

A GIS-Based Hydraulic Modeling Tool for Massachusetts Stream Crossing Replacement Projects in USGS StreamStats



*MAWWG-NEBAWWG Joint Meeting
November 13, 2024*

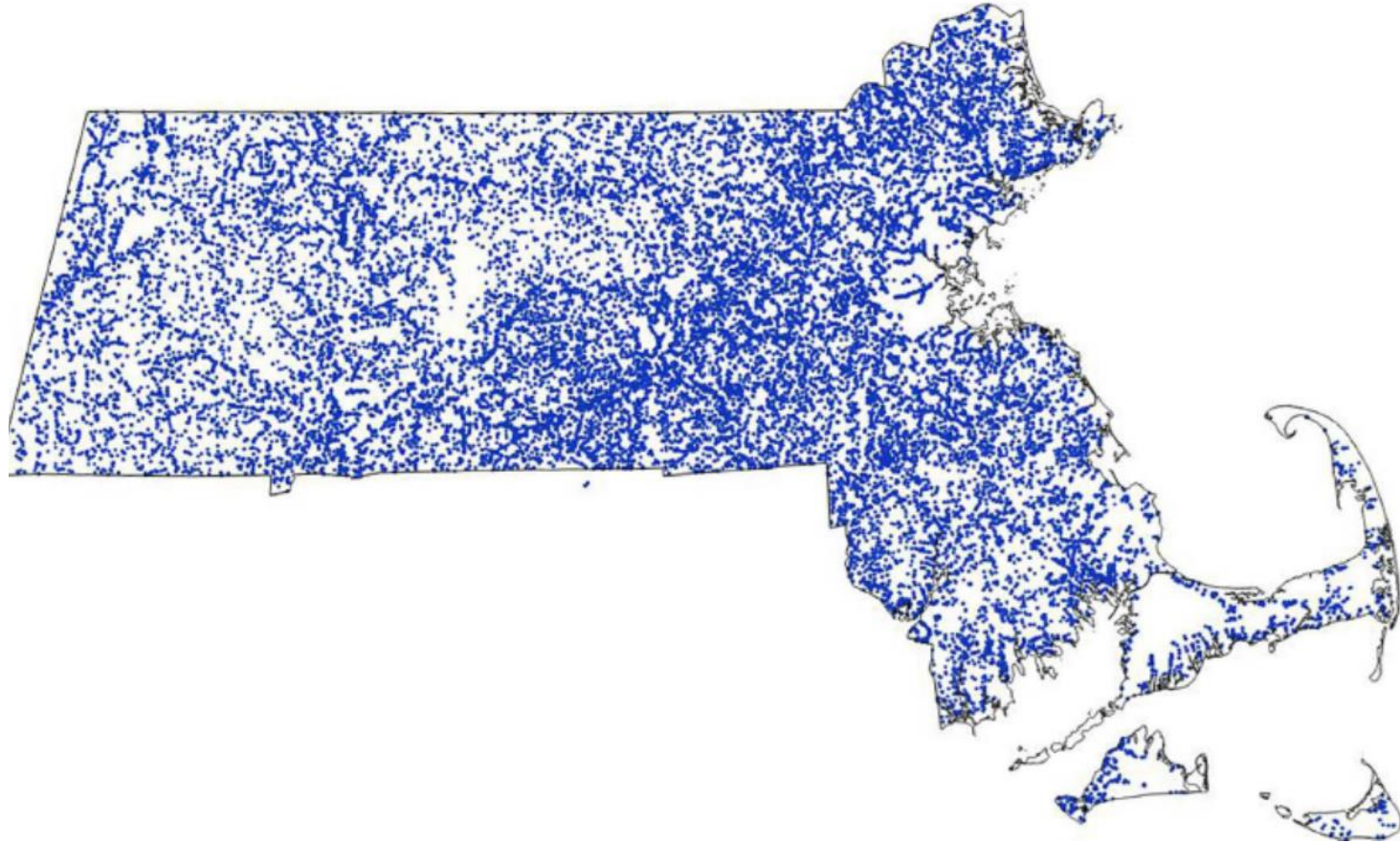
David Hilgeman, MassDEP

UMassAmherst



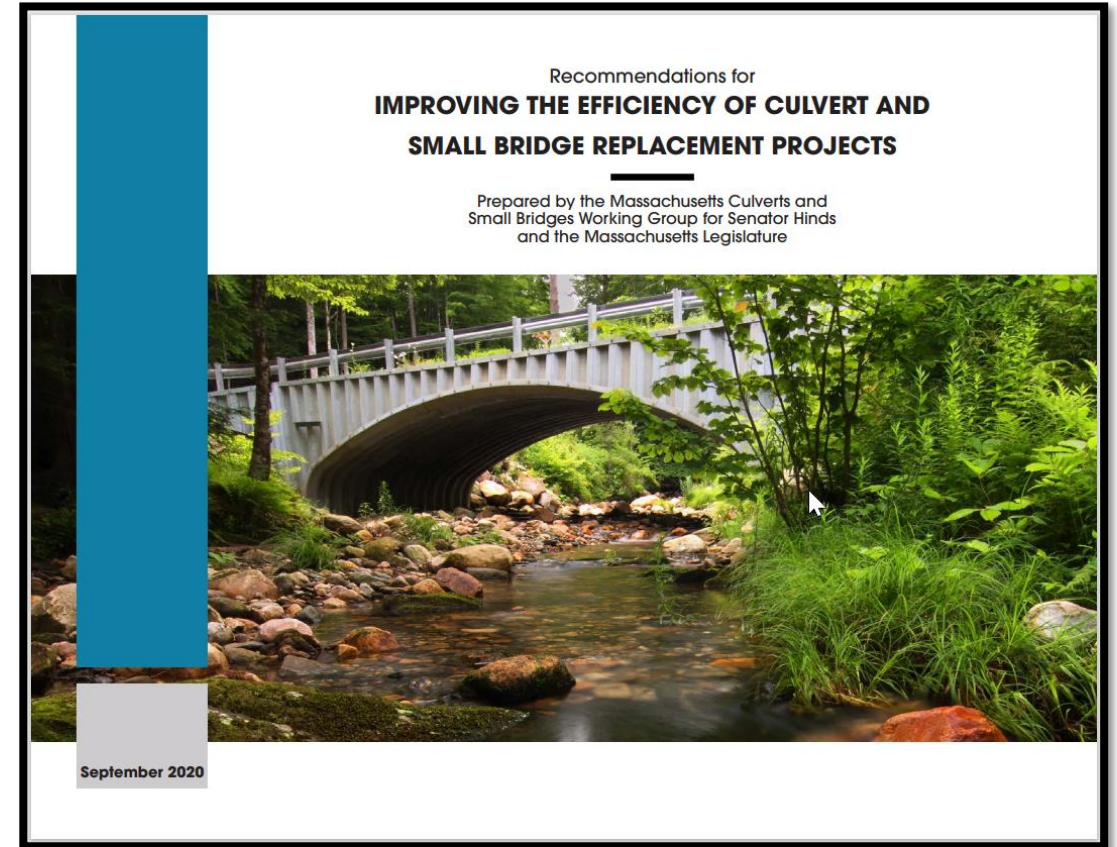
Gardner Bent, USGS

More than 25,000 crossings in Massachusetts.
Many are Undersized and/or Failing.



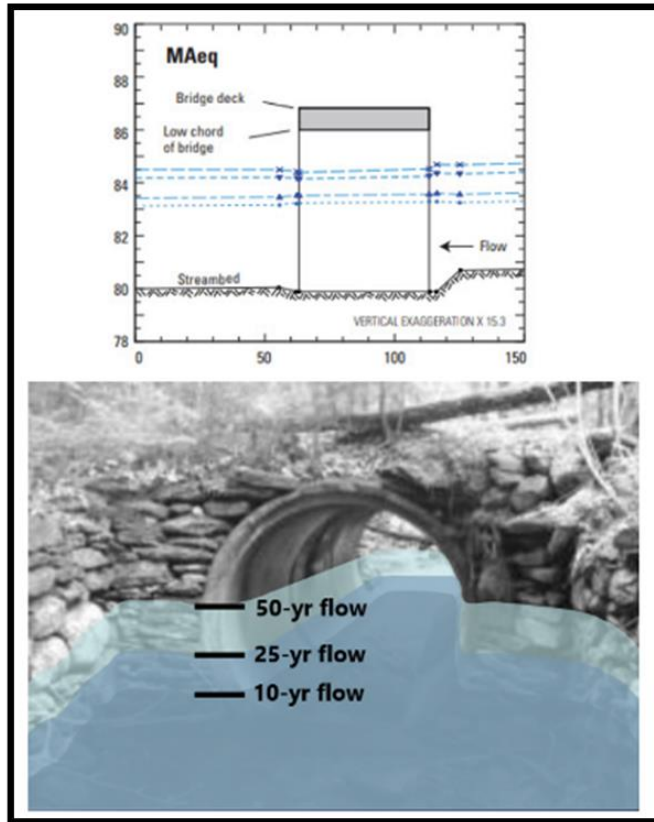
Proponents, Towns, and ConComms Need More Resources

- *Improving the Efficiency of Culvert and Small Bridge Replacement Projects* identified the problems and recommended solutions
- Recommended next steps (7 in total) included the development of a web-based tool and statewide hydraulic model to identify the most appropriate replacement crossing structure size

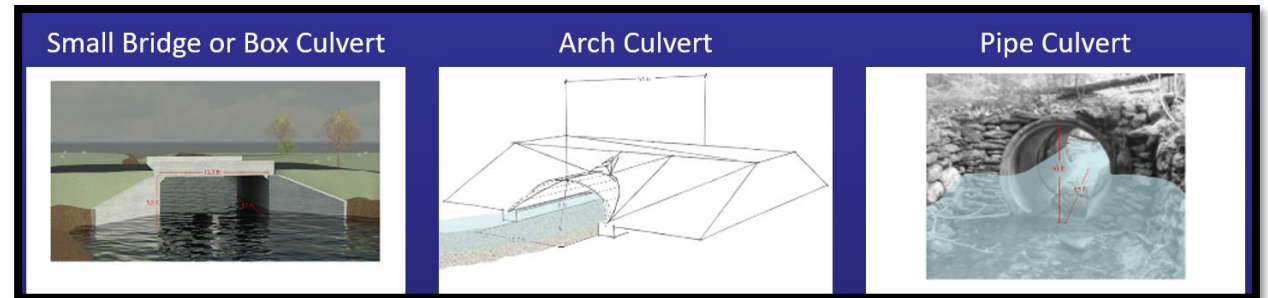
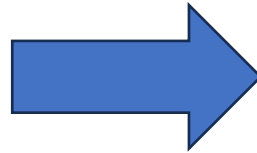


Design Standard + Design Flow + Terrain

Preliminary Stream Crossing Sizes



Hydraulic Model



Stream Crossing Planning Tool Helps Both Proponents and Conservation Commissions

- Proactive applications / benefits of the Statewide Hydraulic Model as a Stream Crossing Planning Tool:
 1. Eliminates need for engineering early in the non-design process
 2. Assists with proactive capital prioritization
 3. Provides preliminary designs for grant applications
- Reactive applications include assessing temporary measures and preventing replacement in-kind.

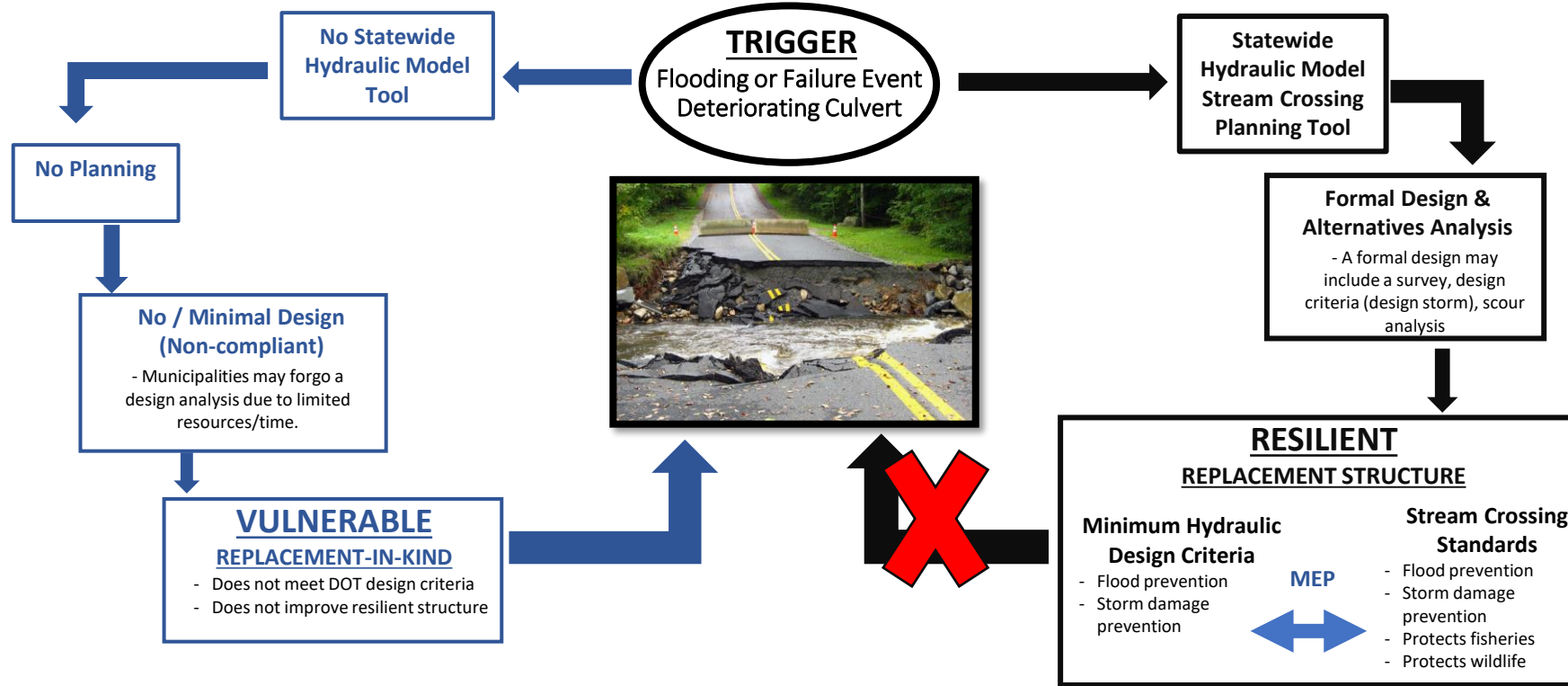


Clockwise from Top Left: 2009 (Pre-storm), 2011 (Post-hurricane Irene), 2011 (Temporary Replacement), 2016 (Replacement Bridge)

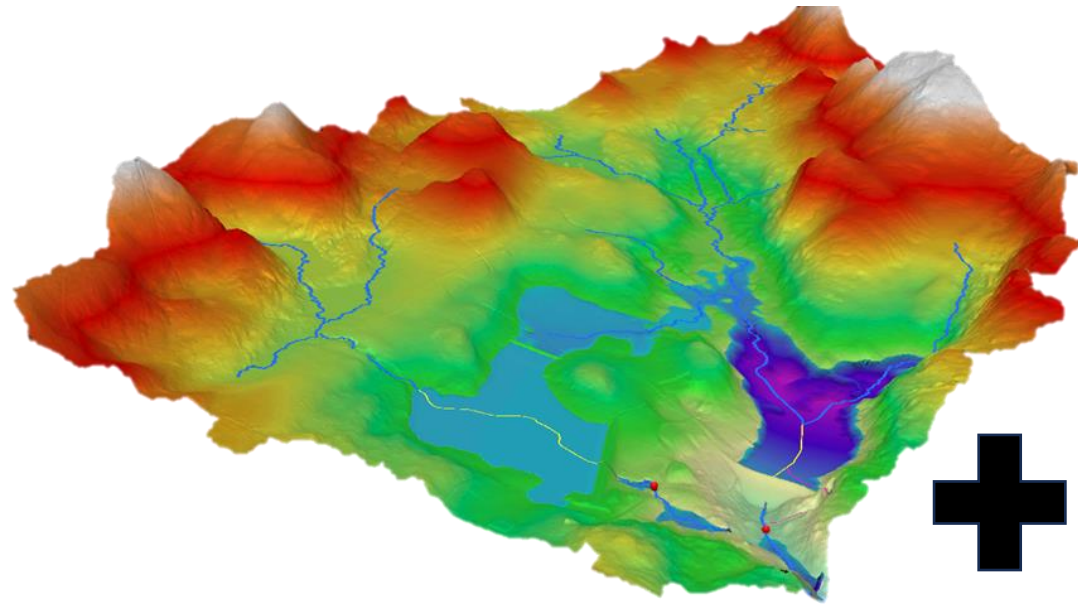


<https://www.mass.gov/doc/massachusetts-culverts-and-small-bridges-working-group-report/download>

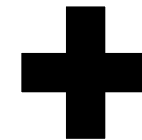
Statewide Hydraulic Model as a Stream Crossing Planning Tool



GIS-BASED Hydraulic Model Development



+Arcpy functions



GIS-Based Hydraulic Model Development

Looking Upstream



Upstream Face



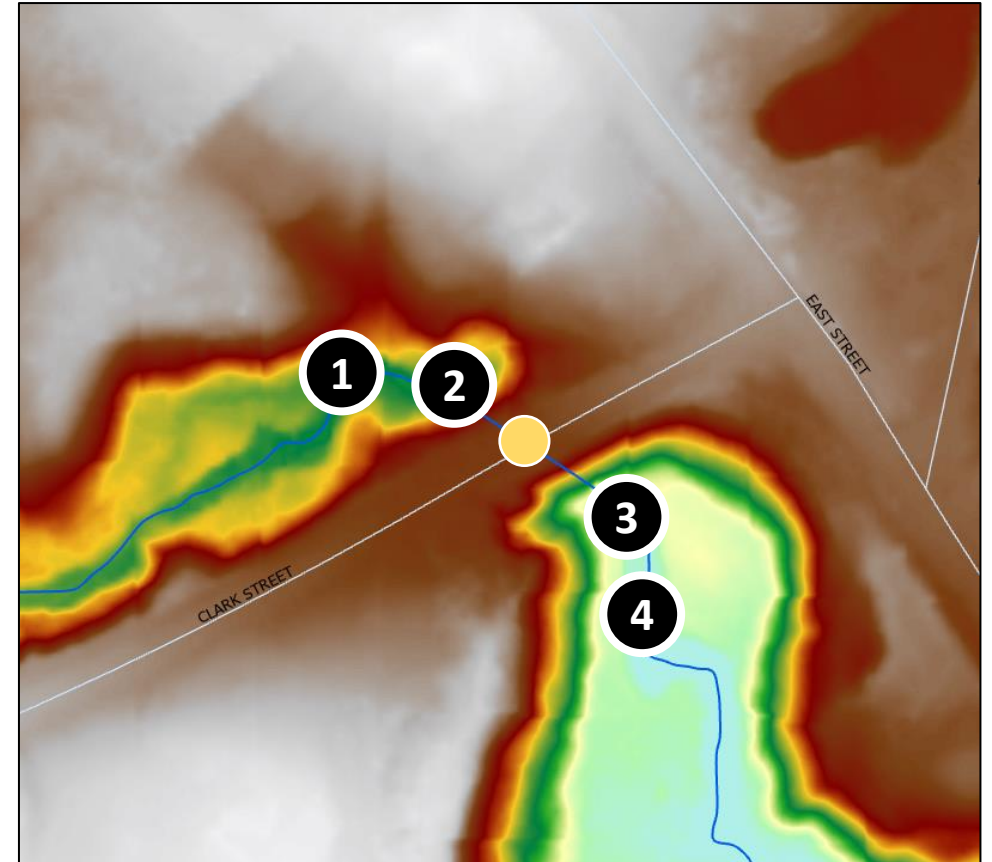
Downstream Face



Looking Downstream

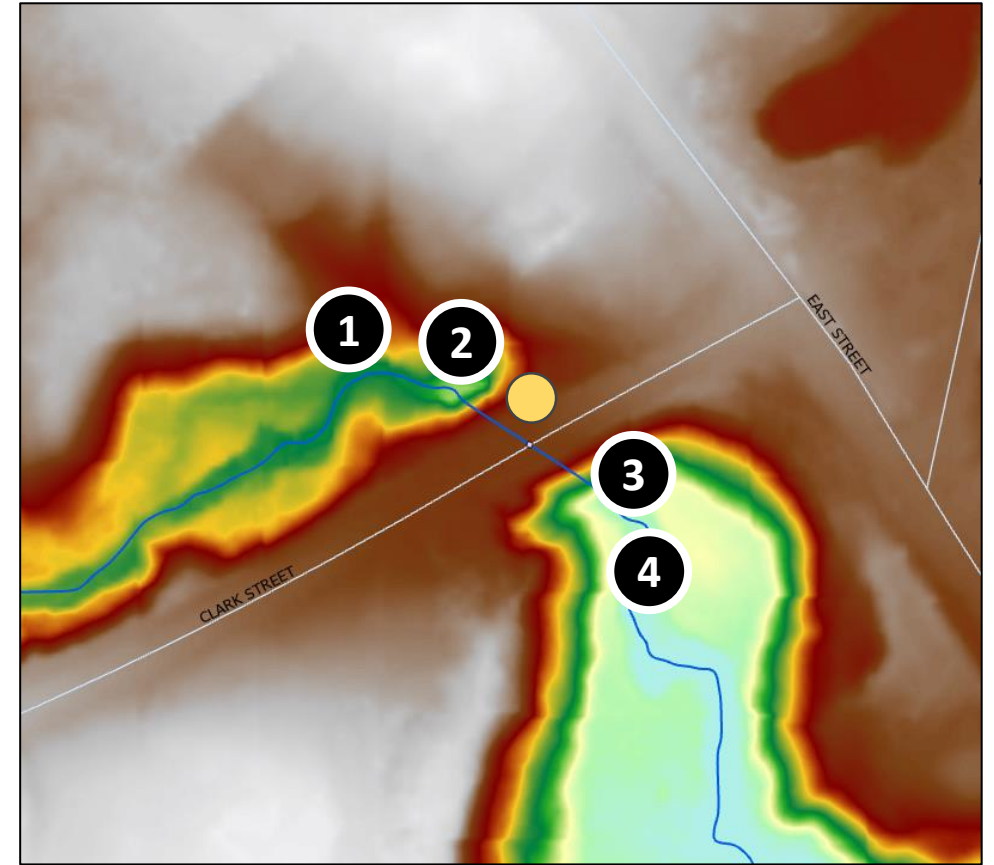
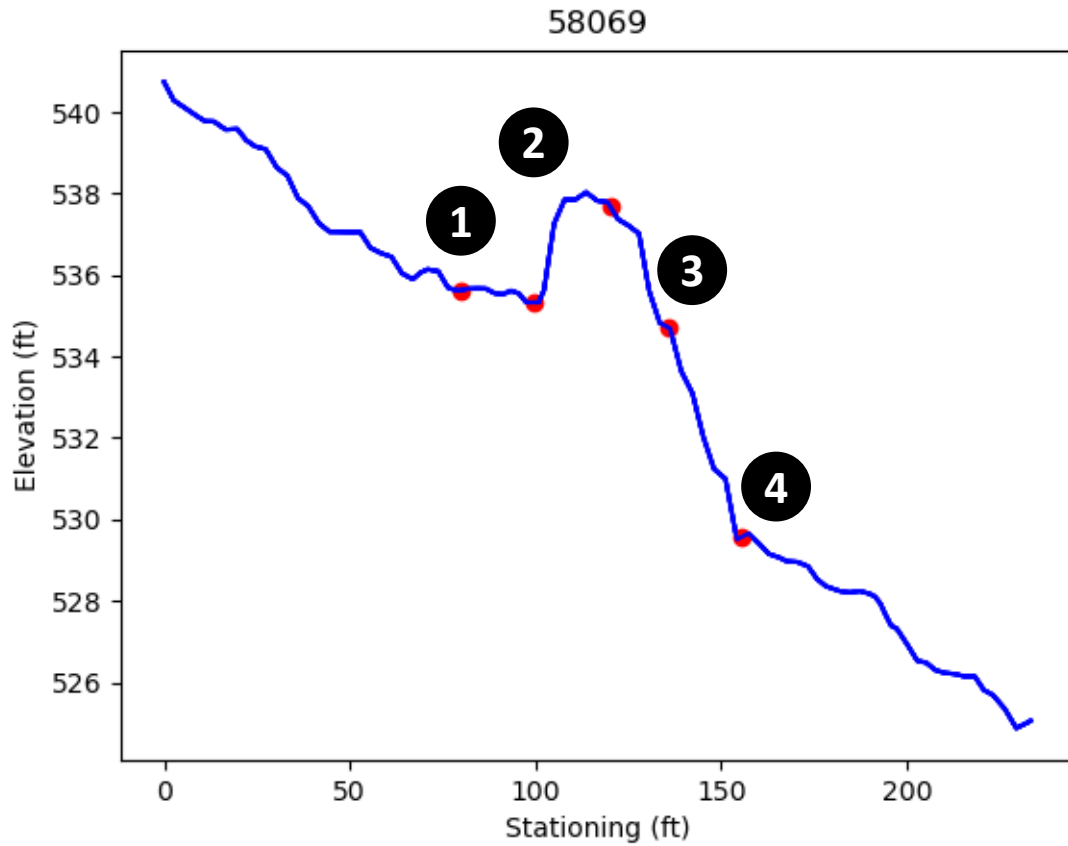


Unnamed Tributary to Manhan River, Southampton, MA

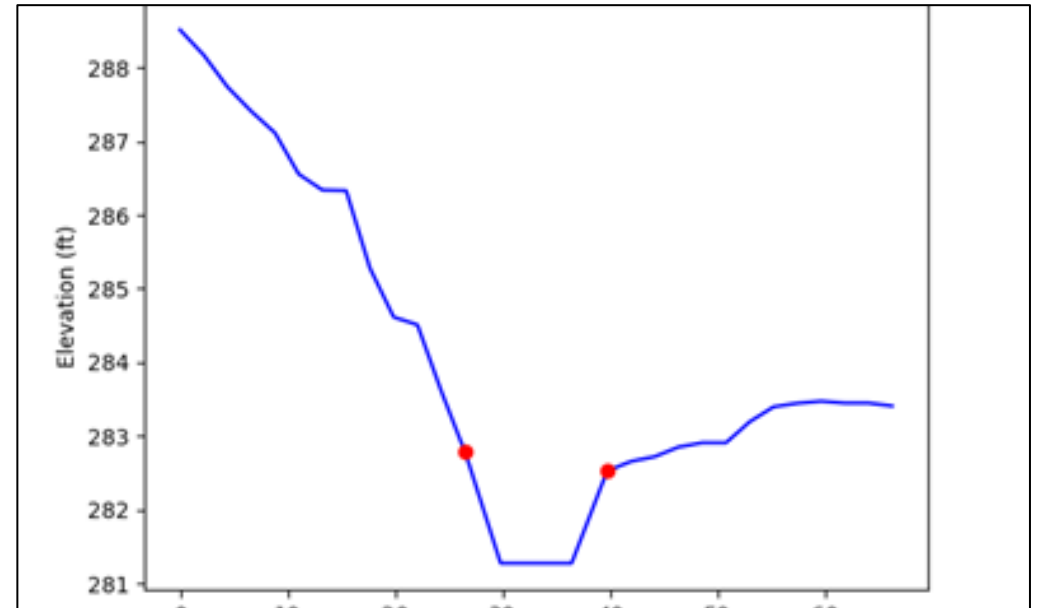
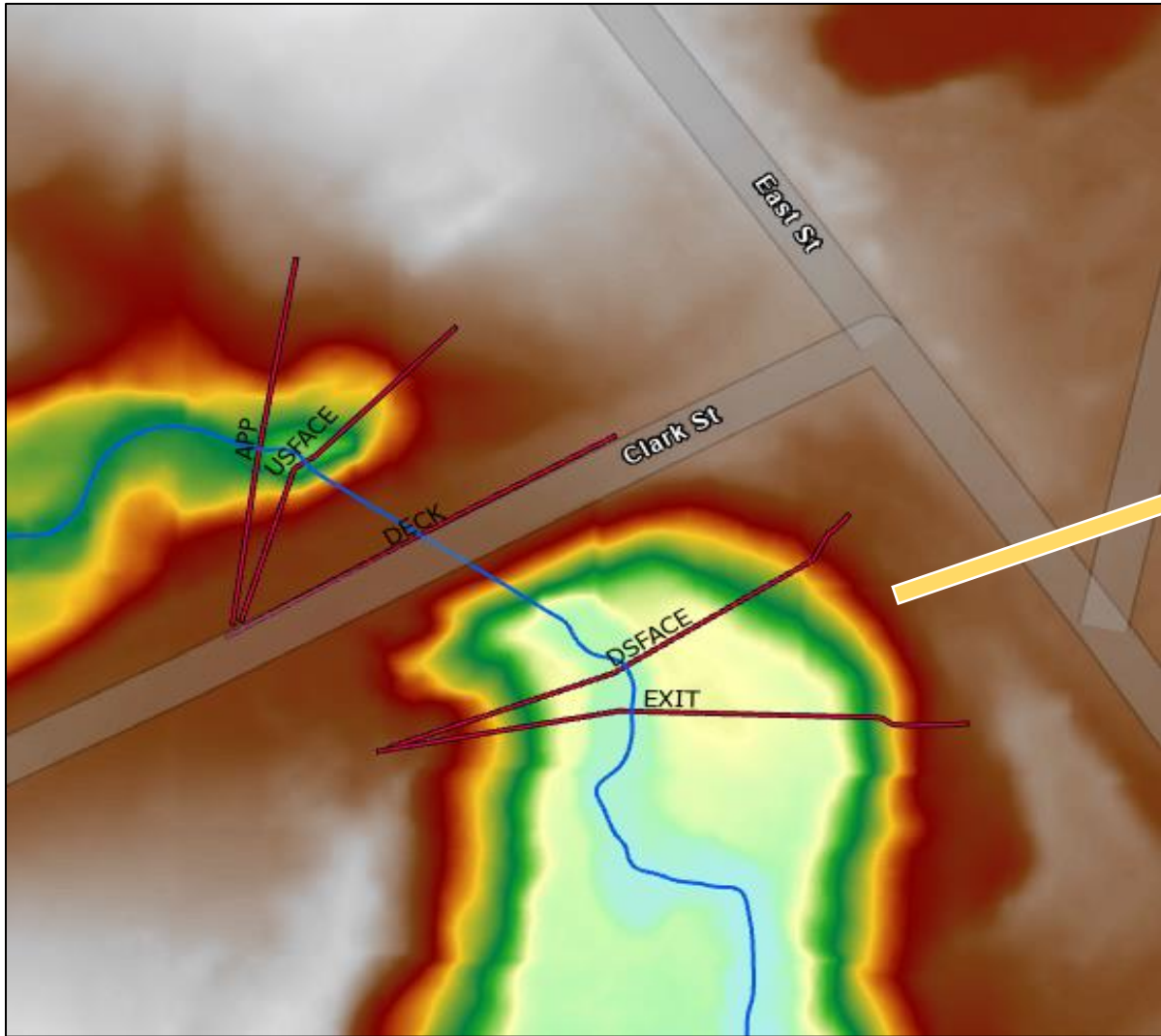


GIS-Based Hydraulic Model Development – Lidar Derived Elevation Data

Unnamed Tributary to Manhan River, Southampton, MA



GIS-Based Hydraulic Model Development – Cross Sections

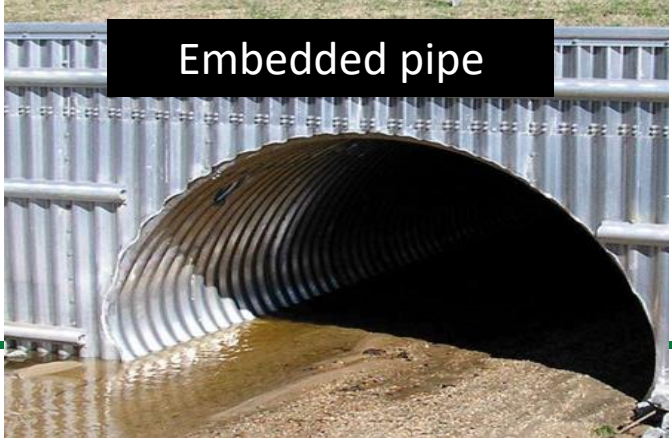
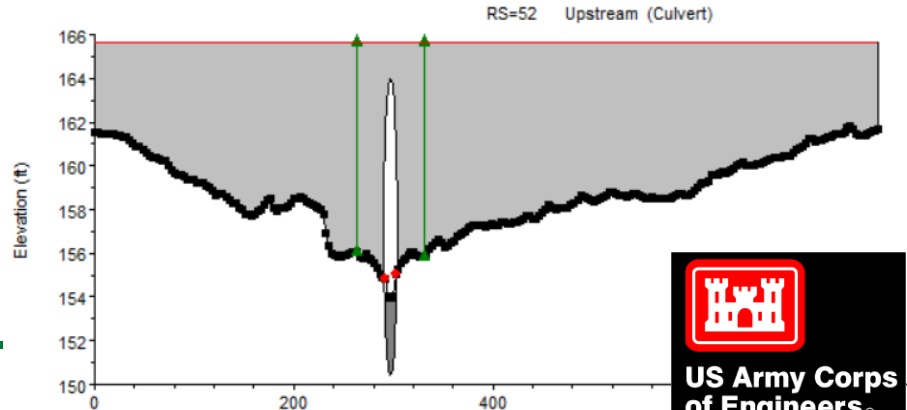
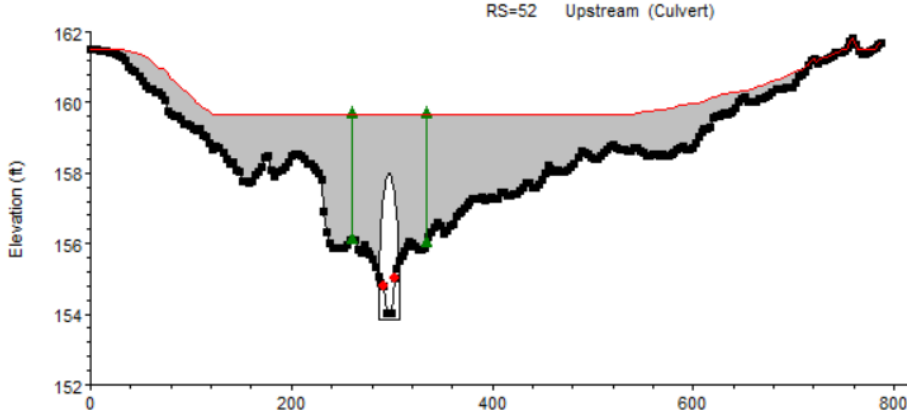
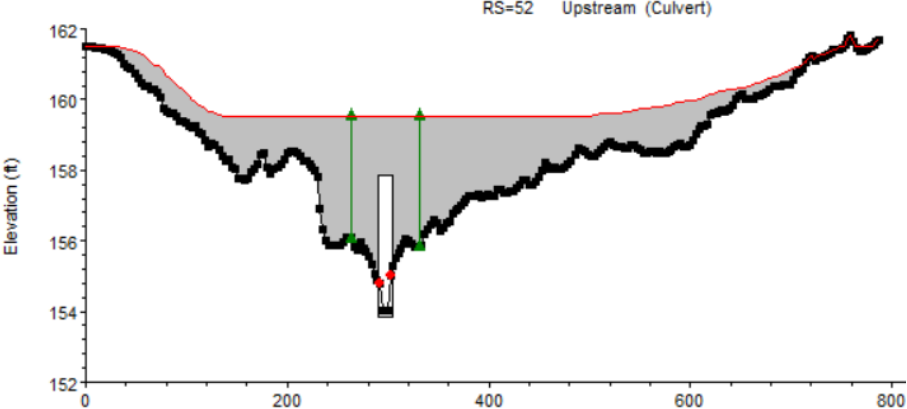


- Channel width and depth determined by Massachusetts Bankfull Channel Geometry Equations (Bent and Waite, 2013)



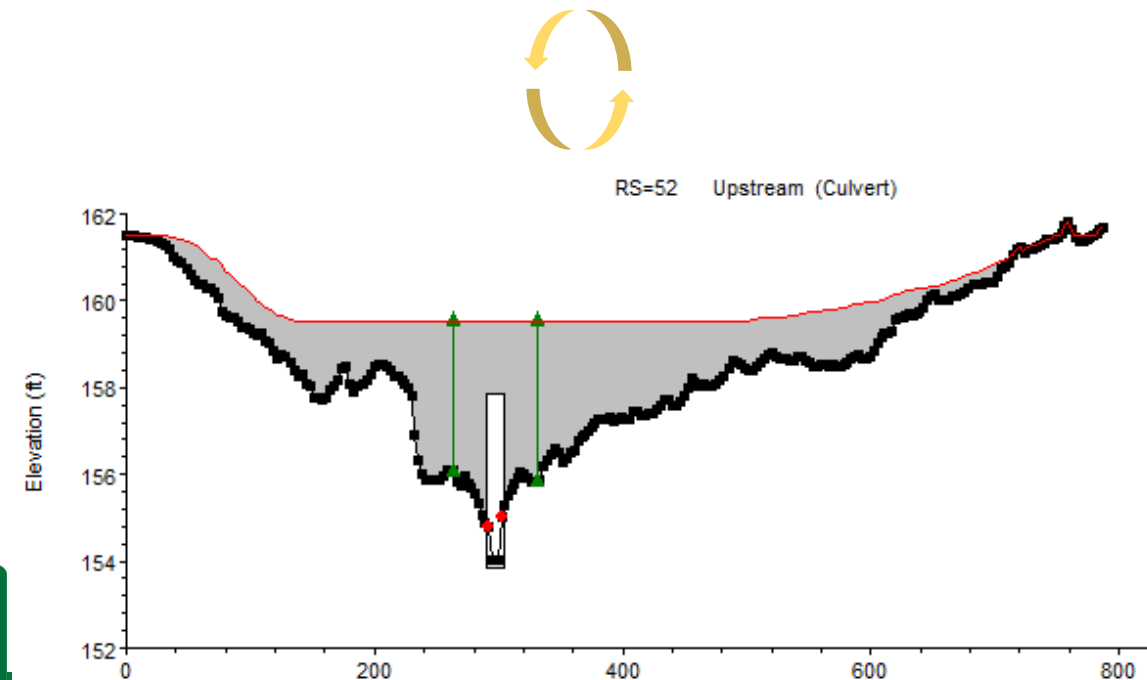
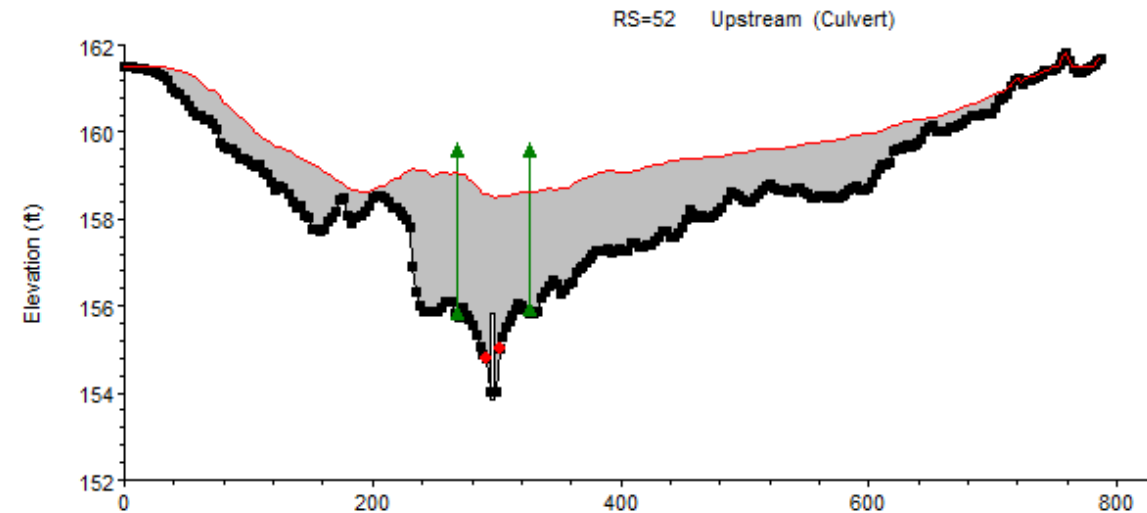
Preliminary Culvert Designs

- Culverts types:
 - 3-sided box
 - 3-sided arch
 - Embedded pipe
- Convey 10-, 4-, 2-, and 1-percent AEP flood flows
- Meet stream crossing standards



Hydraulic Models

- Manning's n-values of 0.045 for channel and 0.10 for overbank
- Freeboard of at least 1 ft, and 2 ft if specified by MassDOT Chap. 85 Section 35
- Precast concrete sizes for box and pipe culverts
- Arch sizes limited to those in HEC-RAS
- Stream crossing sites with drainage areas ≤ 2 mi² and $< 20\%$ impervious area
- Minimum spans:
 - 10% AEP = $0.8 \times$ BFW
 - 4% AEP = $0.9 \times$ BFW
 - 2% and 1% AEP = $1.0 \times$ BFW
 - SCS = $1.2 \times$ BFW



Habitat Quality and stream connectivity



BioMap Aquatic



Coldwater Fisheries Resource



Diadromous Fish Run

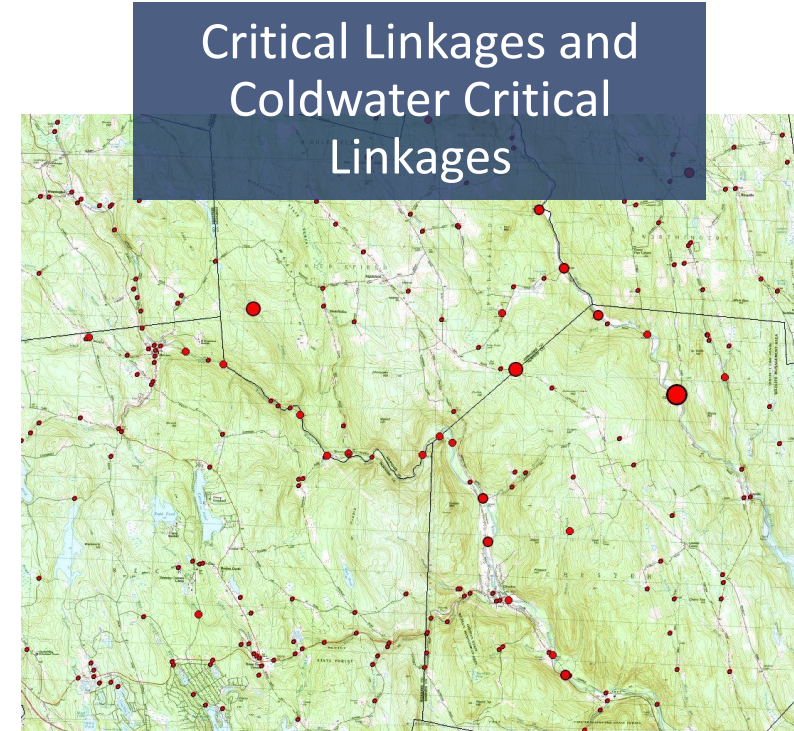


Photo courtesy of *University of Massachusetts at Amherst, Conservation Assessment and Prioritization System*



Area of Critical Environmental Concern

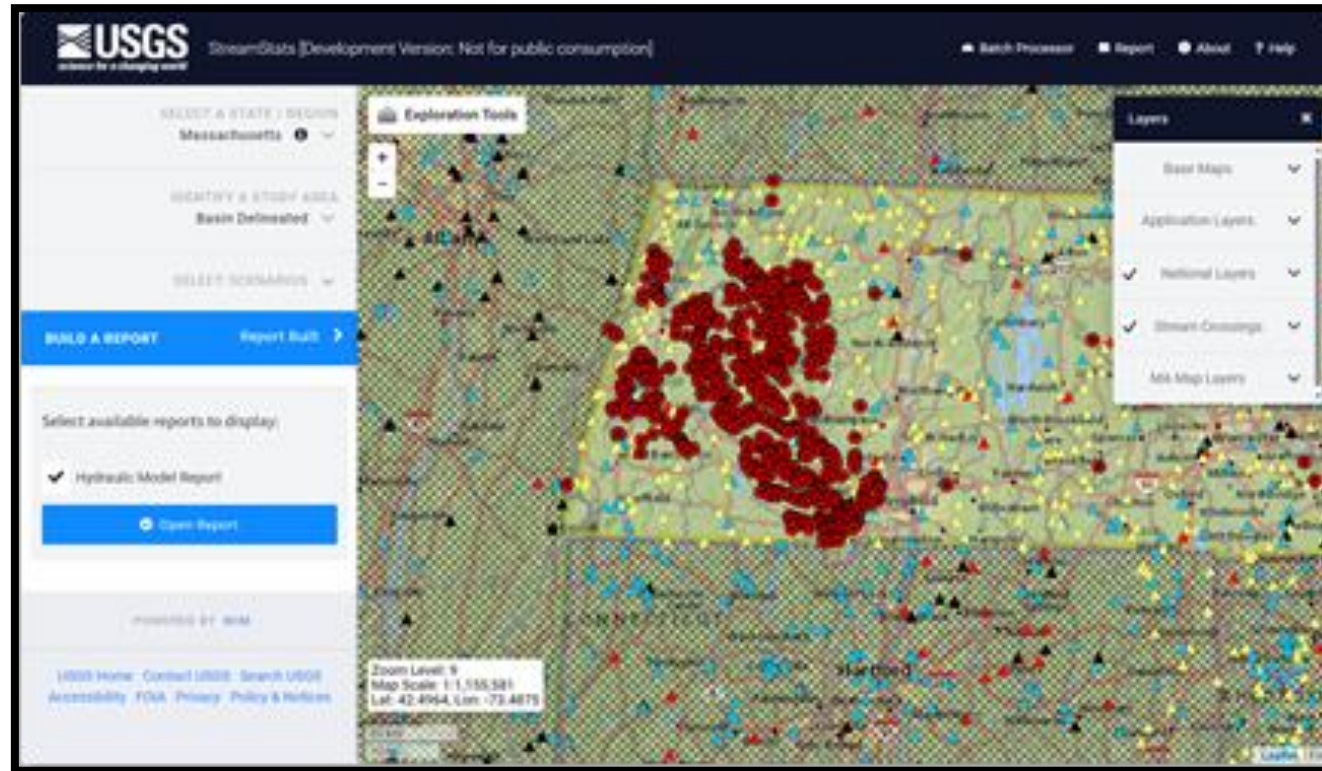


Wild & Scenic River

Photos courtesy of MA DFW, USFS, MA EOEAA, Kenneth Zirkel



1. USGS StreamStats is an Existing Website with Various Applications



StreamStats: <https://streamstats.usgs.gov/ss/>

SHM Web Application: <https://dev.streamstats.usgs.gov/ma-culverts/>



2. Choose the Crossing

USGS science for a changing world StreamStats [Development Version: Not for public consumption]

Batch Processor Report About Help

SELECT A STATE / REGION
Massachusetts

IDENTIFY A STUDY AREA
Basin Delineated

SELECT SCENARIOS

BUILD A REPORT

Select available reports to display:

- Hydraulic Model Report

Open Report

POWERED BY WIM

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Zoom Level: 13
Map Scale: 1:72,223
Lat: 42.6675, Lon: -71.8312

1 km
3000 ft

Exploration Tools

Stream Crossings

NAACC Code: xy4265299571758875

Habitat Quality Score: High Quality

Restoration Connectivity Potential Score: High Restoration Potential

Hydraulic Design Flood: 10 Year

Build Report

Layers

- Base Maps
- Application Layers
- National Layers
- Stream Crossings
- MA Map Layers

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3. Report Provides Prior Assessments and Watershed Details

USGS StreamStats

SELECT A STATE / REGION
Massachusetts

IDENTIFY A STUDY AREA
Basin Delineated

SELECT SCENARIOS

BUILD A REPORT Report Builder

Select available reports to display:

- Hydraulic Model Report

Open Report

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Site Information

Parameter Name	Value	Unit
NAACC Survey ID	55571	
NAACC Code	xy4265299571758875	
NAACC Type	Culvert	
Road	New Fitchburg Road	
Stream Name	trib to Pearl Hill Brook	
Town	Townsend	

Site Information Citations

North Atlantic Aquatic Connectivity Collaborative, 2021, NAACC Data Center: website accessed August 3, 2021 at https://naacc.org/naacc_data_center_home.cfm.

Basin Characteristics

Parameter Name	Value	Unit
Drainage Area	0.85	Square Miles
Mean Basin Elevation	613	Feet
Percent Storage from NLCD2006	5.76	Percent
Mean Basin Slope from 10m DEM	7.539	Percent

Basin Characteristics Citations

Drainage area determine from digital elevation models derived from lidar data (Massachusetts)

Report About Help

Layers

- Base Maps
- Application Layers
- National Layers
- MA Map Layers
- Stream Crossings

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4. Report Provides Habitat Connectivity and Restoration Potential

The screenshot displays the USGS StreamStats report interface. On the left is a navigation sidebar with options like 'SELECT A STATE / REGION' (Massachusetts), 'IDENTIFY A STUDY AREA' (Basin Delineated), and 'SELECT SCENARIOS'. The main content area is titled 'Stream Habitat and Connectivity Characteristics' and contains a table with the following data:

Parameter Name	Value	Unit
Coldwater Fisheries Resources ⓘ	0	
Areas of Critical Environmental Concerns ⓘ	1	
BioMap 2 Aquatic Core ⓘ	0	
Wild and Scenic Rivers ⓘ	0	
Critical Linkages ⓘ	20	
Cold Water Critical Linkages ⓘ		
Habitat Quality Score ⓘ	High Quality	
Restoration Connectivity Potential Score ⓘ	High Restoration Potential	
Maximum Extent Practicable (MEP) Cost Factor ⓘ	20-percent above baseline	

Below the table is a section for 'Stream Habitat and Connectivity Characteristics Citations' with the following links:

- [Massachusetts Division of Fisheries, 2022, Coldwater fish resources, website accessed April 30, 2022 at https://www.mass.gov/info-details/coldwater-fish-resources.](https://www.mass.gov/info-details/coldwater-fish-resources)
- [Massachusetts Department of Conversation and Recreation, Ecology and ACEC Program, 2022, ACEC program overview: website, accessed April 30, 2022 at https://www.mass.gov/service-details/acec-program-overview.](https://www.mass.gov/service-details/acec-program-overview)
- [Massachusetts Department of Fish and Game, Natural Heritage Endangered Species Program, 2022, BioMap2 web site, accessed April 29, 2022 at http://maps.massgis.state.ma.us/dfg/biomap2.htm](http://maps.massgis.state.ma.us/dfg/biomap2.htm)
- [National Wild and Scenic Rivers System, 2022, Massachusetts: website, accessed April 30, 2022 at https://www.rivers.gov/massachusetts.php.](https://www.rivers.gov/massachusetts.php)
- [University of Massachusetts at Amherst, Conservation Assessment and Prioritization System, 2022, The critical linkage project: website, accessed April 30, 2022 at http://www.umasscaps.org/applications/critical-linkages.html.](http://www.umasscaps.org/applications/critical-linkages.html)

On the right side of the interface is a map showing a stream network with several red circular markers. A 'Layers' panel is open, showing the following layers:

- Base Maps
- Application Layers
- National Layers
- MA Map Layers
- Stream Crossings

5. Report Provides DOT Road Classification and Design Flow

The screenshot displays the USGS StreamStats report interface. On the left is a navigation sidebar with options like 'SELECT A STATE / REGION', 'IDENTIFY A STUDY AREA', and 'BUILD A REPORT'. The main content area is divided into two sections: 'Road Crossing Characteristics' and 'Peak-Flow Statistics Flow Report'. The 'Road Crossing Characteristics' section includes a table with two rows: 'Hydraulic Design Flood' (Value: 10, Unit: Year) and 'Roadway Classification' (Value: Urban collector or rural minor). Below this table are two citations. The 'Peak-Flow Statistics Flow Report' section includes a table with four rows: '10-year Peakflow' (Value: 94, Unit: Cubic Feet per second), '25-year Peakflow' (Value: 130, Unit: Cubic Feet per second), '50-year Peakflow' (Value: 160, Unit: Cubic Feet per second), and '100-year Peakflow' (Value: 192, Unit: Cubic Feet per second). Below this table is a citation. On the right side of the interface is a map with a 'Layers' panel open, showing 'National Layers', 'MA Map Layers', and 'Stream Crossings' checked.

Road Crossing Characteristics

Parameter Name	Value	Unit
Hydraulic Design Flood ⓘ	10	Year
Roadway Classification ⓘ	Urban collector or rural minor	

Road Crossing Characteristics Citations

[Massachusetts Department of Transportation, 2020, Load and resistance factor design \(LRFD\) Bridge Manual – Part I, Chapter 1 bridge site exploration, January 2020 revision, 26 p, accessed October 1, 2021 at <https://www.mass.gov/doc/chapter-1-bridge-site-exploration/download>.](#)

[Massachusetts Department of Transportation, 2021, Roadway culverts, accessed October 20, 2021 at <https://geo-massdot.opendata.arcgis.com/datasets/MassDOT::culverts-1/about>.](#)

Peak-Flow Statistics Flow Report

Parameter Name	Value	Unit
10-year Peakflow ⓘ	94	Cubic Feet per second
25-year Peakflow ⓘ	130	Cubic Feet per second
50-year Peakflow ⓘ	160	Cubic Feet per second
100-year Peakflow ⓘ	192	Cubic Feet per second

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, 54 p., <https://doi.org/10.3133/sir20165156>.](#)

6. Report Provides Bankfull Width

The screenshot displays the USGS StreamStats web application interface. On the left is a navigation sidebar with options like 'SELECT A STATE / REGION', 'IDENTIFY A STUDY AREA', and 'BUILD A REPORT'. The main content area is divided into two report sections. The top section, 'Peak-Flow Statistics Flow Report', contains a table with peakflow data for 10, 25, 50, and 100-year return periods. Below this is a citation for Zarriello (2017). The bottom section, 'Bankfull Statistics Flow Report', contains a table with bankfull width, mean depth, and XS area data, followed by a citation for Bent and Waite (2013). On the right, a map shows the study area with a 'Layers' panel open, listing 'National Layers', 'MA Map Layers', and 'Stream Crossings' as active layers.

USGS StreamStats

SELECT A STATE / REGION
Massachusetts

IDENTIFY A STUDY AREA
Basin Delineated

SELECT SCENARIOS

BUILD A REPORT Report Builder

Select available reports to display:

- Hydraulic Model Report
- Open Report

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Peak-Flow Statistics Flow Report

Parameter Name	Value	Unit
10-year Peakflow ⓘ	94	Cubic Feet per second
25-year Peakflow ⓘ	130	Cubic Feet per second
50-year Peakflow ⓘ	160	Cubic Feet per second
100-year Peakflow ⓘ	192	Cubic Feet per second

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, 54 p., <https://doi.org/10.3133/sir20165156>.

Bankfull Statistics Flow Report

Parameter Name	Value	Unit
Bankfull Width ⓘ	14.2	Feet
Bankfull Mean Depth ⓘ	0.91	Feet
Bankfull XS Area ⓘ	12.8	Square Feet

Bankfull Statistics Citations

Bent, G.C., and Waite, A.M., 2013, Equations for estimating bankfull channel geometry and discharge for streams in Massachusetts: U.S. Geological Survey Scientific Investigations Report 2013-5155, 62 p., <http://dx.doi.org/10.3133/sir20135155>.

Report About Help

Layers

- Base Maps
- Application Layers
- National Layers
- MA Map Layers
- Stream Crossings

Leaflet | Esri

7. Report Provides 3 Crossing Types: Box, Arch, or Pipe

The screenshot displays the USGS StreamStats web application interface. On the left, a navigation sidebar includes options for selecting a state/region (Massachusetts), identifying a study area (Basin Delineated), and selecting scenarios. The main content area features a report titled "Preliminary 3-Sided Box Culvert Design meeting the 10-, 25-, 50-, and 100-Year Flood Flows and Stream Crossing Standards". Above the report title, there are tabs for "Box", "Arch", and "Pipe", with "Box" selected. A disclaimer for preliminary culvert designs is provided, stating that the tool uses a GIS-based hydraulic model and that field review is required. A yellow warning banner indicates that highlighted values do not meet the Stream Crossing Standards. Below the text is a 3D perspective diagram of a box culvert structure with dashed lines indicating dimensions. The right side of the interface shows a map of the study area with a "Layers" panel on the right, including options for Base Maps, Application Layers, National Layers, Stream Crossings, and MA Map Layers. The USGS logo and "StreamStats [Development V...]" are visible at the top left.

8. Report Provides 3 Sizes for Each (15 Designs Total)

USGS StreamStats [Development V...]
science for a changing world

SELECT A STATE / REGION
Massachusetts ⓘ

IDENTIFY A STUDY AREA
Basin Delineated

SELECT SCENARIOS

BUILD A REPORT Report Built

Select available reports to display:

- Hydraulic Model Report

POWERED BY WIM

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[Accessibility](#) [FOIA](#) [Privacy](#) [Policy & Notices](#)

Zoom
Map S
Lat: 42

500 m
2000 ft

Parameter Name	10-Yr Flow	25-Yr Flow	50-Yr Flow	100-Yr Flow	Meets SCS	Unit
Box Culvert Span ⓘ	12.0	13.0	15.0	15.0	12.0	Feet
Box Culvert Height ⓘ	4.0	No Data	6.0	6.0	4.0	Feet
Box Culvert Length ⓘ	49.3	49.3	49.3	49.3	49.3	Feet
Box Culvert Area ⓘ	48.0	78.0	90.0	90.0	48.0	Square Feet
Box Culvert Material ⓘ	Concrete	Concrete	Concrete	Concrete	Concrete	
Box Culvert Upstream Channel Invert Elevation ⓘ	1165.3	1165.3	1165.3	1165.3	1165.3	Feet - NAVD88
Box Culvert Downstream Channel Invert Elevation ⓘ	1164.9	1164.9	1164.9	1164.9	1164.9	Feet - NAVD88
Box Culvert Original Road Deck Elevation ⓘ	1172.0	1172.0	1172.0	1172.0	1172.0	Feet - NAVD88
Box Culvert Post Road Deck Elevation ⓘ	1170.8	1172.8	1172.8	1172.8	1170.8	Feet - NAVD88
Box Culvert Approach Cross-Section Velocity ⓘ	5.3	5.8	6.2	6.5	5.3	Feet/Second
Box Culvert Culvert Outlet Velocity ⓘ	3.8	4.2	4.0	4.5	2.5	Feet/Second
Box Culvert Approach Cross-Section Depth ⓘ	1.1	1.4	1.6	1.8	1.1	Feet
Box Culvert Culvert Outlet Depth ⓘ	1.4	1.6	1.9	2.1	1.5	Feet

Does culvert design meet the individual variables of the MA Stream Crossing Standards?

Box Embedment ⓘ	No Data	No Data	No Data	No Data	No Data	Feet
Box Substrate ⓘ	Natural	Natural	Natural	Natural	Natural	
Box Span Ratio ⓘ	0.9	No Data	No Data	No Data	0.9	
Box Openness Ratio ⓘ	0.97	1.58	1.83	1.83	0.97	
Box Culvert Velocity Ratio ⓘ	1.4	1.4	1.6	1.5	2.1	
Box Culvert Depth Ratio ⓘ	0.8	0.8	0.8	0.9	0.8	

Hydraulic Model Information

Lidar Publication Date

Massachusetts Stream Crossing Automated Model Software Version

Batch Processor Report About Help

Layers

- Base Maps
- Application Layers
- National Layers
- Stream Crossings
- MA Map Layers

Westfield River
Searis Rd
Rocky Pond
Pond Brook
Cullen Rd
Pond Brook
Bean Hill Rd
Church Hill Rd
Emerald
Cm Gardner State Park

Leaflet | Esri

9. Output Also Provides Preliminary Model Results for Use by Engineer in Final Design

The screenshot displays the USGS StreamStats web application interface. On the left, a sidebar contains navigation options: "SELECT A STATE / REGION" (with "Massachusetts" selected), "IDENTIFY A STUDY AREA" (with "Basin Delineated" selected), "SELECT SCENARIOS", "BUILD A REPORT" (with "Report Builder" selected), and "Select available reports to display:" (with "Hydraulic Model Report" checked). A blue "Open Report" button is visible below the report selection. At the bottom of the sidebar, it says "POWERED BY WIM" and provides links for "USGS Home", "Contact USGS", "Search USGS", "Accessibility", "FOIA", "Privacy", and "Policy & Notices".

The main content area is partially obscured by a central white overlay containing the following text:

[Massachusetts Department of Fish and Game, Division of Ecological Restoration, 2012, Massachusetts stream crossing handbook, 2nd edition, accessed August 1, 2021 at https://www.mass.gov/doc/massachusetts-stream-crossing-handbook/download.](https://www.mass.gov/doc/massachusetts-stream-crossing-handbook/download)

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USGS Product Names Disclaimer: Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Application Version: 4.7.0 [Development Version: Not for public consumption]
StreamStats Services Version: 1.2.22 [Development Version: Not for public consumption]
NSS Services Version: [Development Version: Not for public consumption]

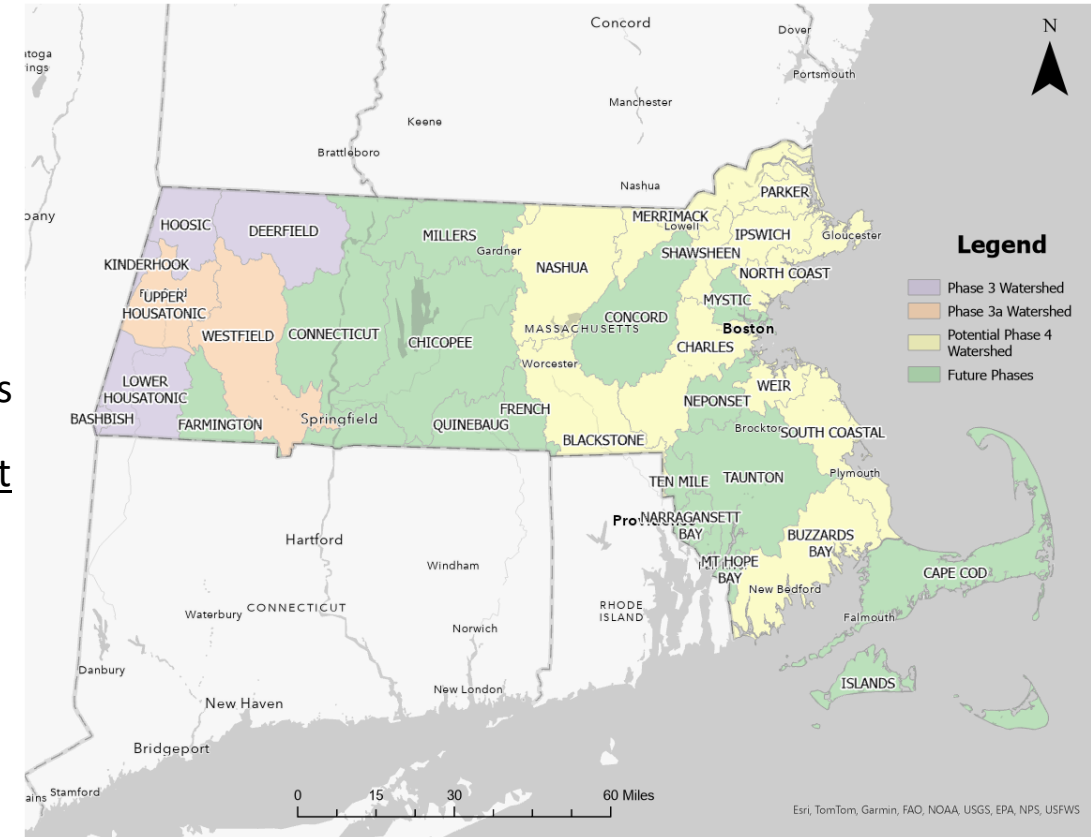
A "Download" menu is open, showing options: GeoJSON, CSV, ShapeFile, KML, and HEC-RAS Model Files. A "Print" button is also visible in the bottom right of the overlay.

On the right side of the interface, a "Layers" panel is open, showing a list of map layers: "Base Maps", "Application Layers", "National Layers" (checked), "MA Map Layers" (checked), and "Stream Crossings" (checked). The background shows a map of a river basin with red dots indicating stream crossings.

Stream Crossing Planning Tool Status

Status:

- Phase 1 (7/19 – 9/22) – Feasibility with USGS Geonarrative Published
- Phase 2 (7/21 – 6/23) – Pilot Watershed and Draft MEP Guidance
- Phase 2A (7/22 – 6/24) – Ground Comparison, Terrain Development, and Methodology Publication
- Phase 3 (5/23 – 6/25) – Deerfield, lower Housatonic, and Hudson Watersheds
- Phase 3A (7/23 – 6/25) – Upper Housatonic / Westfield Watersheds and Draft Tidal Crossing Criteria
- Phase 3B (5/24 – 9/27) – Tidal Regression Equation Development (Model Calibration)
- Phase 4 (7/24 – 6/28) – Statewide Buildout and Urban Regression Equations



Future Phases Beyond Scaling Statewide for all Inland Structures

- Coastal Areas
- Future Flows
- Flood Extents and Depths for Future Flows
- Education and Outreach



Questions

Mass DEP and UMass Teams

Lisa Rhodes, David Hilgeman, Christina Wu, Tom Maguire, and Scott Jackson (UMass Amherst)

USGS Team

Brendan McCarthy, Luke Sturtevant, Amanda Tudor, Ian Armstrong, Meghan McCallister, Carl Carlson, Alex Graziano, Mark Poe, and Gardner Bent

USGS StreamStats and WIM Teams

Andrea Medenblik, Harper Wavra, Blake Draper, and Pete McCarthy

Contacts

- David.Hilgeman@mass.gov
- gbent@usgs.gov



Project Webpage

UMassAmherst

