Culvert and Weir Analysis

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Culvert and Weir Analysis

For

The Cottages at Wandering Pond
Athens Street
Stow, MA

June 20, 2022
Revised: July 6, 2023

Applicant: The Cottages at Wondering Pond Realty Trust
148 Park Street
North Reading, MA 01864

Owner : EFMC Associates Limited Partnership
35 Parmenter Road
Hudson, MA 01749

Goshen Lane Realty Trust
148 Park Street
North Reading, MA 01864

Athens Street, LLC
148 Park Street
North Reading, MA 01864

Greystone Painting Corp.
21 Wellington Avenue
Hudson, MA 01749

SM-3719C File: 3719C Culvert Report Cover.doc

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Narrative

Culvert and Weir Calculations

The site is located at Athens Street in Stow, Massachusetts and is approximately 114.85 acres with existing barns, buildings, and sheds in various states of disrepair, served by a gravel road. The proposed project is an Active Adult Neighborhood with various unit types.

The site is accessed by an existing gravel road of various widths which crosses a stream in two areas. The first crossing, closer to Hudson Road, crosses the stream with a wooden bridge on stone abutments. This bridge has an opening approximately 63" wide and 42" high.

The second crossing, upstream of the first, consists of two reinforced concrete pipes (RCPs)- 42" and 24" in diameter.

In large storm events, water overtops the gravel road at both existing crossings.

The two stream crossings were modeled in Culvert Studio software program. The flowrates were taken from USGS's StreamStats program. The goal in designing the replacement culverts is to match existing hydrologic conditions while keeping the water from overtopping the road in large storm events, and to prevent the headwater elevation from increasing past FEMA 100-year elevations.

First Stream Crossing

The first stream crossing is proposed to be replaced with an open bottom box culvert preceded by a weir box with an opening. To keep flows through the crossing like existing, the opening in the weir box is sized to allow similar flows under the road as existing conditions, while keeping maximum headwater elevation below FEMA 100-year elevations. This is accomplished with a rectangular orifice 115.4" wide and 22.8" high. If the opening in the weir exactly matched the existing bridge opening, 63"x42", the top of the weir box would have forced headwaters above the 100-year flood elevation. Therefore, a wider but shorter weir box opening is provided, allowing a lower top of weir elevation. So in large storm events, water can overtop the weir and go under the road while still keeping FEMA flood elevations. The length of the weir was determined such that during a 100-year flood, the headwater does not go above the 100-year flood elevation. In typical hydrologic conditions, the weir box is not overtopped and flow continues through the opening in the weir box like it does now through the bridge.

Second Stream Crossing

The second stream crossing is proposed to be replaced with a weir box with orifices and two open bottom box culverts angled the same as the existing culvert pipes. The weir box will encompass the upstream side of the two open bottom box culverts, so the flow rate through them in typical hydrologic conditions and smaller storm events is controlled by the orifice sizes in the weir box. The orifice sizes were calculated to allow the same flows through them as what occurs in existing conditions through the 42" and 24" RCPs, which resulted in 36.6" and 23.9" orifices.

In larger storm events, the weir box is overtopped, and flow is allowed under the road through the two open bottom box culverts. The weir length was calculated to keep the headwater elevation from rising above the 100-year flood elevation during a 100-year flood flow rate.

Sizing Spreadsheets

Cottages at Wandering Pond

Athens Street, Stow, MA Date: 6-Jul-23

Existing First Stream Crossing (closer to Hudson Road)

Q (cfs) (50-percent AEP flood)	Q (cfs) (10-percent AEP flood)	Q (cfs) (1-percent AEP flood)	(per Streamstats peak-flow statistics)
52.7	117	230	

Existing wooden bridge on stone abutments

Span=	63	inches
Height=	42	inches
Length=	19.2	feet
Invert In=	210.64	inches
Invert Out=	210.49	inches
Skew Angle=	14	degrees
Embankment		
Top Width=	15	feet
Top Elevation=	215.3	
Crest Length=	18	ft
Existing flow through bridge 100-year (from Culvert Studio)=	168.22	cfs
Tailwater Elevation in 100-year flood=	214.3	(from FEMA profile)

Determine orifice size to take same flows as existing and keep upstream headwater at 100-year flood elevation

To match 63" x 42" bridge

Orifice Equation:

Q=C x A x (2gh)^0.5

A=Q/C(2gh)^0.5

C=	0.6		g=	32.2
Area=	18.26	SF	Inv.=	210.64
Area=	2630	square inches	h=	3.66

A rectangular orifice, 115.4" span x 22.8" high (area of 2630 square inches) will match flows

Remaining flow to go over weir=	61.78	cfs
Top Weir=	213.54	

Determine length of weir needed so that headwater elevations are 100-year floodplain elevs

100-year floodplain upstream=	214.3

Sharp Crested Weir equation

Q=3.3*L*(H^1.5)

L=Q/(3.3*(H^1.5)

H=100-year floodplain - top weir=	0.76
Weir Length=	28.3

Athens Street, Stow

Existing Second Stream Crossing

Q (cfs) (50-percent AEP flood)	Q (cfs) (10-percent AEP flood)	Q (cfs) (1-percent AEP flood)	(per Streamstats peak-flow statistics)
51.5	114	225	

(1) 42" RCP plus (1) 24" RCP

In order to model in Culvert Studio, separate the culverts and guess and check % flow going to each pipe until headwater elev's match

2-Year			**Headwater elevations (from Culvert Studio)**
	% flow taking	2-year Q	
Existing 42" pipe	0.41	21.115	224.54
Existing 24" pipe	0.59	30.385	224.53

10-Year			
	% flow taking	10-year Q	
Existing 42" pipe	0.6	68.4	224.88
Existing 24" pipe	0.4	45.6	224.89

100-Year			
	% flow taking	100-year Q	
Existing 42" pipe	0.58	130.5	225.21
Existing 24" pipe	0.42	94.5	225.2

Existing flow through (2) culverts in 100-year (ignoring flow overtopping road) (from Culvert Studio)= 106.02 cfs

Existing flow through 42" pipe in 100-year (from Culvert Studio)= 72.33 cfs

Existing flow through 24" pipe in 100-year (from Culvert Studio)= 33.69 cfs

Determine orifice sizes to take same flows as existing and keep upstream headwater at 100-year flood elevation

To match 42" culvert

Orifice Equation:

Q=CA x (2gh)^.5

A=Q/C(2gh)^0.5

C= 0.6 g= 32.2

Orifice Diameter= 36.6 in Inv.= 220.97

Area= 7.30 SF h= 4.23

Area= 1051.76 square inches

To match 24" culvert

C= 0.6 g= 32.2

Orifice Diameter= 23.9 in Inv.= 220.17

Area= 3.12 SF h= 5.03

Area= 449.25 square inches

Remaining flow to go over weir= 118.98 cfs

Top Weir= 224.68

Determine length of weir needed so that headwater elevations are 100-year floodplain elevs

100-year floodplain upstream= 225.2

Sharp Crested Weir equation

Q=3.3*L*(H^1.5)

L=Q/(3.3*(H^1.5)

H=100-year floodplain - top weir= 0.52

Weir Length= 96.2

Culvert Studio Reports

Existing First Crossing
Culvert Studio Reports

Culvert Report

Project filename: 3719C CULVERT STUDIO FIRST CROSSING ONLY 2023.cst

Culvert Studio v 2.0.0.28

07-06-2023

Existing First Crossing

Culvert 1

CULVERT

Shape	= Rect - Open Bottom
Inlet Edge	= Projecting
Material	= Concrete
Manning's n	= 0.012 (0.035 Bottom)
Rise (Inside height)	= 42 in
Span	= 63 in
Invert Elev. Down	= 210.49 ft
Length	= 19.20 ft
Slope	= 0.008 ft/ft
Invert Elev. Up	= 210.64 ft
No. Barrels	= 1
Plan Skew Angle	= 14 degrees

EMBANKMENT

Top Width	= 15.00 ft
Top Elevation	= 215.30 ft
Crest Length	= 18.00 ft

DISCHARGE

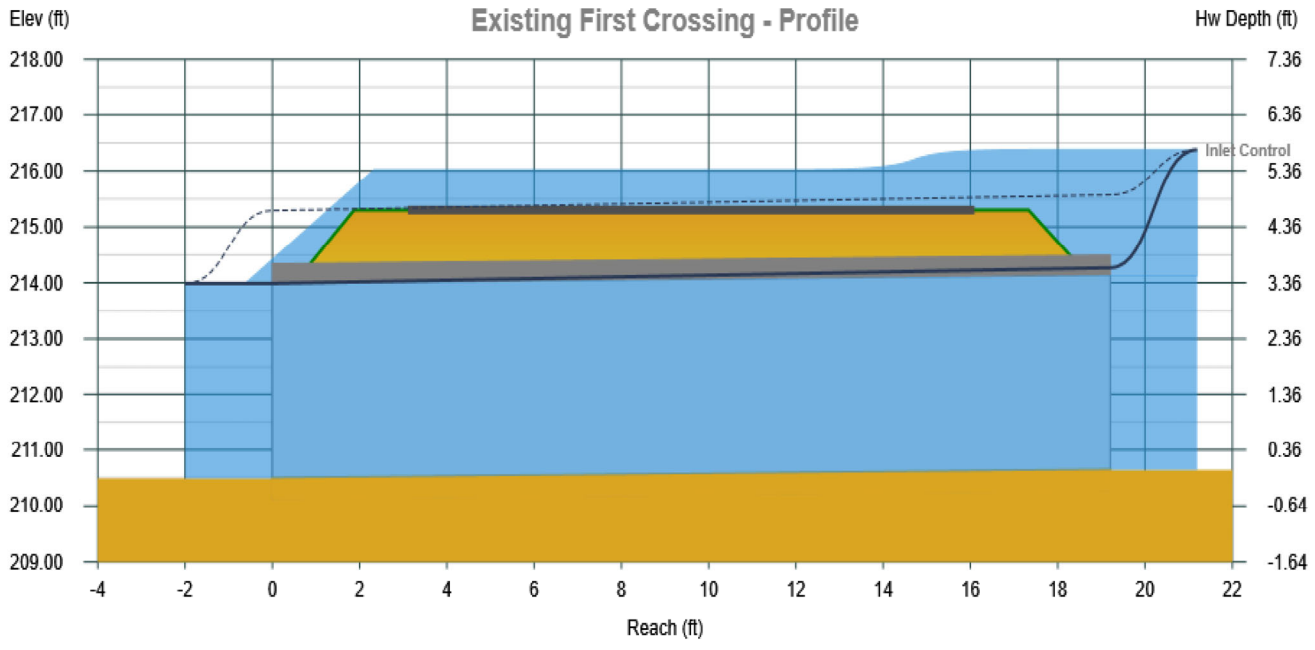
Method	= User-defined

TAILWATER

Tailwater Elevation	= Normal Depth

CALCULATION SAMPLE

Discharge			Velocity		Depth		HGL @ Hw/D = 1.64		
Total	Culvert	Over Top	Down	Up	Down	Up	Down	Up	Hw
(cfs)	(cfs)	(cfs)	(ft/s)	(ft/s)	(in)	(in)	(ft)	(ft)	(ft)
230.00	168.22	61.78	9.15	9.15	42.0	42.0	213.99	214.27	216.38



Proposed First Crossing
Culvert Studio Reports

Culvert Report

Project filename: 3719C CULVERT STUDIO FIRST CROSSING ONLY 2023.cst

Culvert Studio v 2.0.0.28

07-06-2023

Proposed First Crossing

Culvert 2

CULVERT

Shape	= Rect - Open Bottom
Inlet Edge	= Projecting
Material	= Concrete
Manning's n	= 0.012 (0.035 Bottom)
Rise (Inside height)	= 42 in
Span	= 174 in
Invert Elev. Down	= 210.70 ft
Length	= 39.6 ft
Slope	= 0.010 ft/ft
Invert Elev. Up	= 211.10 ft
No. Barrels	= 1
Plan Skew Angle	= 28 degrees

EMBANKMENT

Top Width	= 32.80 ft
Top Elevation	= 218.60 ft
Crest Length	= 18.00 ft

DISCHARGE

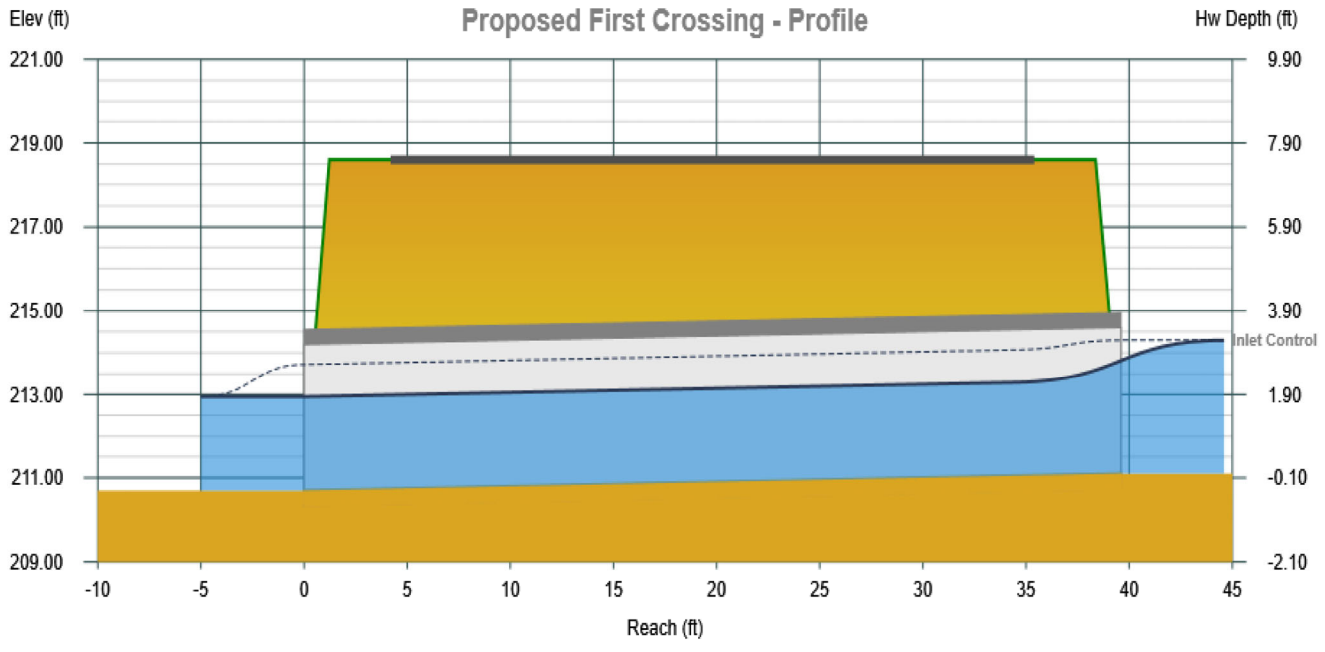
Method	= User-defined

TAILWATER

Tailwater Elevation	= Normal Depth

CALCULATION SAMPLE

Discharge			Velocity		Depth		HGL @ Hw/D = 0.91		
Total	Culvert	Over Top	Down	Up	Down	Up	Down	Up	Hw
(cfs)	(cfs)	(cfs)	(ft/s)	(ft/s)	(in)	(in)	(ft)	(ft)	(ft)
230.00	230.00	0.00	7.05	7.07	27.0	26.9	212.95	213.34	214.30



Existing Second Crossing
Culvert Studio Reports

Culvert Report

Project filename: 3719C CULVERT STUDIO SECOND CROSSING ONLY.cst

Culvert Studio v 2.0.0.28

07-06-2023

100-year Existing Second Crossing

Culvert 5

CULVERT

Shape	= Circular
Inlet Edge	= Projecting
Material	= Concrete
Manning's n	= 0.012
Rise	= 42 in
Span	= 42 in
Invert Elev. Down	= 220.99 ft
Length	= 41.1 ft
Slope	= 0.000 ft/ft
Invert Elev. Up	= 220.97 ft
No. Barrels	= 1
Plan Skew Angle	= 14 degrees

EMBANKMENT

Top Width	= 15.00 ft
Top Elevation	= 224.70 ft
Crest Length	= 53.00 ft

DISCHARGE

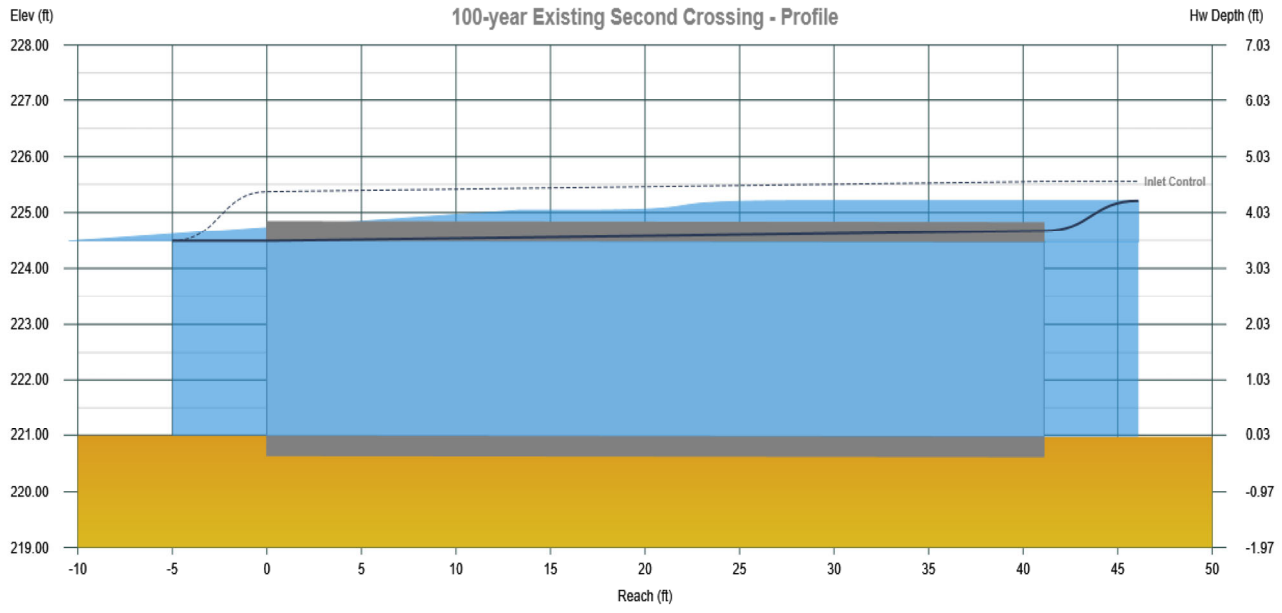
Method	= User-defined

TAILWATER

Tailwater Elevation	= Normal Depth

CALCULATION SAMPLE

Discharge			Velocity		Depth		HGL @ Hw/D = 1.21		
Total	Culvert	Over Top	Down	Up	Down	Up	Down	Up	Hw
(cfs)	(cfs)	(cfs)	(ft/s)	(ft/s)	(in)	(in)	(ft)	(ft)	(ft)
130.50	72.33	58.17	7.52	7.52	42.0	42.0	224.49	224.67	225.21



Culvert Report

Project filename: 3719C CULVERT STUDIO SECOND CROSSING ONLY.cst

Culvert Studio v 2.0.0.28

07-06-2023

100-year Existing Second Crossing

Culvert 6

CULVERT

Shape	= Circular
Inlet Edge	= Projecting
Material	= Concrete
Manning's n	= 0.012
Rise	= 24 in
Span	= 24 in
Invert Elev. Down	= 220.64 ft
Length	= 48.7 ft
Slope	= -0.010 ft/ft
Invert Elev. Up	= 220.17 ft
No. Barrels	= 1
Plan Skew Angle	= 34 degrees

EMBANKMENT

Top Width	= 15.00 ft
Top Elevation	= 224.70 ft
Crest Length	= 53.00 ft

DISCHARGE

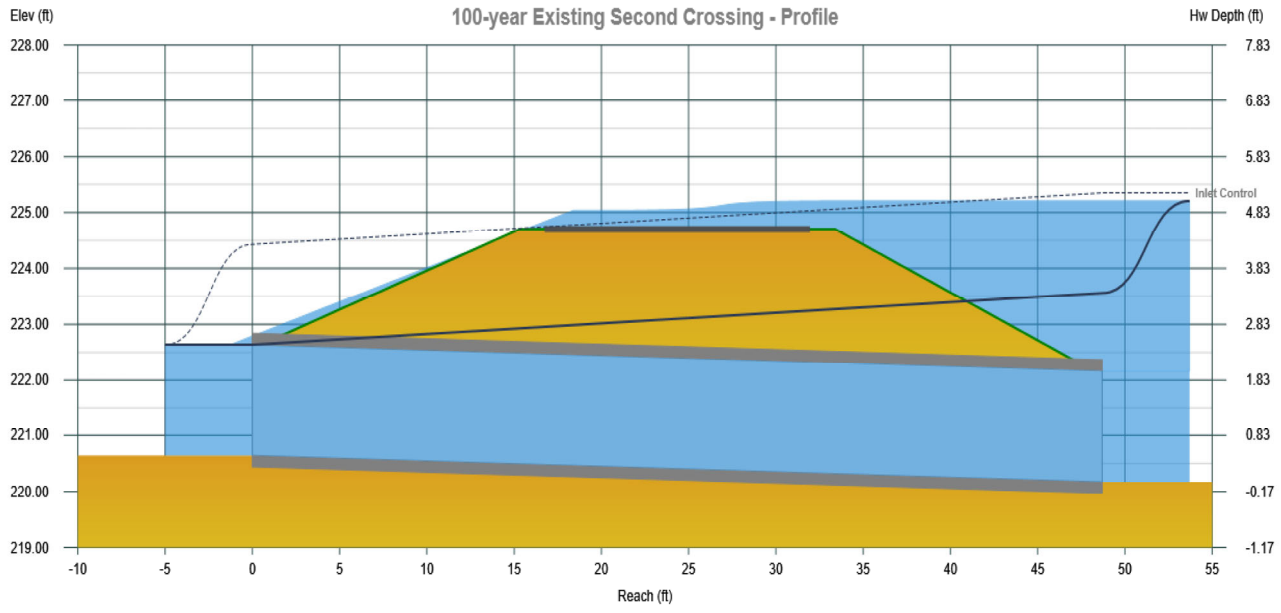
Method	= User-defined

TAILWATER

Tailwater Elevation	= Normal Depth

CALCULATION SAMPLE

Discharge			Velocity		Depth		HGL @ Hw/D = 2.52		
Total	Culvert	Over Top	Down	Up	Down	Up	Down	Up	Hw
(cfs)	(cfs)	(cfs)	(ft/s)	(ft/s)	(in)	(in)	(ft)	(ft)	(ft)
94.50	33.69	60.81	10.72	10.72	24.0	24.0	222.64	223.56	225.20



Proposed Second Crossing
Culvert Studio Reports

Culvert Report

Project filename: 3719C CULVERT STUDIO SECOND CROSSING ONLY.cst

Culvert Studio v 2.0.0.28

07-06-2023

Proposed Second Crossing Past Weir Box

Culvert 8

CULVERT

Shape	= Rect - Open Bottom
Inlet Edge	= Projecting
Material	= Concrete
Manning's n	= 0.012 (0.035 Bottom)
Rise (Inside height)	= 28 in
Span	= 128 in
Invert Elev. Down	= 220.99 ft
Length	= 35.0 ft
Slope	= -0.001 ft/ft
Invert Elev. Up	= 220.97 ft
No. Barrels	= 2
Plan Skew Angle	= 17 degrees

EMBANKMENT

Top Width	= 29.00 ft
Top Elevation	= 229.00 ft
Crest Length	= 75.00 ft

DISCHARGE

Method	= User-defined

TAILWATER

Tailwater Elevation	= Normal Depth

CALCULATION SAMPLE

Discharge			Velocity		Depth		HGL @ Hw/D = 1.15		
Total	Culvert	Over Top	Down	Up	Down	Up	Down	Up	Hw
(cfs)	(cfs)	(cfs)	(ft/s)	(ft/s)	(in)	(in)	(ft)	(ft)	(ft)
225.00	225.00	0.00	4.52	4.52	28.0	28.0	223.32	223.48	223.64

Stream Crossing Standards

Cottages at Wandering Pond- Athens Street, Stow, MA

Stream Crossing Calculations

Date: 6-Jul-23

First Stream Crossing

	Feet			
Average Height streambed to bottom of culvert	3.5			
Width of opening, from foundation edges	14.5			
Length of stream that is crossed	38.9			
Bankfull width	8			
1.2X Bankfull width	9.6			
	Provided		Minimum	
Openness Ratio	1.30	>	0.82	OK
Crossing Span	14.5	>	9.6	OK

Second Stream Crossing

	Feet			
Average Height streambed to bottom of culvert	2.3			
Width of opening, from foundation edges	21.34	(two 10.67' span culverts)		
Length of stream that is crossed	35			
Bankfull width	15			
1.2X Bankfull width	18			
	Provided		Minimum	
Openness Ratio	1.40	>	0.82	OK
Crossing Span	21.34	>	18	OK

Rip-Rap Sizing

Rip-Rap Sizing

FIRST CROSSING

100-YEAR FLOW	230	CFS
CULVERT AREA	50.75	SF
V=Q/A	4.53	FPS

RIP RAP SIZING EQUATION
ISBASH EQUATION

$D= (V^2)/(2G(C^2)(S-1))$

D=MEDIAN DIAMETER OF SPHERICAL STONE OR ROCK
C=ISBASH CONSTANT, 0.86 FOR HIGHLY TURBULENT AND 1.2 FOR LOW TURBULENCE
G=ACCELERATION DUE TO GRAVITY, 32.17 FT/SEC^2
S=SPECIFIC GRAVITY OF STONE OR RACK, TYPICALLY 2.65
V=WATER VELOCITY APPROACHING RIPRAP

C=	0.86		
G=	32.17		
S=	2.65		
D=	0.26	FT	
	3.14	INCHES	minimum size rip-rap diameter

StreamStats Peak Flow Statistics

StreamStats Report

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Workspace ID: MA20220603134806639000
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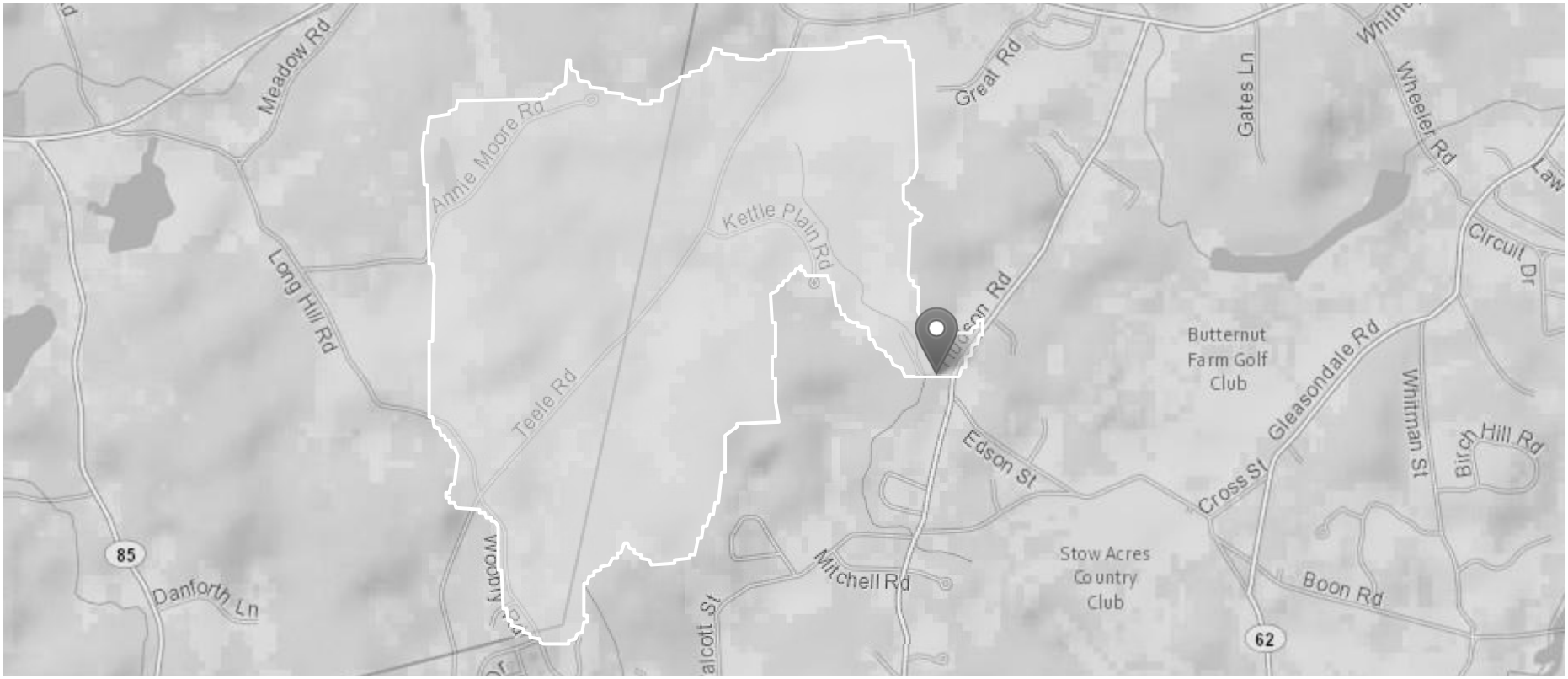
Time: 2022-06-03 09:48:27 -0400



Collapse All

Basin Characteristics

Parameter Code	Parameter Description	Value	Unit
DRNAREA	Area that drains to a point on a stream	1.33	square miles
ELEV	Mean Basin Elevation	316	feet
LC06STOR	Percentage of water bodies and wetlands determined from the NLCD 2006	5.75	percent

Peak-Flow Statistics

Peak-Flow Statistics Parameters [Peak Statewide 2016 5156]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	1.33	square miles	0.16	512
ELEV	Mean Basin Elevation	316	feet	80.6	1948
LC06STOR	Percent Storage from NLCD2006	5.75	percent	0	32.3

Peak-Flow Statistics Flow Report [Peak Statewide 2016 5156]

PIl: Prediction Interval-Lower, PIu: Prediction Interval-Upper, ASEp: Average Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	PIl	PIu	ASEp
50-percent AEP flood	52.7	ft^3/s	26.8	104	42.3
20-percent AEP flood	88.2	ft^3/s	44.2	176	43.4
10-percent AEP flood	117	ft^3/s	57.3	239	44.7
4-percent AEP flood	158	ft^3/s	74.7	334	47.1
2-percent AEP flood	193	ft^3/s	88.3	422	49.4
1-percent AEP flood	230	ft^3/s	102	519	51.8

Statistic	Value	Unit	PII	PIu	ASEp
0.5-percent AEP flood	271	ft^3/s	117	630	54.1
0.2-percent AEP flood	329	ft^3/s	135	802	57.6

Peak-Flow Statistics Citations

Zarriello, P.J.,2017, Magnitude of flood flows at selected annual exceedance probabilities for streams in Massachusetts: U.S. Geological Survey Scientific Investigations Report 2016–5156, 99 p. (https://dx.doi.org/10.3133/sir20165156)

Application Version: 4.9.0
StreamStats Services Version: 1.2.22
NSS Services Version: 2.2.0

StreamStats Report

Region ID: MA
Workspace ID: MA20220603135810805000
Clicked Point (Latitude, Longitude): 42.42335, -71.54220
Time: 2022-06-03 09:58:30 -0400

Collapse All

Basin Characteristics

Parameter Code	Parameter Description	Value	Unit
DRNAREA	Area that drains to a point on a stream	1.3	square miles
ELEV	Mean Basin Elevation	318	feet
LC06STOR	Percentage of water bodies and wetlands determined from the NLCD 2006	5.91	percent

Peak-Flow Statistics

Peak-Flow Statistics Parameters [Peak Statewide 2016 5156]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	1.3	square miles	0.16	512
ELEV	Mean Basin Elevation	318	feet	80.6	1948
LC06STOR	Percent Storage from NLCD2006	5.91	percent	0	32.3

Peak-Flow Statistics Flow Report [Peak Statewide 2016 5156]

PIl: Prediction Interval-Lower, PIu: Prediction Interval-Upper, ASEp: Average Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	PIl	PIu	ASEp
50-percent AEP flood	51.5	ft^3/s	26.2	101	42.3
20-percent AEP flood	86.3	ft^3/s	43.3	172	43.4
10-percent AEP flood	114	ft^3/s	55.8	233	44.7
4-percent AEP flood	155	ft^3/s	73.3	328	47.1
2-percent AEP flood	189	ft^3/s	86.5	413	49.4
1-percent AEP flood	225	ft^3/s	99.8	507	51.8

Statistic	Value	Unit	PII	PIu	ASEp
0.5-percent AEP flood	265	ft^3/s	114	616	54.1
0.2-percent AEP flood	322	ft^3/s	132	785	57.6

Peak-Flow Statistics Citations

Zarriello, P.J.,2017, Magnitude of flood flows at selected annual exceedance probabilities for streams in Massachusetts: U.S. Geological Survey Scientific Investigations Report 2016–5156, 99 p. (https://dx.doi.org/10.3133/sir20165156)

Application Version: 4.9.0
StreamStats Services Version: 1.2.22
NSS Services Version: 2.2.0

FEMA Floodway Data & Profile

FLOODING SOURCE		FLOODWAY			BASE FLOOD WATER-SURFACE ELEVATION (FEET NAVD88)			
CROSS SECTION	DISTANCE	WIDTH (FEET)	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET PER SECOND)	REGULATORY	WITHOUT FLOODWAY	WITH FLOODWAY	INCREASE
Branch of Assabet River								
A	1,589[1]	65	188	1.8	195.3	195.3	196.1	0.8
B	1,943[1]	69	216	1.6	197.5	197.5	198.5	1.0
C	2,862[1]	22	53	2.5	199.0	199.0	200.0	1.0
D	3,105[1]	76	297	0.4	202.2	202.2	202.2	0.0
E	4,087[1]	15	20	6.7	203.1	203.1	203.1	0.0
F	5,169[1]	14	49	2.8	209.3	209.3	210.3	1.0
G	6,325[1]	43	85	1.3	214.3	214.3	214.3	0.0
H	6,405[1]	32	56	1.9	214.3	214.3	214.4	0.1
I	7,413[1]	15	22	4.4	221.5	221.5	222.0	0.5
J	7,608[1]	45	151	0.6	225.2	225.2	225.2	0.0
K	8,527[1]	47	112	0.9	225.4	225.4	225.4	0.0
L	9,573[1]	56	111	0.9	225.6	225.6	225.8	0.2
Branch of Elizabeth Brook 1								
A	401[2]	12	63	2.0	195.0	195.0	196.0	1.0
B	1,062[2]	86	437	0.3	195.1	195.1	196.1	1.0
C	1,183[2]	40	186	0.7	198.8	198.8	199.8	1.0
D	1,299[2]	176	952	0.1	198.9	198.9	199.8	0.9
E	2,017[2]	225	1,809	0.1	198.9	198.9	199.8	0.9
F	2,756[2]	15	49	2.6	198.9	198.9	199.8	0.9
G	2,872[2]	91	180	0.7	202.9	202.9	202.9	0.0
H	2,973[2]	38	195	0.6	202.9	202.9	202.9	0.0

[1] Feet above confluence with Assabet River

[2] Feet above confluence with Elizabeth Brook 1

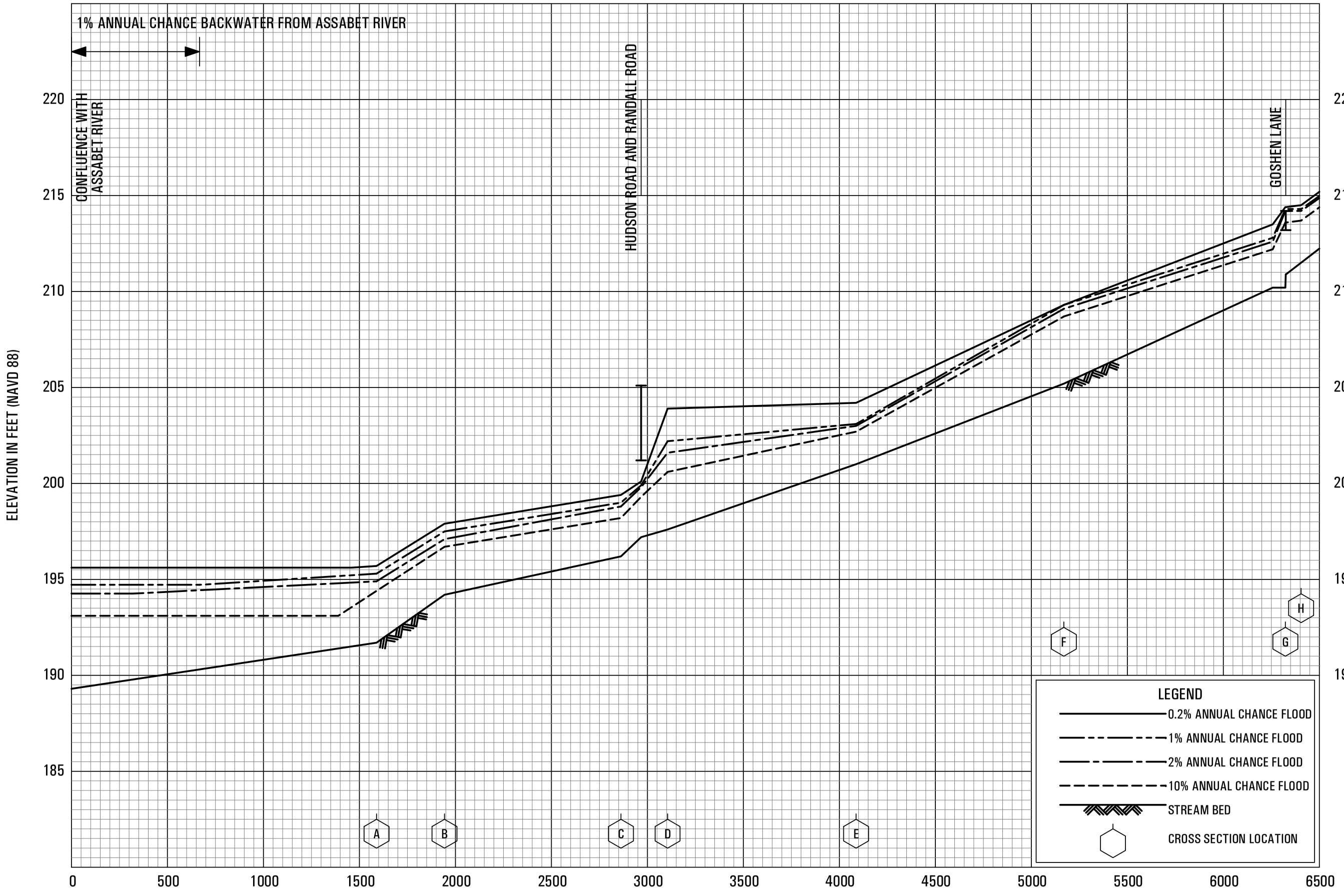
TABLE 12

FEDERAL EMERGENCY MANAGEMENT AGENCY

MIDDLESEX COUNTY, MA
(ALL JURISDICTIONS)

FLOODWAY DATA

BRANCH OF ASSABET RIVER – BRANCH OF ELIZABETH BROOK 1



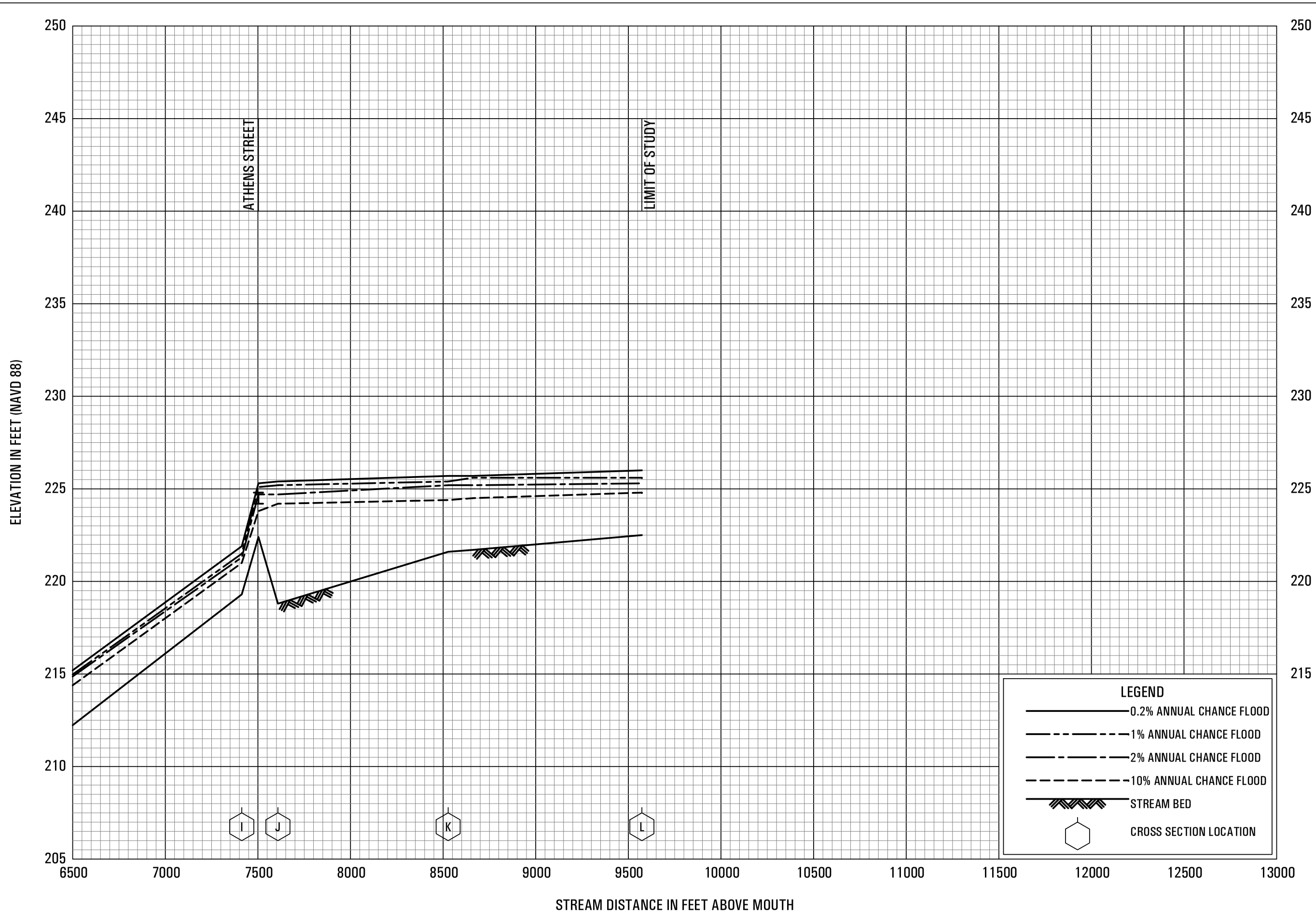
FLOOD PROFILES

BRANCH OF ASSABET RIVER

FEDERAL EMERGENCY MANAGEMENT AGENCY

MIDDLESEX COUNTY, MA

(ALL JURISDICTIONS)



FLOOD PROFILES

BRANCH OF ASSABET RIVER

FEDERAL EMERGENCY MANAGEMENT AGENCY

MIDDLESEX COUNTY, MA

(ALL JURISDICTIONS)

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