to ultraviolet light (including direct sunlight) for a period exceeding five calendar days.

2. **Articulating Block Mat.**
   Before filling with concrete grout, join adjacent fabric form panels by field sewing or zippering the two bottom layers of fabric together and the two top layers of fabric together. Use lap joints only at locations shown in the contract documents.

3. **Armor Units.**
   a. Join typical unreinforced Armor Units together following placement of concrete grout as shown in the contract documents.
   b. Before filling with concrete grout, join Reinforced Armor Units by field sewing or zippering the two bottom layers of fabric together and the two top layers of fabric together to form a continuous unit.

D. Proportioning and Mixing Concrete Grout.
Accurately measure all materials by volume or weight (mass) as they are fed into the mixer. Ensure the quantity of water is such as to produce a grout having a pumpable consistency. Mix grout for no less than one minute. If agitated continuously, the grout may be held in the mixer or agitator for up to 2.5 hours in temperatures below 70°F and up to 2 hours at higher temperatures. If there is a lapse in a pumping operation, recirculate the grout through the pump or through the mixer drum (or agitator) and pump.

E. Concrete Grout Placement.

1. **General.**
   a. Pump concrete grout in such a way that excessive pressure on the fabric forms and cold joints is avoided. A cold joint is defined as one in which the pumping of the concrete grout into a given form is discontinued or interrupted for an interval of 45 minutes or more.
   b. After the concrete grout has set, backfill and compact all anchor, terminal, and toe trenches as specified by the Engineer.
   c. Restrict foot traffic on the filled form to an absolute minimum for one hour after filling.
   d. If a fabric formed concrete unit/mat is to bear on previously installed units, the lower units shall be allotted a minimum of four hours of cure time before beginning installation of a succeeding, vertically adjacent course of fabric formed unit(s). Abutting fabric formed concrete units/mats may be installed immediately after placement of the preceding unit(s).
   e. Do not wash (spray) freshly pumped fabric formed concrete under pressure with water in an effort to clean or remove spills from its surface. Maintain the cement film that bleeds through the top layer of the fabric form through curing on finished surfaces exposed to sunlight. Should the film be removed in these areas, repair the film by spreading a thin layer of a water-cement paste over the effected area.

2. **Articulating Block Mat.**
   Following the placement of the fabric forms, cut small slits (of the minimum length to allow proper insertion of the filling pipe) in the top layer of the fabric form to allow the insertion of the filling pipe at the end of the concrete grout pump hose. Pump concrete grout between the top and bottom layers of fabric, filling the forms to the recommended thickness and configuration. Temporarily cross holes in the fabric forms left by the removal of the filling pipe by inserting a piece of nonwoven fabric or similar material. Remove the nonwoven fabric when the concrete grout is no longer fluid. Clean and smooth the grout surface at the hole by hand.

3. **Armor Units.**
   a. Following the placement of the fabric form, insert the filling pipe at the end of the concrete grout pump hose through the self-sealing filling valve. Pump concrete grout between the top and bottom layers of fabric, filling the forms to the recommended thickness and configuration.
   b. When the contract documents require joining of adjacent Armor Units by inserting reinforcement bar dowels or staples into the Armor Units, insert the dowels or staples into the filled unit(s) no less than one half hour and not more than one hour after filling of the unit, unless the Engineer directs otherwise. When the contract documents require joining of vertically adjacent Armor Units, drive reinforcing dowels into the lower unit in the time frames specified in this paragraph. Place the vertically adjacent fabric form over the reinforcing dowels. Force the dowels through the bottom layer of the vertically adjacent fabric form prior to filling that form.

F. Cold Weather Protection.

1. Concrete grout shall not be placed in forms laying on frozen ground.

2. Grout filled fabric formed concrete less than 48 hours old shall be protected as follows:

Table DS-15008.04-1: Grout Filled Fabric Formed Concrete Protection

Night Temperature Forecast	Type of Protection
32°F to 25°F	One layer of burlap or a 3/4 inch layer of soil.
Below 25°F	Three layers of burlap or equivalent commercial insulating material, or a 1 1/2 inch layer of soil.

3. Protection shall completely cover the fabric formed concrete to the water line on the finished fabric formed concrete surface. Protection of fabric formed concrete below water is not required.

15008.04 METHOD OF MEASUREMENT.

A. Fabric Formed Concrete Revetment.
Square yards shown in the contract documents of the type specified for each installation.

B. Engineering Fabric.
Article 2507.04 applies.

C. Concrete Grout.
Article 2507.04 applies.

15008.05 BASIS OF PAYMENT.

A. Fabric Formed Concrete Revetment.

1. Per square yards for the type specified.

2. Payment is full compensation for all work, including furnishing the forms and all equipment, tools, and labor necessary to place the forms ready for filling with grout and all required work following filling. The work includes but is not limited to joining field seams, cable splices, plastic for lap areas, and reinforcing bars to join Armor Units.

3. Unless otherwise noted in the contract documents, payment is also full compensation for all bank shaping, excavation, and backfilling necessary to complete the work in conformance with the contract documents.

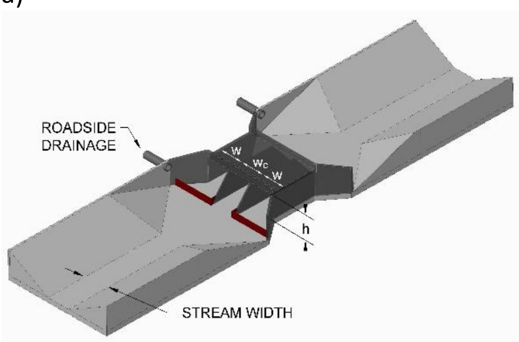
B. Engineering Fabric.
Article 2507.05 of the Standard Specifications applies.

C. Concrete Grout.
Article 2507.05 of the Standard Specifications applies.

A.2. SELF-CLEANING CULVERT DESIGN B: UPSTREAM CURTAIN WALL

Unlike Design A, this design concept has not been investigated through an exhaustive process. The solution has been observed in the field and it seems that it has a beneficial role in minimizing the development of sediment deposits at culverts. The concept is currently under in-situ observation and it is presented herein for completeness.

a)



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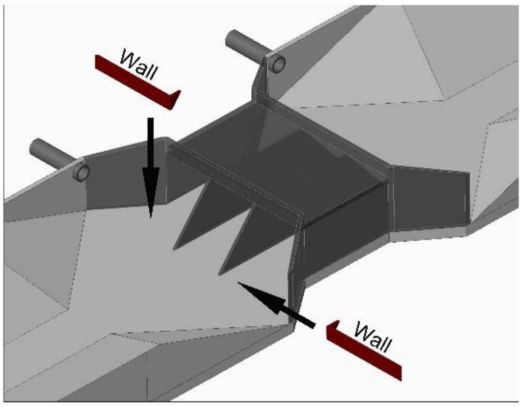

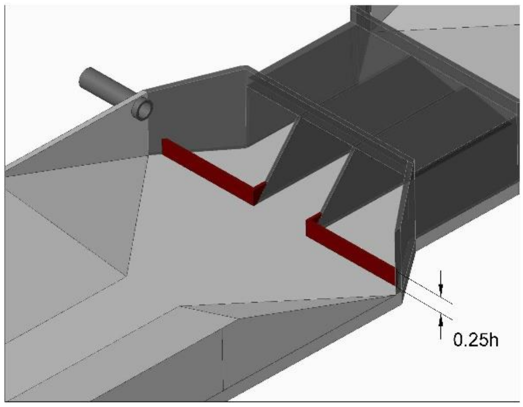

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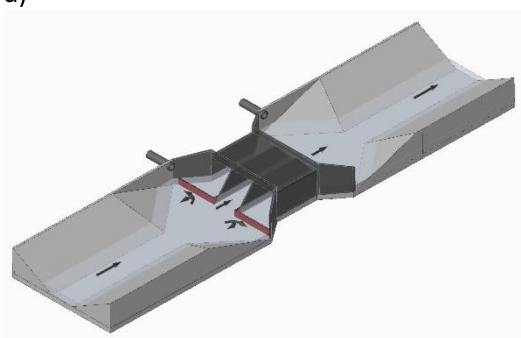


e)

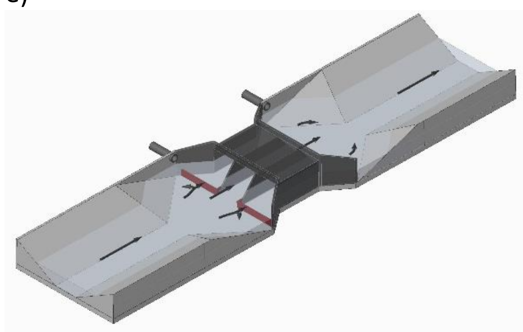


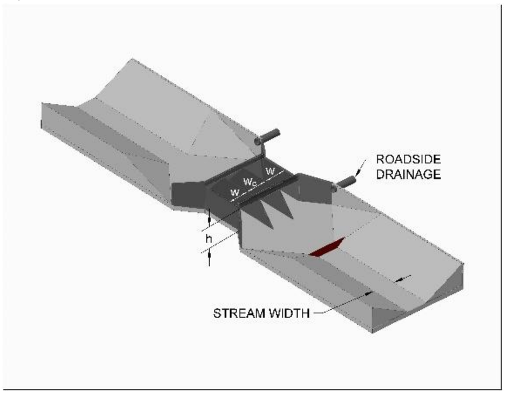
Figure 8A: Self-cleaning culvert design based on upstream curtain wall*: a) culvert with curtain walls; b) photo of the constructed design; c) views of the curtain walls at the culvert inlet; d) flowlines for a low flow situation; e) flowlines for a high flow situation.

*conceptual sketches are provided for a cast-in-place triple-box culvert with flared wingwalls.

A.3. SELF-CLEANING CULVERT DESIGN C: DOWNSTREAM SUBMERGED WEIR

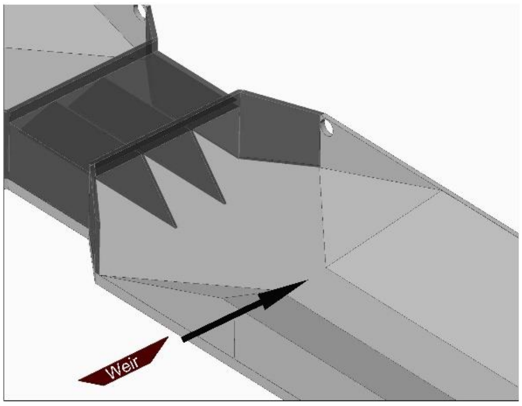
Unlike Design A, this design concept has not been investigating through an exhaustive process. The solution has been observed in the field and it seems that it has a beneficial role in minimizing the development of sediment deposits at culverts. The concept is currently under in-situ observation and it is presented herein for completeness.

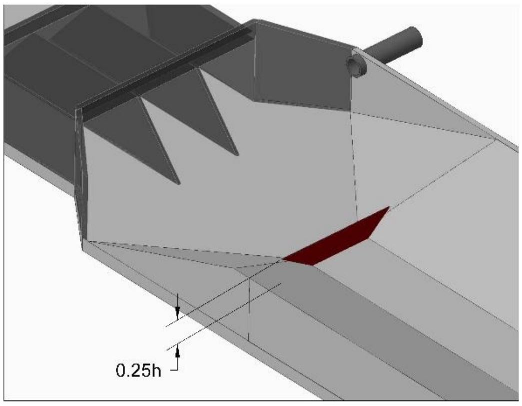
a)



b)

c)





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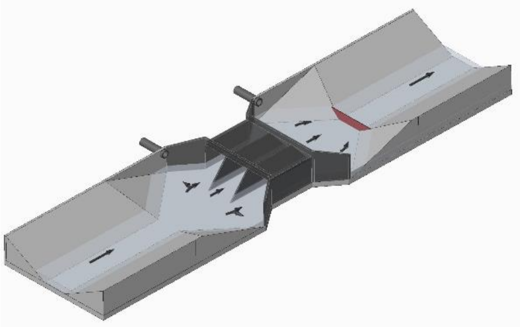


e)

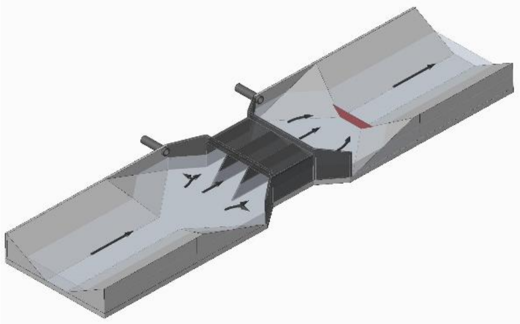


Figure 9A: Self-cleaning culvert design based on downstream submerged weir*: a) culvert with downstream weir; b) photo of the constructed design; c)views of the weir at the culvert outlet; d) flowlines for a low flow situation; e) flowlines for a high flow situation.

*conceptual sketches are provided for a cast-in-place triple-box culvert with flared wingwalls.

APPENDIX B: WORKSHOP WEB ANNOUNCEMENT

IOWA STATE UNIVERSITY
Institute for Transportation

Iowa LTAP | Workshops | Self-Cleaning Multi-Barrel Culverts

Self-Cleaning Multi-Barrel Culverts

Registration

Dates and Locations

Ames, Wednesday, May 31, 2017
Institute for Transportation
2711 South Loop Drive, Building 4, Suite 4700
Ames, Iowa 50010

Ottumwa, Tuesday, June 6, 2017
Bridgeview Center
102 Church Street
Ottumwa, Iowa 52501

Cedar Rapids, Wednesday, June 7, 2017
Kirkwood Community College
Iowa Hall, Room 316A
6301 Kirkwood Boulevard Southwest
Cedar Rapids, Iowa 52404 (map)

Storm Lake, Tuesday, June 13, 2017
King's Pointe Waterpark Resort
1520 East Lakeshore Drive
Storm Lake, Iowa 50588

Red Oak, Wednesday, June 14, 2017
Red Coach Inn & Restaurant
1200 Senate Avenue
Red Oak, Iowa 51566

Registration at 7:45 a.m./Event starts at 8:00 a.m.

Fees

There is no fee to attend this training event. However, **preregistration is REQUIRED** no later than 7 days before the workshop date.

Attendance Limits and Deadline

The number of seats available for this event is limited. The number of remaining spaces can be found on the registration page. Registration is on a first-come/first-served basis and will close when the spaces indicated on the registration page are filled. **Registration is required no later than 7 days before the workshop date**.

Online Registration

- Register for Ames, Wednesday, May 31, 2017
- Register for Ottumwa, Tuesday, June 6, 2017
- Register for Cedar Rapids, Wednesday, June 7, 2017
- Register for Storm Lake, Tuesday, June 13, 2017
- Register for Red Oak, Wednesday, June 14, 2017

Questions?

Call or email Devin Happe at dmhappe@iastate.edu or 515-294-2969.

Description

The Self-Cleaning Multi-Barrel Culvert workshop is an open, interactive dialogue on solutions for mitigating sedimentation at culverts in Iowa. A new web-based program for evaluating the potential of sedimentation at Iowa's multi-box culverts will be also presented and demonstrated to participants through one-to-one training.

Course Instructors

Marian Muste
Dr. Muste is a Research Engineer with IIHR and an Adjunct Professor in the Civil & Environmental Engineering Department. His main area of research is river mechanics. He is an author or co-author of more thhan 185 peer-reviewed journal and conference papers and 75 technical reports.

Haowen Xu
Haowen Xu is a PhD candidate in Civil & Environmental Engineering, at The University of Iowa. His thesis dissertation is focused on development of web-based platforms for problem-solving in various aspects of water resources.

Tentative Agenda

7:45 a.m.	Registration
8:00 a.m.	Introduction Sedimentation at Culverts
10:00 a.m.	Break Solutions for Mitigating Sedimentation
12:00 p.m.	Lunch Demonstration of the Iowa Department of Transportation (Iowa DOT) Web Tool
1:50 p.m.	Break One-to-one Training Session for the Iowa DOT Web Tool Survey
3:00 PM	Course closure

For More Information

If you have any questions or need more information, please contact Keith Knapp at 515-294-8817 or kknapp@iastate.edu.

Acknowledgements

The workshop series is sponsored by the Iowa DOT and the State Transportation Innovation Councils.

APPENDIX C: WORKSHOP FLYER

Sedimentation Mitigation at Multi-box Culverts

INVESTIGATORS:
M. Muste, H. Xu
University of Iowa

COORDINATORS:
V. Goetz, D. Claman, & A. Abu-Hawash
Iowa Department of Transportation

Iowa STIC Workshops:

Ames — May 31, 2017
Ottumwa — June 6, 2017
Cedar Rapids — June 7, 2017
Storm Lake — June 13, 2017
Red Oak — June 14, 2017

The Problem

Sediment deposition at culverts is a prominent problem for multi-box culverts located in areas where streams convey substantial sediment loads, such as the watersheds in the US Midwest. Sediment accumulated at culverts can eventually lead to partial blockage and the reduction of their effective cross-section with adverse consequences on culvert capacity to convey the design flows. Site visits at more than 250 three-box culverts in the state of Iowa revealed that the vast majority of multi-box culverts in the state experience severe blockage due to sedimentation. Illustrations of typical sedimentation cases are provided below for two Iowa culverts. Culvert surveys repeated over time show that sedimentation develops relatively fast. sometimes within the first year after complete cleanup (as indicated in the case studies shown below).

Culvert Sedimentation Sample 1

(3-box culvert on Mill Creek, Iowa; FHWA #: 000000000031910)

Aerial Imagery (2016 Google)

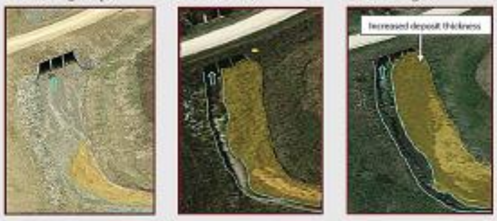
Site visits (upstream views)

The local hydraulics, sediment nature, and vegetation type are all contributing to the location and pace of sedimentation growth at culvert.

Culvert Sedimentation Sample 2

(3-box culvert on Dibble Creek, Iowa; FHWA #: 000000000152811)

2010 (Bing map) 2011 (ESRI) 2013 (Google)



Drone-based aerial survey (2016)

Site visit (2016)

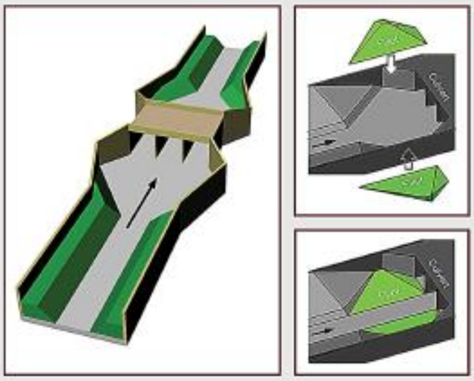
Downstream view of culvert site

Upstream view of culvert site

An Innovative Solution: self-cleaning culvert design

The solution for mitigating sedimentation at multi-box culverts was developed at IIHR—Hydroscience & Engineering (IIHR), a branch of the University of Iowa, with funding provided by the Iowa Highway Research Board. The concept behind the newly developed design makes use of the stream hydraulic power for passing downstream the sediment (suspended and bed load) carried by the stream during storms. The solution does not affect current culvert design specifications; rather it streamlines the flow in the upstream and downstream areas of the structure for enhancing both the flow and sediment transport.

The design method entails using infill fillets in the transition areas connecting the stream with the culvert, so as to maintain the flow distribution as close as possible to the original stream configuration (see figure below).



The fillets raise locally the bed elevation, increasing the flow velocity atop of them and hence the capacity to flush the sediment downstream. Additional enhancement of the sediment transport is obtained by the increased turbulence when flow passes over the fillets. The fillet-based retrofitting can be applied at any time during the culvert operation or can be incorporated in the design of new culverts.

The self-cleaning culvert concept was designed and extensively tested in laboratory conditions at IIHR. The concept was implemented in-situ at a culvert located on Highway 1 in Iowa City, Iowa.

The surface of the fillets was covered with an erosion control mattress (http://www.texicon.com). The role of the mattress is to avoid scouring of the fillets and provide a barrier for vegetation growth. Views of the fillets geometry and final appearance of the retrofitted culvert are illustrated in the photographs below. The right image is a rendering obtained with photogrammetric survey of the culvert site.

Since its implementation in January 2013, the self-cleaning culvert has operated efficiently in high and low flows as shown in the post-construction photos provided below. The self-cleaning design operates efficiently both from hydraulic as well as sediment conveyance perspectives for high and low flows and it is robust over season cycling.

Problem-solving Environment: web-based tools for evaluating culvert sedimentation

The prototype *Iowa Culvert* geo-portal provides a Problem Solving Environment integrating detailed information on culverts and watershed hydromorphology for the state of Iowa. The information is currently dispersed in various data sources (e.g. IDOT SIIMS, NHD, and RUSLE).

The portal enables three main workflows:
(1) Storage and query of culvert specifications and ancillary information;
(2) In-situ monitoring of culverts;
(3) Analysis of the sedimentation potential for any culvert site.

Selected interfaces associated with the workflows and brief descriptions of their functions are described below. The workflows can be applied wto existing or potential culvert sites therefore being able to assist operations and design purposes.

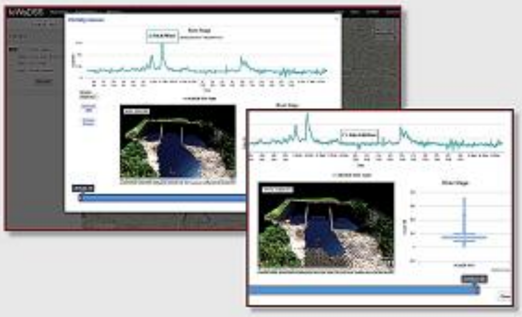
These workflows allow estimation of the current status of the sedimentation at culverts, assist in the preparation of a systematic plan for their monitoring, and offer means for quantitative assessment of the sediment deposits.

Culvert Specifications (site and drainage area)

Search Culverts

The landing page of the portal entails an interactive map of the multi-box (2, 3, and 4) culverts comprised in the IDOT database. The interface allows to search culverts using specifications contained in IDOT database (e.g., by river or road name, ID, geometric specifications, number of barrels, etc).

3-D culvert visualization



Photogrammetric surveys acquired with drone-based images allow 3D visualization of the culvert from any viewing angle. If the surveyed culvert is equipped with a stream gage (over 150 culvert-attached gages in Iowa), the culvert water level can be displayed in real time.

Basic culvert specifications

Culverts can be observed using a customized map viewer provided by aerial imagery of the site along with essential information from IDOT's SIIMS database. For most of the culverts, a bird's eye view (powered by Bing Map API) allows viewing of the culvert vicinity from different directions.

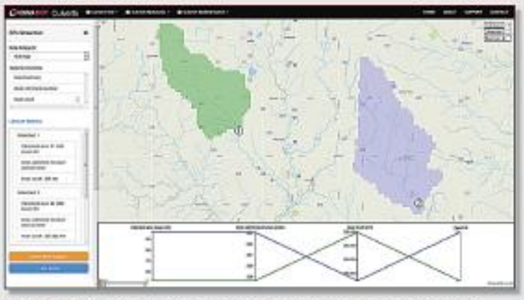
Forest Mapping

Vegetation in the drainage area and at the culvert are further concerns for sedimentation. Large woody debris can accumulate at the culvert site slowing flow and triggering sedimentation. Perennial grass growth on the sediment accumulated at culverts accelerates the rate of sediment deposit.

Design discharge estimation

The platform visualizes the drainage area for any Iowa streams and makes available estimates for flood-frequency discharges for any point selected on stream. Estimates are based on the USGS method (Eash regression equations) for flood discharges that have recurrence intervals of 2, 5, 10, 25, 100, 200 and 500 years.

Comparative analysis of the runoff potential



The degree of sedimentation is proportional to the amount of runoff coming from the culvert drainage area. The runoff potential in this tool is provided by EPA's StreamCAT database. The tool allows comparative analysis of the runoff potential in various watersheds for informing the design of the new culverts.

Problem-solving Environment: web-based tools for evaluating culvert sedimentation

In-Situ Culvert Monitoring

Route and inspection planner

The interface integrates GPS real-time locator functions with weather forecast and route mapping to facilitate planning and conduct of field inspections. In-situ observations are uploaded in servers for real-time sharing with remote users. Field crew locations are tracked in real-time.

Field data uploader

This customized interface allows field observations (survey notes and images) to be uploaded into the home server database. A mobile device—a smartphone or, preferably, a tablet—that can edit text and take photos of adequate quality is all that is required for uploading.

Field data retriever

The database is registered with a Content Management System (CMS). This system facilitates systematic storage, management, and query of the surveyed culverts based on specific criteria (e.g., degree of sedimentation observed in situ, inspection date).

Sedimentation Analysis

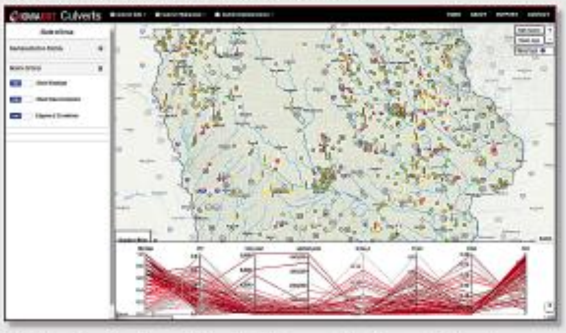
Erosion Potential

This tool uses the RUSLE model to estimate on the fly rates of soil loss caused by rainfall and associated overland flows in the drainage area of a selected culvert. The pre-calculated maps and the dynamic RUSLE runs provide guiding information for assessing potential for sedimentation at any culvert site.

Sedimentation mapping

The tool enables users to trace on aerial imagery maps the extent of the area occupied by the sediment deposits at culverts. The tracing is geo-coded such that the sediment deposit dimensions (i.e., lengths and areas) can be readily available and stored in the database for further analysis.

Multi-criteria sedimentation analysis



The interface displays relationships between the degree of culvert blockage and sedimentation-related features at the culvert site (e.g. stream to culvert ratio, drainage area and relevant characteristics). These relationships can be developed using on-line maps or data acquired through field surveys.

Sponsored by:
- Iowa Highway Research Board — Project TR-665
- State Transportation Innovation Councils (STIC) Incentive, Federal Highway Administration
- Iowa Local Technical Assistance Program, Iowa State University

The University of Iowa

Contact Information:
- Marian Muste, Principal Investigator — marian-muste@uiowa.edu
- Haowen Xu, Investigator — haowen-xu@uiowa.edu

APPENDIX D: SUMMARY OF THE 2-BOX CULVERT SURVEY

Figure 6 provides the survey form submitted to the workshop participants. A synthesis of the participants' input is provided below in graphical and tabular form.

Question #4

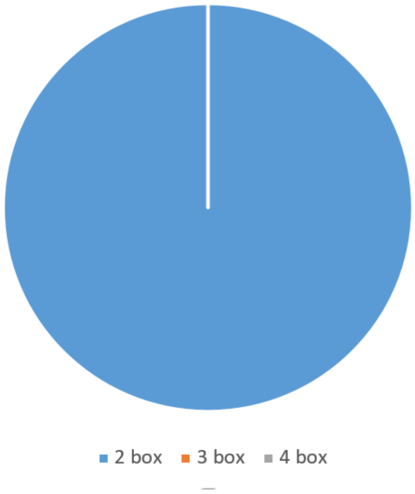


Figure D1. Type of culvert most often overtopped.

Question #5

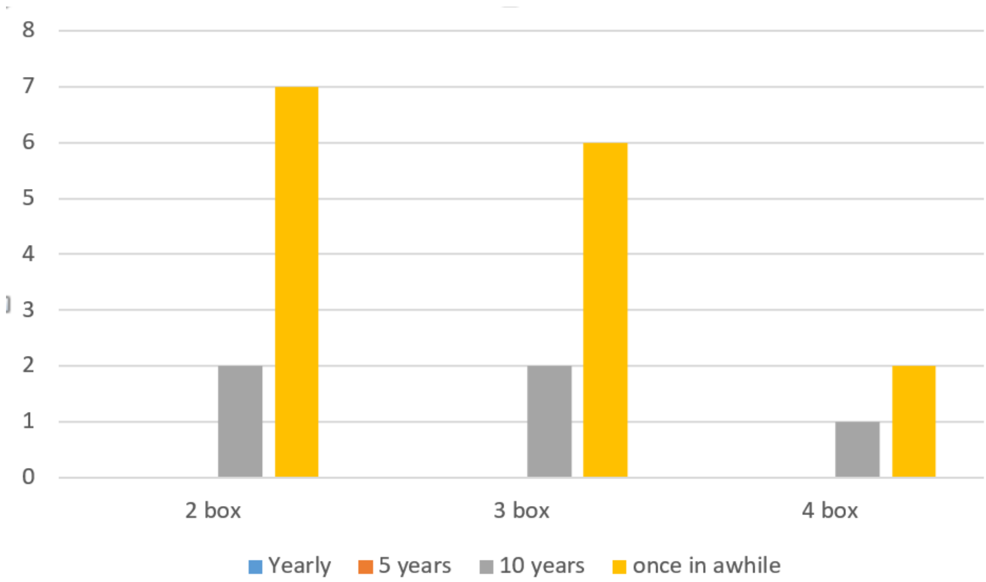


Figure D2. Frequency of cleaning culverts.

Question #6

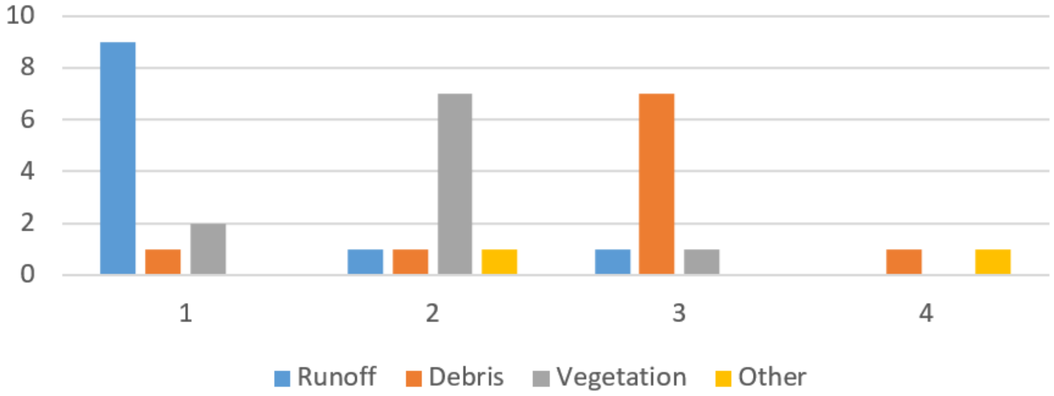


Figure D3. Ranking of the potential causes leading to sedimentation at multi-box culverts.

Question #7

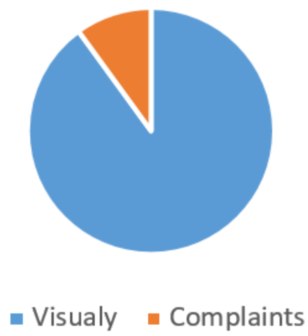


Figure D4. Methods of tracking sediment deposition growth.

Question #8

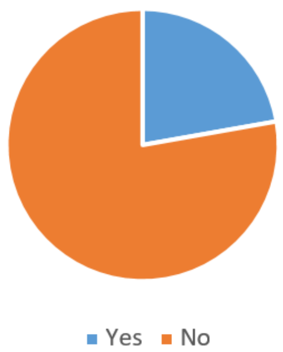


Figure D5. Observation of seasonal patterns in sedimentation growth.

Question #9

Table D1. List of successful solutions for mitigating sedimentation at culverts.

Possibly	1	
No	4	
Yes	2	Offset flow line with multiple barrels similar to MN.
		Mechanical Cleaning.
		Split level.

Question #10

Table D2. List of issues/problems associated with sedimentation at culverts that you consider to need further attention/research.

1	None, generally covered at today's presentation.
2	2-cell box culvert research is the largest problem that I have.
3	Stream bed degradation.
4	Loss of capacity, burying of farm tile.
5	Outlet sediment Control.