G.B. Gunlogson Student Environmental Design Competition Open Format

Project Title: Campbell Hollow Aquatic Organism Passage

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Abstract. *Providing passage for organisms through culvert crossings ensures healthy and enduring ecosystems. A stream restoration and rehabilitation design were created for bridge crossing at Campbell Hollow near Jerusalem, Arkansas. Although the culvert is in working condition, the low stream water elevation during low-flow conditions creates problems for aquatic organisms attempting to cross through the passage. Because of this, the USFS would like to increase the water elevation near the culvert to allow for better aquatic organism passage. Different alternatives were analyzed, including elevating the streambed, implementing rock weirs, and installing cross vanes, to increase the water elevation at the site. The alternatives were viewed through an economic, environmental, and social lens to determine what impacts these solutions might have on the area. The most feasible design was then modeled in HEC-RAS. A mixture of rock weirs and a raised armored streambed at the culvert exit was found to be the best approach. Large rocks at the culvert exit will keep the culvert flush with the stream and prevent scour, while piles of rocks at the entrances of the left and right culverts will funnel water through the center to keep water levels high enough for fish passage during low flow. During high flow events, water will flow through all three culverts so that the bridge does not flood during high flow conditions.*

Acknowledgments.

The senior design team would like to thank the following parties for their contributions and assistance throughout this process:

Matthew Anderson (United States Forest Service) and Sammie McDowell (United States Forest Service) for guidance and providing the opportunity to work on this project.

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Dr. Thomas Costello (U of A Biological Engineering Department) for organization and initiation related to the senior design project.

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INTRODUCTION

BACKGROUND

Solid bottom culverts disrupt streambeds and make movement difficult for aquatic organisms. Culverts that are narrower in diameter than a stream concentrate flow and increase water velocity. Culverts are also generally made of concrete or metal, which are smoother than the rocks and sediments of surrounding streambeds. The smoothness in relation to the surrounding streambed further increases the water velocity through a culvert. This makes upstream passage difficult, especially in headwaters, where most of the aquatic organisms are quite small and unable to swim against a heavy current. The higher water velocity that results from culverts also causes an erosion of the riverbed, as small rocks and sediment are flushed away at the culvert exit. This effect is called scour, and it further impedes aquatic organism movement by lowering the riverbed so that fish must jump to reach a culvert's entrance, which can be impossible for many small aquatic species.

Aquatic organism passage projects are often necessary to alleviate the negative effects of culverts on stream ecosystems. Aquatic Organism Passages are designs or augmentations that allow fish or other aquatic animals to have access to areas upstream of an impactful man-made structure. This can be done by lowering the flow velocity, raising the water level, mimicking the natural streambed, or armoring the streambed against scour.

CLIENT PROFILE

The United States Forest Service (USFS) for the Ozark-St. Francis National Forests is a faction of the US Department of Agriculture. The USFS manages many different national forests and grasslands, including 193 million acres of public land, and conduct sustainable stewardship for 600 million acres of forest land across the US. The agency's purpose is to "support nature in sustaining life" ("About the Agency | US Forest Service," n.d.). Like most government entities, the USFS is given an annual budget to which they must adhere. Their budget for the 2021 fiscal year was $5.3 billion. The Wildlife and Fisheries Habitat Management division of the USFS is devoted to the Aquatic Organism Passage Program. Previously, the USFS has replaced between 150 and 300 road-stream crossings annually (Heredia et al., 2016). Aquatic organism passage is currently difficult at Campbell Hollow. The USFS has been allotted a budget of roughly $10,000 to improve aquatic organism passage at this site. Because the USFS is dedicated to stream restoration and the Aquatic Organism Passage Program, members of the USFS community have offered guidance on approaching the project. Matthew Anderson, a forested fish and wildlife biologist, and Sammie McDowell, a Forest Engineer for the Ozark St. Francis, worked closely with the group throughout the design process.

SITE AND AQUATIC SPECIES DESCRIPTION

Campbell Hollow is a valley in the Ozark St. Francis National Forest through which Brock Creek runs. There is a road that crosses the stream by way of a concrete bridge. This bridge has 3 square close bottomed concrete culverts. For some of the year, the stream is dry and aquatic organisms live in small pools that remain throughout the stream. Observed wildlife within the stream include small species of minnow and crayfish. Our client has recommended that we assume the minnows in this stream have similar swimming abilities to a Redfin Darter, which is present in Brock Creek. This would mean that for fish passage, the water will need a velocity less than 28.0 cm/s (Table 1).

Figure 1. Bridge at Campbell Hollow

Table 1. Swimming Abilities of Fish Species (Layher and Rakstin, n.d.)

	Difficulty		
	Greenside Darter	Redfin Darter	Orangebelly Darter
n	9	8	29
min	15.62	13.72	13.48
max	40.20	40.20	45.81
mean	31.16	28.01	29.55
s.d.	8.11	11.30	10.82
	Cannot Hold		
n	9	8	29
min	19.09	16.82	16.82
max	45.81	45.81	53.56
mean	34.36	13.70	33.20
s.d.	8.95	11.28	11.42

PROBLEM STATEMENT

At the Campbell Hollow Crossing of Brock Creek in Jerusalem, Arkansas, inadequate low-flow conditions are present that prohibit aquatic organism passage through three closed-bottomed, concrete box culverts (Figure 2). High velocity waters have caused scour downstream and prevent stream species, such as minnows, from travelling through the culvert. Armoring needs to be created at the culvert exits that will correct for existing scour and prevent future scour. The goal is to alleviate migration barriers for aquatic and riparian species while holding paramount the priorities of the USFS.

PROJECT GOAL

The goals of this stream restoration, in terms of priority, are described below:

- The safety of the bridge is not compromised.

- Aquatic organisms, in particular the redfin darter, will be able to safely move upstream.
- Scour is prevented at the culvert exit.
- The appearance of the surrounding stream is mimicked and preserved.

Figure 2. Fast, Shallow Water and Drop at Culvert Exit

Figure 3. Natural Weir at Campbell Hollow

PROJECT SCOPE

The geographical scope of this project includes the areas in and around the Campbell Hollow bridge passage. Included in this will be hydrologic analysis, biological and ecological considerations, and structural components associated with the stream restoration. The culvert structure itself will not be modified, but instead will be designing a stream restoration to improve flow height, flow velocities, and scour at the site. Only small-scale hydrologic modeling related to the Campbell Hollow Reach of Brock Creek will be analyzed.

DESIGN OBJECTIVES AND CONSTRAINTS

Design Objectives

The design objectives that need to be satisfied are as follows:

- Use HEC-RAS to model the Campbell Hollow Reach of Brock Creek. Include in the model the Campbell Hollow bridge and culverts.
- Determine the 2-year and 100-year design storm flow rates for Campbell Hollow and model them into HEC-RAS.
- Model potential alternative solutions into the software and select an alternative based on feasibility and functionality.
- Size any rocks needed for scour protection and weirs.
- Write a report detailing the results of the simulation.

Design Constraints

- Design must fit within \$10,000 budget.
- Design must fit within current bridge structure without affecting stability.
- Low flow conditions must not exceed Redfin Darter swimming ability of 28.01 cm/s.

- Design must withstand 100-year storm.

Generation of Alternatives

Raw ideas were envisioned to provide different means or methods of technology that could be used to resolve the low flow issue at the culvert. To do so, fish movement up and downstream was visualized to understand how fish are impacted before and after possibly implementing one of the design alternatives. Those raw ideas are listed below:

- Rock weirs to raise water elevation near culvert.
- Cross veins with slight slopes.
- Raised streambed by adding rocks and possibly sediment.
- Combination of raised streambed and rock weirs.
- Rock wall to decrease width of the stream (grass channels for biological enhancements).
- Implementation of weirs at culvert entrance.

Evaluation of Alternatives

The alternatives were evaluated using a tabular method that compared alternatives based on constraints and desired characteristics (Table 2). Based on the original research and basic knowledge of the stream before designing the stream in HEC-RAS, three alternatives were selected and evaluated as potential solutions.

Rock Weirs

This solution involves placing weirs at various locations throughout the stream. The goal is to slow the volumetric flow rate of the stream, which causes the water elevation to increase towards the culvert exit. The rock weirs, for the purpose of this report, are defined as straight structures that span part or all of the creek. One key aspect of the weir is the notch, which must be sized correctly to allow an appropriate flow down the stream.

Cross Vane

The cross-vane is a grade control structure that typically consists of upstream angled lines of boulders and a connected section of smaller rocks upstream (Rosgen, 2021). According to Rosgen (2021), the cross vane decreases near-bank shear stress, velocity, and stream power, while increasing the energy in the center of the channel. They do this by establishing grade control and reducing bank erosion. Though similar to rock weirs, cross vanes in this report refer to structures that curve across the stream, as shown in Figure 4.

Additionally, the rock structure creates a stable width to depth ratio, improving flow. Implementing a cross vane also maintains channel capacity and sediment transportation capacity. Cross vanes are used to maintain base levels in riffle and pool channels, which might be beneficial for Brock Creek because it often experiences little to no flow. Cross-vanes are especially popular for their ability to improve the stream habitat.

Raised Streambed

This solution involves raising the entire streambed, especially near the exit of the culvert. This solution could be the most effective at raising the water elevation, however, it would be expensive to cover the entire stream bottom. Furthermore, precautions must be taken to match the rock properties that already exist at the

Table 2. Constraints and Desired Characteristics of Alternatives

	Constraints [X][1]		Desired Characteristics [++][2]		
Alternative (Name or Brief Description)	Meets Client Constraints	Fits Design Scope	Reasonable Resources	Mature Technology	Design Objectives
Rock Weirs	√	√	+++	+++	++
Cross Veins	√	√	+++	++++	++
Raised Streambed	√	√	++	++++	+++
Decreased Stream Width	X	√	+++	++++	
Combination of raised bed and rock weirs	√	√	+++	++++	++++
Implementation of Weirs at Culvert Entrances	√	√	++++	++++	++++

[1] X's represent options likely to be eliminated due to key elements not adequately meeting design characteristics.
[2] + symbols reflect the system's ability to reflect a desired characteristic. More +'s represent increased ability.

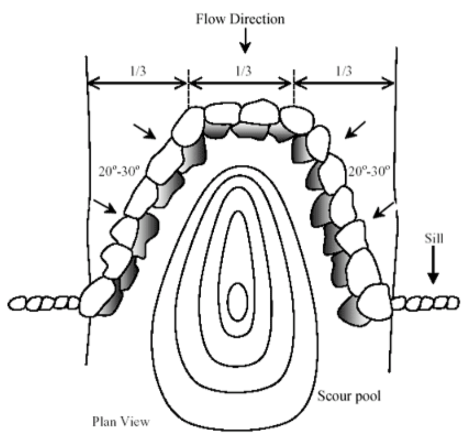

Figure 4. Use of Cross Vanes for Stream Pool Restoration (Rosgen, 2021).

site, as introducing unnatural environments could be harmful to the wildlife at the site. It is also necessary to ensure that the slopes remain slight to prevent scour. This solution might be effective close to the culvert exit, where a large elevation increase is needed to meet the invert of the culvert.

DESIGN DECISION

Ultimately, it was determined that installing rock weirs at the upstream entrance of the left and right culvert and placing rocks to armor the culvert exit was the best way to approach designing the system for adequate fish passage during low flow events. This decision was selected because it successfully raises the low-flow water elevation without causing extensive flooding during high flow events; furthermore, this solution is economically viable and should be reasonable to construct.

DETAILED ENGINEERING ANALYSIS

A detailed engineering analysis was conducted evaluating economic, environmental, and social impacts of the proposed alternatives on the stream, as seen in Appendix A.

ECONOMIC IMPACTS

As stated previously, the expected budget for this project is $10,000. The cost of the rocks needed for this solution is evaluated, as it was assumed that the rest of the work would be outsourced to an engineering, construction, or landscaping firm (Table 3). Since rock prices are based on square area, it was assumed that the weirs only occupied the entrance of the culvert (i.e. the weirs have no depth). A further assumption was that the streambed armoring at the culvert exit would span the entire width of the stream and extend 2 m past the culvert exits. The river rock gravel will be used to correct for scour that has already occurred in the stream. A 10% contingency is placed on the expected cost of the rock to ensure a conservative estimate.

Table 3. Expected Costs of Rock Weir and Armored Streambed Solution.

Capital Cost Inputs				
Good	Cost/lb	Density [lb/ft^3]	Amount [ft^3]	Cost
Rip-Rap Gravel Rocks	*$0.25	**100	51.46	$1,286.50
River Rock Gravel	*$0.20	***89	53.55	$953.19
			Expected Cost	$2,239.69
			10% Contingency	$223.97
			Capital Cost	$2,463.66

*Source: (Home Advisor, 2021)
**Source: (Aqua-Calc, 2021)
***Source: (ConCalc, 2021)

Totals	
Budget of Project	$10,000.00
Cost of Rocks	$2,463.66
Budget for Installation	$7,536.34

ENVIRONMENTAL IMPACTS

The environmental model contains emissions relating to transportation and rock mining. Comet-Farm was used to estimate emissions from transportation, which was assumed to include rock and equipment hauling as well as site visits (“Comet-Farm,” n.d.). Emissions related to rock-mining were separated into explosives, crushed stone processing, and other operations. Emissions from crushed stone processing and other operations were estimated based on existing case-studies of process emissions (Chalekode et al., 1978; Kittipongvises et al., 2016), while explosive emissions were estimated based on the amount of rock needed (Gilmartin, 2020; EPA, 1995). A summary of emissions from the selected alternative (rock weir and armored streambed) is available below in Table 4, with the full calculations available in Appendix A.

Table 4. Environmental Impacts Emissions Summary for Rock Weir and Armored Streambed Alternatives

	Greenhouse Gas Emissions (kg)		
	CO_2	NO_x	CH_4
Transportation	646.23	0.02	0.08
Rock Mining	12.26	0.00	0.00

SOCIAL IMPACTS

The effects of this project on local people's safety and health were considered for potential social impacts. Campbell hollow bridge is remote and does not receive much traffic, though a logging site is present past the bridge. Loggers should be able to cross the bridge safely, even during high-flow conditions. The creation of an aquatic organism passage could help to increase the environmental health of Brock Creek and larger rivers downstream. Opening more habitat for small fish can provide a valuable food source for larger fish that humans eat. This will have a positive social impact on local recreation and health. For example, the improved ecosystems could encourage outdoor recreational activities in the community, such as fishing.

SAFETY CHECK: HAZARDS AND MITIGATION

The biggest safety concern in raising the water elevation is overflow of the bridge during storm events. This could prevent people from crossing the bridge, which could be disastrous in emergency situations or when people simply need to cross the bridge to leave or return home. Routine signage employed by the FS should be deployed as a warning to drivers. Additionally, it should be ensured that the aquatic organism passage modifications should not compromise the structure and safety of the bridge. Furthermore, flooding could cause damage to property, including homes and vehicles. This risk is small, due to the remote location of the stream, but residents may need to be aware of the project and its potential impacts.

During the construction process, workers will also need to be safe while completing the project. Hard hats should be always worn, as well as any personal protection equipment (PPE) and appropriate footwear. These precautions help prevent injury and death for any workers.

ETHICS CHECK: IMPACTS AND MITIGATION

The first fundamental canon of the engineering code of ethics is that engineers shall hold paramount the safety, health, and welfare of the public (Fondriest Environmental, 2014). All engineers involved in the project should act with respect towards this ethical standard. The engineers who approve and implement this project should be qualified within the field of culvert integrity and aquatic organism passage design. There should be complete transparency with the public about the effects of this design. No conflict of interest should be involved in any part of the planning, funding, hiring, or implementation for this project. This project should serve to benefit the ecosystems in the Ozark Natural Forest Region while offering no severe repercussions to the public.

Documentation of Proposed System

System Overview

The goal of the aquatic organism passage is to provide adequate water depth for fish passage during low flow events. To accomplish this, an installation of rock weirs at the upstream entrance of the left and right culverts is proposed (Figure 5). These rock weirs will direct water into the central culvert during low flows only. Water will flow through all three culverts during high flows, which will prevent the bridge from flooding during high flood events, such as a100-year storm. To maintain velocities that allow redfin darter to traverse the culvert, substrate will be placed in the central culvert to create eddies in the current, which will create resting places for the fish. It is assumed that fish will avoid swimming upstream during large storm events. Additionally, the rocks used to create the weir will be large enough that they will not move during high flow events. A further recommendation is to place rocks at the culvert exits to armor the streambed against scour, which is currently an issue at the site (Figure 6). Preventing scour will also allow for easier aquatic passage by eliminating the jump that fish currently need to make to enter the culverts.

Component Details and Specifications

To model the stream, Hydrologic Engineering Center River Analysis System (HEC-RAS) was used. HEC-RAS is a hydraulic modeling software developed by the US Army Corps of Engineers to simulate characteristics of water bodies through steady flow models, unsteady flow models, sediment transport models, and water quality analysis (Benayas Polo, 2015). First, 1 m-resolution DEM files containing terrain elevations for Lake Conway Point were downloaded from USGS and implemented into RAS-Mapper. Then, a 2-dimensional flow model of Brock Creek watershed was created, with the exit point located approximately 150m downstream of Campbell

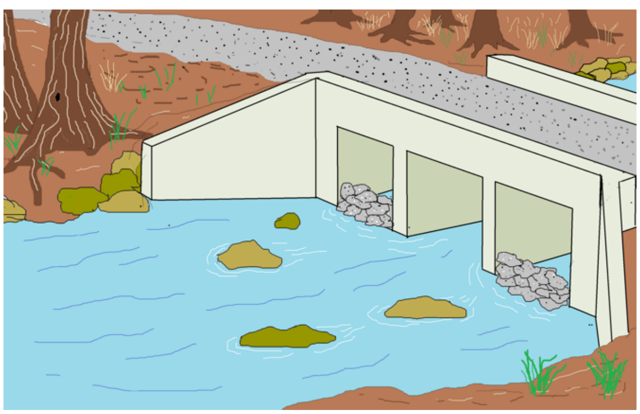

Figure 5. Illustration of Rock Weirs at Culvert Entrance

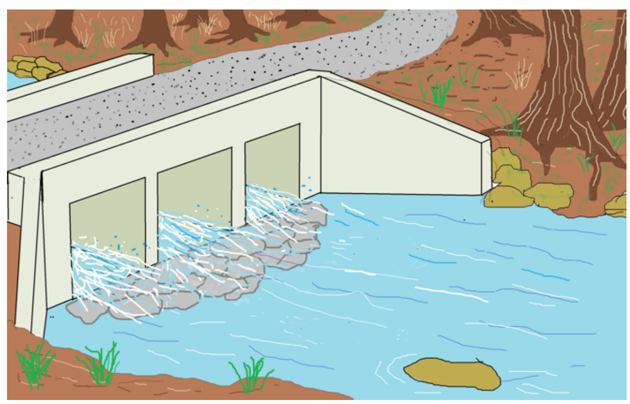

Figure 6. Illustration of Streambed Armoring at Culvert Exit

Table 5. Bridge and Culvert Characteristics at Campbell Hollow

Bridge Characteristics		Culvert Characteristics	
Width [m]	3.85	Span [m]	1.91
Length [m]	20	Rise [m]	1
Elevation [m]	296.2	Length [m]	3.85
		Manning's n	0.015

	Entrance Loss Coefficient	1
	Exit Loss Coefficient	1

Hollow Bridge. The bridge and culvert characteristics, as demonstrated in Table 5, were inputted into the software.

Next, the 2-year, 24-hour and 100-year, 24-hour storms were created for the Brock Creek Watershed (Figure 7 and Figure 9). The SCS method was used to create a unit hydrograph, and StreamStats software from the USGS was used to determine peak flow for the site (USGS, 2021). The full calculations are available in Appendix B. Additionally, Figure 8 and Figure 10 show the plan view when these storms are routed through the Campbell Hollow model. In Figure 5, it is evident that the 2-year storm causes only small pools of water to develop in the stream. For the 100-year storm in Figure 9, some bank overflow occurs, which is to be expected for such a large storm event.

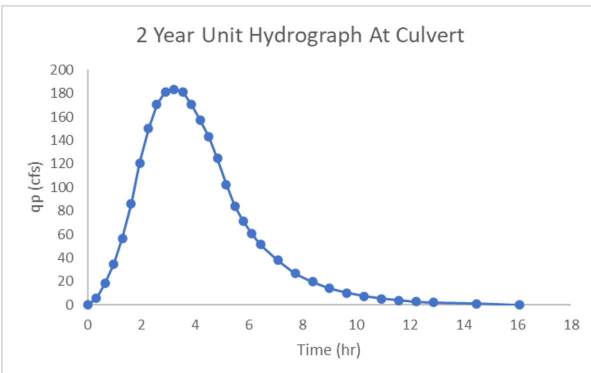

Figure 7. SCS Hydrograph for 2-year, 24-hour Storm at Campbell Hollow

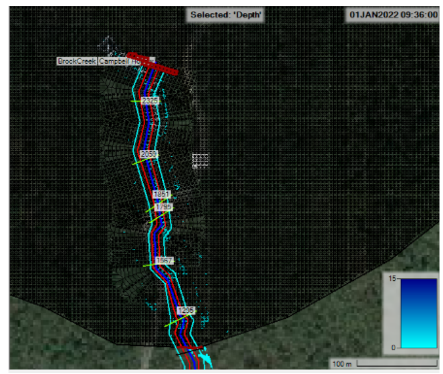

Figure 8. Plan View for 2-year, 24-hour Storm at Campbell Hollow

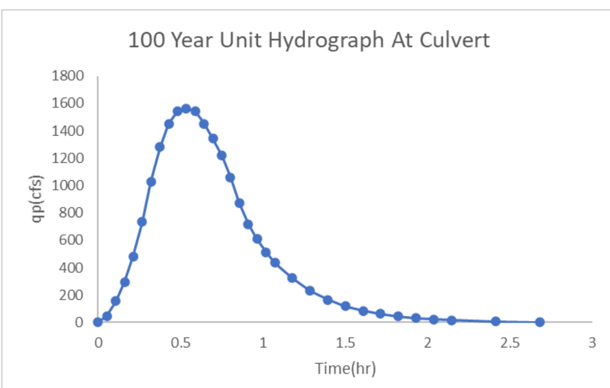

Figure 9. SCS Hydrograph for 100-year, 24-hour Storm at Campbell Hollow

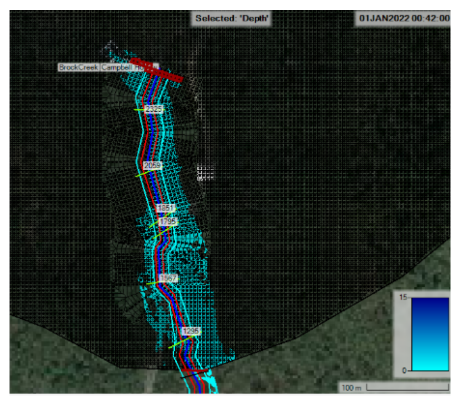

Figure 10. Plan View for 100-year, 24-hour Storm at Campbell Hollow

Once the two flow hydrographs, site elevations, watershed, and bridge and culvert were modelled into the software, an unsteady flow analysis could be completed for the present-day conditions. From Figure 11, it is evident that under low-flow conditions, the model shows a stable water elevation of approximately 0.1 m at the culvert entrance, which is inadequate for fish passage. In Figure 13 and Figure 14, it is evident that moderate scour has occurred at the culvert exit. The stream surface elevation at the culvert exit is approximately 0.5m below that of the culvert exit itself, signaling that scour has occurred at this location. The level of scour was verified by a site visit made. Additionally, Figure 12 demonstrates that the 100-year storm does not cause the bridge to flood. Overall, the stream exhibits flashy characteristics during the 2-year storm, meaning that at many times throughout the storm, the culvert is dry or nearly dry. There appear to be no issues with bridge flooding for the 100-year event under present-day condition.

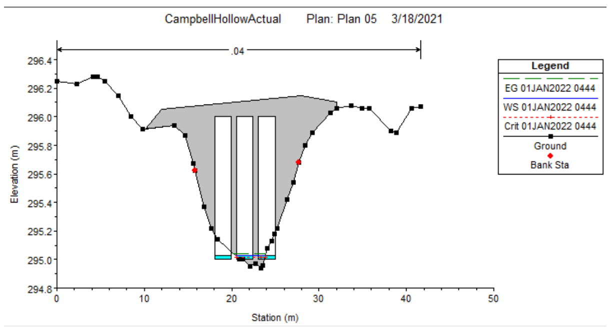

Figure 11. Upstream Culvert Profile under Present-Day Conditions for 2-year, 24-hour Storm

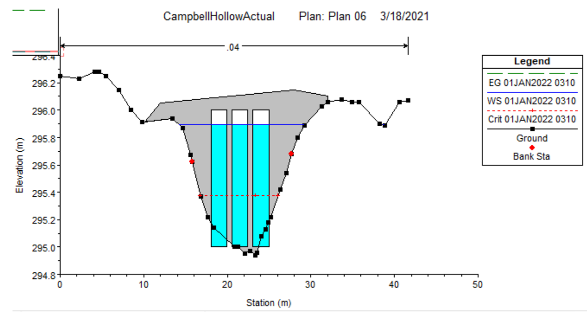

Figure 12. Upstream Culvert Profile under Present-Day Conditions for 100-year, 24-hour Storm

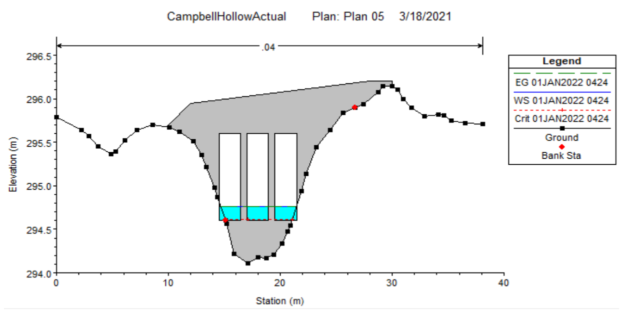

Figure 13. Downstream Culvert Profile under Present-Day Conditions for 2-year, 24-hour Storm

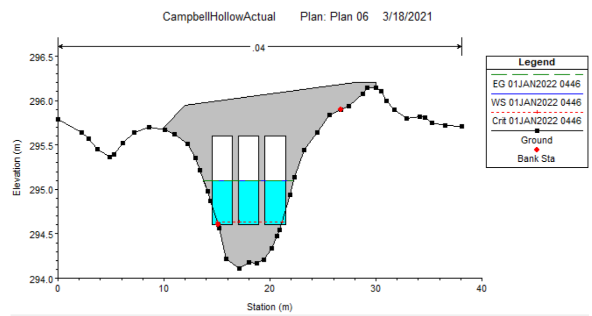

Figure 14. Downstream Culvert Profile under Present-Day Conditions for 100-year, 24-hour Storm

Next, rock weirs with a height of 0.2 m were modeled into the software by shortening the left and right culvert heights. Although the rock weirs will only be located at the culvert entrances, shortening the height of the entire weirs by 0.2 m was sufficient in modeling the effect of the weirs on the flow characteristics in the culverts. Furthermore, shortening the entire weir would represent a “worst-case” scenario for blocking flow, meaning the model provides some contingency for flow elevations during large storm events. Figure 15 shows that the water elevation in the center culvert entrance increased to approximately 0.35 m, which is more adequate than the 0.10 m shown in Figure 11. Figure 17 shows that the water elevation during the 100-year event does not flow over the bridge, meaning the rock weirs alternative meets the objectives as stated in the objectives section. Figure 18 shows that, at the culvert exit, some of the water flows outside of the stream; this is a potential issue for safety and property damage; however, the model shows that the overflow is minimal and deemed the risk as minimal. The USFS professionally licensed engineers should analyze this scenario if they believe there is a potential public safety threat from stream overflow.

It is important to ensure that the redfin darter can swim upstream through the culvert during low-flow conditions. If the velocity of the stream is too high during low flow conditions, fish will not be able to swim upstream, regardless of the height of water in the culvert. Even under current day conditions, passage through the culvert would be difficult for the redfin darter, as even the water velocity for the 2-year storm is greater than 28.01 cm/s for all times throughout the storm. The lowest velocity calculated during the 2-year storm event was 45 cm/s.

To fix this issue, the group proposes that rocks be placed randomly in the central culvert. Like the weirs, this strategy will be modeled by raising the height of the central weir by 0.2 m. Some water will flow around the rocks, so using this method will lead to a conservative estimate for the water elevation through the central culvert. The rocks used for the central culvert will be the same size as the rocks used for the weirs. The rocks will slow the velocity through the culvert and create eddies, which can serve as resting places for fish. The fish will be more likely to move upstream if these resting places are available. Thus, implementing this solution should aid in enabling fish passage, which is currently difficult at the site.

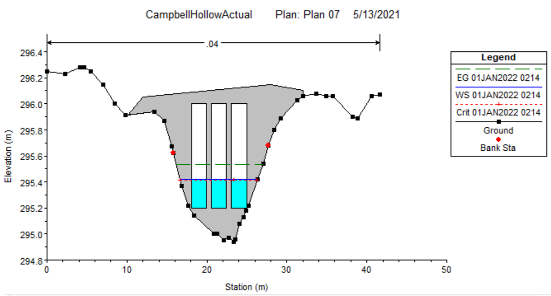

Figure 15. Culvert Upstream Profile under Proposed Conditions for 2-year, 24-hour Storm

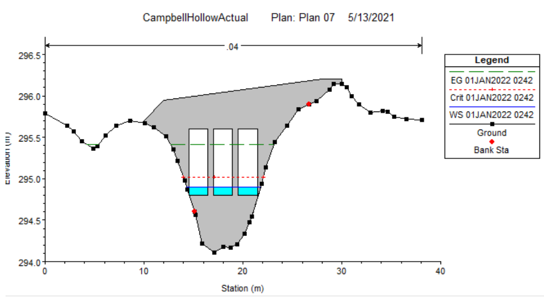

Figure 16. Culvert Downstream Profile under Proposed Conditions for 2-year, 24-hour Storm

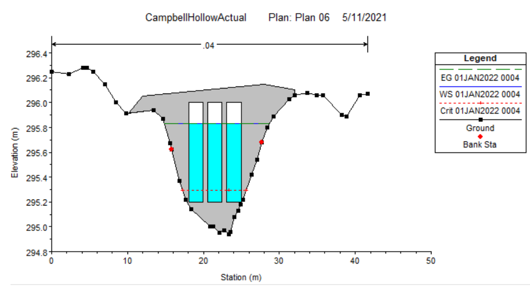

Figure 17. Culvert Upstream Profile under Proposed Conditions for 100-year, 24-hour Storm

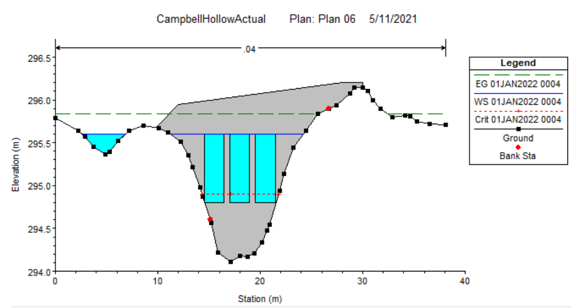

Figure 18. Culvert Downstream Profile under Proposed Conditions for 100-year, 24-hour Storm

With the rock weir solution proven to achieve the objectives of the project, the rock size needs to be calculated to ensure that the weirs are not blown out. The rocks were sized for the 100-year storm to ensure that even during high flows, the rocks would not be moved. Using the Ibash method (USDA, 2007), the average rock size needed for the weirs at the culvert entrance was calculated to be 2.20 ft, or 0.67 m (Appendix C).

CONCLUSION

Brock Creek at Campbell Hollow prohibits aquatic organism passage during low flow events due to inadequate water depth to swim up the culverts and a high culvert entrance due to scour. To create a proposed solution, the team modeled Brock Creek into HEC-RAS software and simulated flow with a design storm. The solution chosen is to place rocks of approximately 0.67 m at the entrance of the left and right culvert entrance to form weirs. This allows for water to flow through only the central culvert during low flow events, raising the water elevation and allowing for organism passage. During high flow events, water will flow through all three culverts, preventing the bridge from flooding. Rocks will also be placed at the culvert exits to prevent scour and keep the streambed flush with the culvert exit. To aid in fish passage, rocks will be placed in the central culvert to create eddies for the fish to rest.

This stream restoration is expected to benefit many of the aquatic organisms present in this region of Arkansas. By increasing the elevation of the stream through the culvert, fish will be able to swim upstream in search of food and spawning grounds. The redfin darter, which was recommended by the client as the design species, will be able to swim upstream under low flow conditions, as the 0.034 cm/s flow velocity through the culvert is slow enough for travel. Furthermore, with rocks armoring the exit of the culverts, scour will be prevented, which could improve water quality downstream due to decreased total suspended solids (TSS) in the stream. Overall, this solution will be effective in improving environmental conditions in the area while maintaining the safety of the bridge and providing social benefits to the people that use the bridge and visit or live in the area.

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May 15, 2021

To: ASABE Student Design Competition Judging Committee

RE: Certification of Project

As per the rules of the Gunlogson (Open) National Student Design Competition. I hereby certify that this submission is not part of any other ASABE student design competition.

Sincerely,

Thomas A. Costello, P.E., Ph.D.
Associate Professor of Biological Engineering
Undergraduate Program Coordinator
Senior Design Coordinator

The University of Arkansas is an equal opportunity/affirmative action institution.

APPENDIX A: ENVIRONMENTAL IMPACT MODELING

Transportation and rock mining will result in greenhouse gas emissions. The emissions from mining were separated into explosives, crushed stone processing, and other operations. To estimate the emissions from crushed stone processing and other operations, case studies from around the United States were analyzed, and average values were taken from these studies (Chalekode et al., 1978; Kittipongvises et al., 2016). For explosives, it was assumed that ANFO dynamite would be used, which has a blast radius of 7 tons rock/kg dynamite (Gilmartin, 2020; EPA, 1995). Explosive emissions were calculated based on the amount of rock needed, which was assumed to be 7.50 tons.

To estimate the transportation emissions, the amount of diesel required was estimated based on fuel economy of dump trucks (5.2 mpg) and the distance traveled by the trucks, which was estimated at 200 miles to be consistent with the economic impact model (Endres, 2018). The fuel efficiency of the truck decreases slightly when hauling the rocks to the site, but because 5.2 mi/gal is a conservative estimate for fuel economy, this decrease was ignored. Additionally, fuel was added to account for 2 group trips that would be taken from Fayetteville, AR to the Campbell Hollow site, which is around 145 miles. 2 trips of 145 miles each result in a total distance travelled of 290 miles. It was assumed that an F-150 would be taken to the site, which has an estimated fuel economy of about 19 mpg (EPA, 2020). Diesel impacts from mining were also included in this section because of fuel that would be needed to haul trucks and equipment around mining sites. The fuel consumption estimate was implemented into COMET-Farm software to determine the NOx, CO2, and CH4 emissions. A summary of the environmental model is available below.

Diesel Impacts								
	Dump Truck [runs on diesel]	Car [runs on gasoline]	Mining Impacts [diesel]		**Explosives**			
Distance [mi]	200.00	190.00			Tons of rock needed	7.50		
Fuel Efficiency [mpg]	5.20	19.00			Blast Ratio (ton rock/kg ANFO)	7.00		
Gas Required [gal]	38.46	10.00	16.43		Conversion to ton ANFO	0.00		
					Conversion to kg Nox	0.01		
					Conversion to kg CH4	N/A		
					Conversion to kg CO2	0.21		
Other Mining Impacts					SOURCE: (Gilmartin, 2020)			
	kg CO2 Emissions/ton rock	kg NOx Emissions/ton rock	kg CH4 Emissions/ton rock		SOURCE: (EPA, 1995)			
Explosives	0.03	0.001	N/A					
Crushed Stone Processing	12.02	N/A	N/A					
Various Operations	0.21	N/A	N/A					
Emissions Related to Hauling					**Greenhouse Gas Emissions (kg)**			
Liquid	Annual Fuel Savings [gal]	MMBtu	CO2	N2O	CH4	Total CO2 Eq	SO2	Nox
No. 2 Diesel	54.89	7.63	557.13	0.01	0.07	562.33	0.01	0.45
Gasoline	30.53	1.2	89.10	0.01	0.01	90.21	0.00	0.05
Total	85.42	8.83	646.23	0.02	0.08	652.54	0.01	0.50
("The owning and operating costs of dump trucks," n.d.)								
("A Dump Truck or A Rock Truck?," 2017)								
("COMET-Farm," n.d.)								

Figure 19. Environmental Impacts Model for Rock Weir and Streambed Armoring

APPENDIX B: DESIGN STORM CALCULATIONS

The SCS curve number method is the most efficient means for determining average annual runoff values by scaling single storm events using the rainfall amount and the curve number of the area. To calculate the peak discharge and create functioning hydrographs, information about the land use, hydrological soil group (HSG), and hydrological conditions of the soil must be collected ("SCS Curve Number Method," n.d.).

The SCS Method utilizes the following equations:

$$S = \left(\frac{1000}{CN}\right) - 10 \quad Q(2{,}24) = \frac{(P_{24} - 0.2S)^2}{P_{24} + 0.8S}$$

$$q_p = q_u A Q \quad I_a = 0.2S$$

Where S is total retention (in), CN is the SCS curve number, Q is total runoff (in), I_a is initial abstraction, P_{24} is the 24-hour precipitation at the desired frequency (in), q_p is peak discharge (csm/in), and q_u is unit peak discharge (csm/in). Based on the soils of the site, which are HSG D, forest, good hydrologic conditions, an appropriate CN value for the site is 77 (USDA, 2019).

$$S = \left(\frac{1000}{77}\right) - 10 = 2.99\ in$$

$$I_a = 0.2 * (2.99\ in) = 0.597$$

P_{24} can be calculated for the 2-year storm and the 100-year storm (NOAA.gov, n.d.):

$$P(2{,}24) = 4.2\ in \quad P(100{,}24) = 8.4\ in$$

From StreamStats (2021), $q_p(2{,}24)=183\ ft^3/s$ and $q_p\ (100{,}24)=1560\ ft^3/s$. The area of the watershed was 0.83 mi^2. With this data calculated, the total runoff and the unit peak flowrate for each storm can be calculated:

$$Q(2{,}24) = \frac{(P_{24} - 0.2S)^2}{P_{24} + 0.8S} = \frac{(4.2 - 0.2(2.987))^2}{4.2 + 0.8(2.987)} = 1.97\ in$$

$$Q(100{,}24) = \frac{(P_{24} - 0.2S)^2}{P_{24} + 0.8S} = \frac{(8.4 - 0.2(2.987))^2}{8.4 + 0.8(2.987)} = 5.64\ in$$

$$q_u(2{,}24) = \frac{q_p(2{,}24)}{AQ} = \frac{183\frac{ft^3}{s}}{(0.83\ mi^2)(1.97\ in)} = 111.92\ csm$$

$$q_u(100{,}24) = \frac{q_p(100{,}24)}{AQ} = \frac{1560\frac{ft^3}{s}}{(0.83\ mi^2)(5.64\ in)} = 333.25\ csm$$

Using this information, the time of concentration, t_c (hrs) and the time to peak, t_p (hrs) can be found from the SCS method graphs with I_a and q_u known (USDA, 1986). A type III rainfall distribution was assumed.

$$\frac{I_a}{P(2{,}24)} = \frac{0.597}{4.2in} = 0.142$$

$$\frac{I_a}{P(100{,}24)} = \frac{0.597}{8.4\ in} = 0.071 = 0.10$$

$$t_c(2{,}24) = 0.8\ hrs \quad t_c(100{,}24) = 4.8\ hrs$$

$$t_p(2{,}24) = 0.67 * (0.8\ hrs) = 0.53\ hrs \quad t_p(100{,}24) = 0.67 * (4.8\ hrs) = 3.22\ hrs$$

APPENDIX C: ROCK SIZING CALCULATIONS

The Isbash method is used to calculate the appropriate size of rocks to be placed at the culvert entrances and exits (USDA, 2007). The rocks must be large enough that a strong flow will not dislodge them and create scour.

$$v_c = C * \left(2 * g * \frac{\gamma_s + \gamma_w}{\gamma_w}\right)^{0.5} * D_{50}^{0.5}$$

D50 is the median stone diameter that should be used at vc, C is the Isbash Constant (0.86 will be used for high turbulence), g=32.2 ft/s2 □s= stone density(lb/ft3) = 169 lb/ft3 for granite ("Density of Selected Solids," n.d.), □w= water density (lb/ft3)= 62.4 lb/ft3 ("Density of Selected Solids," n.d.), and vc=critical velocity (ft/s) of the water approaching the culvert.

Next, the peak flowrate and the cross-sectional area of the stream will be used to calculate vc.

$$\frac{Q_p}{A} = v_c$$

$$A_{culvert\ entrance}\ (100 - year\ storm) = 117.76\ ft^2$$

$$v_c = \frac{1560\ ft^3/s}{117.76\ ft^2} = 13.25\ ft/s$$

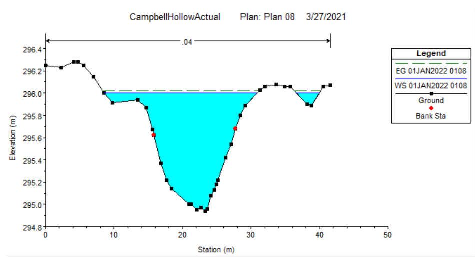

Figure 27. Cross-Sectional Area Upstream of Culvert for 100-year, 24-hour Storm

$$D_{50} = \left(\frac{13.25\frac{ft}{s}}{0.86 * (2 * 32.2\frac{ft}{s^2} * (\frac{169\frac{lb}{ft^3} - 62.4\frac{lb}{ft^3}}{62.4\frac{lb}{ft^3}})^{0.5}}\right)^2$$

Therefore, D50 equals 2.2 feet or 0.67 m.