APPENDIX A

CATOCTIN AQUEDUCT RESTORATION METHODS FOR ALTERNATIVE C

DRAFT

CATOCTIN AQUEDUCT PROJECT METHODOLOGY

Background

Dr. George Lewis and the Catoctin Aqueduct Restoration Fund, Inc. (CAR) engaged the services McMullan and Associates Structural Engineers (M&A) to examine the existing structural conditions of the Catoctin Aqueduct located in the Chesapeake and Ohio Canal National Historical Park (C&O Canal NHP) and to propose restoration measures. The findings of this effort were captured in a feasibility report that has been presented to the C&O Canal NHP. In brief, the report describes the extant conditions and provides two alternatives for the restoration of the aqueduct. The report also provides conceptual cost estimates for the two alternatives.

Using the feasibility report as a starting point the C&O Canal NHP and the CAR have entered into a partnership to execute the restoration of the Catoctin Aqueduct. The project has been reviewed and approved by the National Park Service Development Advisory Board (DAB). This approval has given the project the ability to move forward to the next level of design development.

Park staff consisting of the Park Engineer, Staff Engineering Technician, and the Preservation Project Manager have joined M&A in the overall project design development. From the first meetings of the design development team a series of treatment methodologies have been established to comply with Section 106 of the National Historic Preservation Act and the *Secretary of the Interior's Standards for the Treatment of Historic Properties.*

The following captures the current treatment methodology for the Catoctin Aqueduct Restoration Project. This is a working DRAFT intended to track and document design development decisions and treatment solutions. The descriptions are broken down by project component and or aqueduct feature.

Arches

Elliptical Arch

Structural analysis of the center span elliptical arch performed by both M&A and by structural engineers as part of the post collapse Recommendations for Repair and Restoration, December 1973 has shown the geometry of the elliptical arch develops tensile forces at the quarter points that would cause the stone masonry arch to deform and fail. Therefore, the arch was bound to fail eventually and the fact that it did not fail sooner is contributed to the stiffening properties of the prism parapet walls. With this being the case the only way to restore the center arch span so it can resist dead load and vehicle load forces is to construct the arch using reinforced concrete. The concrete core would be designed to carry the stone masonry spandrels, parapets and prism walls.

This will require both new and reused voussoir stones to be cut to a consistent depth of 12 inches to accommodate the structural cast in place concrete core arch. The soffit or intrados of the arch will be cast using a form liner that will give the concrete the texture and appearance of stone masonry.

Semicircular Arches

East Arch

The east arch is only partially collapsed. The north elevation voussoir stones and a portion of the arch soffit or intrados are missing. To date only 14 voussoir stones from the semicircular arches have been identified amongst the salvaged stones. At this time it is being discussed these stones will be used on the north elevation of the east arch. The intrados of the arch would be repaired with cast in place concrete using the same form liner method described for the elliptical arch. The reused voussoir stones would be laid in their full depth and the cast in place repair would conform to their shape.

West Arch

The semicircular west arch will be treated in a similar manner to the elliptical arch. The core of the arch will be constructed of reinforced cast in place concrete.

Reuse of Salvaged Stone

At this time all of the stock piled stone salvaged after the 1973 collapse has been exposed, roughly sorted, and identified. The team is still waiting for the testing results to determine if the stones can be reused. However, for discussion purposes it is assumed they can and will be reused.

Major floods impacted the aqueduct in 1936, 1942?, and 1972. These floods had caused the up creek elevation to partially collapse. Photographs show a large portion of the central span and the berm parapet were missing prior to the full collapse. There is no record of any effort to salvage any of the stone that had fallen prior to the collapse in 1973. There are stones strewn along the creek bed up to 200 yards below the aqueduct. It is assumed that this stone is from the north elevation. Therefore, the majority of the stone that was recovered following the collapse is assumed to be from the south elevation of the aqueduct.

Based on the observations noted above the focus of the use of salvage stone will be on the south elevation of the aqueduct. This effort will be supported by multiple photographs of the elevation before the collapse (at this time no photographs of the <u>complete</u> north elevation have been located). Using historic photographs an effort will be made by the C&O Canal NHP design team members to match character defining stones to their original locations. This will be accomplished by measuring individual stones on site and cross referencing them with stones in scaled photographs. An elevation drawing showing the outline of each stone in the aqueduct will be used to record the locations of each identifiable stone. New stones will be used to “close” each course or to infill where the historic stone cannot be identified. Limited trimming will be employed to ensure proper bedding of the stone.

Stone not used on the south elevation will be used on the north elevation. They will be laid from the abutments toward the center arch (it is assumed that some of the salvage stone came from these locations when the aqueduct collapsed in 1973) The laying of these stones will be executed in a manner that follows the patterns and rhythms of the south elevation as depicted in historic photographs. Every effort will be made to use the stones in full lengths with only limited trimming. New stones will be cut to length to fit between runs of historic stones. Head joints will be offset by a minimum of the course height.

Salvage stones will be used for the original intent. Stones will not be cut down in height to “make” stones of lower course height. For example a 16 inch course stone will not be cut down to make a 12 inch course stone. The remaining portion of the voussoir stones that are cut down in length to accommodate the cast in place arch core will not be reused to make other voussoir stones.

Analysis of Recovered Salvage Stone

The following is a rudimentary analysis of the stones that were salvaged from the creek bed. The stones are referenced by type and/or course height:

Towpath Coping Stones

> 80 linear feet with railing remnants in place + 48 linear feet with mule rail anchor bolt remnants = 570 square feet of towpath coping.

Berm Coping Stones

> 120 square feet.

Water table

> 72 linear feet.

Spandrel and Parapet Wall Stones

> Course height:
>
> 12” – 763.14 linear feet / 763.14 square feet – Need 513 SF for down creek elevation (located in the spandrels and parapets of both elevations)
>
> 13” – 50.3 linear feet / 54.32 square feet (berm parapet)

14” – 205.13 linear feet / 237.95 square feet (towpath parapet)

15” – 166.40 linear feet / 208.12 square feet (towpath parapet) There is a total of 247 SF needed of the 14” and 15” courses, combined we have 446 SF.

16” – 137 linear feet / 182.8 square feet (berm parapet)

NOTES:

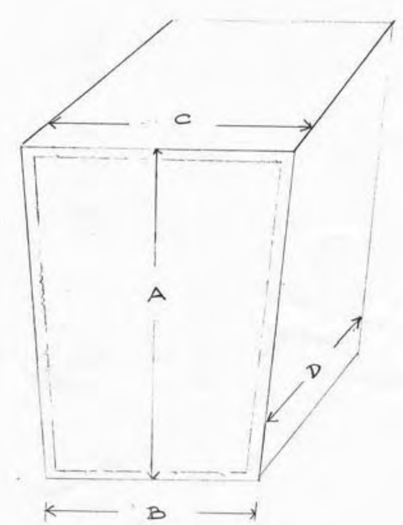
1. The inventory does not differentiate between prism stones and exterior elevation stones. These are identifiable (The prism stones are smooth and water worn) but the differences were not apparent until mid way through the inventory process.
2. The need quantities for the spandrels were taken from the elevation drawing with areas calculated by McMullan & Assoc. The parapet wall stone areas were calculated using the course heights multiplied by 102 linear (the gap between the extant aqueduct west abutment and east arch)

Semi Circular Voussoir Stones

14 – depths range from 20 inches to 34 inches. See accompanying illustration and table.

Elliptical Voussoir Stones

36 – depths range from 20 inches to 66 inches. See accompanying illustration and table.



Voussoir Stone Dimensions

Semi-Circular Voussoir Stones					
No.	A	B	C	D	Notes
1	24”	14”	15”	21”	
2	24”	12”	14”	24”	
3	24”	14”	15”	23”	
4	24”	14 ½”	15”	20”	
5	21”	12 ½”	14”	21” (note)	Broken Face
6	24”	14 ½”	15 ½”	23”	
7	24 ½”	12”	14”	22 ½”	
8	24”	14”	15”	24”	
9	23 ¼”	14”	15”	20”	
10	24”	14”	15”	30”	
11	24”	14 ½”	15 ¼”	23”	
12	25”	12 ¼”	13”	34”	
13	24 ½”	11 ½”	12”	34”	
14	24”	12”	13”	25”	

Elliptical Arch Voussoir Stones					
No.	A	B	C	D	Notes
1	25”	12 ½”	15 ½”	34”	
2	25”	12 ½”	15 ½”	27	
3	25”	15”	18”	24”	
4	25”	12 ½”	15”	34”	
5	25”	12 ½”	14”	23”	
6	25 ½”	13”	16”	28”	
7	25”	12 ½”	15”	33 ½”	
8	25”	12 ½”	15”	66”	
9	25”	12”	15 ½”	33”	
10	25”	12”	15”	24”	
11	25”	12”	15”	22”	
12	25”	12”	15”	24”	
13	25”	12 ½”	14”	44”	
14	25”	13”	15”	21” (note)	Broken Face
15	25”	13”	15”	24”	
16	24 ¼”	14 ¾”	16”	56”	
17	25”	12”	16”	28”	
18	26 ½”	13”	15 ½”	24”	
19	26 ½”	12 ¾”	16”	20” (note)	Broken Face
20	26 ½”	15 ½”	19 ½”	42”	
21	27”	12 ½”	15 ½”	25”	
22	27”	13”	16 ½”	26”	
23	27”	13”	15 ½”	22”	
24	27”	15”	16”	24” (note)	Broken Face

Elliptical Arch Voussoir Stones					
No.	A	B	C	D	Notes
25	29”	13 ½”	15 ½”	35 ½”	
26	30”	17”	17 ½”	48”	
27	25” (note)	17”	21”	34”	Missing half of the face
28	25”	16”	20”	34”	
29	25”	13”	13”	24”	
30	25”	12 ½”	14”	11” (note)	Broken back
31	25”	13” (note)	13” (note)	25”	Broken faces
32	25” (note)	12” (note)	14”	44” (note)	Broken face
33	25” (note)	15” (note)	14”	24” (note)	Broken face
34	25” (note)	18” (note)	20”	18” (note)	Broken Face
35 (note)	25”	12”	15”	24”	May or may not be arch stone
36 (note)	25”	12”	15”	24”	May or may not be arch stone

There are several more steps to take in the stone inventory process. First, templates must be made of the elliptical arch stones in order to identify which ones are missing and to make an attempt of constructing the arch geometry. The templates will be laid out in a warehouse location so the geometry can be established and recorded. During this effort further analysis of the suitability for reuse must be reviewed for these stones. As noted above some have damaged faces and may not provide enough bedding surface for reuse. Second, the wall stones need to be sorted into two categories: prism stones and exterior wall stones. Then an effort will be made to identify the locations for each stone on the south elevation. This will require each stone to be given a discreet number / letter designation. The stone number will be recorded on an elevation drawing for use in the restoration. Stones without an identifiable location will be used on the north elevation as described above. It is anticipated that this will take place over the next month or so.

Stones Still in the Creek Bed

If the stone testing results conclude the stones from the creek bed are reusable the idea of salvaging stone will be studied. The undertaking will have to be reviewed as part of the Environmental Assessment for the overall project.

- END -

APPENDIX B

CATOCTIN AQUEDUCT
SCOUR EVALUATION AND UNDERWATER INSPECTION REPORTS

MEMORANDUM

TO: Mr. Andrzej Kosicki, Assistant Division Chief
OBD - Bridge Hydraulics

FROM: Larry R. Bolt, Assistant Division Chief
Engineering Geology Division

DATE: November 2, 2006

SUBJECT: Catoctin Aqueduct
Scour Evaluation
Frederick County – Lander, Maryland

We have completed our investigation of scour potential for the Catoctin Aqueduct. Site visits were completed by Engineering Geology personnel on August 30 and October 3, 2006. The attached Engineering Geology Report contains our findings and recommendations.

If we can be of further assistance, please contact Karen Kalbaugh at 410-321-3076 or Larry Bolt at 410-321-3080.

LRB/kek

Phone: 410-321-3107
Fax: 410-321-3099

The Catoctin Aqueduct
Scour Evaluation
Frederick County
Lander, Maryland

Executive Summary

The Catoctin Aqueduct, an historical landmark, is part of the C & O Canal in Lander, Maryland. This report outlines the geology of the Catoctin Creek in the vicinity of the aqueduct and provides an assessment of scour potential for the area. Recommendations for the rehabilitation of the west pier are also presented in this report.

Geology

The Catoctin Aqueduct project site is located in the Blue Ridge geological province. The general area is characterized by Neoproterozoic aged rocks (1 to ½ billion years before the present) that have been folded, faulted, and metamorphosed. The folding, faulting, and metamorphism of the Blue Ridge Province is a result of continental drift and the collision of land masses that formed the eastern coast of North America. During this time, intrusions of igneous rock material invaded the area forming multiple diabase dikes; and metamorphic processes of heat and pressure produced the several rock types that are found at the project site. The intermittent upheavals and grinding of rock over this period resulted in a regional shear zone measures several miles long and wide.

Rock types that have resulted from the tectonic forces and metamorphic processes in this area can be classified into three major groups: mylonites; cataclasites; and phyllonites. Mylonites are fine-grained rocks formed from extreme granulation of originally coarser rocks. These rocks are products of extreme dislocation metamorphism without notable chemical alteration. Cataclasites are rocks deformed by shattering without chemical reconstitution. These rocks grade into mylonites with increased deformation. Phyllonites, like mylonites, are formed from granulation of coarser grained rocks. However, phyllonites exhibit advanced chemical alteration and have a silky appearance.

Photo 1. Mylonitic rock along railroad tracks north of project site.

The rock outcrops within the project location consist of alternating layers of metadiabase (greenstone-metamorphosed basaltic lava) and mylonite. Outcrops along the Catoctin Creek trend in a northeast direction and strike from N14°E to N22°E. The rocks dip approximately 52 to 57 degrees to the southeast. Quaternary alluvium and river terraces of a much younger age overlie the greenstone and mylonitic formations. The terraces are composed of sand, gravel, and boulders that underlie relatively flat benches.

Photo 2. Rock outcrop orientation at project site.

The greenstone formations found at Catoctin Creek are coarse-grained with fine-grained chill zones. Chilled contacts are formed from the rapid cooling of magma entering an older, existing rock body. The greenstone is part of the series of intrusive diabase dikes throughout the area that formed by invasion through cracks and fissures of the shear zones. The greenstone is hard, resistant to weathering, and shows high relief in contrast to the adjacent mylonitic rock.

Photo 3. Contact between mylonite and diabase dike.

The mylonites occur within smaller, localized shear zones and is softer material that is more susceptible to differential weathering and scour forces.

North of the project site is a set of railroad tracks that expose rock outcrops along their north side. On examination, the rock outcrops east and west along the railroad tracks display a series of faults and resultant shear zones. The shear zones are concurrent with the strike and dip of the rock formations and conform to the geology at the aqueduct. Secondary shear zones and dike intrusions are also found at this location. Rocks identified in the area of the railroad tracks include mylonites, cataclasites, and phyllonites. The cataclasites are made up of augen gneiss (blue gneiss) as described in the local geology. Rocks along the tracks are typically brown, and highly weathered to crumbly.

Photo 4. Outcrops north of tracks with shear zones.

Photo 5. Weathering of rock (note spherical weathering in lower right).

The Aqueduct

The abutments of the Catoctin Aqueduct are situated on the east and west banks of the Catoctin Creek with east and west piers in the stream channel. Both abutments are built on the hard metadiabase intrusions. Several missing stones from the structures can be seen along the waterline, however, the amount of scour beneath the structures is minimal. Information obtained from divers verifies that little to no scour or undermining is present beneath the abutments. This is evidenced by the absence of cracking, movement, and settlement of the structures. The channel bottom the structures rest on is described as being rocky and uneven.

Photo 6. East abutment and wingwall.

Photo 7. West abutment and wingwall.

The geological foundation of the east pier is similar to that of the bridge abutments. The east pier is built on the hard material of the metadiabase dike, therefore little scour was detected beneath the structure.

The west pier has experienced the most structural deterioration of all the aqueduct components; an extensive void is visible above the waterline. The underwater investigation revealed a void on the east side of the structure that measures approximately 8'x 3'x 5'. The material in the channel at this location is described as being gravel-sized, loose and unstable. The characteristics of the geological formation that the pier is built on correlates to the softer mylonite rock that alternates with greenstone within the shear zones.

Photo 8. West pier along its east side.

Recommendations

To retain the existing pier, the rock material that is susceptible to scour should be covered to secure the area from scour forces and abrasion. Cement grouting by tremie pipe behind temporarily placed grout bags is an effective and economical method for stabilizing the foundation.

Removal and replacement of the west pier and its foundation is an alternative that will provide greater structural stability of the pier. This method of rehabilitation can be achieved by cataloging the individual stone before deconstruction of the pier, placing a spread footing, then replacing the stones as a façade to resemble the original structure. Water flow in the channel will need to be stopped either by diverting the stream or by the construction of a temporary cofferdam.

UNDERWATER INSPECTION

AND EVALUATION

OF

CATOCTIN AQUEDUCT

OVER

CATOCTIN CREEK

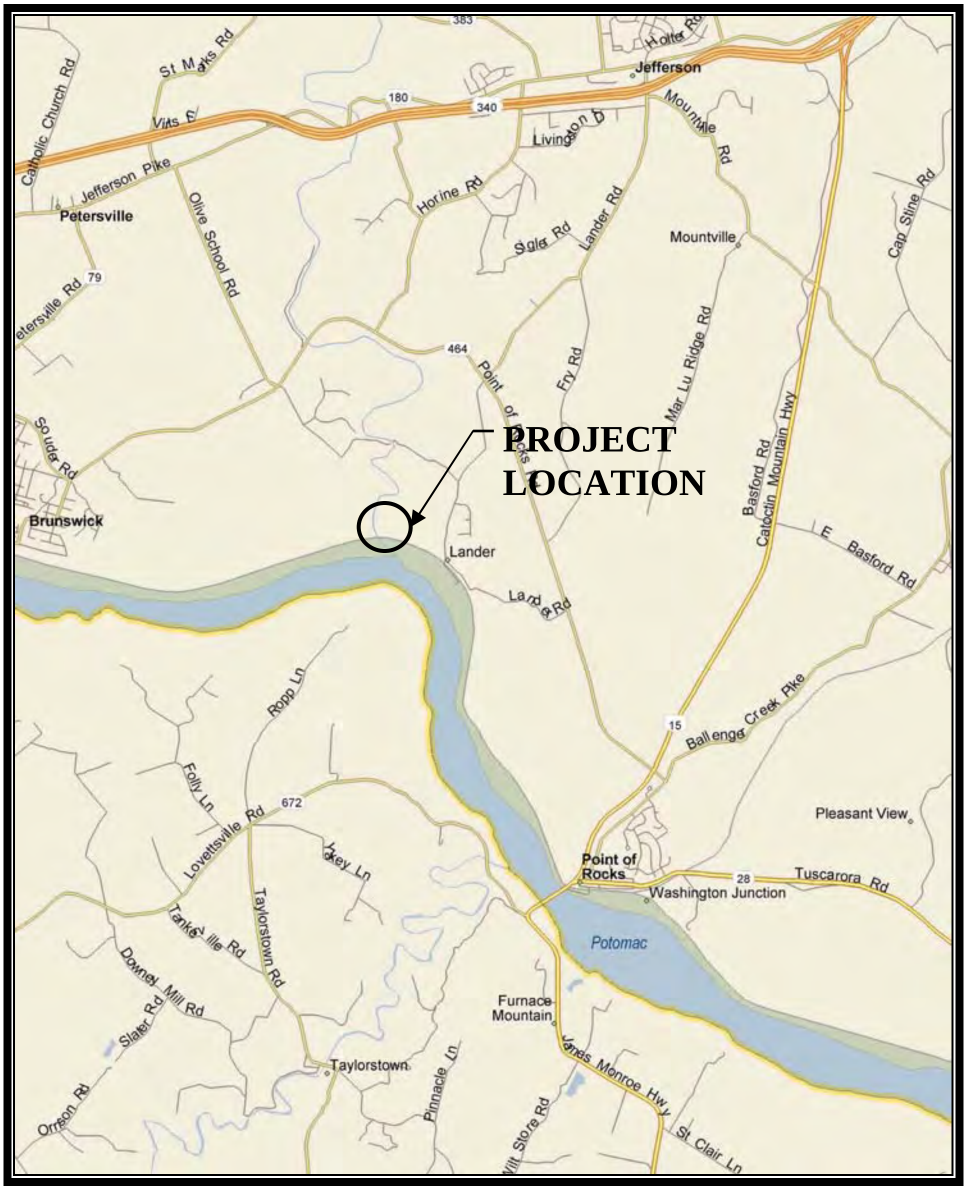
LANDER, MARYLAND

<u>Prepared For:</u>
McMullan & Associates, Inc.
8381 Old Courthouse Road, Ste. 350
Vienna, VA 22182

<u>Prepared By:</u>
W.J. Castle, P.E. & Associates, P.C.
P.O. Box 586 - 693 Main Street, B1
Lumberton, NJ 08048

William J. Castle, P.E.	**Date**
MD License No. 13701	

CATOCTIN CREEK



GENERAL LOCATION MAP

TABLE OF CONTENTS

UNDERWATER INSPECTION
CATOCTIN AQUEDUCT
SEPTEMBER, 2006

I. GENERAL INFORMATION

W.J. Castle, P.E. & Associates, P.C. was retained by McMullan & Associates, Inc. to perform an underwater inspection and evaluation of the Catoctin Aqueduct over the Catoctin Creek located in Lander, Maryland. Partial plans of the aqueduct were available for our use before, during and after the inspection. However, no plans of the existing portion of the substructure units are known to exist. The underwater inspection included the following substructure units:

1. West Abutment & Wingwall
2. West Pier
3. East Pier
4. East Abutment & Wingwall

Access to the structure was obtained by traveling up the Catoctin Creek using a 14' motorized zodiac boat which was launched from a public ramp in the park area.

The aqueduct has partially collapsed at various locations and is no longer functional. A temporary Bailey Bridge has been constructed just south of the aqueduct and is currently used to cross the Catoctin Creek.

The intent and objective of the inspection was to determine the overall condition of the substructure units, the degree of deterioration, missing stones, water depths and repair feasibilities as may be required.

II. INSPECTION PROCEDURES

The inspection was performed using surface supplied air with two-way communications. The dive console or station was set up on the West Pier and the entire inspection was coordinated from this location. The inspection consisted of only two persons instead of three due to the type and limited hazards of the inspection. The underwater inspection was performed by William J. Castle, P.E. with assistance from Mark Kremper, Tech./CBSI.

UNDERWATER INSPECTION
CATOCTIN AQUEDUCT
SEPTEMBER, 2006

The inspection was performed on August 30, 2006 over a 3 to 4 hour period and started at the East Abutment and wingwall. The inspection then proceeded west inspecting the East Pier, West Pier and finally the West Abutment and wingwall. Soundings were taken at various locations around each substructure unit. These soundings were then tied into a permanent location for future reference. The permanent location was on the temporary bridge at the south end of the West Pier. The channel bottom was also visually inspected for type of material and any scouring activity.

The substructure units were inspected from above the waterline down to the channel bottom for loose, missing or misaligned stones, scouring activity, debris, etc.

III. INSPECTION RESULTS

The results or findings of our inspection area as follows:

A. East Abutment & South Wingwall

The overall condition of the stone abutment and wingwall was found to be satisfactory with no cracking or settlement. No mortar was found at any joint location in the stone foundation. The stones below water were found to be placed non-uniformly and not level at the channel bottom. The stones were placed on an un-even rock formation at the channel bottom and then eventually filled-in or leveled as the foundation was constructed.

This resulted in voids located at various locations along the abutment face at the channel bottom. Large voids with missing stones were found near the north end of the abutment. However, no settlement or movement was found along the East Abutment or wingwall as a result of these voids. Extensive timber debris at the north end limited the underwater inspection in this area. The channel bottom in this area and also between the abutment and East Pier was found to be primarily rocky (rock ledges and loose rock) with soft silt. The silt reduced the overall visibility to zero when disturbed during the inspection. Water depths varied from 2'-0" at the south end to 3'-6" at the north end.

B. East Pier

The East Pier was found to be in overall satisfactory condition. Stone construction is similar to the East Abutment with rocky channel bottom. No mortar was found in any of the joints around the pier. The north end of the pier could not be thoroughly inspected due to extensive timber debris, broken concrete, and reinforcing steel. A concrete end panel was found to be constructed at the north end in front of the pier and is in satisfactory condition. A concrete T-beam was found on the bottom along the west side of the pier with steel reinforcing exposed. Similar channel bottom material along the west side as found and described for the East Abutment. This has resulted in voids along the bottom, primarily near the north end. Stones found to bear on a level section of channel bottom along the east side with minimal voids.

Random cracking was observed in the bottom of the arch running east to west in approximately five stones. This arch is still intact and extends from the East Abutment to the East Pier.

A small void was found at the southwest corner just below water due to a missing stone. Vertical cracking was found at the southeast corner that extended from the water up through a minimum of four stone courses.

Water depth varied from 4’-0” to 5’-6” along the east side and from 4’-6” to 9’-0” along the west side. Silty bottom up to 4” thick found along both sides of the pier.

C. West Pier

The overall condition of this pier was found to vary from fair to poor due to the extensive void found along the east side and at the north end at the channel bottom. This pier was capped with concrete approximately 4’-0” above the water. A concrete ledge, approximately 1’-0” wide was found to be constructed at the north end and extends around the east and west ends. Both the concrete cap and concrete ledge were found to be in overall satisfactory condition. Stone extends down to the channel bottom along the west side and bears on a rocky bottom with minimal voids. The south end was found to also bear on a rocky bottom with a build-up of silt, gravel, and river rock. Extensive timber debris located at the north end, and voids were found along the channel bottom at this end apparently due to an un-even rocky channel bottom. Silt scattered on the channel bottom around the entire pier.

No evidence of settlement along the north, west or south sides. A large void was located near the center of the pier along the east side. This void or opening is approximately 8’-0” wide by 2’-0” – 3’-0” high and extends back towards the west approximately 5’-0” deep. No loose stones were found inside the void or directly below the void. Probing up to 3’-6” could not find a firm or solid foundation in this area. The material in this area consisted of gravel type material varying in size up to ½” maximum. The stones directly above this opening were loose and unstable. Diver could not penetrate or go into this area due to this unstable stones which could collapse. The channel bottom between the West and East Pier was checked but no large stone could be found (possibly from this void or opening). The gravel material sloped downwards towards the east on an approximate 5:1 pitch.

Water depth varies from 4’-0” at the south end to over 9’-0” at the northwest corner.

D. West Abutment & Wingwall

The overall condition of the abutment and wingwall was found to be satisfactory. Same construction with no mortar below water as described for the previous substructure units. Stones all found to bear on fairly uniform or level channel bottom along the abutment and wingwall. Only random minimal voids found along the channel bottom. Two areas of missing stones found near the south corner of the abutment. The first area starts 2’-0” north of the corner and is approximately 13’-0” long by 2’-0” high by 3’-0” deep. The second area starts approximately 8’-0’ north of the first area and is 6’-0” long by 4’-0” high and 5’-0” deep. Stones from these areas could be found along the channel bottom. Channel bottom was found to be rocky with silt along the abutment and wingwall. Water depth varied from 2’-0” at the south end of the abutment to over 6’-0” along the wingwall. The area at the end of the wingwall beside the gabion foundation was found to be intact with no undermining or movement.

IV. CONCLUSIONS & RECOMMENDATIONS

Based upon our inspection, we found the overall condition of the aqueduct substructure to be poor based upon the apparent scouring and undermining of the West Pier.

No separate footing was found on any substructure unit as shown on Drawing 3 of 15 dated 8/20/74. The stone piers, abutments, and wingwalls were found to have a ledge near the water level or springline. This ledge varied in width from 6” to 12” and then extended vertically down the rocky channel bottom. The channel bottom is not level, and was not leveled during construction of the aqueduct, which resulted in voids at the base of each substructure unit. This rock formation can be observed above water at the north end near the railroad bridge.

No rock or firm bottom could be found at the opening along the east side of the West Pier. Based upon the direction and flow of the Catoctin Creek, the east side of the pier would appear to be somewhat protected from scouring action. Additional investigation and probing is needed to determine the depth of solid foundation material. We recommend that the West Pier be repaired as soon as possible to prevent further deterioration, which will result in collapsing of the center section of the West Pier.

PHOTOGRAPHS

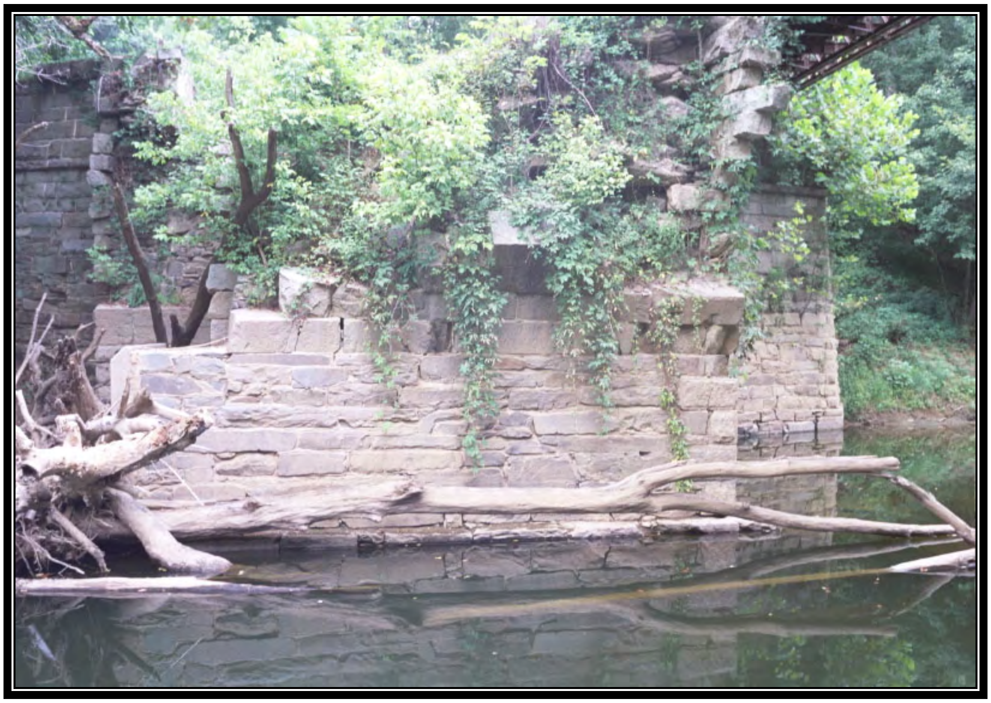


Photo No. 1: West face of East Pier.

Photo No. 2: West Abutment, north wingwall.

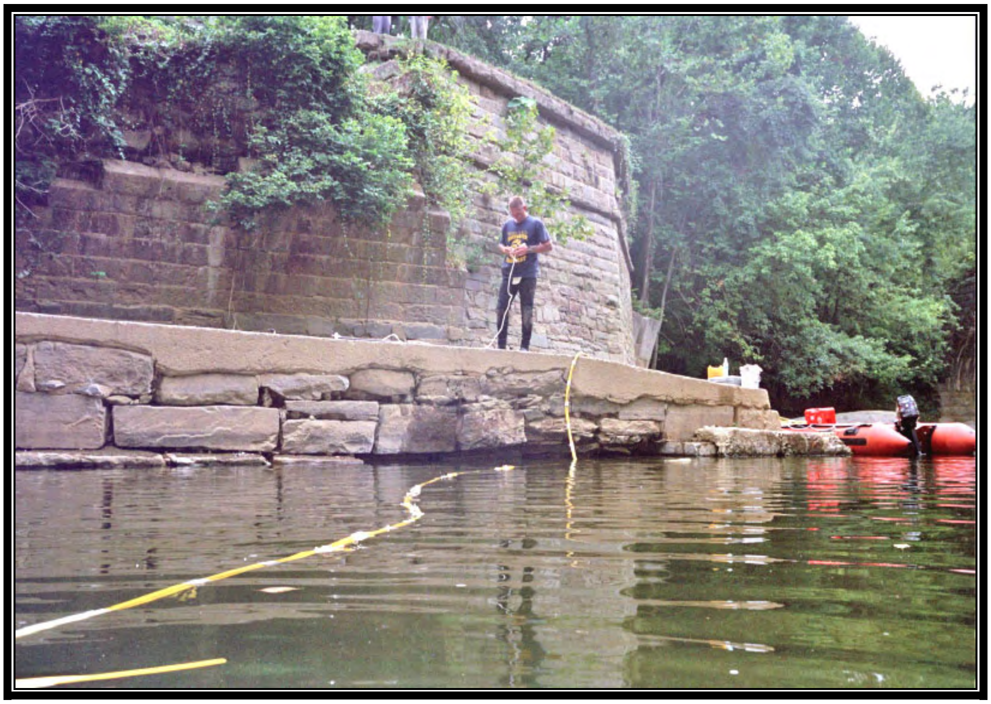


Photo No. 3: West Pier, east face looking at the void.

Photo No. 4: West Pier, typical channel bottom material in void on east side.

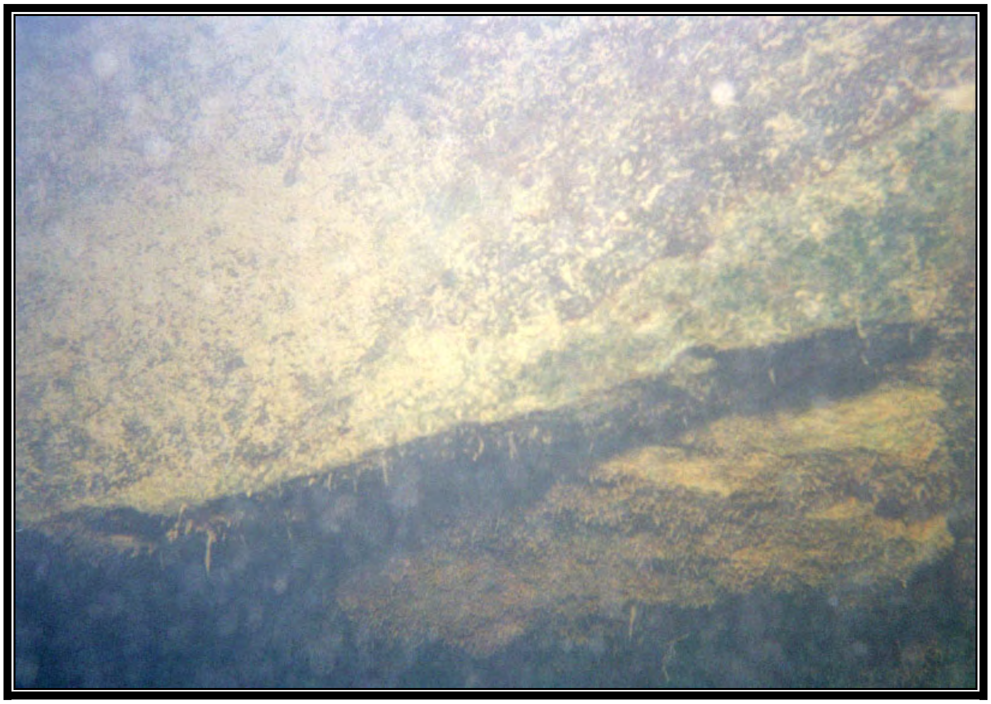


Photo No. 5: Typical rock along the west face of the West Pier.

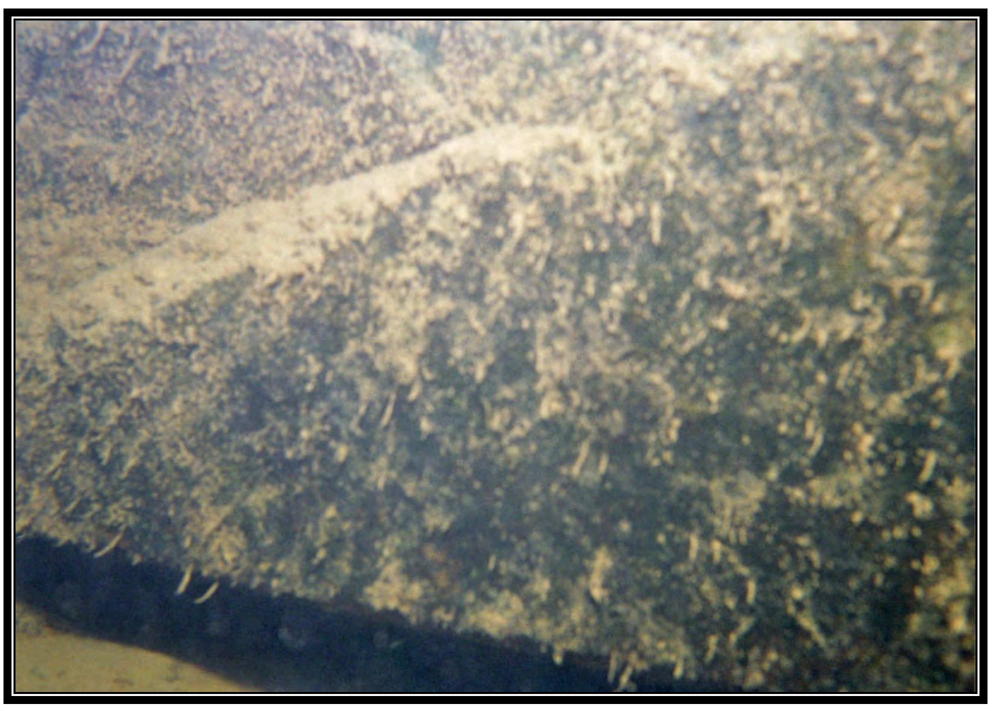


Photo No. 6: Typical rock along the West Abutment and North Wingwall.

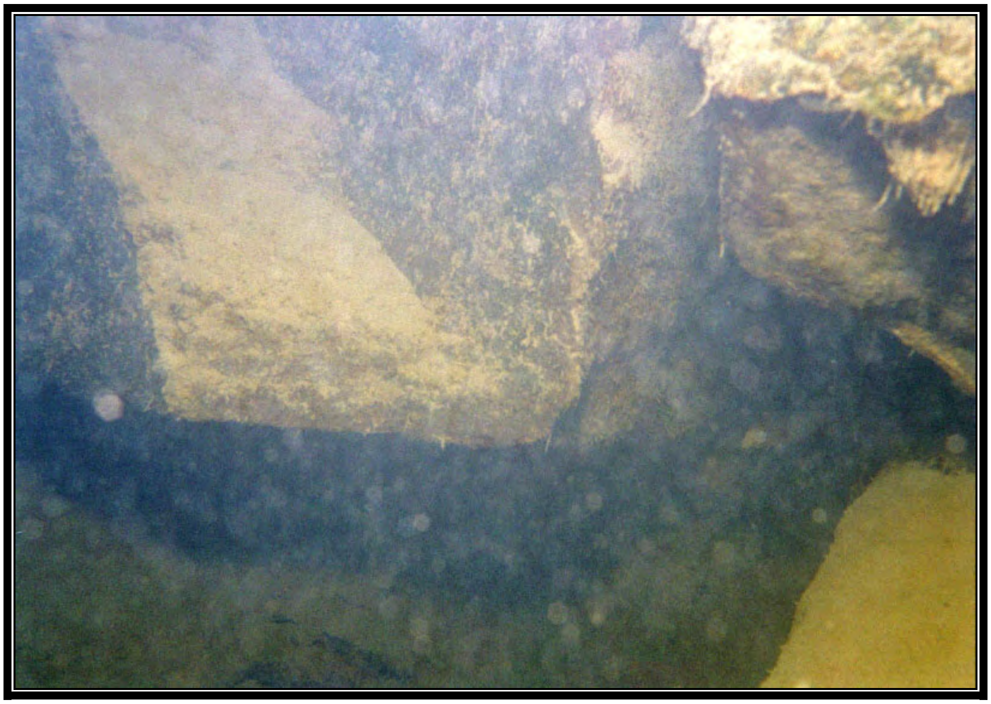


Photo No. 7: Typical rock along the East Pier.

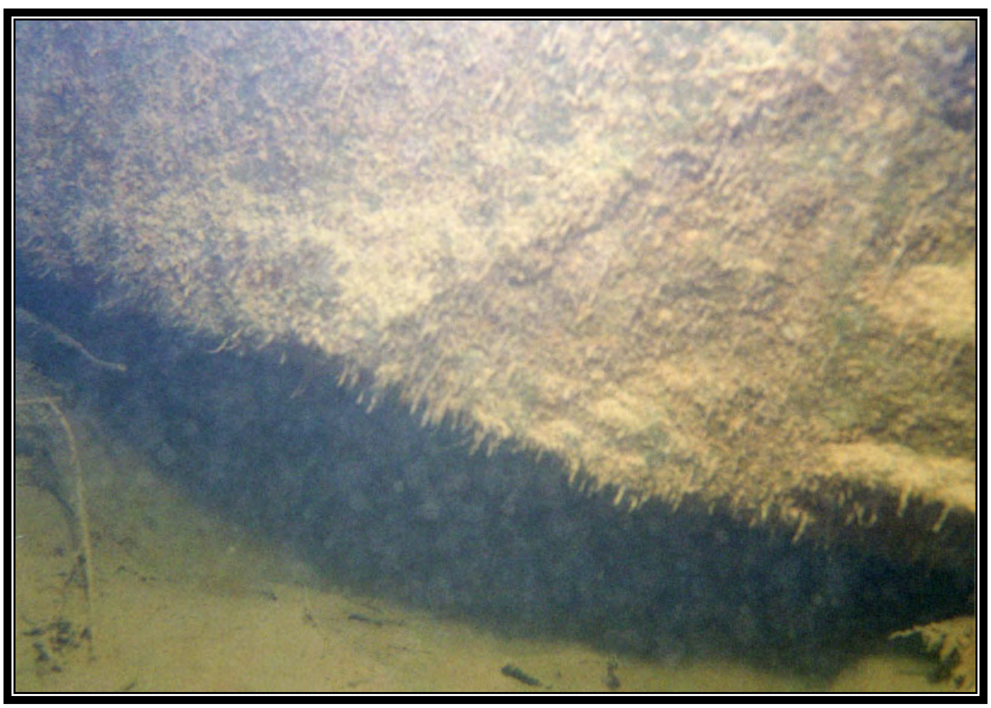


Photo No. 8: Typical rock at the East Pier, north end.

Photo No. 9: East Pier showing small typical rock on the channel bottom.

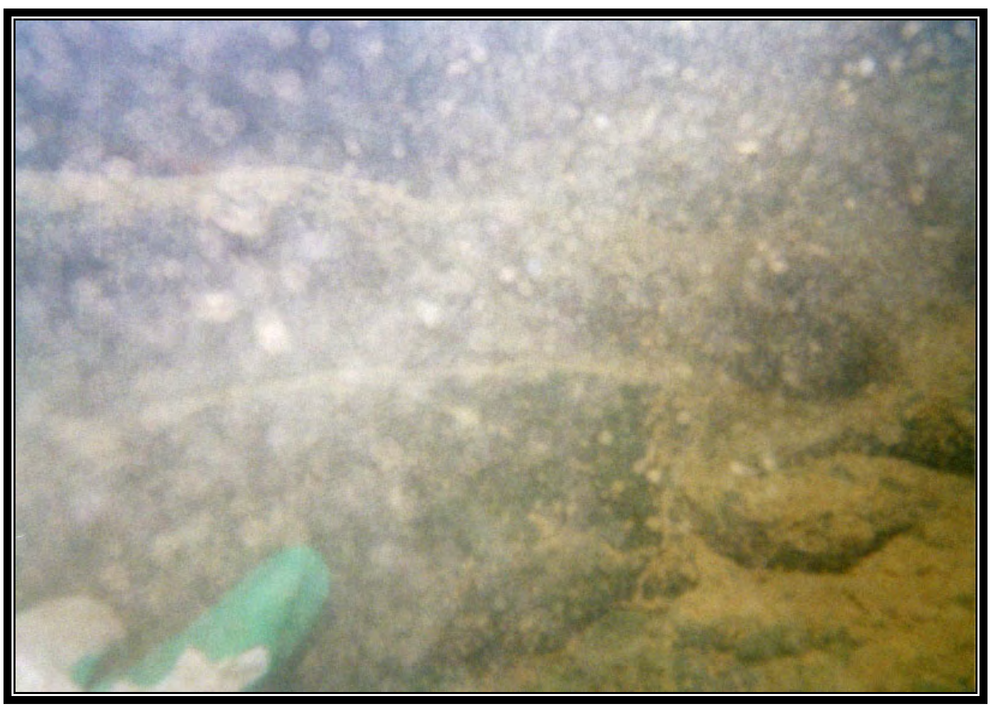
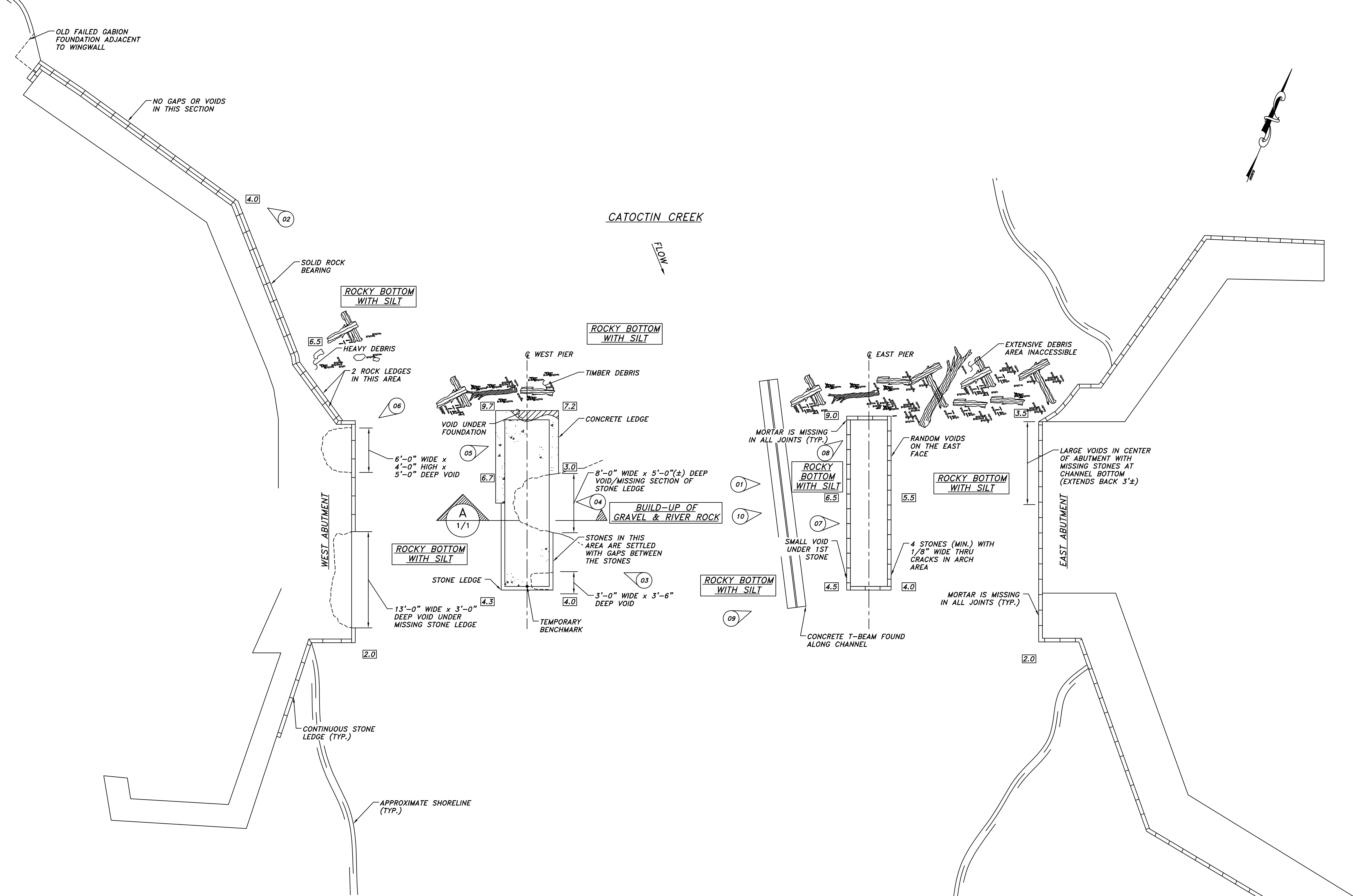


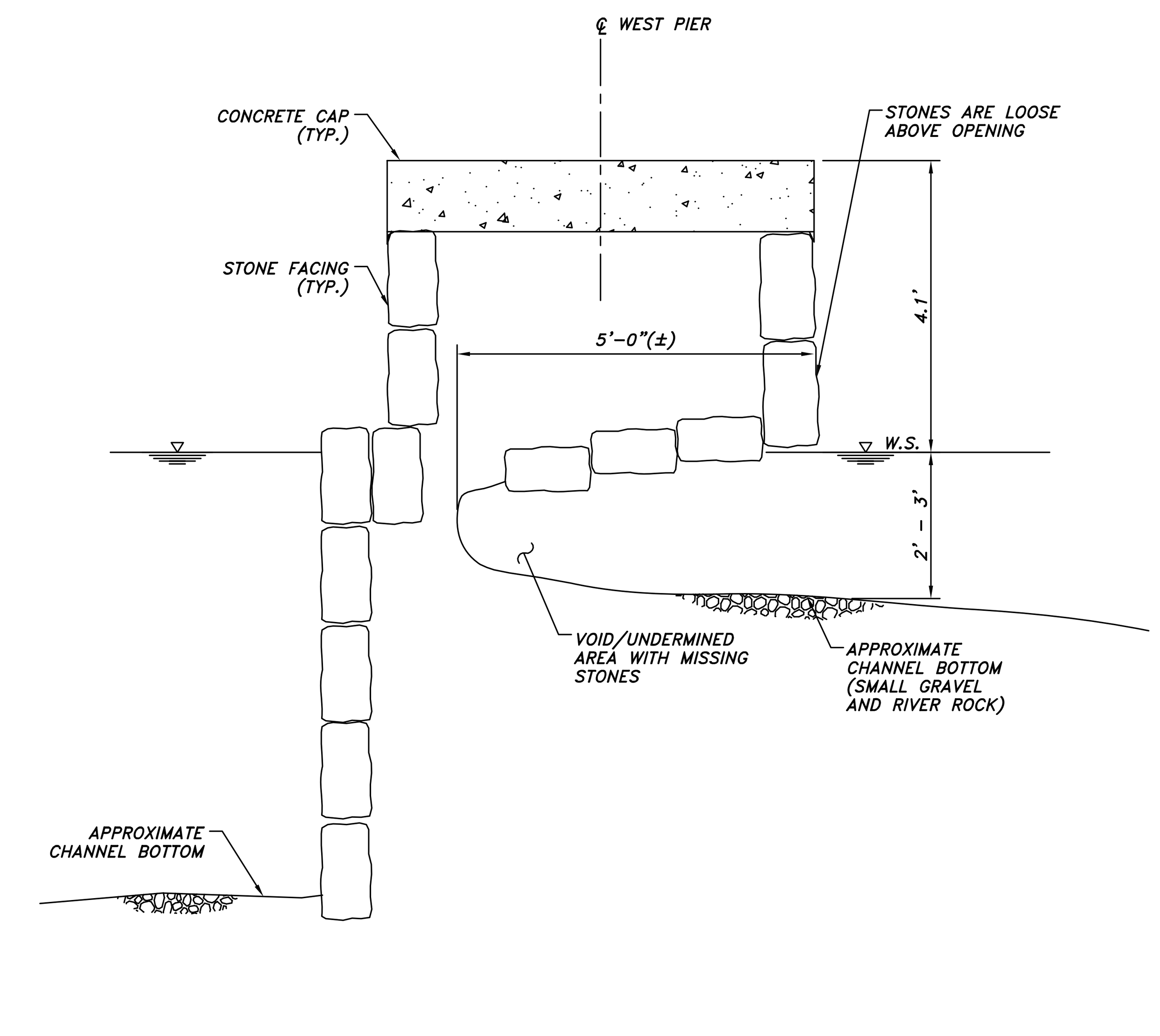
Photo No. 10: Typical channel bottom between East and West Pier.

DRAWINGS



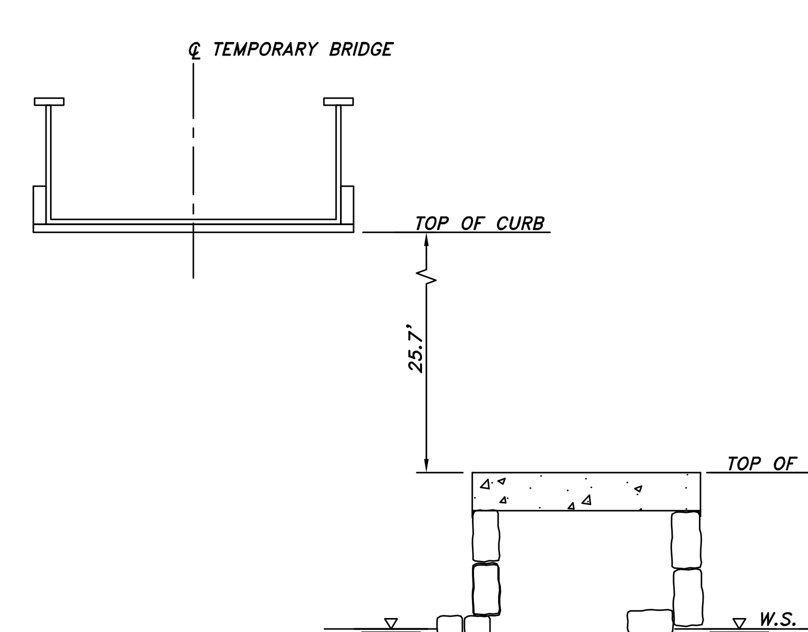
PLAN VIEW

SCALE: 1/8" = 1'-0"



SECTION (A 1/1)

SCALE: 1/2"=1'-0"



TEMPORARY BENCHMARK

SCALE: N.T.S.

GENERAL NOTES:

- THE UNDERWATER INSPECTION OF THE CATOCTIN AQUEDUCT WAS PERFORMED ON AUGUST 30, 2006 BY W.J. CASTLE, P.E. & ASSOCIATES, P.C.
- DRAWINGS DEVELOPED FROM FIELD NOTES AND DRAWINGS SUPPLIED BY CLIENT.
- EXTENSIVE DEBRIS FOUND AT THE NORTH END OF BOTH THE EAST AND WEST PIERS HINDERED THE INSPECTION.

LEGEND:

4.5 – DENOTES WATER DEPTH IN FEET.

XX – DENOTES PHOTO LOCATION.

SCALE: 1/8" = 1'-0"
48" 24" 0 2' 4' 6' 8'

SCALE: 1/2" = 1'-0"
12" 6" 0 1' 2' 3'

DATE	NO.	REVISIONS	BY

INSPECTION RESULTS

INSPECTION & EVALUATION
CATOCTIN AQUEDUCT
OVER CATOCTIN CREEK
LANDER, MARYLAND
CLIENT: McMULLAN & ASSOCIATES

WILLIAM J. CASTLE, P.E.
MD LICENSE NO. 13701

DATE

W.J. CASTLE, P.E. & ASSOCIATES, P.C.
Consulting Engineers
P.O. Box 586 • Lumberton, New Jersey 08048

SCALE	DRAWN BY	CHECKED BY	JOB NO.	DATE	DRAWING No.
AS SHOWN	C.A.D.	W.J.C.	10-1634-06	09/21/06	1 OF 1

APPENDIX C

CATOCTIN AQUEDUCT
HYDROLOGIC AND HYDRAULIC ANALYSIS

TECHNICAL MEMORANDUM

May 25, 2007

To: Dan Copenhaver, Park Engineer, National Park Service, Chesapeake and Ohio Canal National Historical Park

From: Andrea Bendlin, P.E.; Robert Larsen, P.E.; and Mark Collins; Parsons

Subject: Hydrologic and Hydraulic Analysis for the Proposed Restoration of the Catoctin Aqueduct, Chesapeake and Ohio Canal National Historical Park

Introduction

This technical memorandum presents the methods and findings of a hydrologic and hydraulic (H&H) analysis conducted by Parsons for the National Park Service (NPS), Chesapeake and Ohio (C&O) Canal National Historical Park (NHP). The Catoctin Aqueduct (also referred to as the Catoctin Creek Aqueduct) partially collapsed in 1973 and the NPS is proposing to restore the aqueduct to its original configuration. The NPS is currently preparing an Environmental Assessment (EA) with technical assistance from Parsons to evaluate potential impacts of the proposed project to the natural, cultural, and human environment. The H&H analysis was conducted in support of the EA to evaluate potential effects of the proposed restoration on surface water resources and floodplains. Andrea Bendlin, P.E. (Colorado) compiled the required data and conducted the H&H modeling under the direction of Robert Larsen, P.E. (Maryland). Robert Larsen reviewed all model inputs, methods, and results, and has approved this technical memorandum.

Site Description

The Catoctin Aqueduct is located at Milepost 51.5 of the C&O NHP near Lander, in Frederick County, Maryland (Figure 1). Completed in 1834, the aqueduct once carried waters of the C&O Canal over Catoctin Creek. The stone masonry structure was 92 feet (ft) long between abutments and had 3 arches. The center arch was elliptical in form with a 40-foot span and 10-foot rise. The two side arches were semicircular with a 20-foot span and 10-foot rise. The center and west arches collapsed in 1973. The east arch, wing walls, and east and west abutments remain standing today, but are vulnerable to further deterioration. Remains of the west pier have been covered with a concrete slab. A metal Bailey bridge was installed immediately downstream of the aqueduct following the collapse to carry the C&O Canal towpath over Catoctin Creek. The Bailey bridge completely spans the creek channel, and would be removed following restoration of the aqueduct.

The study area for the H&H analysis extends from approximately 5,800 ft upstream of the Catoctin Aqueduct to approximately 350 ft downstream of the aqueduct. The study area was defined based on the extent of topographic and stream cross section data provided by NPS. Structures located in the H&H study area include the aqueduct ruins, Bailey bridge, and CSX Railroad bridge. Residential structures and associated outbuildings are located off East Boss Arnold Road near the east bank of Catoctin Creek

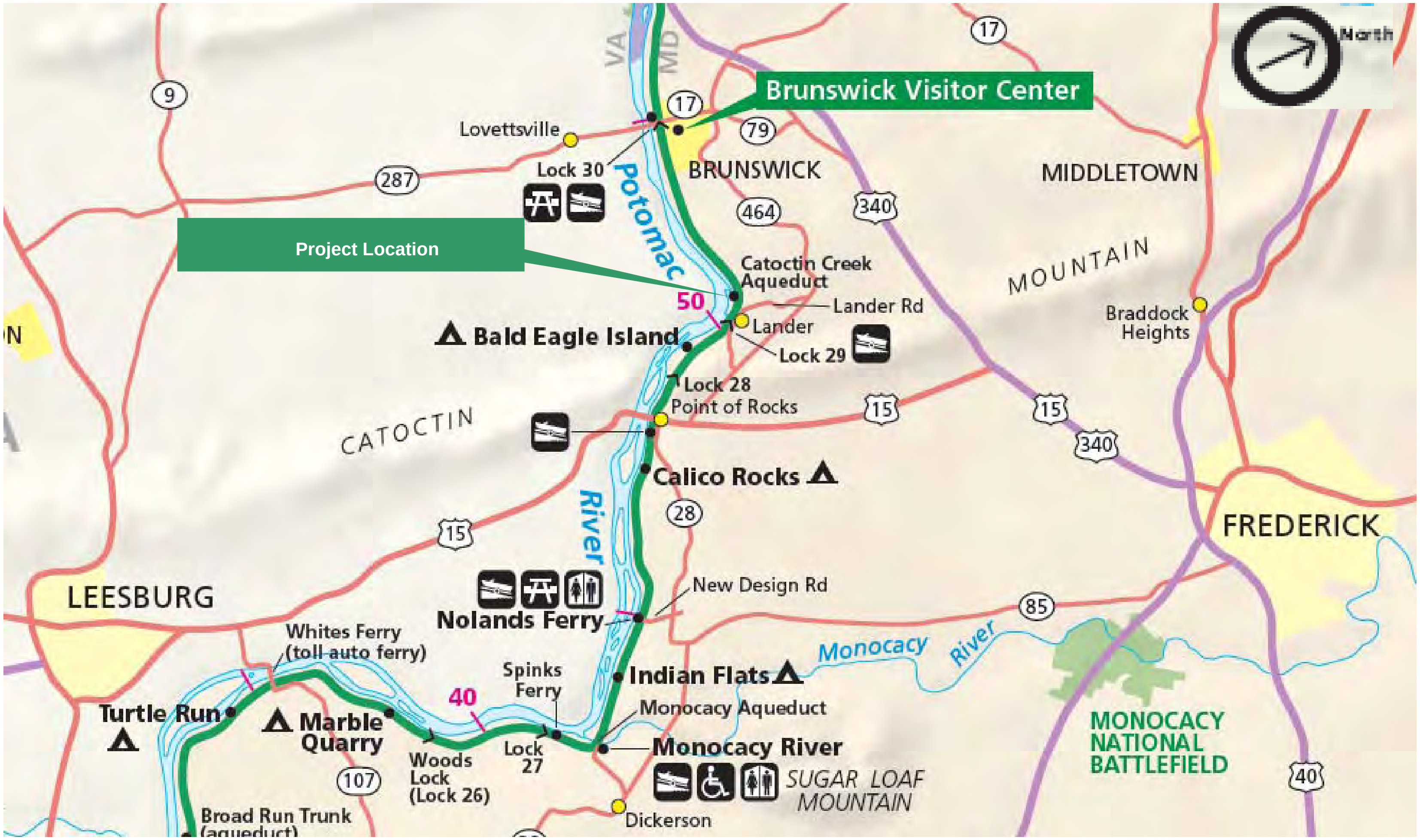


FIGURE 1
CATOCTIN AQUEDUCT PROJECT LOCATION

in the upper reaches of the study area. From the Catoctin Aqueduct, Catoctin Creek flows southeast for approximately 1,500 ft to its confluence with the Potomac River. A side channel of the river meets Catoctin Creek approximately 600 ft downstream of the aqueduct. Lands between the aqueduct and river are part of the C&O Canal NHP and are undeveloped. The CSX Railroad crosses Catoctin Creek via a double barrel stone masonry arch bridge approximately 190 ft upstream (north) of the aqueduct and forms the C&O Canal NHP boundary. Undeveloped forested and agricultural lands are located along Catoctin Creek immediately north of the railroad bridge. East and West Boss Arnold Road are located approximately 3,700 ft upstream (north) of the aqueduct. A bridge does not exist at this location, but the 1970 U.S. Geological Survey (USGS) quadrangle indicates a ford. Maryland Route 464 (Point of Rock Road) crosses Catoctin Creek approximately 2.5 miles upstream (north, northwest) of the Catoctin Aqueduct.

The August 8, 1980, Flood Insurance Rate Map (FIRM) for Frederick County, Maryland Unincorporated Areas, Community Panel No. 240027 0250 B indicates that the Catoctin Aqueduct is located in a Federal Emergency Management Agency (FEMA) regulated Zone A. FEMA uses Zone A to designate areas of the approximate 100-yr flood, where base flood elevations and flood hazard factors were not determined. A data request was made to the FEMA project library, managed by Michael Baker Jr., Inc., for the back-up data to the Flood Insurance Study in Frederick County, MD on September 7, 2006. There was no data available. A copy of the FIRM is included in Appendix A. The FEMA Q3 digital flood data, which are derived from the FIRM, are also provided in Appendix A, with the 2005 aerial photograph as a base map. The FEMA map shows that both the Catoctin Aqueduct and the CSX Railroad structure are within the 100-yr flood limits of the Potomac River, as well as the 100-yr flood limits of Catoctin Creek. The residential structures identified above are located outside of the 100-yr flood limits.

Objectives

The overall objective of this H&H analysis was to support preparation of the EA by evaluating potential long-term effects of the proposed Catoctin Aqueduct restoration on surface water resources and floodplains. Reconstruction of the aqueduct's west and center arches within and above Catoctin Creek would alter the existing channel, and has the potential to increase water surface elevations (i.e., increase the area subject to flooding) and increase stream velocity downstream of the aqueduct. Increased velocity can lead to increased channel erosion. Specific objectives of the H&H analysis included conducting hydrologic and hydraulic modeling to calculate the following:

- Existing peak discharges in cubic feet per second (cfs) at the Catoctin Aqueduct for the 2-year (yr), 10-yr, 25-yr, 50-yr, and 100-yr frequency flood events.
- Existing and proposed water surface elevations (WSELs) in feet above mean sea level associated with the 2-yr, 10-yr, 25-yr, 50-yr, and 100-yr frequency flood events.

- Existing and proposed stream velocities associated with the 2-yr, 10-yr, 25-yr, 50-yr, and 100-yr frequency flood events.
- Existing and proposed Froude numbers associated with the 2-yr, 10-yr, 25-yr, 50-yr, and 100-yr frequency flood events. The Froude number is defined as the ratio between the inertial to gravity forces in the flow. Stated differently the ratio between the mean flow velocity and the speed of a gravity (surface or disturbance) wave traveling over the water surface. Where the Froude number is less than one, flow is considered tranquil or laminar and referred to as subcritical flow. When the Froude number is above one, flow is considered turbulent or rapidly varied and referred to as supercritical flow. When the Froude number is equal to one, flow is considered unsteady and referred to as critical flow.

Based on the rural setting of the Catoctin Aqueduct and limited development immediately upstream, the primary concerns addressed by the H&H analysis include:

- Potential flooding impacts to the upstream CSX Railroad bridge.
- Increased velocities and potential channel erosion downstream of the aqueduct.

The analysis was limited to the localized impacts on the Catoctin Creek watershed due to the replacement of the Catoctin Aqueduct. An analysis of impacts, if any, to the Potomac River watershed were not evaluated. All information in regards to the Potomac River was used on the sole basis of ensuring that the Catoctin Creek H&H analysis was more complete.

As discussed above, the scope of the H&H analysis was limited to impact analysis to support the EA. The H&H analysis scope was limited to evaluating the impacts of both the existing and proposed waterway opening and did not include a cost evaluation nor any analyses of structural, foundation, geologic, or construction conditions or requirements. Permit requirements for construction aspects of the structure replacement were not assessed. As such, use of the H&H analysis data beyond the impact analysis in the EA should be limited. Additional analysis might be required for design and permitting purposes.

Methods

The methods used to perform the H&H analysis for the Catoctin Aqueduct conform to recognized standards and methodologies in the field. All models used are recognized H&H models by FEMA. Specifically the hydrologic analysis employed HEC-1 using the Watershed Modeling System (WMS). The hydraulic analysis employed HEC-RAS. The following briefly outlines the models, methods, input data and description of any assumptions.

Hydrologic Analysis

A hydrologic analysis was performed for the Catoctin Aqueduct. Design discharges for the structure were determined by the Snyder Method in HEC-1 using WMS.

WMS

Developed at the Environmental Modeling Research Laboratory (EMRL) at Brigham Young University, WMS is a geographic information system (GIS) model that interfaces with several standard hydrologic models including HEC-1, NFF, Rational Method, HSPF, TR-55 and TR-20. WMS uses GIS data to automatically delineate watershed boundaries and compute various hydrologic parameters. WMS uses either Digital Elevation Models (DEMs) or Triangulated Irregular Networks (TINs) to delineate basin boundaries and measure channel lengths associated with each subbasin. WMS has subroutines that prepare the input data in the proper format for any selected model, based on the data generated from the DEMs or TINs.

HEC-1

The HEC-1 Flood Hydrograph Package, developed by the U.S. Army Corps of Engineers, Hydrologic Engineering Center (see References), provides a variety of options for simulating precipitation-runoff processes. The version contained in WMS is used in this report. Hydrologic elements are arranged in a branched tree-like network, and computations are performed in an upstream-to-downstream sequence. Types of elements are subbasin, routing reach, reservoir, and diversion. Input requirements are basin data, design storm precipitation, loss method and parameters, unit hydrograph method and parameters, and routing method and parameters.

Basin data includes basin area, travel times, and channel lengths, all of which are determined by WMS. Precipitation options include basin average, rain gage data, or hypothetical design storm. Storm distribution can be input or made to match standard Soil Conservation Service (SCS, now known as the Natural Resources Conservation Service) synthetic storm distributions; Type I, Type Ia, Type II, or Type III, or the alternating blocked Intensity Duration Frequency (IDF) curve. Methods for calculating losses include uniform, exponential, Green-Ampt, Holton, and SCS curve number. The composite curve number (CN) is determined by WMS based on distribution of the hydrologic soil groups and the land uses of the watershed.

Transformation of precipitation excess to direct runoff is achieved in HEC-1 by synthetic unit hydrograph or kinematic wave methods. Unit hydrograph methods include Snyder, SCS dimensionless, and Clark. River and reservoir routing methods include Muskingum, Muskingum-Cunge, Kinematic Wave, and Modified Puls Storage.

Hydraulic Analysis

The hydraulics of the Catoctin Aqueduct were evaluated using HEC-RAS. Water surface elevations, velocities, and Froude numbers were determined for both the existing and proposed conditions.

HEC-RAS

The HEC-RAS River Analysis System, developed by the U.S. Army Corps of Engineers, Hydrologic Engineering Center (see References) is an interactive, integrated, menu-driven program that uses the standard step method to calculate water surface profiles. The program allows three options for computing the flow profile: subcritical, supercritical, or mixed. For the mixed mode, the program computes the profile twice, once using a subcritical flow regime and the second using a supercritical flow regime. Of the two regimes analyzed, the regime with the greater specific force is assumed the correct profile. The following additional assumptions are used by HEC-RAS in computing water surface profiles, and are valid for our project location:

- Steady flow;
- Gradually varied flow;
- One-dimensional flow; and
- Channel slopes are small, less than 1:10

Subcritical steady flow was assumed for the hydraulic analyses. This assumption was based on several engineering guidelines. The first being that the general topography of Catoctin Creek is relatively flat, with an average slope of 0.22 percent. Further, the backwater effects of the Potomac River at this location decrease the velocity of Catoctin Creek as the tailwater conditions are relatively high. Lastly, the study area is relatively small, i.e. not the entire watershed. These factors combine together suggest that the flow in Catoctin Creek at the Catoctin Aqueduct will be laminar, thus a subcritical flow regime is appropriate.

Storage and unsteady flow effects of the structures on incoming hydrographs and stages were not considered for this analysis. Therefore, the resulting WSEL data are considered conservative.

Manning's roughness coefficients used in the analysis were based on field observations, site photographs, experience from past studies, and values published in standard references. (see references).

The known WSEL boundary condition was used for the hydraulic analysis. This is because Catoctin Creek at the project location is approximately 0.27 miles upstream of the confluence with the Potomac River. When a structure crosses a tributary, here Catoctin Creek, in the backwater of a receiving stream, here the Potomac River, the design becomes more complicated by the necessity to consider the joint probability distribution of concurrent flooding on the two courses. Using the Joint Probability procedure outlined by the American Association of State Highway and Transportation Officials (AASHTO) the concurrent flooding of both the Potomac River and Catoctin Creek was determined (see References). The area ratio of the Potomac River to Catoctin Creek is approximately 100:1. Per the AASHTO procedure Catoctin Creek, the tributary, would experience a 10-yr storm event concurrently with the 5-yr storm event of the Potomac River. Similarly, Catoctin Creek would experience a 100-yr storm event concurrently with the 25-yr storm event of the Potomac River. For the storm events between the 10-yr and 100-yr a straight-line interpolation was performed to calculate the concurrent flooding of the Potomac River.

In addition, a single run was made to account for a peak 100-yr storm event on the Potomac River. Using the same concurrent flooding concept outlined above the Potomac River would be experiencing a 100-yr event concurrently with a 25-yr event on Catoctin Creek. This would be the most extreme flooding event experienced at the project location.

Data Sources and Model Input Data

Following is a list of data sources and model inputs used in the H&H analysis (see References):

- Existing site conditions and topography – Existing topography of the project area and bathymetry of Catoctin Creek was provided by the NPS on November 16, 2006. Additional geometry data for the CSX Railroad bridge was provided by NPS on April 9, 2007. All elevations provided are in NGVD 1929.

- Catoctin Creek cross sections – Provided by the NPS on November 16, 2006 as part of the existing site conditions topography. Additional cross sections for upstream areas in the vicinity of East Boss Arnold Road were provided by NPS on April 9, 2007. All elevations provided are in NGVD 1929.

- Watershed topography – 24K USGS Digital Elevation Models (DEM) downloaded from GIS Data Depot for Blue Ridge Summit, Buckeystown, Catoctin Furnace, Frederick, Funkstown, Haggerstown, Harpers Ferry, Keedysville, Middletown, Myersville, Point of Rocks, and Smithsburg, MD were used to determine and delineate the watershed boundary for the Catoctin Creek watershed.

- Watershed soils – Soils information for the watershed was downloaded from the Soil Survey Geographic (SSURGO) Database for Frederick County, MD.

- Watershed landuse - Landuse data for the watershed was downloaded from the U.S. Environmental Protection Agency Surf Your Watershed website Hydrologic Unit Code (HUC) #02070008.

- Composite Curve Number (CN) – A composite CN was generated in WMS using the above listed soils data and landuse data, based on standard values published by the SCS for each of the four (A, B, C, and D) hydrologic soil groups. Abstraction of losses from the rainfall data was accomplished by this composite SCS CN method.

- Precipitation data – Rainfall data for the 2-yr, 10-yr, 25-yr, 50-yr and 100-yr storms was obtained from National Oceanic and Atmospheric Administration

(NOAA) Atlas 14. Based on the large watershed area, a 24-hour storm and Type II distribution was used. This rainfall data was converted to hydrographs using the Snyder Unit Hydrograph method and the basin average storm option in HEC-1.

- Other watershed conditions – Other watershed conditions used in the Snyder Unit Hydrograph method such as % imperviousness, Snyder method peaking coefficient (C_p) and Snyder method lag time in hours (t_p) were calculated in WMS using the above mentioned data. A summary of the parameters used in HEC-1 is shown in Table 1.

Table 1 - Summary of Hydrologic Parameters - HEC-1 Snyder Method

Sub-basin	Watershed Area, square miles	SCS Curve Number	% Imperviousness	Cp	tp
Upper Basin	67.95	66.2	7.36%	0.70	7.13
Lower Basin	53.60	65.3	7.36%	0.70	6.25

- Hydrologic calculations of design flows for the Catoctin Aqueduct were made with a computation time step of 5 minutes.

- Manning's roughness coefficients used in the HEC-RAS model for both the existing and proposed conditions were obtained from field notes, photos and standard reference materials. The values used are shown in Table 2.

Table 2 - Selected Manning's Roughness Coefficients

Section Location	Left Overbank	Main Channel	Right Overbank
Catoctin Creek Aqueduct			
1. Downstream of Structure	0.06	0.04	0.06
2. At Structure Section	0.06	0.04	0.06
3. Upstream of Structure	0.06	0.04	0.06

- Known WSELs for the downstream boundary condition in HEC-RAS were determined for each relevant storm event of the Potomac River. A corresponding WSEL was obtained from the USGS gage #01638500 Potomac River at Point of Rocks, MD, by adding the reported gage height to the gage datum elevation (NGVD 1929). The resulting WSELs used for the boundary conditions are provided in Table 3 as well.

Table 3 – Known Water Surface Elevations			
Catoctin Creek Storm Event	**Concurrent Potomac River Storm Event**	**Potomac River Gage Height (ft)**	**Resulting Known WSEL (ft)**
2-yr	1-yr	7.15	207.69
10-yr	5-yr	22.00	222.54
50-yr	14-yr	29.89	230.43
100-yr	25-yr	32.20	232.74
25-yr	100-yr	40.43	240.97

- Existing and proposed conditions geometry for the Catoctin Aqueduct – Both existing and proposed geometry for the Catoctin Aqueduct was determined from the Feasibility Report of the Restoration of The Catoctin Aqueduct by McMullen & Associates, Inc., as well as the existing topography and cross section data provided by the NPS (see supra). A bridge skew option in HEC-RAS was used for both existing and proposed conditions. It was measured from the existing topography that the structure is skewed approximately 20^o to the flow of the channel. It was assumed that the proposed aqueduct would sit in the same alignment as the existing structure.

- Existing geometry for the upstream CSX Railroad bridge – The existing geometry for the upstream railroad bridge was based on limited field measurements provided by NPS and photographs. Bridge as-builts were not obtained for the structure. It was assumed that both arches were similar in size with a 34 ft opening and 17 ft from keystone to springline. It was measured from the existing topography that the structure is skewed approximately 45^o to the flow of the channel.

- Catoctin Creek discharge data – Discharge and stage information was obtained for Catoctin Creek from the USGS gage #01637500 Catoctin Creek near Middletown, MD. The HEC-1 model was calibrated to this information by adjusting the HEC-1 parameters until there was a close correlation between the corresponding gage and the flowrates generated by the model.

- Potomac River discharge data – Discharge and stage information was obtained for the Potomac River from the USGS gage #01638500 Potomac River at Point of Rocks, MD. This information was used in calculating the known WSELs for the downstream boundary condition of the HEC-RAS model (see supra).

Results

The results from the H&H analysis for the Catoctin Aqueduct are presented below. The results are based on the above input parameters and the assumptions stated above.

Hydrologic Analysis

The resulting 2-yr, 10-yr, 25-yr, 50-yr, and 100-yr peak discharges, based on information provided above is shown in Table 4. A detailed HEC-1 output report has been submitted to the Park Engineer, Dan Copenhaver, in electronic format.

Table 4 - Summary of Peak Discharges

Sub-basin	2-yr Flowrate (cfs)	10-yr Flowrate (cfs)	25-yr Flowrate (cfs)	50-yr Flowrate (cfs)	100-yr Flowrate (cfs)
Upper Basin	2,590	5,710	8,450	11,210	14,110
Lower Basin	2,160	4,880	7,300	9,760	12,370
Total	4,450	10,090	15,100	20,120	25,470

Hydraulic Analysis

The resulting 2-yr, 10-yr, 50-yr and 100-yr WSELs for the existing and proposed Catoctin Aqueduct are provided in Table 5. The resulting 2-yr, 10-yr, 50-yr and 100-yr velocities and Froude numbers for the existing and proposed Catoctin Aqueduct are provided in Table 6. A detailed HEC-RAS output report been submitted to the Park Engineer, Dan Copenhaver, in electronic format. In addition, the existing and proposed 100-yr floodplain extents are delineated and shown in Figure 2.

Table 5 – Water Surface Elevations Catoctin Creek – Existing and Proposed Conditions																
Cross Section Location	**Cross Section Distance from Aqueduct**	**2-yr Existing WSEL (ft)**	**2-yr Proposed WSEL (ft)**	**Δ (ft)**	**10-yr Existing WSEL (ft)**	**10-yr Proposed WSEL (ft)**	**Δ (ft)**	**50-yr Existing WSEL (ft)**	**50-yr Proposed WSEL (ft)**	**Δ (ft)**	**100-yr Existing WSEL (ft)**	**100-yr Proposed WSEL (ft)**	**Δ (ft)**	**100-yr Event Potomac River Existing WSEL (ft)**	**100-yr Event Potomac River Proposed WSEL (ft)**	**Δ (ft)**
Farthest Downstream (XS 1000)	351 ft	211.23	211.23	0.00	222.54	222.54	0.00	230.43	230.43	0.00	232.74	232.74	0.00	240.97	240.97	0.00
Downstream of Aqueduct (XS 1327)	24 ft	214.09	214.24	+0.15	222.57	222.64	+0.07	230.08	230.22	+0.14	232.13	232.33	+0.20	240.98	240.98	0.00
Upstream of Aqueduct (XS 1375)	24 ft	214.83	214.66	-0.17	223.23	223.19	-0.04	231.40	233.36	+1.96	234.08	237.74	+3.66	241.60	242.46	+0.86
Downstream of RR Structure (XS 1561)	210 ft	214.99	214.83	-0.16	223.29	223.25	-0.04	231.56	233.44	+1.88	234.35	237.91	+3.56	241.54	242.40	+0.86
Upstream of RR Structure (XS 1630)	279 ft	215.68	215.56	-0.12	223.90	223.86	-0.04	232.57	234.37	+1.80	235.91	239.44	+3.53	242.15	243.02	+0.87
Upstream (XS 2175)	824 ft	217.49	217.46	-0.03	224.71	224.67	-0.04	232.57	234.37	+1.80	235.91	239.44	+3.53	242.44	243.34	+0.87
Upstream House Site 1 (XS 4977)	3,626 ft	226.04	226.04	0.00	230.23	230.23	0.00	236.31	237.22	+0.91	239.29	241.65	+2.36	242.76	243.59	+0.83
Upstream House Site 2 (XS 7138)	5,787 ft	232.12	232.12	0.00	236.58	236.58	0.00	242.09	242.25	+0.16	244.40	245.12	+0.72	243.85	244.51	+0.66

Table 6 – Average Velocities and Froude Number Catoctin Creek – Existing and Proposed Conditions

Cross Section Location	Cross Section Distance from Aqueduct	2-yr Existing Velocity (fps)	2-yr Proposed Velocity (fps)	2-yr Existing Froude Number	2-yr Proposed Froude Number	10-yr Existing Velocity (fps)	10-yr Proposed Velocity (fps)	10-yr Existing Froude Number	10-yr Proposed Froude Number	50-yr Existing Velocity (fps)	50-yr Proposed Velocity (fps)	50-yr Existing Froude Number	50-yr Proposed Froude Number	100-yr Existing Velocity (fps)	100-yr Proposed Velocity (fps)	100-yr Existing Froude Number	100-yr Proposed Froude Number
Farthest Downstream (XS 1000)	351 ft	10.70	10.70	1.00	1.00	5.72	5.72	0.26	0.26	6.75	6.75	0.25	0.25	7.39	7.39	0.26	0.26
Downstream of Aqueduct (XS 1327)	24 ft	6.97	6.26	0.40	0.36	8.02	7.27	0.33	0.30	10.99	9.94	0.38	0.35	12.82	11.57	0.43	0.39
Upstream of Aqueduct (XS 1375)	24 ft	5.28	5.38	0.29	0.30	6.38	6.32	0.26	0.26	8.73	7.95	0.30	0.26	10.02	8.67	0.33	0.27
Downstream of RR Structure (XS 1561)	210 ft	6.82	6.95	0.42	0.43	7.67	7.69	0.33	0.33	10.18	9.46	0.36	0.32	11.58	10.25	0.39	0.32
Upstream of RR Structure (XS 1630)	279 ft	4.65	4.70	0.24	0.24	6.22	6.23	0.24	0.24	8.66	8.15	0.28	0.26	9.82	8.85	0.31	0.26
Upstream (XS 2175)	824 ft	4.67	4.69	0.27	0.27	5.90	5.92	0.25	0.25	7.24	6.63	0.25	0.22	7.62	6.52	0.25	0.20
Upstream House Site 1 (XS 4977)	3,626 ft	8.00	8.00	0.57	0.57	10.51	10.51	0.60	0.60	12.31	11.49	0.55	0.50	12.40	10.60	0.51	0.41
Upstream House Site 2 (XS 7138)	5,787 ft	5.68	5.68	0.39	0.39	7.12	7.12	0.38	0.38	8.82	8.71	0.39	0.38	9.51	9.09	0.39	0.36

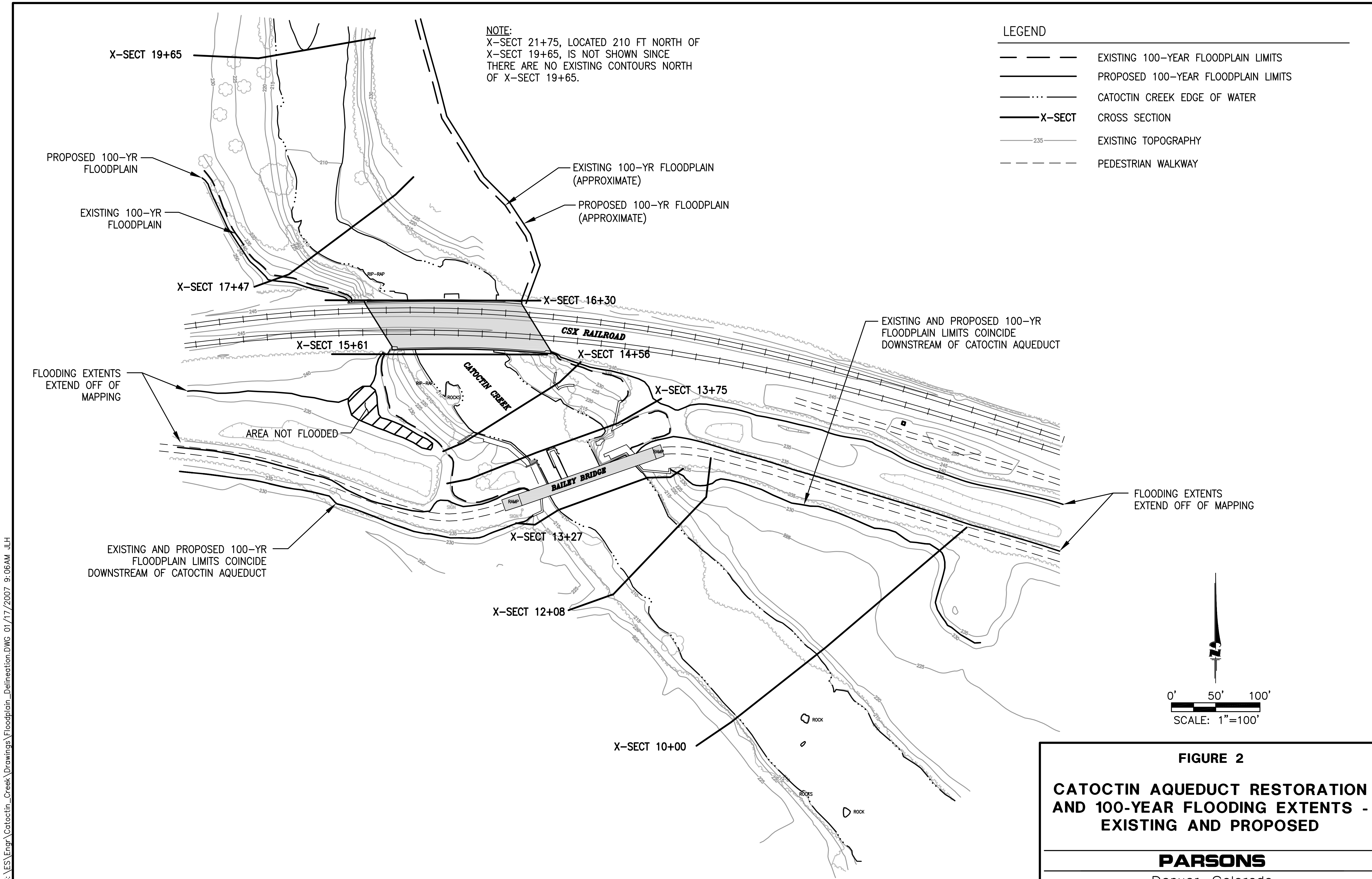


FIGURE 2

CATOCTIN AQUEDUCT RESTORATION AND 100-YEAR FLOODING EXTENTS - EXISTING AND PROPOSED

PARSONS

Denver, Colorado

S:\ES\Engr\Catoctin_Creek\Drawings\Floodplain_Delineation.DWG 01/17/2007 9:06AM JLH

Discussion and Conclusions

As summarized in Table 5, results of this H&H analysis indicate that the proposed restoration of Catoctin Aqueduct to its original configuration would increase Catoctin Creek WSELs associated with the 50-yr and 100-yr flood events. Changes to Catoctin Creek 100-yr storm event WSELs within the study area are shown in Figure 2. These increases in WSELs result from decreases in the existing opening and low chord elevation. The low chord elevation for much of the existing aqueduct/Bailey bridge opening is the existing low chord of the Bailey bridge that carries the towpath across Catoctin Creek. This low chord elevation is substantially higher than the low chord elevation of the proposed reconstructed arches, thus causing more of the flow area of Catoctin Creek to be blocked.

A decrease in hydraulic efficiency would result from the increase in blocked area, causing the restored aqueduct to run under pressure conditions for the 50-yr and 100-yr storm events. A structure acts under pressure flow conditions when the structure blocks enough of the flow area to cause both the upstream and downstream WSELs to be above the low chord elevation, thus acting like a sluice gate or orifice. As modeled, the proposed 50-yr and 100-yr Catoctin Creek WSELs would exceed the low cord of the aqueduct (228.14 ft), but would not overtop the aqueduct (top of aqueduct elevation = 240.49 ft based on spot elevation data from NPS site survey). The modeling indicates that WSELs associated with the 100-yr Potomac River flood event would overtop the aqueduct for existing and proposed conditions.

With pressure flow, the maximum velocity immediately at the restored aqueduct would increase from 14.11 to 16.37 feet per second (fps) for the 100-yr storm event. (Note that Table 6 reports the average velocity of the cross sections upstream and downstream of the Catoctin Aqueduct, not maximum velocity.) This increase in velocity would increase the potential for localized scour at the abutments and piers of the replacement structure. However, it appears that the increase in velocity is localized and that the potential for downstream scour is minimal based on the backwater effects of the Potomac River, relatively low Froude numbers, and the substantial amount of rock outcropping in the area. A more detailed analysis with a detailed geo-technical report would need to be conducted to completely determine this issue. The Froude number for the existing and proposed conditions models are below 1.0. This means that the Catoctin Creek channel is a subcritical flow regime, which is characterized by relatively smooth laminar type flow.

As modeled, the existing CSX Railroad structure effectively passes all flow from the 2-yr, 10-yr, 50-yr and 100-yr storm events. Upstream of the railroad structure the Catoctin Creek proposed 100-yr WSEL (239.44 ft) would be 0.61 ft above the low cord of the railroad structure (238.83 ft), but the WSEL would be 0.92 ft below the low cord downstream of the structure. This indicates that the railroad structure would not run under pressure flow conditions for the Catoctin Creek 100-yr storm event. The existing WSEL for the Potomac River 100-yr event is 3.32 ft above the railroad structure low chord and the proposed Potomac River WSEL would be 4.19 ft above the railroad structure low chord. The railroad structure would not be overtopped in any of the storm events modeled (top of rail elevation = 245.8 ft based on elevation data from NPS).

The H&H analysis results indicate that WSEL increases would also be expected to occur in the upper reaches of the study area in the vicinity of East Boss Arnold Road, but no structures would be affected. As modeled for the upstream house site 1, the proposed WSEL for the Catoctin Creek 100-yr storm event would be 241.65 ft and the proposed WSEL for the Potomac River 100-yr storm event would be 243.59 ft. The structure elevation at this site is 283.45 ft. As modeled for the upstream house site 2, the proposed WSEL for the Catoctin Creek 100-yr storm event would be 245.12 ft and the proposed WSEL for the Potomac River 100-yr storm event would be 244.51 ft. The structure elevation at this site is 249.07 ft. Both structures would continue to be outside the 100-yr flood limits.

References

American Association of State Highway and Transportation Officials Transportation Research Board, *Procedures for Determination of the Joint Probability of Design Flood Discharges at the Confluence of Two Watercourses*, April 2004.

Brigham Young University, Environmental Modeling Research Laboratory, *WMS Watershed Modeling System, Reference Manual*, 1999.

Chow, Ven Te, *Open Channel Hydraulics*, McGraw Hill Book Company, 1959.

Dillow, J.J.A., *Techniques for Estimating Magnitude and Frequency of Peak Flows in Maryland*, U.S. Geological Survey Water-Resources Investigations Report 95-4154, 1996.

Map Service Center, *The FEMA Flood Map Store*, http://web1.msc.fema.gov/webapp/commerce/command/ExecMacro/MSC/macros/welcome.d2w/report

McMullen & Associates, Inc., *Feasibility Report of The Restoration of the Catoctin Aqueduct*, Frederick County, Maryland, May 2006.

NOAA's National Weather Service, Hydrometeorological Design Studies Center, *Precipitation Frequency Data Server, NOAA Atlas 14 Precipitation Frequency Estimates*, www.nws.noaa.gov/hdsc/pfds/orb/md_pfds.html

U.S. Army Corps of Engineers, Hydrologic Engineering Center, *HEC-1 Flood Hydrograph Package, User's Manual*, Davis, California, June 1998.

U.S. Army Corps of Engineers, Hydrologic Engineering Center, *HEC-RAS River Analysis System, Hydraulic Reference Manual*, Davis, California, January 2001.

U.S. Army Corps of Engineers, Hydrologic Engineering Center, *HEC-RAS River Analysis System, User's Manual*, Davis, California, January 2001.

U.S. Department of Agriculture, Natural Resources Conservation Service, *Soil Data Mart*, http://soildatamart.nrcs.usda.gov/

U.S. Department of Agriculture, Soil Conservation Service, *A Method for Estimating Volume and Rate of Runoff in Small Watersheds,* Technical Paper No. 149, January 1968.

U.S. Department of Agriculture, Soil Conservation Service, *Urban Hydrology for Small Watersheds*, Technical Release 55, Engineering Division, Second Edition, June 1986.

U.S. Department of the Interior, Geological Survey, *1:24,000 scale, 7.5 minute map, Point of Rocks, Maryland, Quadrangle*.

References (cont.)

U.S. Environmental Protection Agency, *Surf Your Watershed*, http://cfpub.epa.gov/surf/locate/map2.cfm

U.S. Geological Survey, *The National Flood Frequency Program – Methods for Estimating Flood Magnitude and Frequency in Rural Areas in Maryland*, 2001.

U.S. Geological Survey, National Water Information System, *Peak Streamflow for the Nation, USGS 01637500 Catoctin Creek Near Middletown, MD*, http://nwis.waterdata.usgs.gov/nwis/peak?site_no=01637500&agency_cd=USGS&format=html

U.S. Geological Survey, National Water Information System, *Peak Streamflow for the Nation, USGS 01638500 Potomac River at Point of Rocks, MD*, http://nwis.waterdata.usgs.gov/nwis/peak?site_no=01638500&agency_cd=USGS&format=html

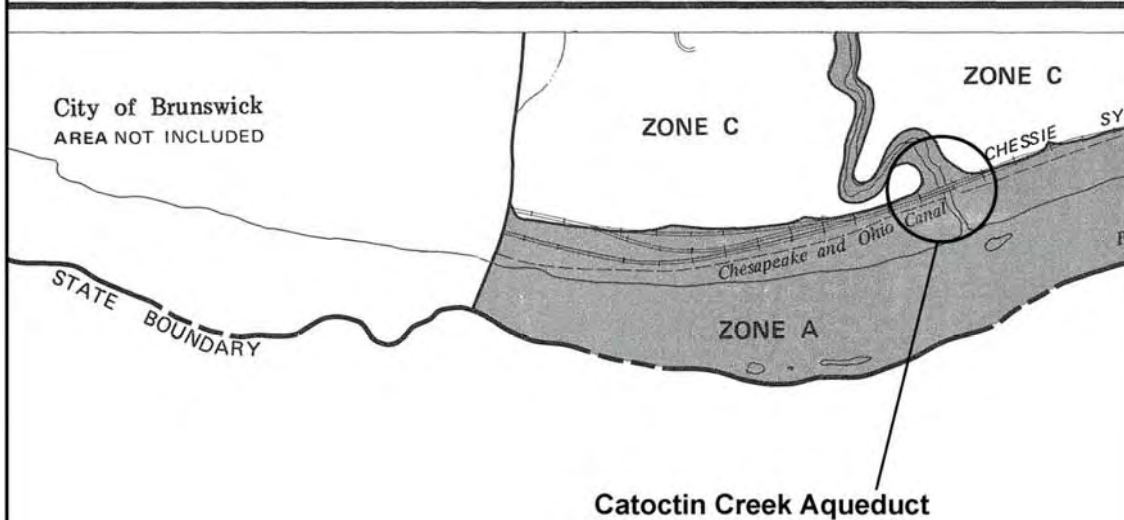
U.S. Geological Survey, Water-Resources Investigations Report 94-4002, *Nationwide Summary of U.S. Geological Survey Regional Regression Equations for Estimating Magnitude and Frequency of Floods for Ungaged Sites*, Reston, Virginia, 1994.

U.S. Geological Survey, Water-Supply Paper 1849, *Roughness Characteristics of Natural Channels*, Washington D.C., 1967.

Viessman, Warren and Gary L. Lewis, *Introduction to Hydrology*, 5th Ed., Pearson Education Publishers, 2003.

Appendix A

FEMA Maps



APPROXIMATE SCALE

2000 0 2000 FEET

NATIONAL FLOOD INSURANCE PROGRAM

FLOOD INSURANCE RATE MAP

FREDERICK COUNTY, MARYLAND
UNINCORPORATED AREAS

COMMUNITY-PANEL NUMBER
240027 0250 B

PAGE 250 OF 275
(SEE MAP INDEX FOR PAGES NOT PRINTED)

MAP REVISED:
AUGUST 8, 1980

U.S. DEPARTMENT OF HOUSING
AND URBAN DEVELOPMENT
FEDERAL INSURANCE ADMINISTRATION

This is an official copy of a portion of the above referenced flood map. It was extracted using F-MIT On-Line. This map does not reflect changes or amendments which may have been made subsequent to the date on the title block. For the latest product information about National Flood Insurance Program flood maps check the FEMA Flood Map Store at www.msc.fema.gov

Catoctin Aqueduct Floodplain

Frederick County, MD

Legend

100-Year Floodplain

Data Sources:

Aerial Photo - National Agriculture Imagery Program 2005
Floodplain - FEMA Q3 Flood Data derived from FIRMS

0 400 800 1,600 2,400 3,200 Feet

Scale:	1:15,000
Created By:	Parsons
File:	Fed\Park_Service\Catoctin_Creek\Maps\FloodPlain.mxd
Date:	01/16/2007

PARSONS

APPENDIX D

CONSULTATION CORRESPONDENCE, SCOPING NOTICE, AND PUBLIC COMMENTS

United States Department of the Interior
NATIONAL PARK SERVICE
C&O Canal National Historical Park
1850 Dual Highway, Suite 100
Hagerstown, Maryland 21740

IN REPLY REFER TO:
D2215(CHOH)

November 8, 2006

Mr. J. Rodney Little
State Historic Preservation Officer
Maryland Historical Trust
100 Community Place, 3rd Floor
Crownsville, Maryland 21032-2023

Dear Mr. Little:

The National Park Service is pressing forward with the environmental study and cultural resource evaluations for the restoration of the Catoctin Aqueduct. On February 3, 2006, we officially notified you and your staff about the proposed project and received correspondence from your office, dated February 16. As requested, we conducted a site visit with members of your staff on June 13, 2006. Since it has been some months since that site visit, we are sending this correspondence as an update of the project.

We are in the process of drafting the environmental assessment. Our consultant is undertaking this task to prepare the project description and identify the project alternatives. They are also undertaking a hydrology/hydraulic study.

Park staff have been actively uncovering the stockpiled/salvaged stones that were stored in the canal prism, east of the aqueduct. We are discovering that many more stones had been salvaged than was anticipated. Masonry specialists are sorting the stones and trying to identify as many stones as possible from historic photographs. Within a few weeks, we will be able to convey information to the design engineer on the estimated quantity of salvaged stones that we will be able to use in the structure. One problem is that very few photographs exist of the upstream side of the structure. Most photographs were taken from a downstream location, showing the south wall.

Shortly after the site visit with your staff, we conducted another site visit with the Army Corps of Engineers and the Maryland Department of the Environment. Maryland Department of Natural Resources was unable to attend the meeting, but have been briefed regarding the project. We are currently in process of requesting agency reviews for natural resource concerns of threatened and endangered species.

Since this project has been high profile within the Frederick County area, we have decided not to conduct a public scoping meeting. We are currently soliciting public scoping comments through our National Park Service website *Planning, Environment, and Public Comment (PEPC)*. The public scoping comment period began on November 1 and will conclude November 30. To view the current project information, you can go to http://parkplanning.nps.gov/choh.

We anticipate having a draft environmental assessment this winter. In accordance with the 1999 revised regulations, 36 CFR 800.8(c)(2)(i), this Draft EA will serve as the Determination of Effect for cultural resources under Section 106 of the National Historic Preservation Act.

We look forward to working through the Section 106 process with you. If you have any questions, please contact Lynne Wigfield, Compliance Officer, at (301) 745-5802.

Sincerely,

Kevin Brandt
Superintendent

bcc:
Bill Justice, CHOH
Sam Tamburro, CHOH
Robert Hartman, CHOH
Lynne Wigfield, CHOH
Scott Bell, CHOH
Dan Copenhaver, CHOH
John Noel, CHOH
Mark Collins, Parsons

United States Department of the Interior

FISH AND WILDLIFE SERVICE
Chesapeake Bay Field Office
177 Admiral Cochrane Drive
Annapolis, MD 21401
410/573-4575

Bob 12/22/06

RECEIVED 12/19/06

December 7, 2006

RHD SBH Bradley Lynne

AB

U.S. Department of the Interior
National Park Service
C&O Canal National Historical Park
1850 Dual Highway, Suite 100
Hagerstown, MD 21740

RE: Natural Heritage Information, Proposed Catoctin Aqueduct Restoration, Chesapeake and Ohio Canal National Historical Park, Frederick County, Md

Dear: Kevin Brandt

This responds to your letter, received November 14, 2006, requesting information on the presence of species which are federally listed or proposed for listing as endangered or threatened within the vicinity of the above reference project area. We have reviewed the information you enclosed and are providing comments in accordance with section 7 of the Endangered Species Act (87 Stat. 884, as amended; 16 U.S.C. 1531 *et seq.*).

Except for occasional transient individuals, no federally proposed or listed endangered or threatened species are known to exist within the project impact area. Therefore, no Biological Assessment or further section 7 Consultation with the U.S. Fish and Wildlife Service is required. Should project plans change, or if additional information on the distribution of listed or proposed species becomes available, this determination may be reconsidered.

This response relates only to federally protected threatened or endangered species under our jurisdiction. For information on the presence of other rare species, you should contact Lori Byrne of the Maryland Wildlife and Heritage Division at (410) 260-8573.

An additional concern of the Service is wetlands protection. Federal and state partners of the Chesapeake Bay Program have adopted an interim goal of no overall net loss of the Basin's remaining wetlands, and the long term goal of increasing the quality and quantity of the Basin's wetlands resource base. Because of this policy and the functions and values wetlands perform, the Service recommends avoiding wetland impacts. All wetlands within the project area should be identified, and if construction in wetlands is proposed, the U.S. Army Corps of Engineers, Baltimore District, should be contacted for permit requirements. They can be reached at (410) 962-3670.

We appreciate the opportunity to provide information relative to fish and wildlife issues, and thank you for your interests in these resources. If you have any questions or need further assistance, please contact Devin Ray at (410) 573-4531.

Sincerely,

Mary Ratnaswamy

Mary J. Ratnaswamy, Ph.D.
Program Supervisor, Threatened and Endangered Species

MARYLAND
DEPARTMENT OF
NATURAL RESOURCES

RECEIVED
1/5/07

Robert L. Ehrlich, Jr., *Governor*
Michael S. Steele, *Lt. Governor*
C. Ronald Franks, *Secretary*

December 29, 2006

KB
Bob
Bradley
Lynne
JBH

Mr. Kevin Brandt
US Dept. of the Interior
National Park Service
C&O Canal National Historical Park
1850 Dual Highway, Suite 100
Hagerstown, MD 21740

RE: Environmental Review for Proposed Catoctin Aqueduct Restoration, Chesapeake and Ohio Canal National Historical Park, Frederick County, Maryland.

Dear Mr. Brandt:

The Wildlife and Heritage Service has determined that there is a record for a population of White Trout Lily (*Erythronium albidum*) and of Shumard's Oak (*Quercus shumardii*), both state-listed threatened species, that occur in very close proximity to the project site. These populations fall with two wetland areas (on either side of Catoctin Creek) that are designated as Nontidal Wetlands of Special State Concern (NTWSSCs) and regulated by Maryland Department of the Environment. NTWSSCs are regulated, along with their 100-foot upland buffers, as NTWSSCs and this project might need review by Maryland Department of the Environment for any necessary wetland permits associated with the NTWSSCs. We would also encourage coordination with our regional ecologist Richard Wiegand at 301-845-8997 to ensure that these occurrences of state-listed plants are protected from any disturbance proposed by this project.

In addition, there are records downstream from this project site in the Potomac River for the state-listed endangered Brook Floater (*Alasmidonta varicosa*) and for the Squawfoot (*Strophitus undulatus*), a species with In Need of Conservation state status. Freshwater mussels such as these require fish hosts for part of their life cycle and are filter feeders, therefore the maintaining of water quality is crucial to their continued existence. We would encourage strict enforcement of all appropriate best management practices during all phases of construction.

Our analysis of the information provided also suggests that the forested area on the project site contains Forest Interior Dwelling Bird habitat. Populations of many Forest Interior Dwelling Bird species (FIDS) are declining in Maryland and throughout the eastern United States. The conservation of FIDS habitat is strongly encouraged by the Department of Natural Resources.

Thank you for allowing us the opportunity to review this project. If you should have any further questions regarding this information, please contact me at (410) 260-8573.

Sincerely,

Lori A. Byrne

Lori A. Byrne,
Environmental Review Coordinator
Wildlife and Heritage Service
MD Dept. of Natural Resources

ER #2006.2873.fr
Cc: E.L. Thompson, DNR
R.H. Wiegand, DNR

Environmental Assessment for Catoctin Aqueduct Restoration

The National Park Service, in partnership with Catoctin Aqueduct Restoration, Inc. and the Community Foundation of Frederick County, Inc., is proposing to restore the Catoctin Aqueduct. The partnership groups are conducting fundraising for this endeavor.

The historic Catoctin Aqueduct, which once carried waters of the Chesapeake and Ohio (C&O) Canal over Catoctin Creek, is located at Milepost 51.5 of the C&O Canal National Historical Park in Frederick County, Maryland. The project proposes to restore the aqueduct to its original design and appearance, while providing a stable and sustainable structure. The National Park Service has initiated work on an Environmental Assessment (EA) to evaluate potential impacts of the proposed project to the natural, cultural, and human environment.

Project location

Purpose and Need

The purpose of the project is to preserve the historic Catoctin Aqueduct and to enhance the continuity of the C&O Canal towpath, the interpretive value of the Catoctin Aqueduct, and the understanding of the canal's history by park visitors. The action is needed because the Catoctin Aqueduct partially collapsed in 1973. Although the aqueduct ruins were stabilized in 1974 and 1975, they remain susceptible to further damage from flooding. A temporary metal bridge erected across Catoctin Creek currently allows towpath users, park maintenance vehicles, and emergency vehicles to cross the creek. However, this bridge detracts from the historic landscape and visitors crossing the bridge are not likely to fully notice and appreciate the historic aqueduct beneath. Consequently, opportunities to understand and appreciate the canal's history are being missed.

Catoctin Aqueduct (Jack E. Boucher, Photographer, April 1959)

Catoctin Aqueduct's remaining east arch and metal bridge above (2006)

Resources and Impact Topics

Initial internal project scoping identified the following resources and impact topics for consideration in the EA:

- Geology
- Soil
- Surface Water
- Floodplains
- Vegetation
- Wetlands
- Wildlife and Aquatic Life
- Endangered and Threatened Species
- Archaeological Resources
- Cultural Landscape
- Architectural Resources
- Museum Collections
- Visitor Use and Experience
- Park Operations
- Public Safety
- Socioeconomic Environment

Alternatives

Initial internal project scoping and a feasibility study identified the following alternatives for consideration in the EA:

A. No Action – Current maintenance would continue.

B. Stone Masonry Arches – The aqueduct would be restored by reconstructing the center and west arches using stone masonry similar to the original construction. An internal, structural concrete saddle would be installed above both arches, which would increase the height of the aqueduct prism by one foot compared to the original structure.

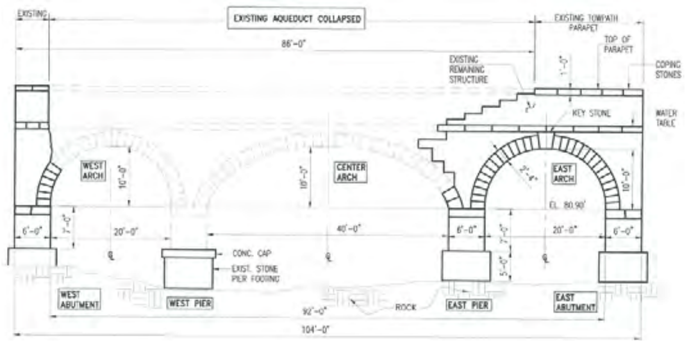
C. Reinforced Concrete Arches – The aqueduct would be restored by reconstructing the center and west arches using reinforced concrete in the original shape. The concrete arches would be faced on the sides with stones matching the extant span, while the undersides of the arches would be textured with a form-liner and stained to give the appearance of the original stone arches.

Stones that were salvaged following collapse of the Catoctin Aqueduct would be used to the extent feasible under both Alternatives B and C.

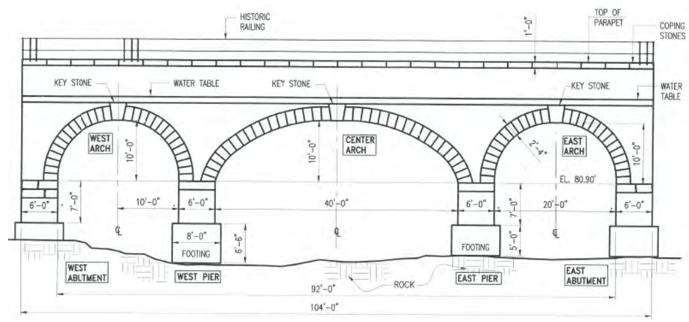
Overview of the Process

Project milestones include:

- Feasibility study (completed May 4, 2006).
- Public scoping (closes November 30, 2006).
- Preparation of EA.
- Public review of EA.
- Analysis of public comment.
- Preparation of decision document.
- Announcement of decision on proposal.



Existing conditions (McMullan and Associates, Inc.)



Proposed conditions (McMullan and Associates, Inc.)

Public Scoping Period

At this time, the Superintendent is announcing a 30-day public scoping period to solicit public comments on this proposal. During this scoping period, the public is invited to identify any issues or concerns they might have with the proposed project so that the National Park Service can appropriately consider them in the EA. You may submit comments electronically at the National Park Service's Planning, Environment, and Public Comment website (http://parkplanning.nps.gov) or submit written comments to:

Superintendent
C&O Canal National Historical Park
1850 Dual Highway, Suite 100
Hagerstown, MD 21740

Please submit your scoping comments by November 30, 2006. Once the EA is developed, it will be made available for public review for a 30-day period. If you wish to be added to the park's mailing list for this or other announcements, please be sure to indicate that in your response.

Author Information

Keep Private:	No
Name:	Eric DeLony
Organization:	
Organization Type:	I - Unaffiliated Individual
Address:	21 Cagua Road Santa Fe, NM 87508 USA
E-mail:	Pontist@Comcast.new

Correspondence Information

Status: **Reviewed**	Park Correspondence Log:
Date Sent: 12/04/2006	Date Received: 12/04/2006
Number of Signatures: 1	Form Letter: No
Contains Request(s): No	Type: Other

Notes: This information was entered in PEPC under Public Request. Information has been entered here by park staff.

Correspondence Text

Dear Kevin,

We've met. As you know Doug and I were contemporaries - I retired to NM, while Doug suddenly and trgically died.

You've got the best historic structure engineers, Denis McMullen and Abba Lichtenstein, working with you. Their work on the Monacacy was brilliant.

I'm not sure which way I'd lean on Cactoctin, B or C. I have yet to see a tinted, concrete stone liner application that works. It's been used on the Walnut Street Bridge over the Susquehanna, in Harrisburg, and more recently on Bow Bridge in Hadley, NY.

You can't get close to the concrete, tinted and cast to look like stone piers on the Walnut Street Bridge, so visually, few would realize that the surfaces are conc. The conc was cast over the original stone piers. I question the duration and longevity of this solution. I fear that the conc application will eventually begin exfoliating.

I haven't seen the Bow Bridge Piers and abutments since the treatment was completed this summer.

What is clear is that the tops of the piers and abutments were capped to allow bearing space for two deep girders that actually carry an H-20 or 25 load, resulting in a clumsy solution.

The tinted concrete, formed to look like stone, looks fake. I question its durability as well.

I would approach this in the context of survivng aqueduct structures of which the family of aqueducts on the c&o canal are the best in the country.

I would be happy to look into this question further if interested.

Eric