Massachusetts Department of Fish and Game
Division of Ecological Restoration
Invested in Nature and Community

LONG TERM CULVERT REPLACEMENT TRAINING PROJECT

VALLEY ROAD OVER UNNAMED BROOK
BOXFORD, MA

JULY 2017

BAYSIDE ENGINEERING
600 UNICORN PARK DRIVE
WOBURN, MA 01801

eDEP#1026068

LONG-TERM CULVERT REPLACEMENT TRAINING PROJECT

VALLEY ROAD OVER UNNAMED BROOK

1.0 Executive Summary

The Massachusetts Department of Fish and Game through the Division of Ecological Restoration's (DER) Stream Continuity Program awarded a grant to the Town of Boxford to replace a degraded culvert. The grant has provided an opportunity for the Town to replace the undersized culvert with one that that meets the Massachusetts River and Stream Crossing Standards. The grant also provides a training opportunity for municipal road managers to learn effective, sustainable methods for culvert replacement. This report will provide the findings of the data collection phase of the culvert replacement process. The findings will be used in selecting and developing a suitable culvert replacement that will increase wildlife connectivity and aquatic passage, reduce upstream flooding, reduce debris clogging and reduce roadway overtopping during high-flow storm events.

2.0 Fieldwork

2.1 Existing Conditions

The crossing is located in Boxford on Valley Road just north of the 67 Valley Road driveway (see locus map in Appendix A). The brook flows from northeast to southwest and is tributary to the headwaters of the Parker River. The existing culvert is an 18-inch diameter corrugated metal pipe (CMP) measuring 43 feet in length. The headwalls are constructed of dry-laid stone masonry. The downstream headwall has partially collapsed as a result of roadway runoff and roadway overtopping during high-flow storm events. There are no underground utilities in the vicinity of the culvert.

Fieldwork was performed to document existing site conditions including, bordering vegetated wetland delineation, mean annual high water/ordinary high water, topographic survey, stream bankfull width measurements, stream grade control elements, streambed elements, and streambed material documentation. The topographic survey was performed at the same time that other field/stream conditions were documented to simplify data collection and avoid unnecessary coordination measures.

A topographic survey of the site and surroundings (roadway and embankments) was performed including 100 feet along the road to the north, and 200 feet to the south. The stream was surveyed 300 feet upstream and downstream. Using the survey information, a baseplan, stream profile and cross sections were developed (Appendix B).

To define the anticipated stream characteristics for the crossing replacement, a reference stream reach was defined. The reference reach is a representative section of stream that is beyond the influence of the existing crossing. The reference reach is used to document pertinent stream elements such as streambed substrate, and grade control elements. Streambed substrate is documented by performing a pebble count using a “Gravelometer” or pebble count board. The data form and gravel distribution is included in Appendix C.

3.0 Geotechnical Evaluation

3.1 Subsurface Investigation

Miller Engineering and Testing performed two borings in the vicinity of the existing culvert to determine the subsurface conditions. Boring B-1 was performed approximately 20 feet north of the culvert and Boring B-2 was performed approximately 8 feet south of the culvert. The borings were completed to refusal in both locations (15.5 feet and 19.1 feet, respectively).

Split spoon samples were taken every 10 feet or change in soil material type. Soil samples were analyzed by Miller Engineering for sieve analysis. The boring logs and test results are in Appendix D & E, respectively.

Based on the collected geotechnical information, there is a 5-inch thick layer of asphalt followed by 2-4 foot layer of medium dense, fine to coarse sand with some gravel above and around the culvert pipe - likely a fill material used during the roadway construction. Beneath the existing culvert pipe is medium dense fine sand with some gravel and a trace of silt which is approximately 2-4 feet thick. At 9 feet is a very dense fine sand and weathered rock layer which varies between 1.5 to 2-feet thick. Groundwater was encountered at 6 and 8 feet below the surface of the roadway in each boring respectively.

3.2 Soil Properties

The material sampled varied from loose to very dense. Most of the deeper soil lenses were dense to very dense. The soil was generally classified as a very dense, gray, highly weathered rock with silt and very dense brown fine sand weathered rock with silt. The analyzed material had 49%-60% passing the #4 sieve and 16%-20% passing the #200 sieve. The AASHTO soil classification is A-1-b. Unified Soil Classification (ASTM D2487) for the materials was assumed to be somewhere between a SM – Silty Sand with Gravel and a GM – Silty Gravel with Sand.

An in-situ unit weight of 120 pounds per cubic foot and a design wet unit weight of 125 pounds per cubic foot were used to represent all the encountered soils at the site. Those unit weights also fall within typical empirical values based on the average Standard Penetration Numbers (SPT N Values) for the soils encountered.

3.3 Soil Parameters for Foundation Design

Generally, soils were analyzed from 9 feet to 12 feet below grade for foundation design based on an approximate foundation depth for the proposed culvert. This provided a more conservative estimate for soil design parameters since the deep material below 14 feet became very dense. If the denser material located below 14 feet was included in the analysis, it could result in an over estimate of soil capacities. Soil parameters should be re-evaluated during final design based on the selected alternative and associated foundation depth for the culvert.

3.3.1 Friction Angle

The internal friction angles for soils classified as medium dense, silty, clayey sand or gravel are at a minimum of 38 degrees and a maximum of 43 degrees. Using the assumed unit weights, boring depths and average SPT blow counts, SPT corrections were performed to represent the encountered soils for the analyzed depths. Corrected blow counts varied from 57 to 63 blows per foot between depths of 9 to 12 feet below the ground surface in two of the representative borings. Based on the corrected blow counts, an average friction angle of 38 degrees is selected as a conservative design parameter.

Please note that the friction angle of soil is used as a variable to select several soil strength properties and should not be confused with the angle of repose for the soil. The angle of repose would provide an estimate of the maximum stable slope angle for the soil to be used for grading and excavation purposes. Generally, a 3H:1V is the most stable slope for most soils encountered, but due to variability, it is recommended that the proper angle of repose be calculated based on a detailed geotechnical analysis.

3.3.1 Allowable Bearing Capacity

An allowable bearing pressure range was identified based on the AASHTO Classification of the encountered materials. A value was selected from the range based on corrected blow count data determined from the boring analysis. Based the boring data, the allowable bearing capacity could range between 6,000 and 10.000 psf.

3.4 Geotechnical Design Parameters

Based on the completed geotechnical analysis, the following design parameters are recommended for foundations for building and chamber footings, foundation walls and any required retaining walls. The following assumptions were made to select these design parameters:

- Average Corrected SPT N values (10-12 feet deep) = 68 bpf
- Assume ground water at an approximate depth of 7 feet
- In-Situ Unit Weight = 120 pcf (assumed)
- For design purposes, a wet unit weight of 125 pcf should be used.
- Internal Friction Angle = 38 degrees

3.4.1 Bearing Capacity Factors

It is recommended that the allowable bearing capacity of 6,500 psf be used. Based on a selected internal friction angle of 38 degrees for the encountered material, the following bearing capacity design factors are provided for estimating bearing resistance of slabs on grade and footings:

- Cohesion bearing capacity factor - Nc = 61.4
- Surcharge bearing capacity factor - Nq = 48.9
- Unit Weight bearing capacity factor - Nɣ = 78.0

Shape and depth factors should be adjusted accordingly based on the foundation design when determining soil bearing resistance of foundation elements.

3.4.2 Earth Pressure Coefficients

Earth pressure coefficients for fine and coarse grained sands were calculated based on the assumed internal friction angle of soil. Based on the friction angle of 38 degrees, the Rankine earth pressure coefficients are as follows:

- At-rest Earth Pressure Coeff. (Ko) = 0.384
- Active Earth Pressure Coeff. (Ka) = 0.238
- Passive Earth Pressure Coeff. (Kp) = 4.204

3.4.3 Earth Pressures & Stresses

Effective stresses were calculated down to 12 feet based on the approximate extent of soil analysis. Based on subsurface exploration, ground water depths ranged between 6 to 8 feet below roadway level. However, for design purposes, it is recommended that an average groundwater depth of 7 feet be used for this site.

Assuming a design wet unit weight of 125 pcf and estimated groundwater depth of 7 feet, the effective stresses could range from 0 – 1,465 psf from 0-12 feet deep. Based on this scenario, maximum active lateral earth pressures could be up to 350 psf.

3.4.4 Settlement Factors

The following are recommended design parameters that should be used to complete future anticipated settlement computations.

For a very dense sand mixture, the range for Young’s Modulus is 2.78 to 9.17 ksi. Based on the corrected SPT N values, Young’s Modulus is estimated to be 9,000 psi (9.0 ksi). Poisson’s Ratio is estimated at 0.25. The void ratio for the encountered materials could range between 0.40 and 0.85 and for this material is assumed to be approximately 0.60. Foundation Shape Factors will vary based on foundation element type.

3.5 Seismic Design Parameters

Based on Hazard mapping, Boxford, MA is located within a Seismic Zone 2A and has relatively low hazard for seismic activity. Despite the low hazard, the encountered soils through the 12-foot depth had some loose silts and sand layers which would have a moderate susceptibility to liquefaction. The encountered groundwater depth is moderate and based on observations during subsurface exploration. Based on boring samples, some of the encountered loose material was saturated. There is a slight possibility that the soils could experience liquefaction during seismic activity. However, the loose soils are confined by dense material. The ten percent probability peak ground acceleration (PGA) for Boxford, MA is less than 0.12 g, therefore the potential for liquefaction is low, but should be reviewed during final design depending on the type of foundation alternative that is selected.

3.5.1 Seismic Design Category Evaluation

Site Class Definition: C. Very Dense Soil & Soil Rock with SPT N Values greater than 50 in accordance with 2011 AASHTO Guide Spec. for LRFD Seismic Bridge Design. Table 3.4.2.1-1.

Based on the USGS Earthquake Hazards Program, the Seismic Factors for Design (ASCE 7-05) are as follows: Ss= 0.190 g, Si = 0.060 g.

3.6 Construction Constraints

Impacts to environmentally sensitive resource areas during construction will be a major factor the structure type selection. It is anticipated that a full road closure and accelerated construction will be used. Construction would be performed during low flow months (July-September). Any residual minor flow would be bypass-pumped. The contractor will be required to control groundwater elevations using an accepted practice approved by the local conservation commission, such as well points and groundwater pumps, with discharge into sedimentation bags located on relatively level ground in vegetated, stabilized areas prior to discharging downstream.

4.0 Hydrologic and Hydraulic Evaluation

4.1 Hydrologic Study

HydroCAD v 10 stormwater modelling software was used to estimate peak discharge rates for the tributary watershed. The watershed was delineated using USGS StreamStats website. StreamStats provided the estimated watershed area, percentage of area covered by forest, and estimated bankfull flow statistics. USGS Orthophoto imagery was obtained from MassGIS to supplement the StreamStats groundcover information. Watershed soil data was obtained from NRCS Web Soil Survey. Local Rainfall data was obtained from NRCS extreme precipitation (Cornell Study) dataset. Digital terrain model data was used to determine time of concentration. The hydraulic model data is included in Appendix F.

Table 4.1 – Peak Runoff

Recurrence Interval	Runoff (cfs)
1-year	3.8
10-year	34.5
25-year	59.1
50-year	84.0
100-year	115.5
500-year	219.8

4.2 Hydraulic Study

Valley Road is classified by MassDOT as a local rural road. According to the MassDOT LRFD Bridge Manual, the design flood frequency for a local rural roadway is the 10-year event. The MassDOT standard for replacement structures is a minimum of 2 feet of clearance under the low chord to the maximum extent practicable. The scour design and scour check flood return frequencies are the 25-year and 50-year storm events, respectively, for structures requiring foundation designs.

HEC-RAS software was used to compute water surface elevations along the stream. Peak stormwater runoff flows calculated in HydroCAD, cross-section and top of bank survey data was imported into the software. Existing culvert and roadway data was input based on field survey and direct measurements.

The existing conditions and proposed structure alternatives were analyzed and compared for typical flood recurrence intervals (1, 10, 25, 50, 100 and 500 years). The proposed structure alternatives consist of an embedded metal pipe arch, embedded metal pipe, three-sided concrete box and embedded concrete box. Peak water surface elevations at stream cross sections upstream and downstream of the structure, as well as peak flow velocities within the structure and immediately downstream, are provided for each alternative in the following table. Detailed model output is included in Appendix G.

10-year Flood Recurrence Interval Hydraulic Summary (Section G – Station 1021)

	Embedment	Peak Elevation (ft)		Peak Velocity (ft/s)	
		Upstream	Downstream	Culvert Barrel	Downstream
Existing 18" CMP	None	133.67	128.59	11.19	7.98
Proposed 4'x8' 3-Sided Concrete Box	Open Bottom	127.94	126.99	5.39	4.95
Proposed 6'x8' Concrete Box	2-feet	127.94	126.99	5.39	4.95
Proposed 71"x103" CMP Pipe arch	2-feet	128.75	127.47	5.02	4.96
Proposed 8' CMP	4-feet	128.71	127.47	5.22	4.96

The proposed culvert installation would include channel regrading from Section E to just upstream of Section G to match the reference reach. This would include the installation of natural channel substrate within the culvert. The culvert replacement would include a crash-tested highway guard to prevent errant vehicles from leaving the travelled way.

The upstream channel velocity is expected to increase under all storm scenarios as a result of the increased culvert flow area. It is likely that there would be some vertical adjustment in the channel over time. However, further fieldwork is necessary to determine the extent of adjustment. Additional details are presented in Section 5.

5.0 Structure Type Selection

The structure selection is based on cost, environmental constraints and the variables identified in the field data collection phase. How the variable interact ultimately determines the best structure for the location.

5.1 Site Constraints

5.1.1 Traffic

The existing roadway pavement width is approximately 17.5 feet in the vicinity of the crossing, which is consistent with the approach roadway north and south. There are currently no highway guard rails installed. The roadway alignment is relatively straight and traffic volume is very low. Based on these factors, the following items are recommended:

- Complete road closure and detour plan for replacement
- Inclusion of crash-compliant highway guard on both sides of the roadway
- Reduction of, or no change in existing culvert length

5.1.2 Utilities

There are no underground utilities in the vicinity of the bridge. Overhead wires are located on the west side of the road. Based on these factors, consideration must be given to construction equipment clearances with respect to the overhead wires (i.e. – excavation equipment swing zones and overhead crane location to place culvert sections.)

5.1.3 Environmental

The project will require work within jurisdictional resource areas including bordering vegetated wetlands (BVW), buffer to BVW and possibly riverfront area and buffer to inland bank. The project will is also subject to the Boxford wetland bylaw. Based on preliminary investigation, the project is located within Natural Heritage and Endangered Species Program (NHESP) priority habitat and upstream from a designated wellhead protection area. The project is not located within or adjacent to any known historic areas nor is it expected to contain hazardous substances.

Based on these factors, any work within the area will require permitting. All options will provide for better connectivity for aquatic, semi-aquatic species and wildlife. Consideration should be given to the replacement option that is least disruptive to the surrounding areas.

5.2 Hydraulic Constraints

The existing culvert has contributed greatly to the stream dynamics upstream and downstream. The culvert conveys the baseflow and smaller storm events. However, larger events are heavily restricted by the culvert's limited capacity. This has contributed to different upstream and downstream channel structure. The upstream section consists of very soft to soft organic sediment and silt with some areas of fine sand with a weak pool riffle structure generally caused by downed trees. The downstream section consists of coarse to fine sand and gravel with a plunge pool/scour hole at the downstream invert which transitions to a strong pool-riffle structure. Higher storm events also create excessive velocity within and immediately downstream of the culvert in addition to overtopping the roadway. This has likely contributed to the deterioration of the downstream headwall. The historic bankfull width was measured in several locations within the reference reach. The average bankfull width is 6.5 feet.

Long term stream aggradation and degradation is a key component to be considered when selecting a replacement culvert. Based on the channel structure in the reference reach and the relative consistency with other sections of the channel in the vicinity of the crossing, an estimation of the vertical adjustment potential (VAP) can be approximated. Using a VAP adjustment factor based on the channel structure multiplied by the maximum pool depth measured in the reference reach will provide an estimate of maximum adjustment. Based on our channel and pool depth, the maximum adjustment would be 1 foot.

The preferred culvert replacement should include a natural streambed with a channel structure that closely approximates the reference reach. Additionally, replacement culverts should span the banks of the natural channel by a factor of 1.2x to the maximum extent practicable.

All of the proposed alternatives will provide a minimum of 1.2x the bankfull width and have a significantly greater cross-section. This will provide for a lower culvert barrel velocity, lower upstream water surface elevations and less frequent roadway overtopping. This will however increase the upstream channel velocity which can lead to vertical adjustment in the channel. As a result, further field investigation should be performed to document channel grade control features and depth to historic (upstream) streambed material. The additional data can be used to determine whether a grade control feature of cobbles and stones would be necessary to prevent excessive stream incising.

Based on the above hydraulic constraints, the following action items are recommended:

- Additional field investigation is necessary to determine upstream channel stability and adjustment potential.
- Using the additional information a determination will be made whether additional grade control structure design is warranted for the site.

5.2 Geotechnical Constraints

Foundation types vary greatly in design and construction costs. The geotechnical data collect as part of this study has provided the necessary information to select the most suitable foundation for the culvert and site. Based on these constraints, soil strength, construction cost/installation time and permitting will affect the selection of an economically suitable foundation.

5.4 Cost Categories

Alternatives are ranked based on their respective costs to determine the most economical option. The cost categories are listed in the table below.

Cost	**Design and Permitting**	**Materials**	**Construction**
Low	< $10,000	< $25,000	< $25,000
Moderate	$10,000 - $35,000	$25,000 - $50,000	$25,000 - $100,000
High	> $35,0000	> $50,0000	> $100,0000

5.5 Alternative Analysis

General

The absence of underground utilities, low traffic volume and detour length will allow for a complete road closure for replacement for all scenarios. This will lower costs and result in shorter project duration. All alternatives will require permitting.

5.5.1 Concrete Box

Two Concrete box options were evaluated. A 6-foot high x 8-foot wide 4-sided box embedded 2 feet; and a 4-foot high x 8-foot wide 3-sided concrete box.

Site Constraints - Both alternatives are hydraulically equivalent and can be designed to carry the statutory HL-93 loading. The 3-sided box will require a more extensive resource area impact due to deeper excavation. Construction duration for the 3-sided box would be slightly longer because of the extra construction steps necessary for footing installation.

Hydraulic Constraints – Both alternatives are hydraulically similar and would provide a natural channel/streambed structure. Substrate installation in the 3-

sided culvert would be easier. Both alternatives will provide freeboard for the design storm and span a minimum of 1.2x the bankfull width. The 100-year flood would not discharge over the roadway. Velocities in culvert barrels and the downstream channel are similar, however, the upstream channel velocity would increase, so appropriate measures would be necessary to accommodate any VAP for both options. The upstream water surface elevation would be lower for all storms analyzed.

Geotechnical Constraints – The 3-sided box would require more extensive design and construction effort and therefore would cost more than the slab footing associated with the 4-sided culvert. Unsuitable material removal and replacement with structural fill will be necessary for both options.

Cost – Design and permitting for the 3-sided box would be high and 4-sided box would be moderate. Material and construction cost would be high for both options. As such, the 4-sided box is a more economical choice.

5.5.2 Corrugated Metal Pipe and Pipe Arch

Two corrugated metal pipe alternatives were evaluated as replacements; a 71-inch high x 103-ich wide metal pipe arch embedded 2 feet; and an 8-foot diameter metal pipe embedded 4 feet.

Site Constraints - Both alternatives are hydraulically equivalent and with over 2-feet of cover can be designed to carry the statutory HL-93 loading. The 8-foot diameter pipe will require a more extensive resource area impact due to a much deeper excavation. As such construction duration for the pipe would be slightly longer because of the extra excavation. Both alternatives may require the design and installation of one or two headwalls.

Hydraulic Constraints – Both alternatives are hydraulically similar and would provide a natural channel/streambed structure. Substrate installation would be similar for both options. Both alternatives will provide freeboard for the design storm and span a minimum of 1.2x the bankfull width. The 100-year flood would not discharge over the roadway. Velocities in culvert barrels and the downstream channel are similar (the pipe arch option has a slightly lower barrel velocity), however, the upstream channel velocity would increase, so appropriate measures would be necessary to accommodate any VAP for both options. The upstream water surface elevation would be lower for all storms analyzed.

Geotechnical Constraints – Both options are pipes, so foundation design is minimal. Unsuitable material removal and replacement with structural fill will be necessary for both options.

Cost – Design and permitting for the both options would be moderate. Material and construction cost would be low without headwalls or moderate with headwalls for both options. Because of the additional excavation required for the metal pipe, the pipe arch is the more economical choice.

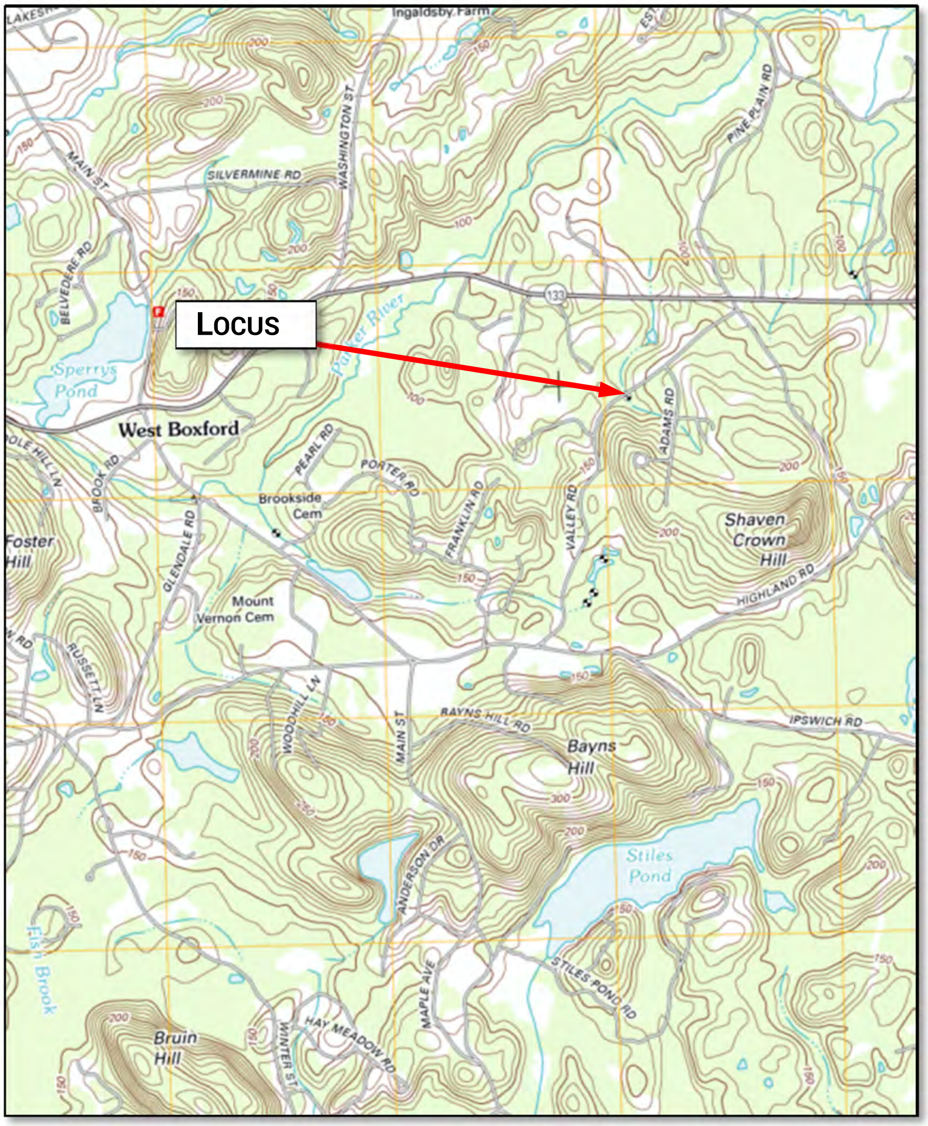
5.6 Preferred Alternative

Based on the findings presented in this report, the 71-inch high x 103-inch wide corrugated metal pipe arch embedded 24-inches is the most economical culvert replacement considering the site, hydraulic, permitting, geotechnical constraints and associated costs.

Appendices

PROJECT LOCUS MAP

CULVERT REPLACEMENT
VALLEY ROAD OVER UNNAMED BROOK
BOXFORD, MA



Reference: USGS TopoQuad – South Groveland Quadrangle

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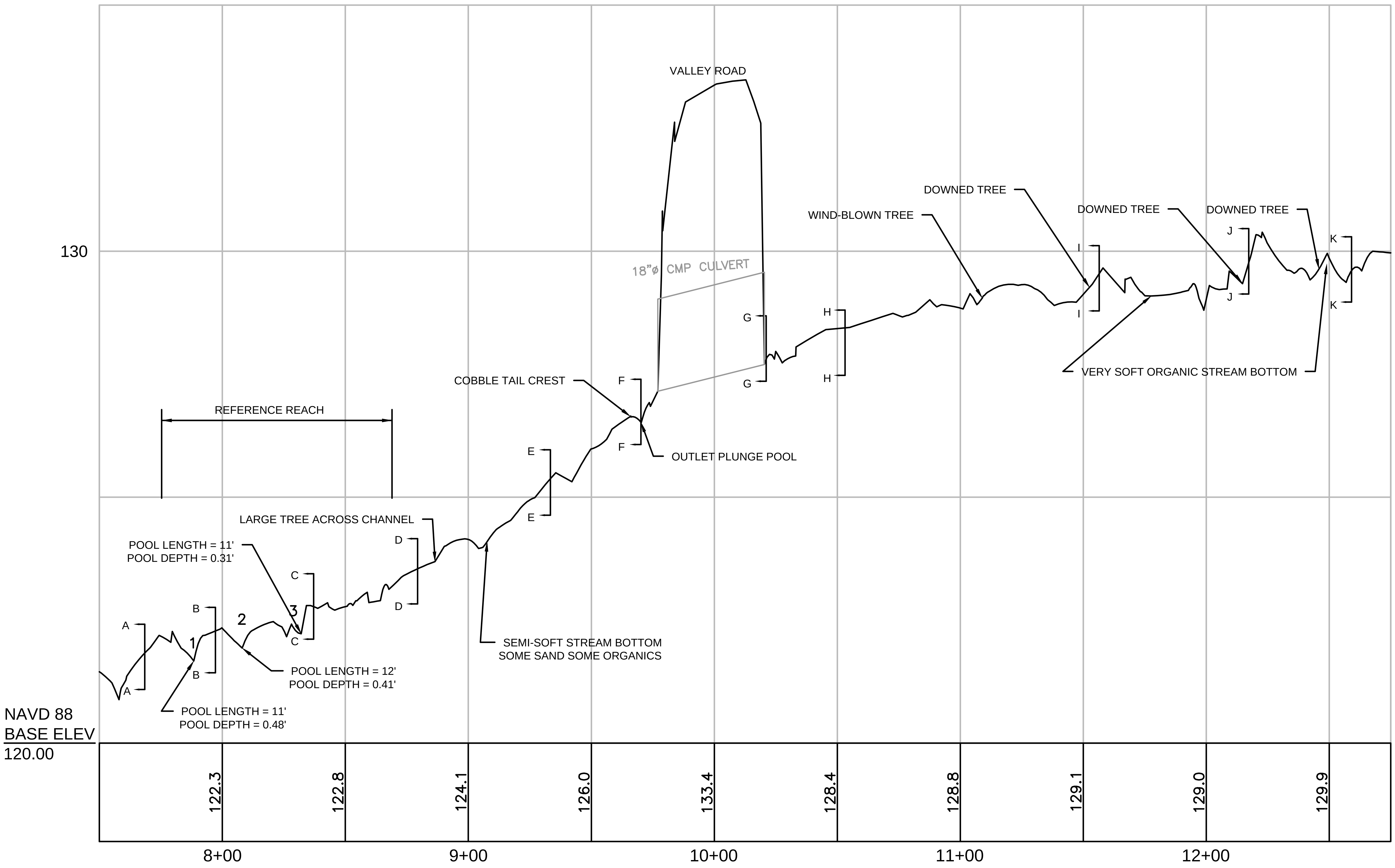
Appendix B
Baseplan, Profile, Cross-Sections



STREAM THALWEG PROFILE
UNNAMED BROOK

VERT. SCALE: 1" = 2' 0 2 6
HORIZ. SCALE: 1" = 40' 0 40 120

GRAPHIC SCALE

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PROJECT
VALLEY ROAD
CULVERT REPLACEMENT
BOXFORD, MA

6/25/2017
DATE

DATE

DATE

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DRAWN BY

REVIEWED BY

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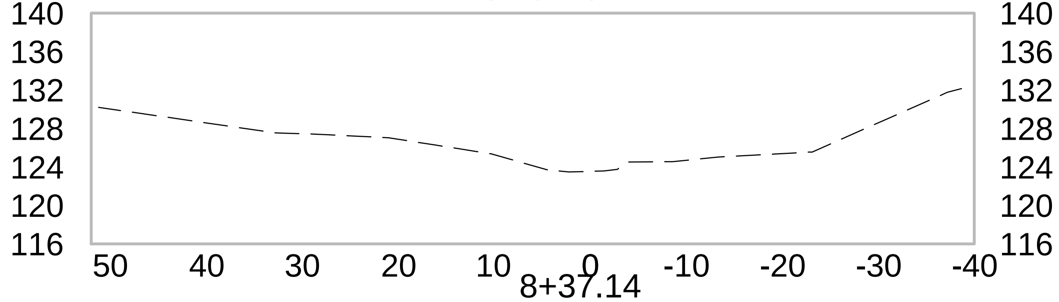
EXISTING CONDITIONS
STREAM PROFILE

SHEET 1 OF 4

8+79.37

SECTION D-D



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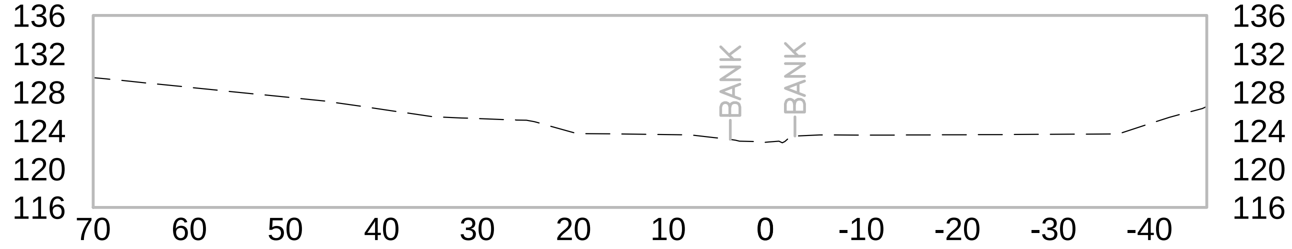

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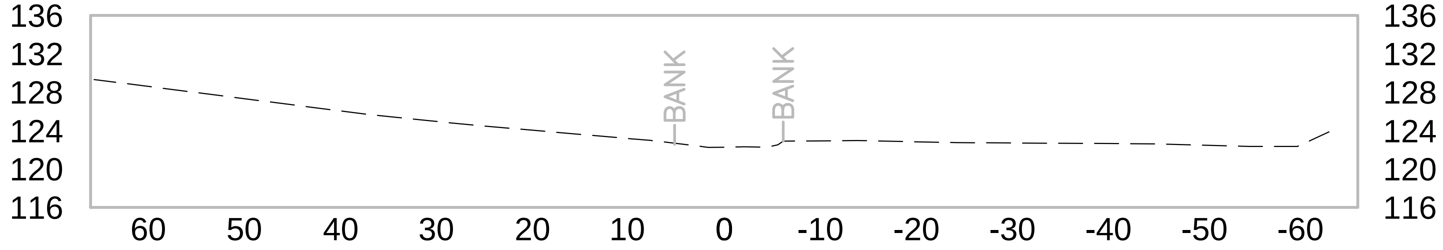
SECTION B-B



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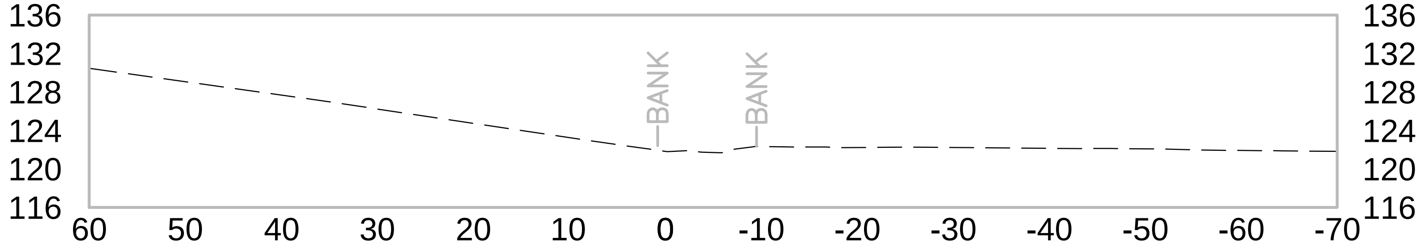
SECTION A-A



STREAM SECTIONS
UNNAMED BROOK

GRAPHIC SCALE
SCALE: 1"=20'
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PROJECT
VALLEY ROAD
CULVERT REPLACEMENT
BOXFORD, MA

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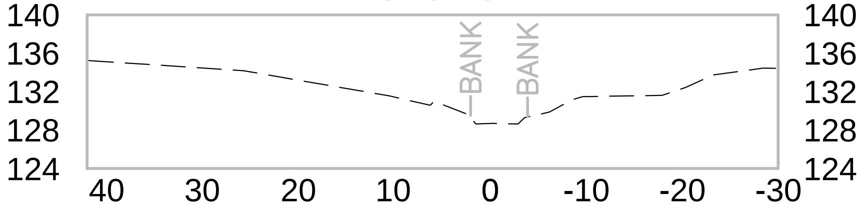
EXISTING CONDITIONS
STREAM PROFILE

2 SHEET 4 OF

10+70.18
SECTION H-H



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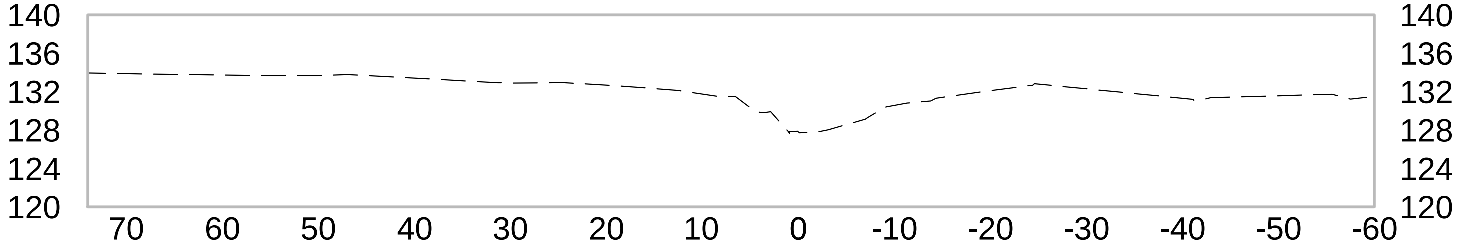

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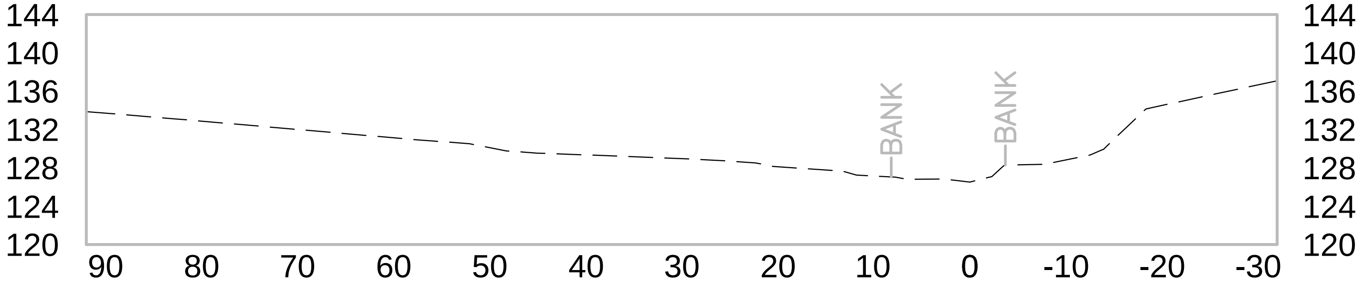

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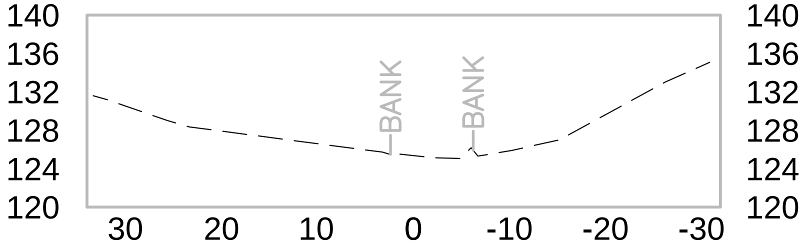

STREAM SECTIONS
UNNAMED BROOK

0 20 60

GRAPHIC SCALE
SCALE: 1" = 20'

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EXISTING CONDITIONS
STREAM PROFILE

3
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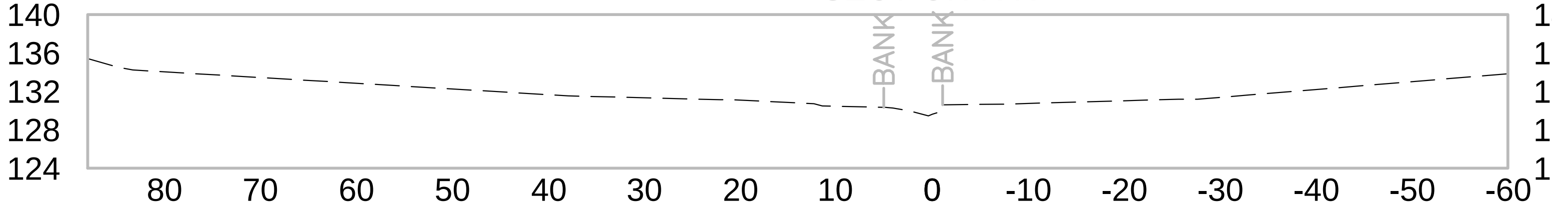
12+59.08

SECTION K-K



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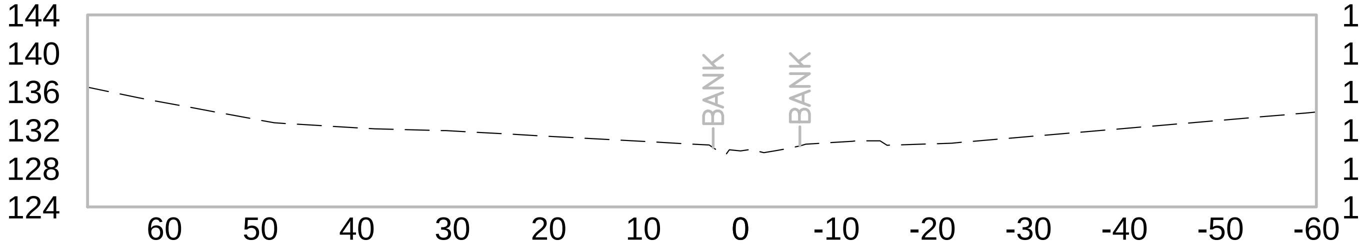

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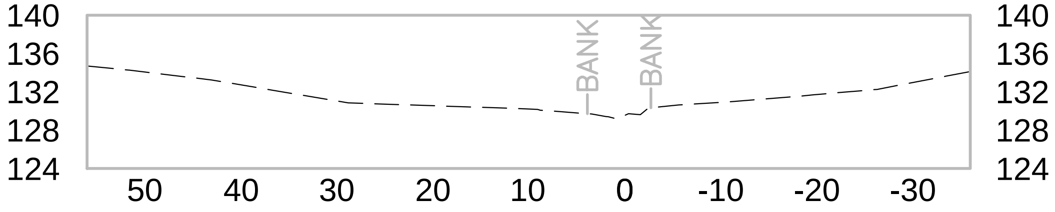

STREAM SECTIONS
UNNAMED BROOK

GRAPHIC SCALE
SCALE: 1"=20'
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PROJECT
VALLEY ROAD
CULVERT REPLACEMENT
BOXFORD, MA

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REVIEWED BY:	DATE:
APPROVED BY:	DATE:

EXISTING CONDITIONS
STREAM PROFILE

SHEET 4 OF 4

Appendix C
Streambed Gradation

OSU Oregon State University Extension Service

StreamWebs™

Student Stewardship Network

PEBBLE COUNT

Share your field data quickly and easily using StreamWebs. Find out what the macroinvertebrates you found say about your stream, keep track of your photopoints, graph water quality data, upload a video, and much more.

www.streamwebs.org

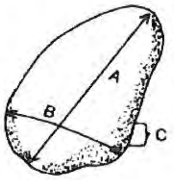
Name: B. Sullivan / T. Chorey

School: ______ Teacher: ______

Date: 6/13/17 Time: 9:30 AM

Stream/Site Name: Valley Rd Boxford / Unnamed Stream

Weather: ______



(A) Long axis
(B) Intermediate axis
(C) Short axis

The intermediate axis is the pebble's diameter.

Pebble counts are an important component of analyzing stream characteristics. The distribution of sediment material on the streambed can inform you about a variety of different stream functions and hydrologic conditions, including erosion potential, woody debris, and aquatic species habitat.

Material	Size (mm)	Tally	#
silt/clay	0 - 0.062		
very fine sand	0.062 - 0.125		
fine sand	0.125 - 0.25		
medium sand	0.25 - 0.5		
coarse sand	0.5 - 1		
very coarse sand	1 - 2		
very fine gravel	2 - 4		
fine gravel	4 - 6		
fine gravel	6 - 8	|	1
medium gravel	8 - 11	||||	4
medium gravel	11 - 16	𝍸 ||	7
coarse gravel	16 - 22	𝍸 |||	8
coarse gravel	22 - 32	𝍸 𝍸 𝍸 𝍸 |	21
very coarse gravel	32 - 45	𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 ||||	34
very coarse gravel	45 - 64	𝍸 𝍸 𝍸 𝍸 𝍸 |	26
small cobble	64 - 90	𝍸 𝍸 𝍸 𝍸	20
medium cobble	90 - 128	𝍸 𝍸 𝍸 |	31
large cobble	128 - 180	𝍸 |||	8
very large cobble	180 - 256		
small boulder	256 - 362		
small boulder	362 - 512		
medium boulder	512 - 1024		
large boulder	1024 - 2048		
very large boulder	2048 - 4096		

Bankfull Channel ▼

Material	Size Range (mm)	Count
silt/clay	0 - 0.062	
very fine sand	0.062 - 0.125	
fine sand	0.125 - 0.25	
medium sand	0.25 - 0.5	
coarse sand	0.5 - 1	
very coarse sand	1 - 2	
very fine gravel	2 - 4	
fine gravel	4 - 6	
fine gravel	6 - 8	**1**
medium gravel	8 - 11	**4**
medium gravel	11 - 16	**7**
coarse gravel	16 - 22	**8**
coarse gravel	22 - 32	**21**
very coarse gravel	32 - 45	**34**
very coarse gravel	45 - 64	**26**
small cobble	64 - 90	**20**
medium cobble	90 - 128	**16**
large cobble	128 - 180	**8**
very large cobble	180 - 256	
small boulder	256 - 362	
small boulder	362 - 512	
medium boulder	512 - 1024	
large boulder	1024 - 2048	
very large boulder	2048 - 4096	

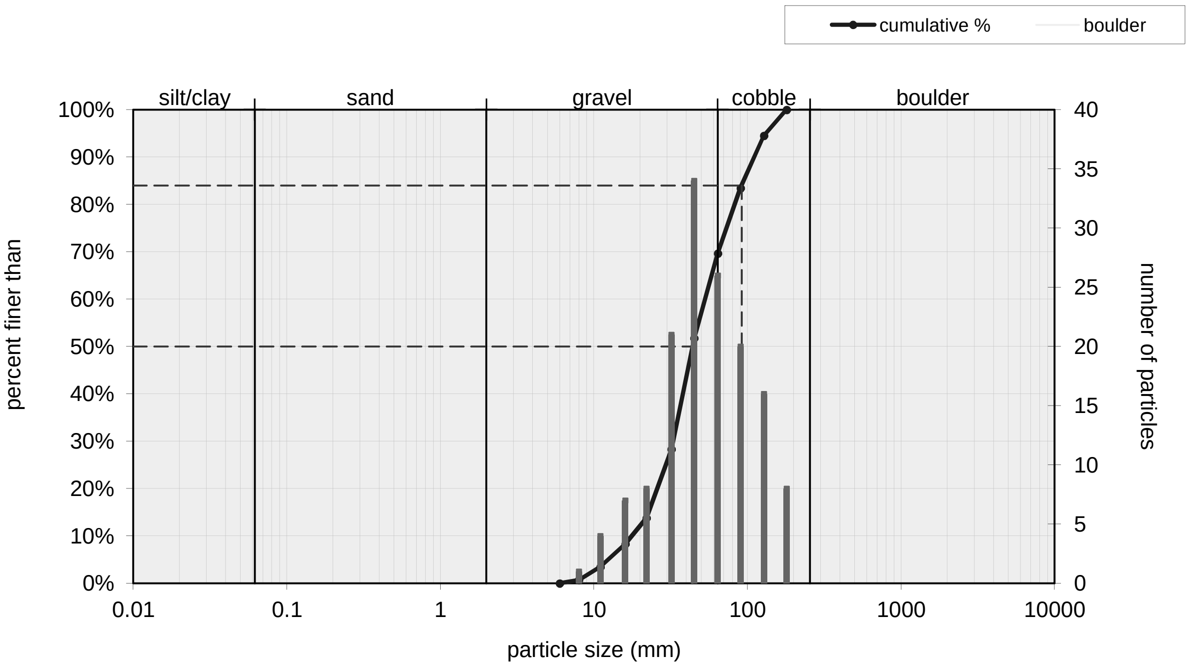
total particle count: 145

bedrock -------------	
clay hardpan -------------	
detritus/wood -------------	
artificial -------------	

total count: 145

Note: Artificial = large chunk of asphalt (boulder)

Surface Pebble Count, Brook/Valley Rd - Boxford, MA



Size (mm)	
D16	23
D35	35
D50	44
D65	58
D84	92
D95	130

Size Distribution	
mean	46.0
dispersion	2.0
skewness	0.02

Type	
silt/clay	0%
sand	0%
gravel	70%
cobble	30%
boulder	0%

Appendix D
Boring Logs

TEST BORING LOG

MILLER ENGINEERING & TESTING, INC.
100 Sheffield Road - Manchester, NH 03103
Ph. (603) 668-6016 - Fax: (603) 668-8641

Project: Valley Rd. Bridge Culvert
Boxford, MA
Project No: 17.128.NH
Date Start: 06-22-17
Date End: 06-22-17

Sheet 1 **of** 1
Boring No: B-1
Location: See Sketch
Approx. Surface Elev:

	CASING	SAMPLER	GROUNDWATER OBSERVATIONS			
			Date	**Depth**	**Casing At**	**Stabilization Period**
Type	HSA	SS	06-22-17	6'	14'	Upon Completion
Size	2-1/4" ID	1-3/8" ID				
Hammer		140 lbs.				
Fall		30"				

Depth/ Elev.	Cas bl/ft	SAMPLE				BLOWS				Strata Change	Sample Description	Notes
		Sample No.	Depth Range	Pen.	Rec.	0-6"	6-12"	12-18"	18-24"			
0		-	0.0-0.4	5							-: 5" Asphalt	
		S-1	0.5-2.0	18	10		8	7	6		S-1: Loose, brown, fine to coarse sand, little gravel, little silt	
		S-2	2.0-3.5	18	12	3	3	4			S-2: Loose, dark brown, topsoil, roots	
		S-2A	3.5-4.0	6	5				13		S-2A: Medium dense, brownish orange, fine to coarse sand and gravel, some silt	
4		S-3	4.0-6.0	24	10	8	9	39	26		S-3: Dense, brown, fine to coarse sand and gravel, little silt	
8												
		S-4	9.0-11.0	24	14	16	25	31	32		S-4: Very dense, gray, highly weathered rock	
12												
		S-5	14.0-15.0	12	12	46	6	5			S-5: Very dense, gray, weathered rock	
16											BORING TERMINATED AT 15.5 ft	
20												
24												

Driller: R. Marcoux
Helper: K. Schwotzer
Inspector:

COHESIVE CONSISTENCY (Blows/Foot)	COHESIONLESS (Blows/Foot)	PROPORTIONS USED
0-2 VERY SOFT	0-4 VERY LOOSE	TRACE: 0-10%
2-4 SOFT	4-10 LOOSE	LITTLE: 10-20%
4-8 MEDIUM STIFF	10-30 MEDIUM DENSE	SOME: 20-35%
8-15 STIFF	30-50 DENSE	AND: 35-50%
15-30 HARD	50+ VERY DENSE	

NOTES:

eDEP#1026068

REMARKS: THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY BETWEEN SOIL TYPES. TRANSITION MAY BE GRADUAL. WATER LEVEL READINGS HAVE BEEN MADE IN THE DRILL HOLES AT TIMES AND UNDER CONDITIONS STATED ON THE BORING LOGS. FLUCTUATIONS IN THE LEVEL OF THE GROUNDWATER MAY OCCUR DUE TO OTHER FACTORS THAN THOSE PRESENT AT THE TIME MEASUREMENTS WERE MADE.

TEST BORING LOG

MILLER ENGINEERING & TESTING, INC.
100 Sheffield Road - Manchester, NH 03103
Ph. (603) 668-6016 - Fax: (603) 668-8641

Project: Valley Rd. Bridge Culvert
Boxford, MA
Project No: 17.128.NH
Date Start: 06-22-17
Date End: 06-22-17

Sheet 1 **of** 1
Boring No: B-2
Location: See Sketch
Approx. Surface Elev:

			GROUNDWATER OBSERVATIONS			
	CASING	**SAMPLER**	**Date**	**Depth**	**Casing At**	**Stabilization Period**
Type	HSA	SS	06-22-17	8'	14'	Upon Completion
Size	2-1/4" ID	1-3/8" ID				
Hammer		140 lbs.				
Fall		30"				

Depth/ Elev.	Cas bl/ft	SAMPLE				BLOWS				Strata Change	Sample Description	Notes
		Sample No.	Depth Range	Pen.	Rec.	0-6"	6-12"	12-18"	18-24"			
0		-	0.0-0.4	5							-: 5" Asphalt	
		S-1	0.5-2.0	18	6	10	13	7			S-1: Medium dense, brown, fine to coarse sand, gravel, trace silt	
		S-2	2.0-4.0	24	12	6	6	10	17		S-2: Medium dense, brown, fine to coarse sand, little silt, little gravel	
4		S-3	4.0-6.0	24	12	60	11	9	13		S-3: Medium dense, brown, fine sand, some gravel, trace silt	
8												
		S-4	9.0-10.5	18	16	15	23	57			S-4: Very dense, brown, fine sand, weathered rock	
12												
		S-5	14.0-16.0	24	18	15	23	25	29		S-5: Dense, gray, fine sand, some silt, trace to little gravel	
16												
		S-6	19.0-19.1	1	0	50/1"					S-6: No recovery	
20											Auger Refusal at 19.1' BORING TERMINATED AT 19.1 ft	
24												

Driller: R. Marcoux
Helper: K. Schwotzer
Inspector:

COHESIVE CONSISTENCY (Blows/Foot)	COHESIONLESS (Blows/Foot)	PROPORTIONS USED
0-2 VERY SOFT	0-4 VERY LOOSE	TRACE: 0-10%
2-4 SOFT	4-10 LOOSE	LITTLE: 10-20%
4-8 MEDIUM STIFF	10-30 MEDIUM DENSE	SOME: 20-35%
8-15 STIFF	30-50 DENSE	AND: 35-50%
15-30 HARD	50+ VERY DENSE	

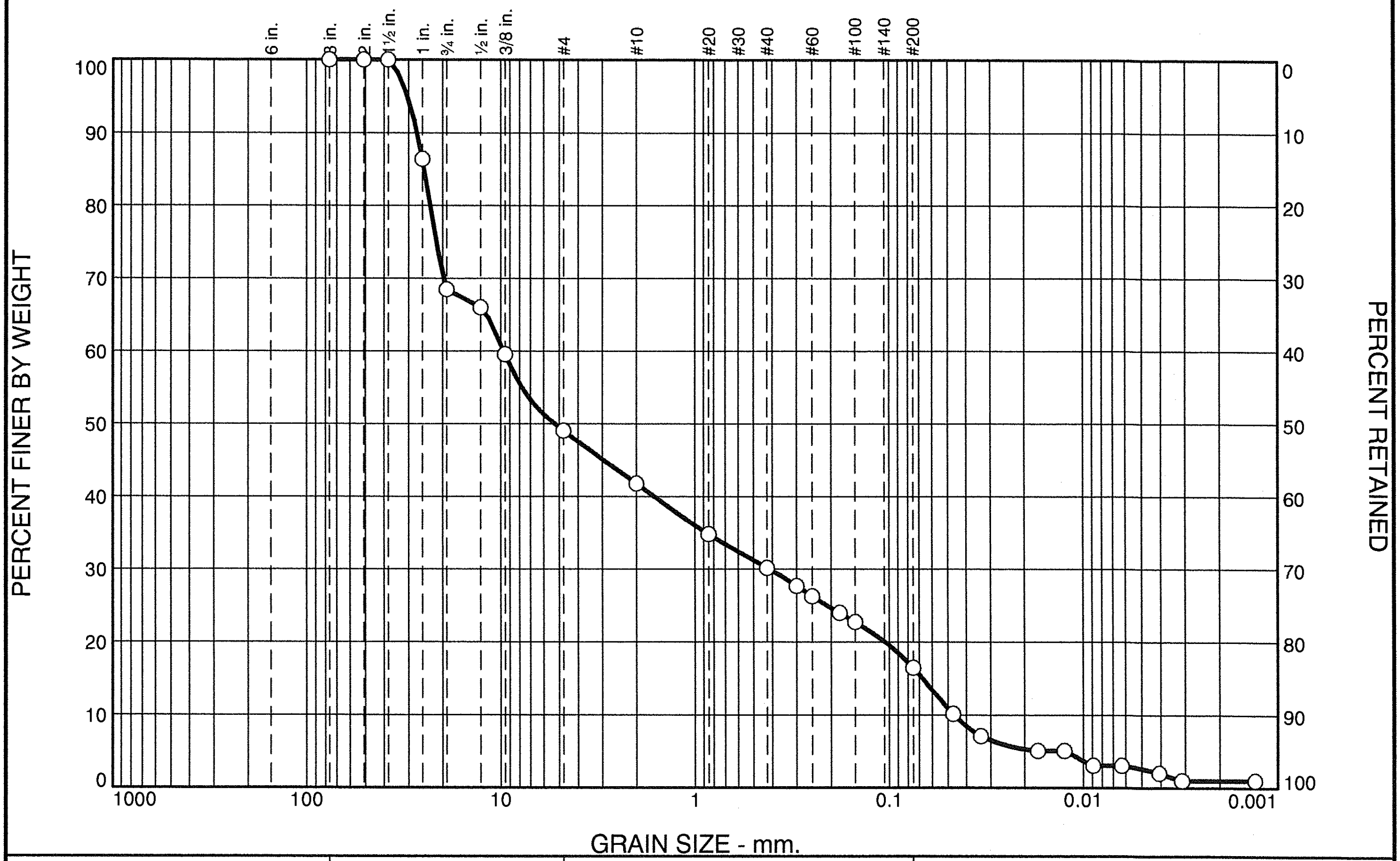
NOTES:

eDEP#1026068

REMARKS: THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY BETWEEN SOIL TYPES. TRANSITION MAY BE GRADUAL. WATER LEVEL READINGS HAVE BEEN MADE IN THE DRILL HOLES AT TIMES AND UNDER CONDITIONS STATED ON THE BORING LOGS. FLUCTUATIONS IN THE LEVEL OF THE GROUNDWATER MAY OCCUR DUE TO OTHER FACTORS THAN THOSE PRESENT AT THE TIME MEASUREMENTS WERE MADE.

Appendix E
Soil Gradation

GRAINSIZE DISTRIBUTION REPORT



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0	32	19	7	12	14	13	3

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
3"	100		
2"	100		
1.5"	100		
1"	86		
.75"	68		
.5"	66		
.375"	60		
#4	49		
#10	42		
#20	35		
#40	30		
#50	28		
#60	26		
#80	24		
#100	23		
#200	16		

* (no specification provided)

Material Description

Very dense, gray, highly weathered rock

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 27.0346 D_{85}= 24.8436 D_{60}= 9.6911
D_{50}= 5.2515 D_{30}= 0.4123 D_{15}= 0.0671
D_{10}= 0.0463 C_u= 209.18 C_c= 0.38

Classification

USCS= AASHTO=

Remarks

BORING JAR SAMPLE

Source of Sample: B-1 **Depth:** 9
Sample Number: S-4

Date: 7-14-17

MILLER ENGINEERING & TESTING, INC.

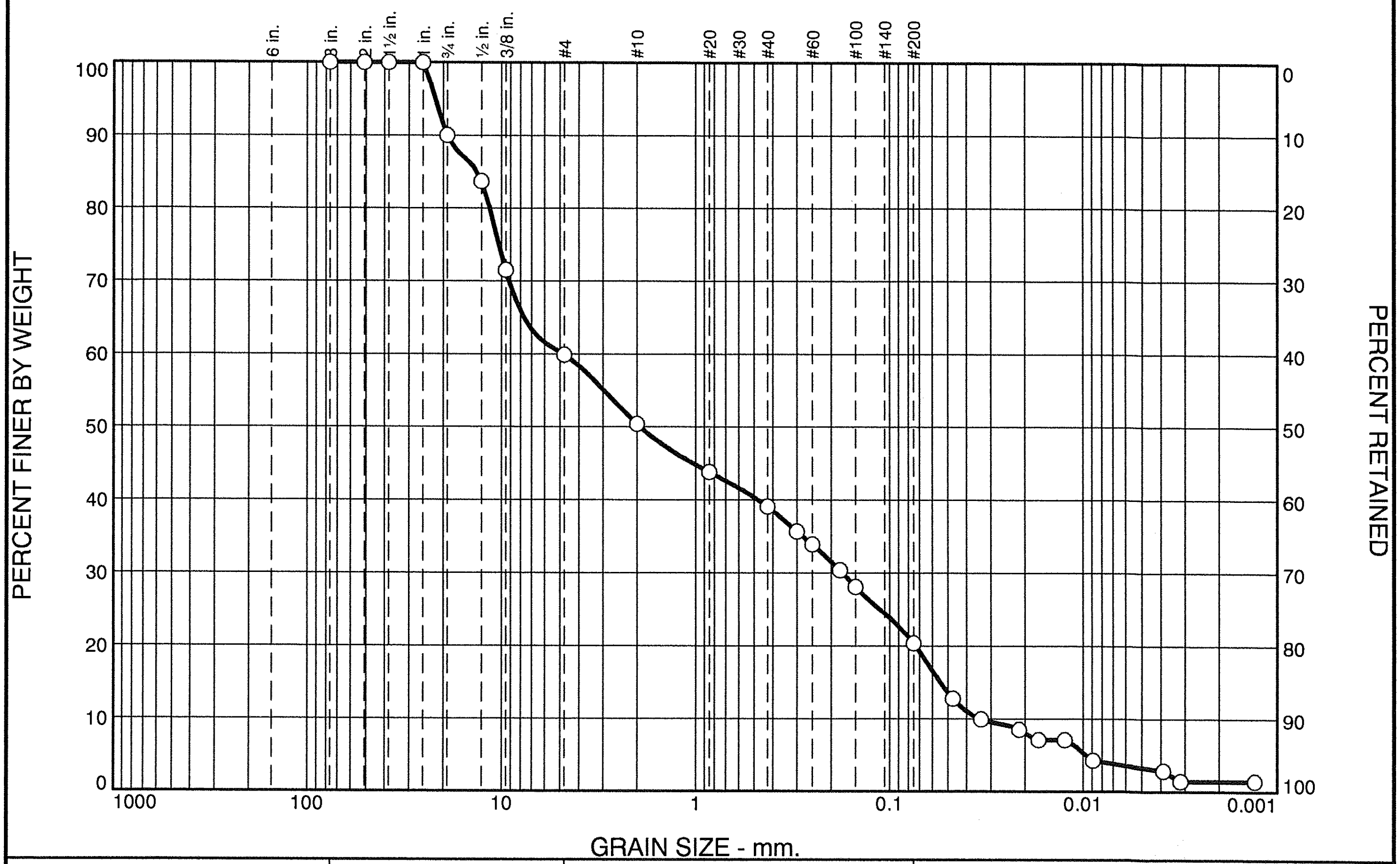
Client: Bayside Engineering
Project: Valley Rd. Bridge Culvert

Project No: 17.128.NH **Figure** L170227A

eDEP#1026068

Tested By: DM

GRAINSIZE DISTRIBUTION REPORT



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0	10	30	10	11	19	17	3

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
3"	100		
2"	100		
1.5"	100		
1"	100		
.75"	90		
.5"	84		
.375"	72		
#4	60		
#10	50		
#20	44		
#40	39		
#50	36		
#60	34		
#80	30		
#100	28		
#200	20		

* (no specification provided)

Material Description

Very dense, brown, fine sand, weathered rock

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 19.0082 D_{85}= 13.3672 D_{60}= 4.8090

D_{50}= 1.9230 D_{30}= 0.1739 D_{15}= 0.0544

D_{10}= 0.0341 C_u= 141.13 C_c= 0.18

Classification

USCS= AASHTO=

Remarks

BORING JAR SAMPLE.

Source of Sample: B-2 **Depth:** 9

Sample Number: S-4

Date: 7-14-17

MILLER ENGINEERING & TESTING, INC.

Client: Bayside Engineering

Project: Valley Rd. Bridge Culvert

Project No: 17.128.NH **Figure** L170227B

Tested By: DM

eDEP#1026068

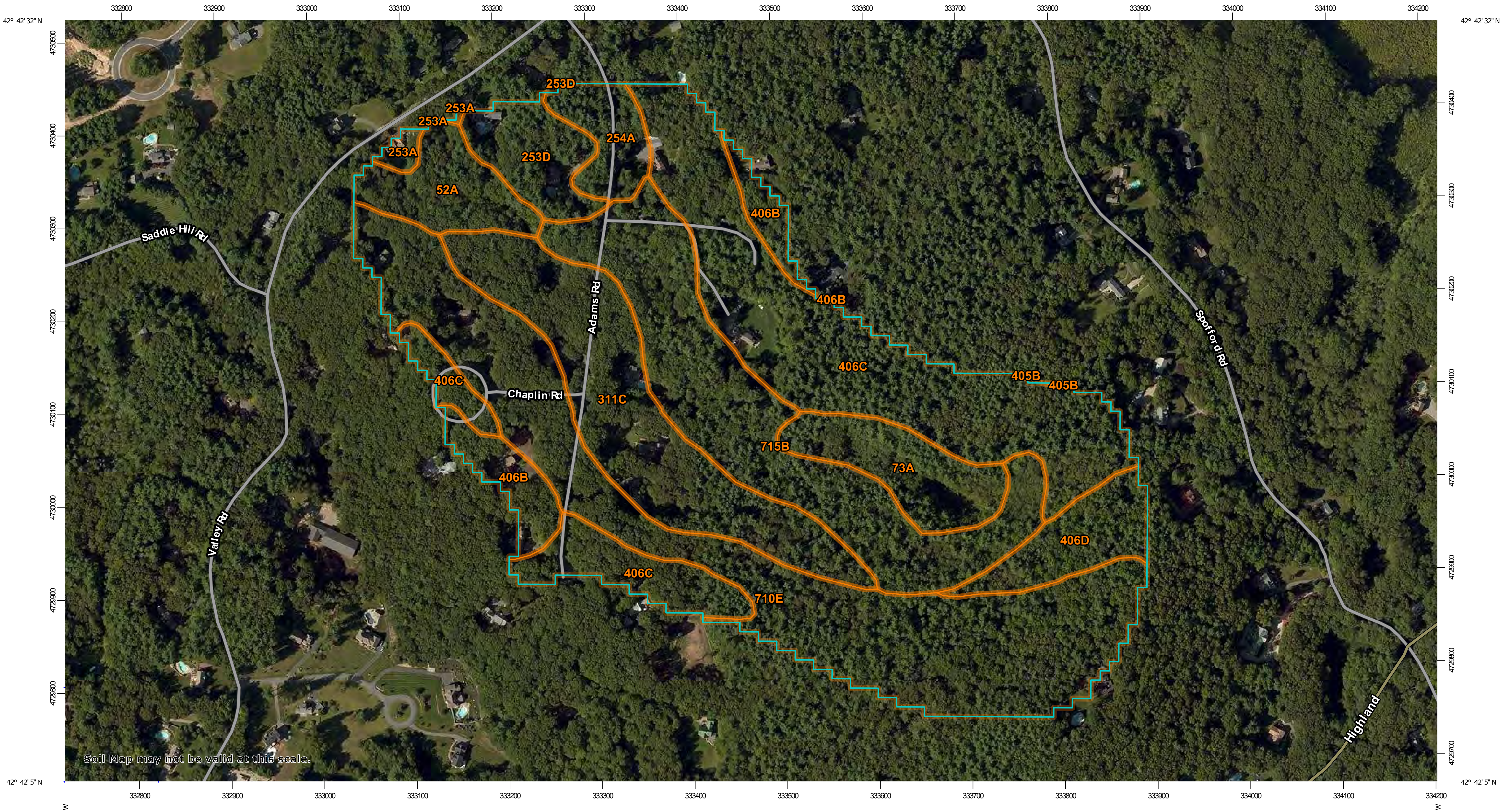
Appendix F
Hydrologic Analysis

Basin Characteristics Ungaged Site Report

Date: Tues June 6, 2017 2:40:57 PM GMT-4
Study Area: Massachusetts
NAD 1983 Latitude: 42.7079 (42 42 29)
NAD 1983 Longitude: -71.0378 (-71 02 17)

Label	Value	Units	Definition
DRNAREA	0.13	square miles	Area that drains to a point on a stream
STRMTOT	0.27	miles	Total length of mapped streams in basin
DRFTPERSTR	0.0845	square mile per mile	Area of stratified drift per unit of stream length
MAREGION	0	dimensionless	Region of Massachusetts 0 for Eastern 1 for Western
FOREST	66.38	percent	Percentage of area covered by forest
CRSDFT	17.29	percent	Percentage of area of coarse-grained stratified drift
BSLDEM10M	8.817	percent	Mean basin slope computed from 10 m DEM
BSLDEM250	3.851	percent	Mean basin slope computed from 1:250K DEM
ACRSDFT	0.0226	square miles	Area underlain by stratified drift
LC11IMP	0.4	percent	Average percentage of impervious area determined from NLCD 2011 impervious dataset
LC11DEV	7.66	percent	Percentage of developed (urban) land from NLCD 2011 classes 21-24
ELEV	201	feet	Mean Basin Elevation
PRECPRIS00	47	inches	Basin average mean annual precipitation for 1971 to 2000 from PRISM
LAKEAREA	0	percent	Percentage of Lakes and Ponds
OUTLETX	237855	State plane coordinates	Basin outlet horizontal (x) location in state plane coordinates
OUTLETY	939805	State plane coordinates	Basin outlet vertical (y) location in state plane coordinates
MAXTEMPC	15	degrees	Mean annual maximum air temperature over basin area, in degrees Centigrade
WETLAND	9.98	percent	Percentage of Wetlands
CENTROIDX	238222.1	State plane coordinates	Basin centroid horizontal (x) location in state plane coordinates
CENTROIDY	939507.6	State plane coordinates	Basin centroid vertical (y) location in state plane units
PCTSNDGRV	17.29	percent	Percentage of land surface underlain by sand and gravel deposits
LC06STOR	8.62	percent	Percentage of water bodies and wetlands determined from the NLCD 2006

Soil Map—Essex County, Massachusetts, Northern Part
(Valley Road Culvert Replacement)



Map Scale: 1:3,990 if printed on B landscape (17" x 11") sheet.

N

0 50 100 200 300 Meters

0 150 300 600 900 Feet

Map projection: Web Mercator Corner coordinates: WGS84 Edge tics: UTM Zone 19N WGS84

eDEP#1026068

MAP LEGEND

Area of Interest (AOI)

- □ Area of Interest (AOI)

Soils

- □ Soil Map Unit Polygons
- Soil Map Unit Lines
- ■ Soil Map Unit Points

Special Point Features

- Blowout
- ☒ Borrow Pit
- Clay Spot
- ◇ Closed Depression
- Gravel Pit
- Gravelly Spot
- Landfill
- Lava Flow
- Marsh or swamp
- Mine or Quarry
- ◎ Miscellaneous Water
- ○ Perennial Water
- Rock Outcrop
- + Saline Spot
- Sandy Spot
- Severely Eroded Spot
- ◇ Sinkhole
- Slide or Slip
- Sodic Spot
- Spoil Area
- Stony Spot
- Very Stony Spot
- Wet Spot
- △ Other
- Special Line Features

Water Features

- Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

- Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:15,800.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL:
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Essex County, Massachusetts, Northern Part
Survey Area Data: Version 12, Sep 14, 2016

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Aug 29, 2014—Sep 19, 2014

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Map Unit Legend

Essex County, Massachusetts, Northern Part (MA605)			
Map Unit Symbol	**Map Unit Name**	**Acres in AOI**	**Percent of AOI**
52A	Freetown muck, 0 to 1 percent slopes	3.4	4.0%
73A	Whitman fine sandy loam, 0 to 3 percent slopes, extremely stony	4.0	4.7%
253A	Hinckley loamy sand, 0 to 3 percent slopes	0.4	0.5%
253D	Hinckley loamy sand, 15 to 25 percent slopes	3.1	3.6%
254A	Merrimac fine sandy loam, 0 to 3 percent slopes	2.3	2.7%
311C	Woodbridge fine sandy loam, 8 to 15 percent slopes, very stony	11.2	13.1%
405B	Charlton fine sandy loam, 3 to 8 percent slopes	0.0	0.0%
406B	Charlton fine sandy loam, 3 to 8 percent slopes, very stony	2.9	3.4%
406C	Charlton fine sandy loam, 8 to 15 percent slopes, very stony	19.5	22.9%
406D	Charlton fine sandy loam, 15 to 25 percent slopes, very stony	3.2	3.7%
710E	Canton and Charlton fine sandy loams, 15 to 35 percent slopes, extremely stony	21.5	25.3%
715B	Ridgebury and Leicester fine sandy loams, 3 to 8 percent slopes, extremely stony	13.6	16.0%
Totals for Area of Interest		**85.2**	**100.0%**

Area Listing (all nodes)

Area (acres)	CN	Description (subcatchment-numbers)
2.366	46	2 acre lots, 12% imp, HSG A (1S)
7.588	65	2 acre lots, 12% imp, HSG B (1S)
0.680	77	2 acre lots, 12% imp, HSG C (1S)
2.382	82	2 acre lots, 12% imp, HSG D (1S)
6.574	30	Woods, Good, HSG A (1S)
36.355	55	Woods, Good, HSG B (1S)
29.159	77	Woods, Good, HSG D (1S)
85.104	**62**	**TOTAL AREA**

Soil Listing (all nodes)

Area (acres)	Soil Group	Subcatchment Numbers
8.940	HSG A	1S
43.943	HSG B	1S
0.680	HSG C	1S
31.541	HSG D	1S
0.000	Other	
85.104		**TOTAL AREA**

Ground Covers (all nodes)

HSG-A (acres)	HSG-B (acres)	HSG-C (acres)	HSG-D (acres)	Other (acres)	Total (acres)	Ground Cover	Subcatchment Numbers
2.366	7.588	0.680	2.382	0.000	13.016	2 acre lots, 12% imp	1S
6.574	36.355	0.000	29.159	0.000	72.088	Woods, Good	1S
8.940	**43.943**	**0.680**	**31.541**	**0.000**	**85.104**	**TOTAL AREA**	

Time span=5.00-20.00 hrs, dt=0.05 hrs, 301 points
Runoff by SCS TR-20 method, UH=SCS, Weighted-CN
Reach routing by Stor-Ind+Trans method - Pond routing by Stor-Ind method

Subcatchment 1S: (new Subcat) Runoff Area=85.104 ac 1.84% Impervious Runoff Depth>0.19"
Flow Length=2,785' Tc=70.4 min CN=62 Runoff=3.76 cfs 1.333 af

Total Runoff Area = 85.104 ac Runoff Volume = 1.333 af Average Runoff Depth = 0.19"
98.16% Pervious = 83.542 ac 1.84% Impervious = 1.562 ac

Summary for Subcatchment 1S: (new Subcat)

Runoff = 3.76 cfs @ 13.30 hrs, Volume= 1.333 af, Depth> 0.19"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 5.00-20.00 hrs, dt= 0.05 hrs
MA-Boxford 24-hr S1 1-yr Rainfall=2.63"

Area (ac)	CN	Description
2.366	46	2 acre lots, 12% imp, HSG A
7.588	65	2 acre lots, 12% imp, HSG B
0.680	77	2 acre lots, 12% imp, HSG C
2.382	82	2 acre lots, 12% imp, HSG D
6.574	30	Woods, Good, HSG A
36.355	55	Woods, Good, HSG B
4.896	77	Woods, Good, HSG D
24.263	77	Woods, Good, HSG D
85.104	62	Weighted Average
83.542		98.16% Pervious Area
1.562		1.84% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
13.1	100	0.0700	0.13		**Sheet Flow,** Woods: Light underbrush n= 0.400 P2= 3.15"
4.4	185	0.0800	0.71		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
50.0	1,500	0.0100	0.50		**Shallow Concentrated Flow,** Woodland Kv= 5.0 fps
2.9	1,000	0.0070	5.75	137.93	**Channel Flow,** Area= 24.0 sf Perim= 8.0' r= 3.00' n= 0.045 Winding stream, pools & shoals
70.4	2,785	Total			

Time span=5.00-20.00 hrs, dt=0.05 hrs, 301 points
Runoff by SCS TR-20 method, UH=SCS, Weighted-CN
Reach routing by Stor-Ind+Trans method - Pond routing by Stor-Ind method

Subcatchment 1S: (new Subcat) Runoff Area=85.104 ac 1.84% Impervious Runoff Depth>0.35"
Flow Length=2,785' Tc=70.4 min CN=62 Runoff=9.19 cfs 2.494 af

Total Runoff Area = 85.104 ac Runoff Volume = 2.494 af Average Runoff Depth = 0.35"
98.16% Pervious = 83.542 ac 1.84% Impervious = 1.562 ac

Summary for Subcatchment 1S: (new Subcat)

Runoff = 9.19 cfs @ 13.15 hrs, Volume= 2.494 af, Depth> 0.35"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 5.00-20.00 hrs, dt= 0.05 hrs
MA-Boxford 24-hr S1 2-yr Rainfall=3.15"

Area (ac)	CN	Description
2.366	46	2 acre lots, 12% imp, HSG A
7.588	65	2 acre lots, 12% imp, HSG B
0.680	77	2 acre lots, 12% imp, HSG C
2.382	82	2 acre lots, 12% imp, HSG D
6.574	30	Woods, Good, HSG A
36.355	55	Woods, Good, HSG B
4.896	77	Woods, Good, HSG D
24.263	77	Woods, Good, HSG D
85.104	62	Weighted Average
83.542		98.16% Pervious Area
1.562		1.84% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
13.1	100	0.0700	0.13		**Sheet Flow,** Woods: Light underbrush n= 0.400 P2= 3.15"
4.4	185	0.0800	0.71		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
50.0	1,500	0.0100	0.50		**Shallow Concentrated Flow,** Woodland Kv= 5.0 fps
2.9	1,000	0.0070	5.75	137.93	**Channel Flow,** Area= 24.0 sf Perim= 8.0' r= 3.00' n= 0.045 Winding stream, pools & shoals
70.4	2,785	Total			

Time span=5.00-20.00 hrs, dt=0.05 hrs, 301 points
Runoff by SCS TR-20 method, UH=SCS, Weighted-CN
Reach routing by Stor-Ind+Trans method - Pond routing by Stor-Ind method

Subcatchment 1S: (new Subcat) Runoff Area=85.104 ac 1.84% Impervious Runoff Depth>0.70"
Flow Length=2,785' Tc=70.4 min CN=62 Runoff=21.09 cfs 4.937 af

Total Runoff Area = 85.104 ac Runoff Volume = 4.937 af Average Runoff Depth = 0.70"
98.16% Pervious = 83.542 ac 1.84% Impervious = 1.562 ac

Summary for Subcatchment 1S: (new Subcat)

Runoff = 21.09 cfs @ 13.05 hrs, Volume= 4.937 af, Depth> 0.70"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 5.00-20.00 hrs, dt= 0.05 hrs
MA-Boxford 24-hr S1 5-yr Rainfall=4.02"

Area (ac)	CN	Description
2.366	46	2 acre lots, 12% imp, HSG A
7.588	65	2 acre lots, 12% imp, HSG B
0.680	77	2 acre lots, 12% imp, HSG C
2.382	82	2 acre lots, 12% imp, HSG D
6.574	30	Woods, Good, HSG A
36.355	55	Woods, Good, HSG B
4.896	77	Woods, Good, HSG D
24.263	77	Woods, Good, HSG D
85.104	62	Weighted Average
83.542		98.16% Pervious Area
1.562		1.84% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
13.1	100	0.0700	0.13		**Sheet Flow,** Woods: Light underbrush n= 0.400 P2= 3.15"
4.4	185	0.0800	0.71		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
50.0	1,500	0.0100	0.50		**Shallow Concentrated Flow,** Woodland Kv= 5.0 fps
2.9	1,000	0.0070	5.75	137.93	**Channel Flow,** Area= 24.0 sf Perim= 8.0' r= 3.00' n= 0.045 Winding stream, pools & shoals
70.4	2,785	Total			

Time span=5.00-20.00 hrs, dt=0.05 hrs, 301 points
Runoff by SCS TR-20 method, UH=SCS, Weighted-CN
Reach routing by Stor-Ind+Trans method - Pond routing by Stor-Ind method

Subcatchment 1S: (new Subcat) Runoff Area=85.104 ac 1.84% Impervious Runoff Depth>1.09"
Flow Length=2,785' Tc=70.4 min CN=62 Runoff=34.53 cfs 7.722 af

Total Runoff Area = 85.104 ac Runoff Volume = 7.722 af Average Runoff Depth = 1.09"
98.16% Pervious = 83.542 ac 1.84% Impervious = 1.562 ac

Summary for Subcatchment 1S: (new Subcat)

Runoff = 34.53 cfs @ 13.01 hrs, Volume= 7.722 af, Depth> 1.09"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 5.00-20.00 hrs, dt= 0.05 hrs
MA-Boxford 24-hr S1 10-yr Rainfall=4.84"

Area (ac)	CN	Description
2.366	46	2 acre lots, 12% imp, HSG A
7.588	65	2 acre lots, 12% imp, HSG B
0.680	77	2 acre lots, 12% imp, HSG C
2.382	82	2 acre lots, 12% imp, HSG D
6.574	30	Woods, Good, HSG A
36.355	55	Woods, Good, HSG B
4.896	77	Woods, Good, HSG D
24.263	77	Woods, Good, HSG D
85.104	62	Weighted Average
83.542		98.16% Pervious Area
1.562		1.84% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
13.1	100	0.0700	0.13		**Sheet Flow,** Woods: Light underbrush n= 0.400 P2= 3.15"
4.4	185	0.0800	0.71		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
50.0	1,500	0.0100	0.50		**Shallow Concentrated Flow,** Woodland Kv= 5.0 fps
2.9	1,000	0.0070	5.75	137.93	**Channel Flow,** Area= 24.0 sf Perim= 8.0' r= 3.00' n= 0.045 Winding stream, pools & shoals
70.4	2,785	Total			

Time span=5.00-20.00 hrs, dt=0.05 hrs, 301 points
Runoff by SCS TR-20 method, UH=SCS, Weighted-CN
Reach routing by Stor-Ind+Trans method - Pond routing by Stor-Ind method

Subcatchment 1S: (new Subcat) Runoff Area=85.104 ac 1.84% Impervious Runoff Depth>1.83"
Flow Length=2,785' Tc=70.4 min CN=62 Runoff=59.07 cfs 13.012 af

Total Runoff Area = 85.104 ac Runoff Volume = 13.012 af Average Runoff Depth = 1.83"
98.16% Pervious = 83.542 ac 1.84% Impervious = 1.562 ac

Summary for Subcatchment 1S: (new Subcat)

Runoff = 59.07 cfs @ 12.97 hrs, Volume= 13.012 af, Depth> 1.83"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 5.00-20.00 hrs, dt= 0.05 hrs
MA-Boxford 24-hr S1 25-yr Rainfall=6.18"

Area (ac)	CN	Description
2.366	46	2 acre lots, 12% imp, HSG A
7.588	65	2 acre lots, 12% imp, HSG B
0.680	77	2 acre lots, 12% imp, HSG C
2.382	82	2 acre lots, 12% imp, HSG D
6.574	30	Woods, Good, HSG A
36.355	55	Woods, Good, HSG B
4.896	77	Woods, Good, HSG D
24.263	77	Woods, Good, HSG D
85.104	62	Weighted Average
83.542		98.16% Pervious Area
1.562		1.84% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
13.1	100	0.0700	0.13		**Sheet Flow,** Woods: Light underbrush n= 0.400 P2= 3.15"
4.4	185	0.0800	0.71		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
50.0	1,500	0.0100	0.50		**Shallow Concentrated Flow,** Woodland Kv= 5.0 fps
2.9	1,000	0.0070	5.75	137.93	**Channel Flow,** Area= 24.0 sf Perim= 8.0' r= 3.00' n= 0.045 Winding stream, pools & shoals
70.4	2,785	Total			

```
                    Time span=5.00-20.00 hrs, dt=0.05 hrs, 301 points
                    Runoff by SCS TR-20 method, UH=SCS, Weighted-CN
          Reach routing by Stor-Ind+Trans method  -  Pond routing by Stor-Ind method

Subcatchment 1S: (new Subcat)      Runoff Area=85.104 ac   1.84% Impervious   Runoff Depth>2.62"
                                Flow Length=2,785'   Tc=70.4 min   CN=62   Runoff=84.02 cfs  18.599 af

        Total Runoff Area = 85.104 ac   Runoff Volume = 18.599 af   Average Runoff Depth = 2.62"
                                  98.16% Pervious = 83.542 ac     1.84% Impervious = 1.562 ac
```

Summary for Subcatchment 1S: (new Subcat)

Runoff = 84.02 cfs @ 12.94 hrs, Volume= 18.599 af, Depth> 2.62"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 5.00-20.00 hrs, dt= 0.05 hrs
MA-Boxford 24-hr S1 50-yr Rainfall=7.44"

Area (ac)	CN	Description
2.366	46	2 acre lots, 12% imp, HSG A
7.588	65	2 acre lots, 12% imp, HSG B
0.680	77	2 acre lots, 12% imp, HSG C
2.382	82	2 acre lots, 12% imp, HSG D
6.574	30	Woods, Good, HSG A
36.355	55	Woods, Good, HSG B
4.896	77	Woods, Good, HSG D
24.263	77	Woods, Good, HSG D
85.104	62	Weighted Average
83.542		98.16% Pervious Area
1.562		1.84% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
13.1	100	0.0700	0.13		**Sheet Flow,** Woods: Light underbrush n= 0.400 P2= 3.15"
4.4	185	0.0800	0.71		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
50.0	1,500	0.0100	0.50		**Shallow Concentrated Flow,** Woodland Kv= 5.0 fps
2.9	1,000	0.0070	5.75	137.93	**Channel Flow,** Area= 24.0 sf Perim= 8.0' r= 3.00' n= 0.045 Winding stream, pools & shoals
70.4	2,785	Total			

```
                    Time span=5.00-20.00 hrs, dt=0.05 hrs, 301 points
                   Runoff by SCS TR-20 method, UH=SCS, Weighted-CN
          Reach routing by Stor-Ind+Trans method  -  Pond routing by Stor-Ind method

Subcatchment1S: (new Subcat)        Runoff Area=85.104 ac   1.84% Impervious   Runoff Depth>3.65"
                               Flow Length=2,785'   Tc=70.4 min   CN=62   Runoff=115.45 cfs  25.907 af

         Total Runoff Area = 85.104 ac   Runoff Volume = 25.907 af   Average Runoff Depth = 3.65"
                                      98.16% Pervious = 83.542 ac     1.84% Impervious = 1.562 ac
```

Summary for Subcatchment 1S: (new Subcat)

Runoff = 115.45 cfs @ 12.93 hrs, Volume= 25.907 af, Depth> 3.65"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 5.00-20.00 hrs, dt= 0.05 hrs
MA-Boxford 24-hr S1 100-yr Rainfall=8.96"

Area (ac)	CN	Description
2.366	46	2 acre lots, 12% imp, HSG A
7.588	65	2 acre lots, 12% imp, HSG B
0.680	77	2 acre lots, 12% imp, HSG C
2.382	82	2 acre lots, 12% imp, HSG D
6.574	30	Woods, Good, HSG A
36.355	55	Woods, Good, HSG B
4.896	77	Woods, Good, HSG D
24.263	77	Woods, Good, HSG D
85.104	62	Weighted Average
83.542		98.16% Pervious Area
1.562		1.84% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
13.1	100	0.0700	0.13		**Sheet Flow,** Woods: Light underbrush n= 0.400 P2= 3.15"
4.4	185	0.0800	0.71		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
50.0	1,500	0.0100	0.50		**Shallow Concentrated Flow,** Woodland Kv= 5.0 fps
2.9	1,000	0.0070	5.75	137.93	**Channel Flow,** Area= 24.0 sf Perim= 8.0' r= 3.00' n= 0.045 Winding stream, pools & shoals
70.4	2,785	Total			

Time span=5.00-20.00 hrs, dt=0.05 hrs, 301 points
Runoff by SCS TR-20 method, UH=SCS, Weighted-CN
Reach routing by Stor-Ind+Trans method - Pond routing by Stor-Ind method

Subcatchment 1S: (new Subcat) Runoff Area=85.104 ac 1.84% Impervious Runoff Depth>7.31"
Flow Length=2,785' Tc=70.4 min CN=62 Runoff=219.78 cfs 51.844 af

Total Runoff Area = 85.104 ac Runoff Volume = 51.844 af Average Runoff Depth = 7.31"
98.16% Pervious = 83.542 ac 1.84% Impervious = 1.562 ac

Summary for Subcatchment 1S: (new Subcat)

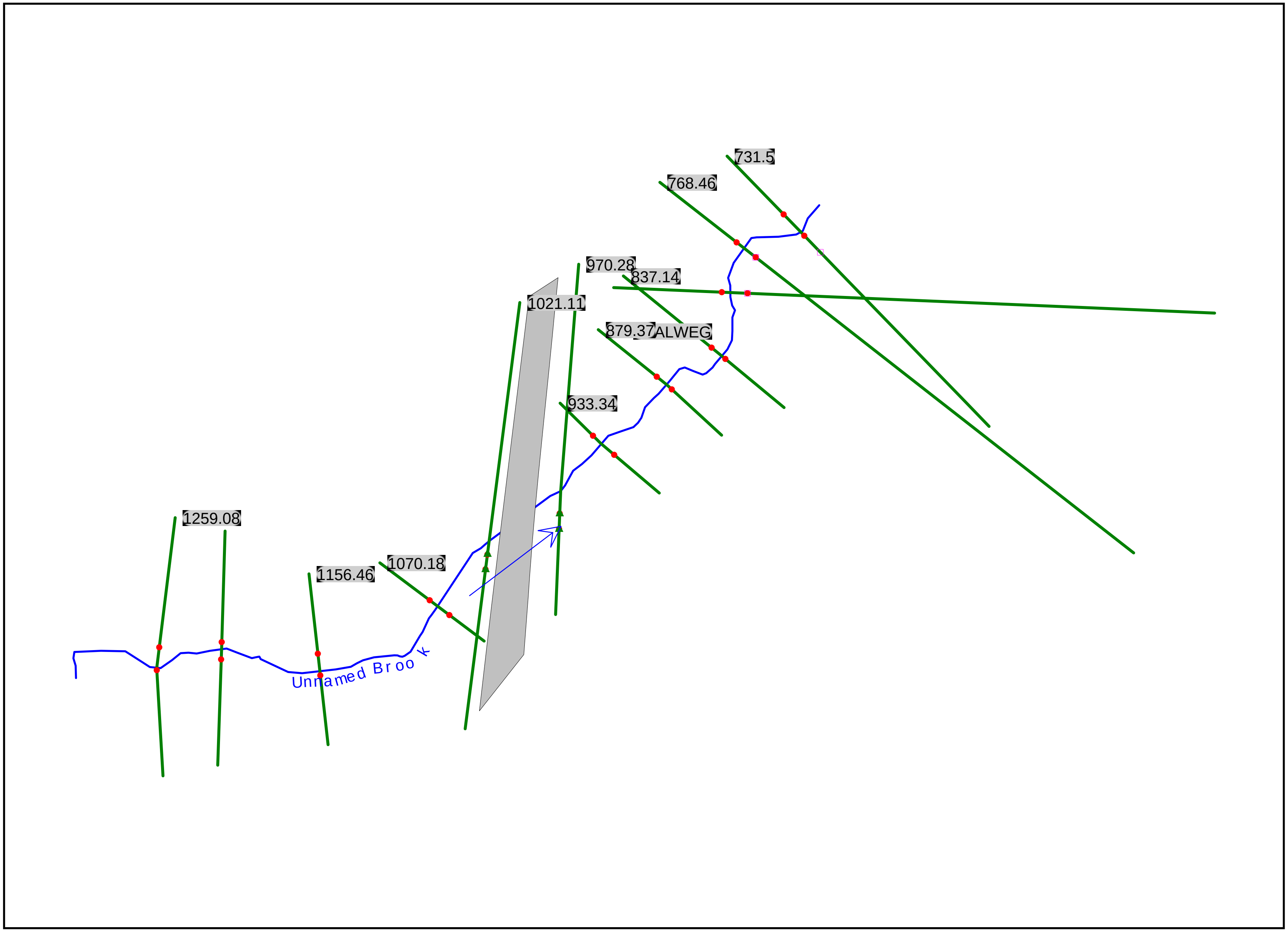
Runoff = 219.78 cfs @ 12.91 hrs, Volume= 51.844 af, Depth> 7.31"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 5.00-20.00 hrs, dt= 0.05 hrs
MA-Boxford 24-hr S1 500-yr Rainfall=13.84"

Area (ac)	CN	Description
2.366	46	2 acre lots, 12% imp, HSG A
7.588	65	2 acre lots, 12% imp, HSG B
0.680	77	2 acre lots, 12% imp, HSG C
2.382	82	2 acre lots, 12% imp, HSG D
6.574	30	Woods, Good, HSG A
36.355	55	Woods, Good, HSG B
4.896	77	Woods, Good, HSG D
24.263	77	Woods, Good, HSG D
85.104	62	Weighted Average
83.542		98.16% Pervious Area
1.562		1.84% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
13.1	100	0.0700	0.13		**Sheet Flow,** Woods: Light underbrush n= 0.400 P2= 3.15"
4.4	185	0.0800	0.71		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
50.0	1,500	0.0100	0.50		**Shallow Concentrated Flow,** Woodland Kv= 5.0 fps
2.9	1,000	0.0070	5.75	137.93	**Channel Flow,** Area= 24.0 sf Perim= 8.0' r= 3.00' n= 0.045 Winding stream, pools & shoals
70.4	2,785	Total			

Appendix G
Hydraulic Analysis



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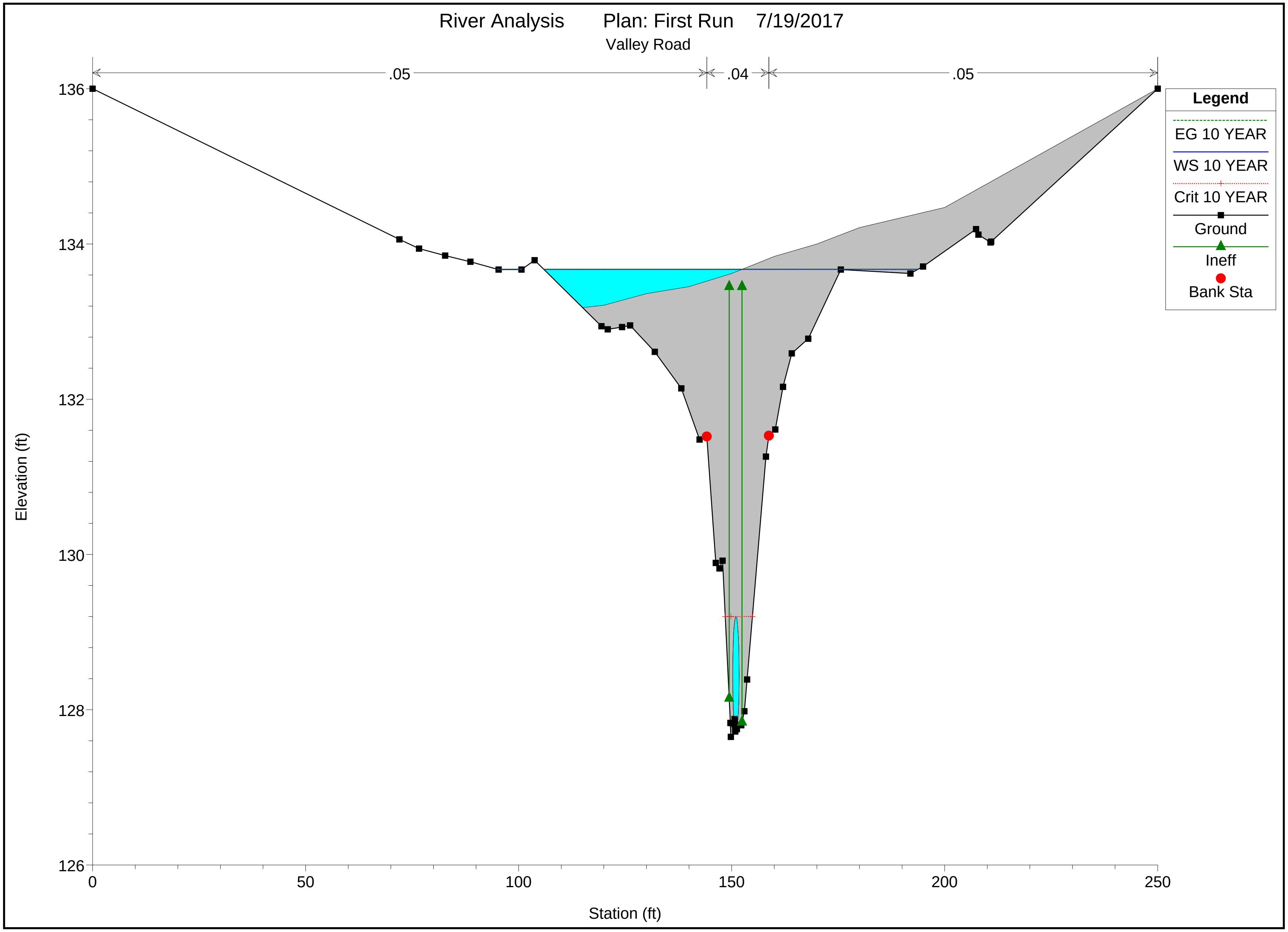

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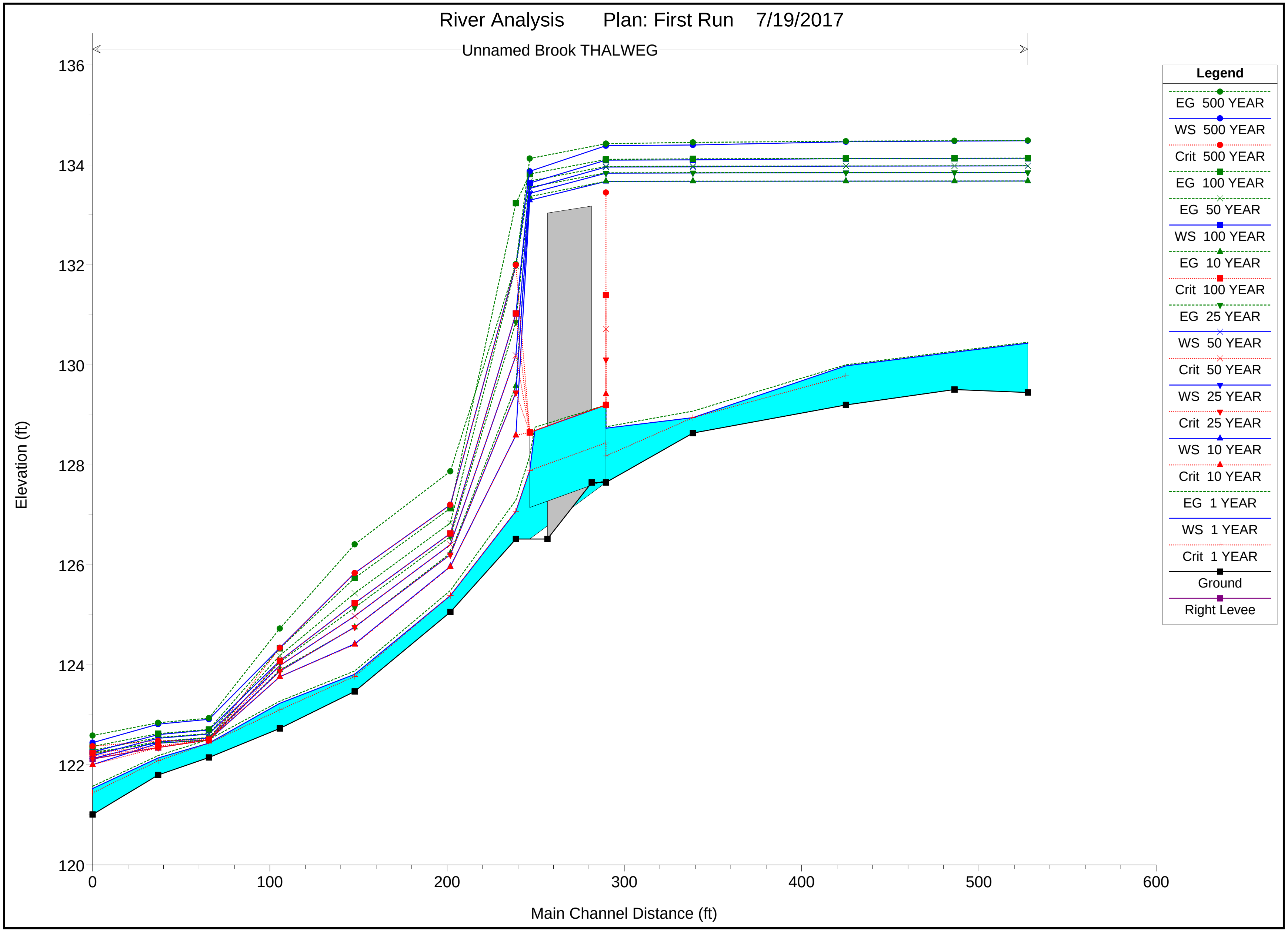
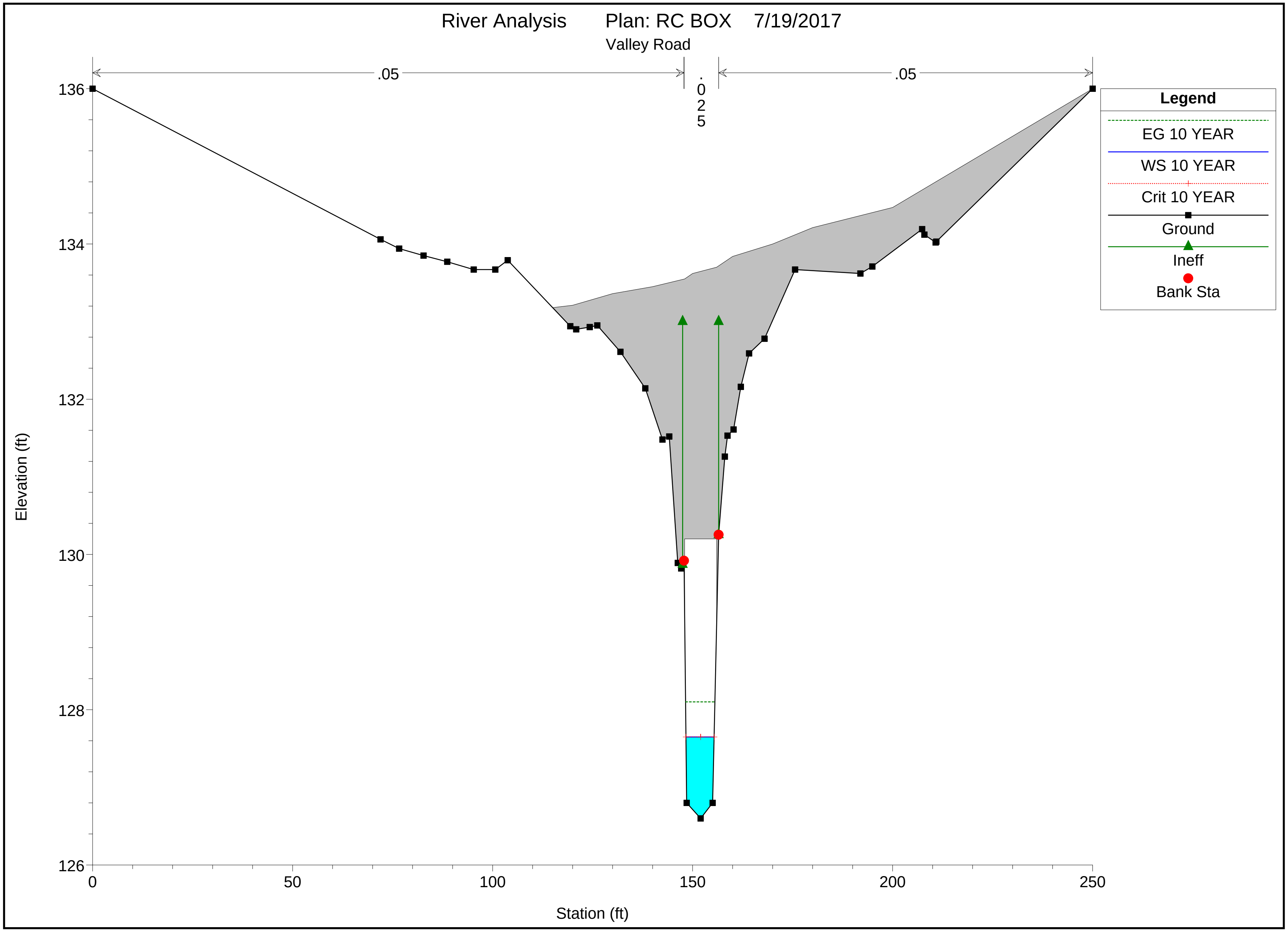

River Analysis Plan: First Run 7/19/2017
Unnamed Brook THALWEG
Elevation (ft)
136
134
132
130
128
126
124
122
120
0
100
200
300
400
500
600
Main Channel Distance (ft)
Legend
EG 500 YEAR
WS 500 YEAR
Crit 500 YEAR
EG 100 YEAR
EG 50 YEAR
WS 100 YEAR
EG 10 YEAR
Crit 100 YEAR
EG 25 YEAR
WS 50 YEAR
Crit 50 YEAR
WS 25 YEAR
Crit 25 YEAR
WS 10 YEAR
Crit 10 YEAR
EG 1 YEAR
WS 1 YEAR
Crit 1 YEAR
Ground
Right Levee



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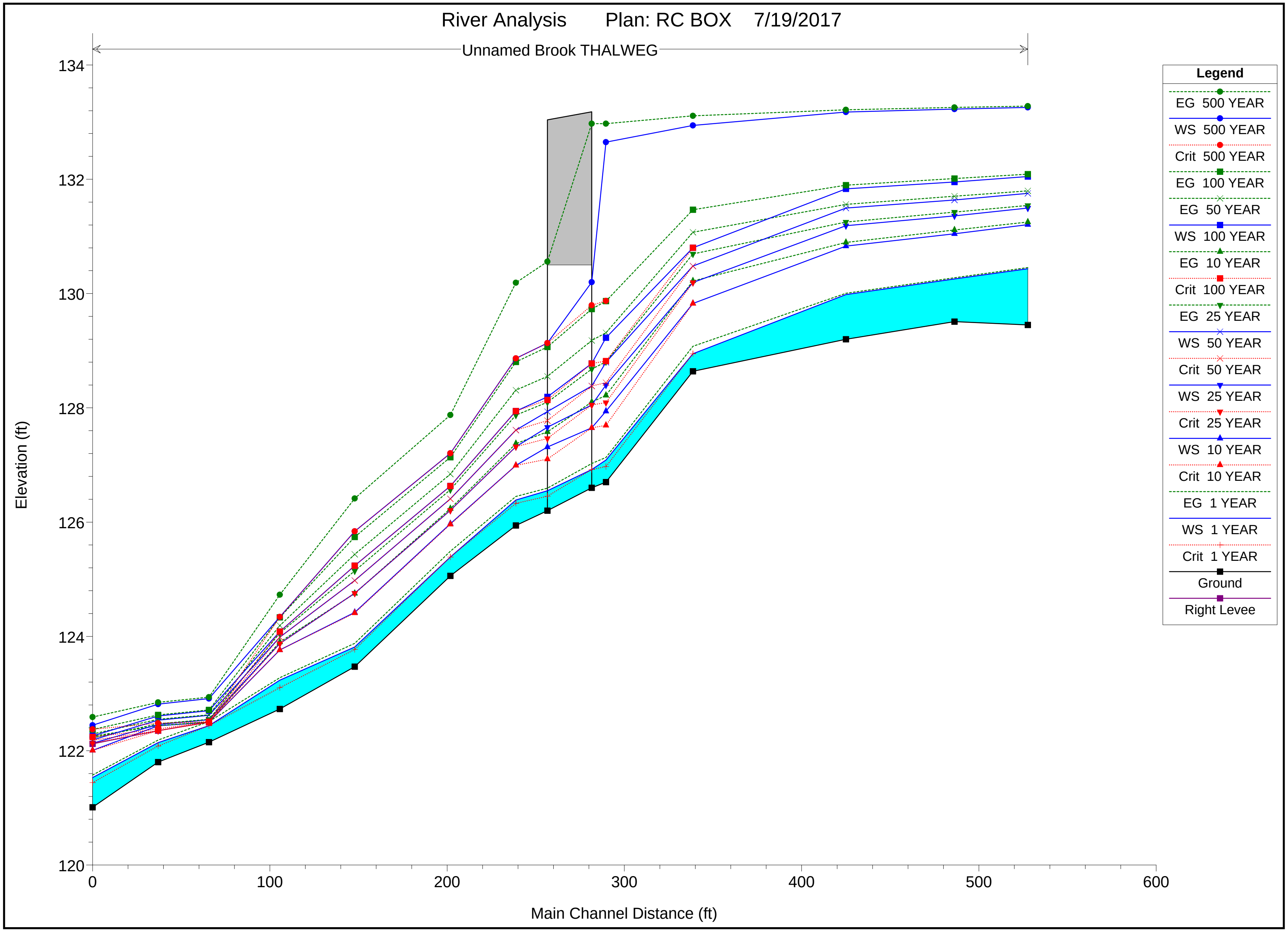

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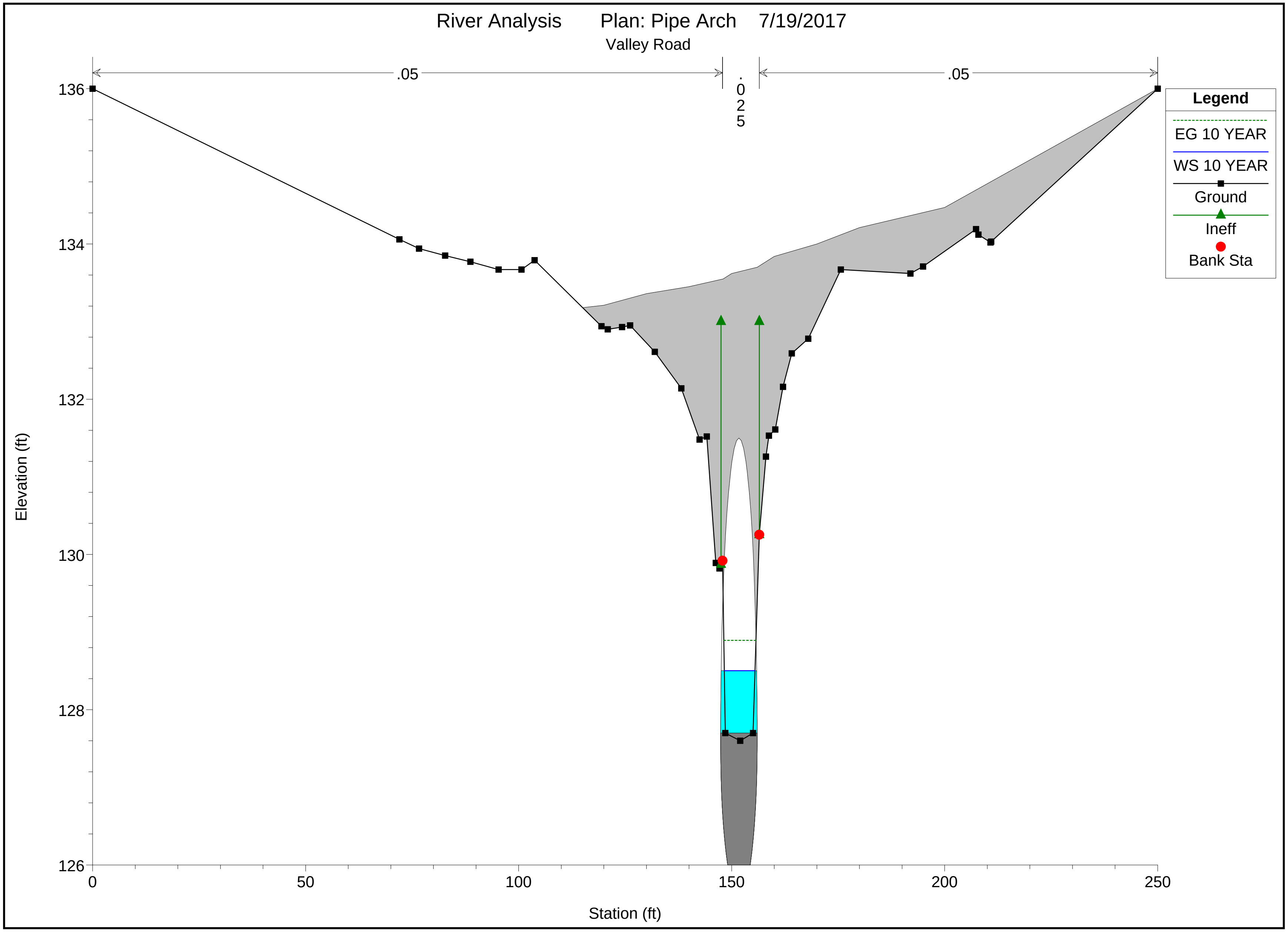
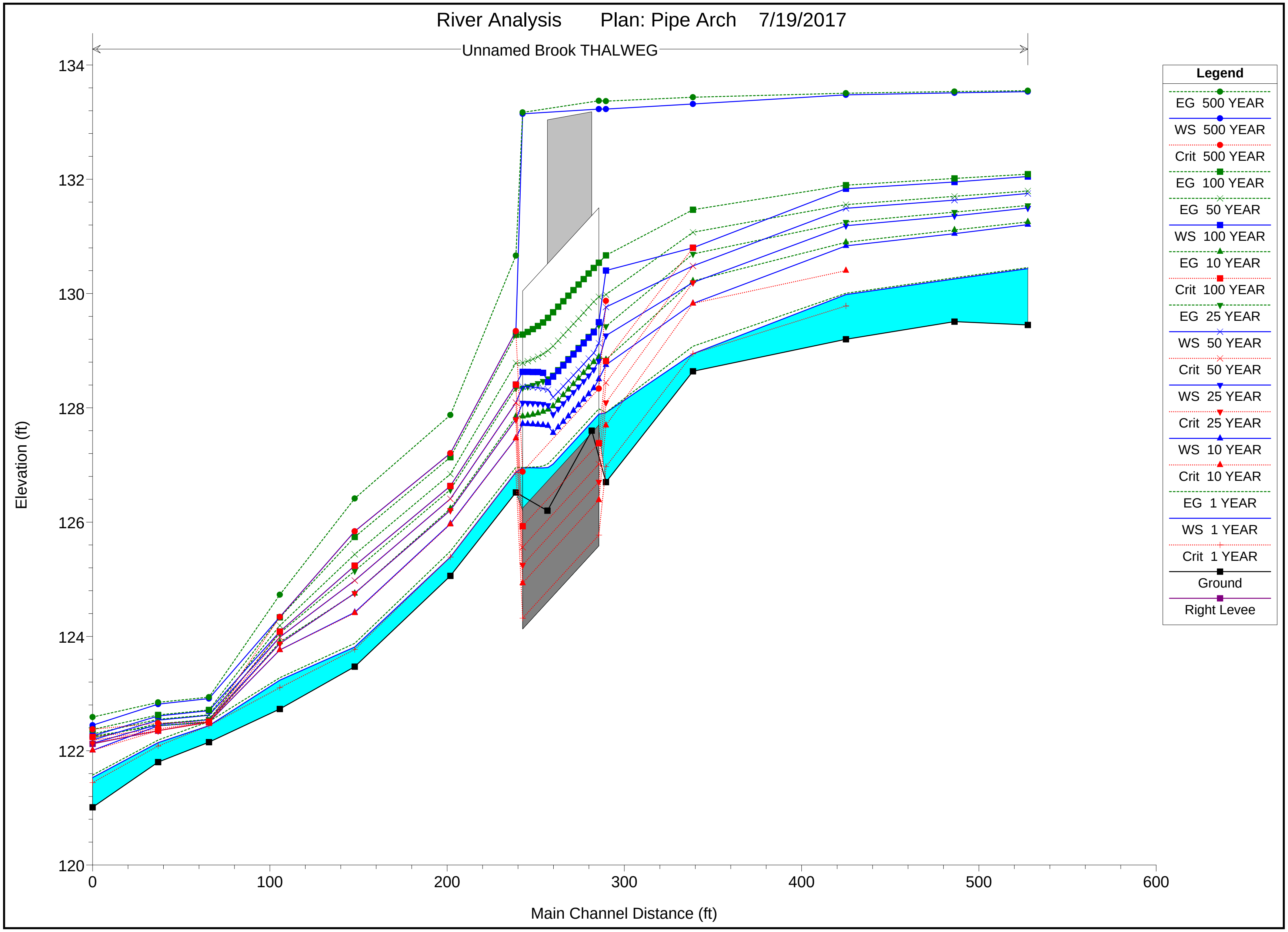
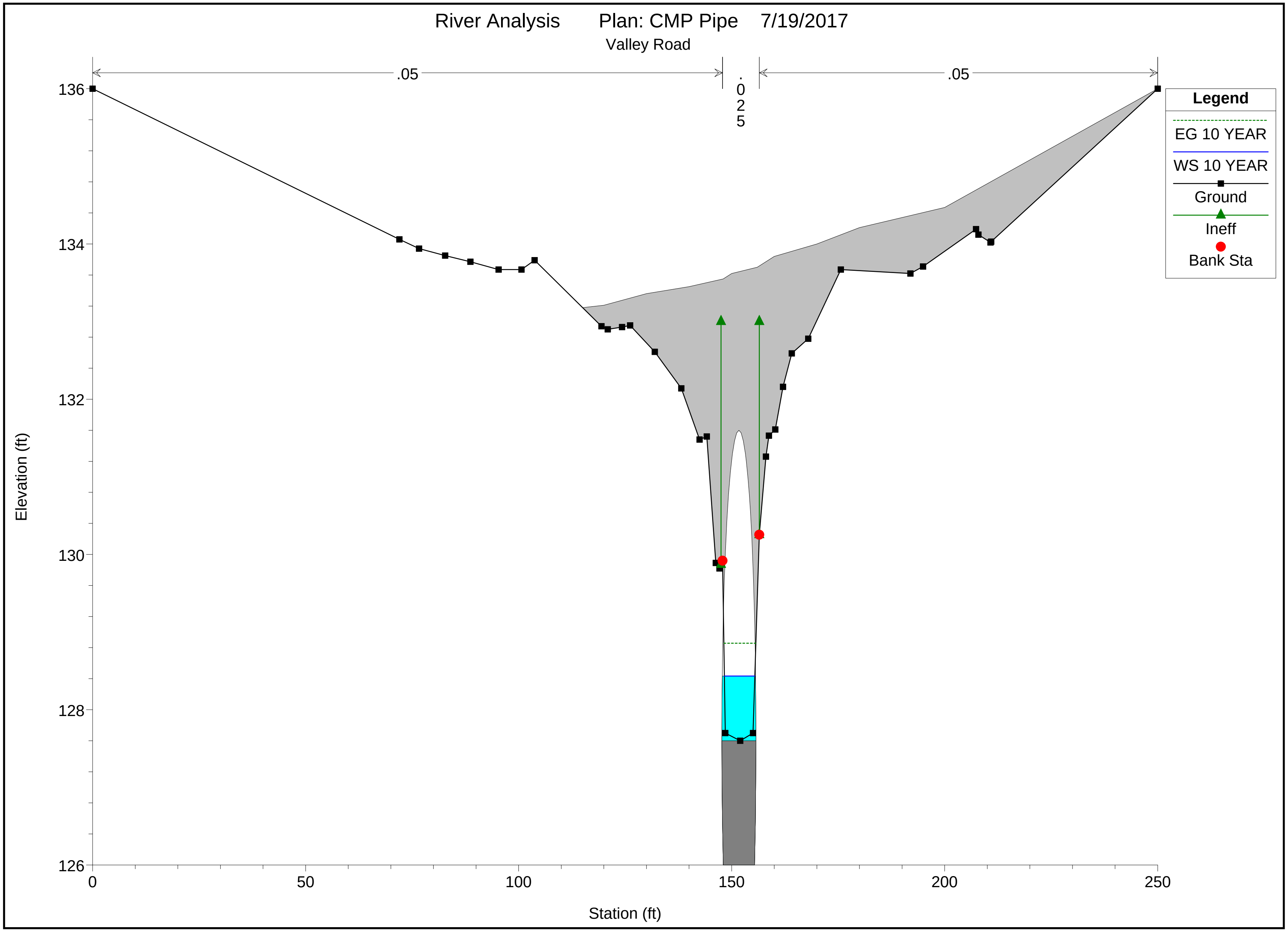
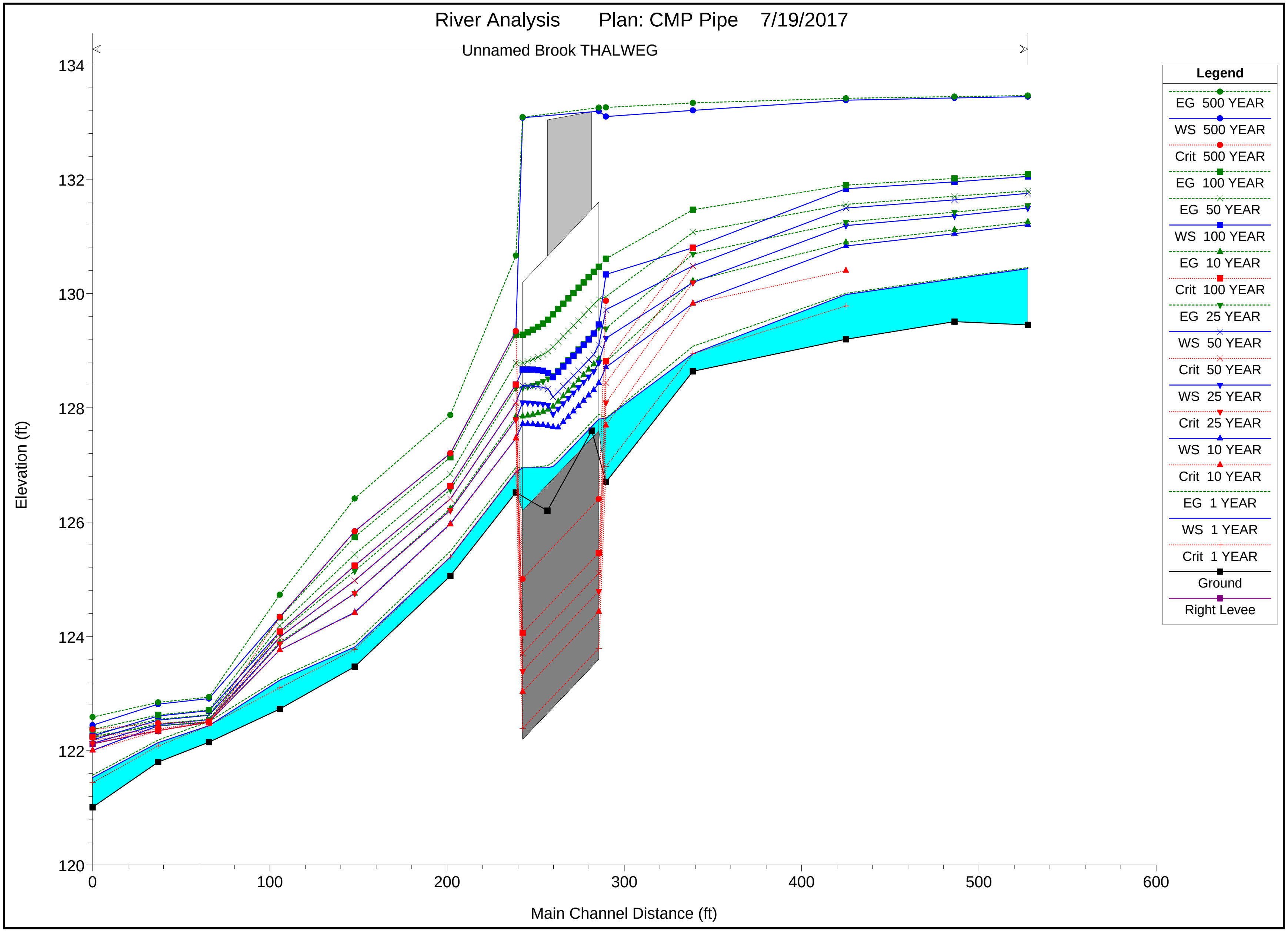

River Analysis
Plan: Pipe Arch
7/19/2017
Valley Road
.05
.025
.05
Legend
EG 10 YEAR
WS 10 YEAR
Ground
Ineff
Bank Sta
Elevation (ft)
136
134
132
130
128
126
Station (ft)
0
50
100
150
200
250



River Analysis Plan: Pipe Arch 7/19/2017
Unnamed Brook THALWEG
Elevation (ft)
134
132
130
128
126
124
122
120
Main Channel Distance (ft)
0
100
200
300
400
500
600
Legend
EG 500 YEAR
WS 500 YEAR
Crit 500 YEAR
EG 100 YEAR
EG 50 YEAR
WS 100 YEAR
EG 10 YEAR
Crit 100 YEAR
EG 25 YEAR
WS 50 YEAR
Crit 50 YEAR
WS 25 YEAR
Crit 25 YEAR
WS 10 YEAR
Crit 10 YEAR
EG 1 YEAR
WS 1 YEAR
Crit 1 YEAR
Ground
Right Levee


River Analysis
Plan: CMP Pipe
7/19/2017
Valley Road
.05
.025
.05
Legend
EG 10 YEAR
WS 10 YEAR
Ground
Ineff
Bank Sta
Elevation (ft)
136
134
132
130
128
126
Station (ft)
0
50
100
150
200
250



eDEP#1026068

HEC-RAS Locations: User Defined   Profile: 10 YEAR

River	Reach	River Sta	Profile	Plan	E.G. Elev	W.S. Elev	Vel Head	Frctn Loss	C & E Loss	Q Left	Q Channel	Q Right	Top Width
					(ft)	(ft)	(ft)	(ft)	(ft)	(cfs)	(cfs)	(cfs)	(ft)
Unnamed Brook	THALWEG	1021.11	10 YEAR	FR	133.68	133.67	0.00			5.01	27.95	1.57	93.36
Unnamed Brook	THALWEG	1021.11	10 YEAR	pipe arch	128.84	128.75	0.09				34.53		7.75
Unnamed Brook	THALWEG	1021.11	10 YEAR	RC BOX	128.22	127.94	0.28	0.10	0.02		34.53		7.23
Unnamed Brook	THALWEG	1021.11	10 YEAR	Pipe	128.81	128.71	0.10				34.53		7.73
Unnamed Brook	THALWEG	1012.79			Culvert								
Unnamed Brook	THALWEG	970.28	10 YEAR	FR	129.58	128.59	0.99	0.85	0.22		34.53		32.11
Unnamed Brook	THALWEG	970.28	10 YEAR	pipe arch	127.85	127.47	0.38	0.99	0.04		34.53		18.32
Unnamed Brook	THALWEG	970.28	10 YEAR	RC BOX	127.37	126.99	0.38	1.01	0.04		34.53		12.09
Unnamed Brook	THALWEG	970.28	10 YEAR	Pipe	127.85	127.47	0.38	0.99	0.04		34.53		18.32

HEC-RAS Locations: User Defined   Profile: 10 YEAR

River	Reach	River Sta	Profile	Plan	E.G. US.	W.S. US.	E.G. IC	E.G. OC	Min El Weir Flow	Q Culv Group	Q Weir	Delta WS	Culv Vel US	Culv Vel DS
					(ft)	(ft)	(ft)	(ft)	(ft)	(cfs)	(cfs)	(ft)	(ft/s)	(ft/s)
Unnamed Brook	THALWEG	1012.79 Culvert #1	10 YEAR	FR	133.68	133.67	133.68	133.78	133.46	19.77	14.76	5.08	11.19	11.19
Unnamed Brook	THALWEG	1012.79 Culvert #1	10 YEAR	pipe arch	128.85	128.75	128.85	129.09	133.19	34.53		1.28	5.02	2.90
Unnamed Brook	THALWEG	1012.79 Culvert #1	10 YEAR	Pipe	128.81	128.71	128.81	129.07	133.19	34.53		1.24	5.22	2.91

HEC-RAS Locations: User Defined Profile: 10 YEAR

River	Reach	River Sta	Profile	Plan	E.G. US.	Min El Prs	BR Open Area	Prs O WS	Q Total	Min El Weir Flow	Q Weir	Delta EG	BR Sluice Coef
					(ft)	(ft)	(sq ft)	(ft)	(cfs)	(ft)	(cfs)	(ft)	
Unnamed Brook	THALWEG	1012.79	10 YEAR	RC BOX	128.22	130.50	26.10		34.53	133.19		0.84	

HEC-RAS Locations: User Defined   Profile: 100 YEAR

River	Reach	River Sta	Profile	Plan	E.G. Elev	W.S. Elev	Vel Head	Frctn Loss	C & E Loss	Q Left	Q Channel	Q Right	Top Width
					(ft)	(ft)	(ft)	(ft)	(ft)	(cfs)	(cfs)	(cfs)	(ft)
Unnamed Brook	THALWEG	1021.11	100 YEAR	FR	134.11	134.10	0.02			21.13	83.50	10.82	137.93
Unnamed Brook	THALWEG	1021.11	100 YEAR	pipe arch	130.67	130.40	0.26			0.23	115.22		11.11
Unnamed Brook	THALWEG	1021.11	100 YEAR	RC BOX	129.87	129.23	0.64	0.11	0.03		115.45		8.06
Unnamed Brook	THALWEG	1021.11	100 YEAR	Pipe	130.61	130.33	0.28			0.19	115.26		10.91
Unnamed Brook	THALWEG	1012.79			Culvert								
Unnamed Brook	THALWEG	970.28	100 YEAR	FR	133.24	131.03	2.21	0.63	0.51		115.45		73.68
Unnamed Brook	THALWEG	970.28	100 YEAR	pipe arch	129.28	128.41	0.87	0.74	0.11		115.45		29.62
Unnamed Brook	THALWEG	970.28	100 YEAR	RC BOX	128.80	127.94	0.86	0.75	0.11		115.45		24.11
Unnamed Brook	THALWEG	970.28	100 YEAR	Pipe	129.28	128.41	0.87	0.74	0.11		115.45		29.62

Appendix H
Site Photos

Photo No. 1 – Valley Road looking southwest

Photo No. 2 – Valley Road looking northeast

Photo No. 3 – Looking east at upstream channel

Photo No. 4 – Looking west at downstream channel

Photo No. 5 – Looking upstream from headwall

Photo No. 6 – 18-inch corrugated metal pipe upstream invert

Photo No. 7 – 18-inch corrugated metal pipe downstream invert

Photo No. 8 – Looking downstream from headwall

Photo No. 9 – Outlet plunge pool

Photo No. 10 – West (downstream) headwall