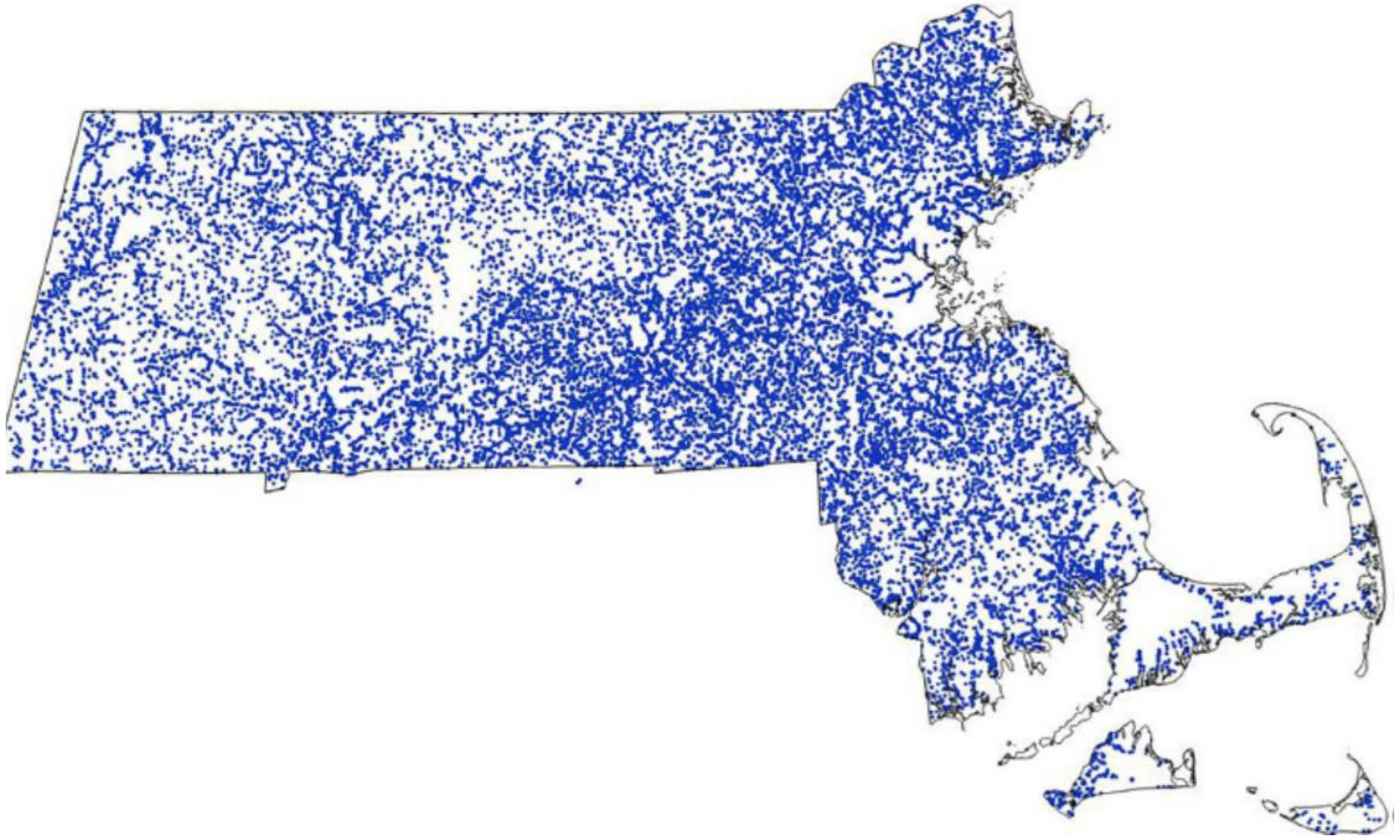
A GIS-Based Hydraulic Modeling Tool for Massachusetts Stream Crossing Replacement Projects in USGS StreamStats

MAWWG-NEBAWWG Joint Meeting
November 13, 2024

David Hilgeman, MassDEP

Gardner Bent, USGS

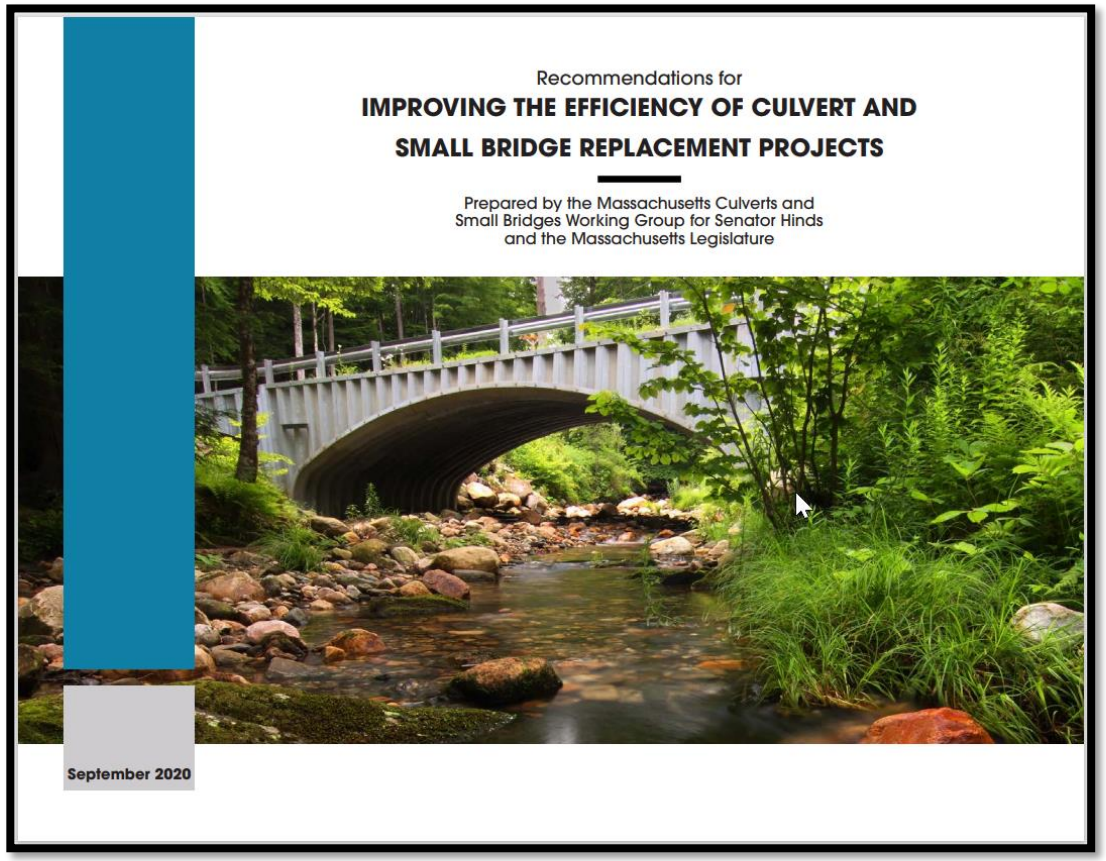
More than 25,000 crossings in Massachusetts. Many are Undersized and/or Failing.



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

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



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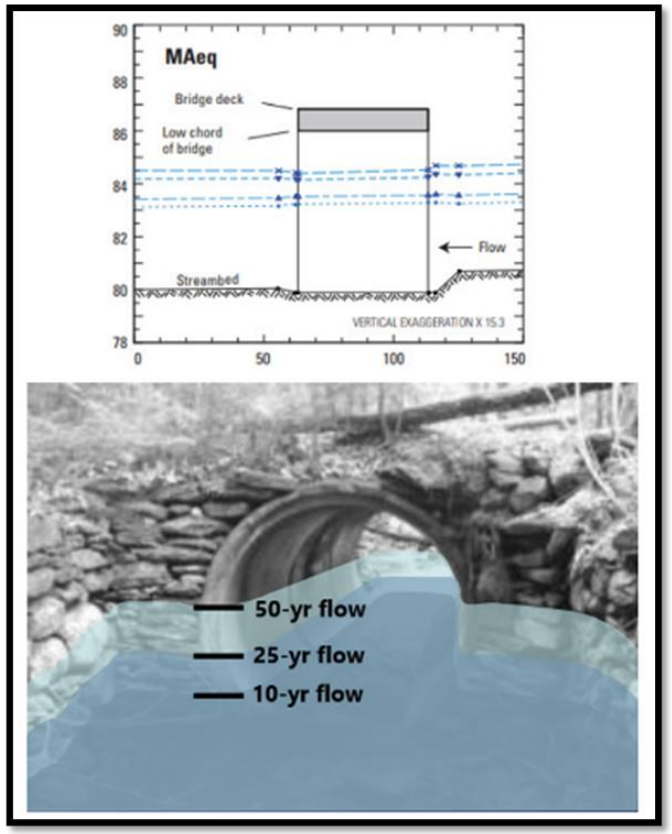
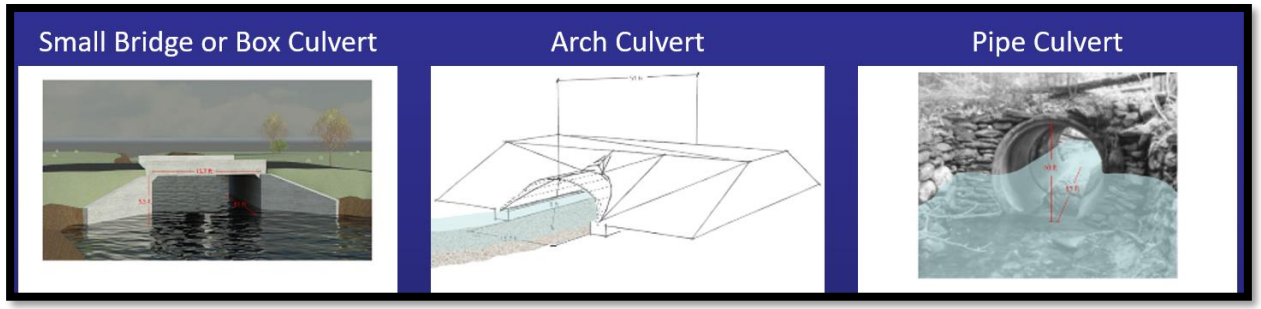
Design Standard + Design Flow + Terrain



Hydraulic Model

Preliminary Stream Crossing Sizes



Images modified from Zarriello and Barbaro, 2014

Images modified from Benjamin Frempong-Mensah, Ah Fong, Culvert Condition Assessment Manual, 2019 Edition

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)

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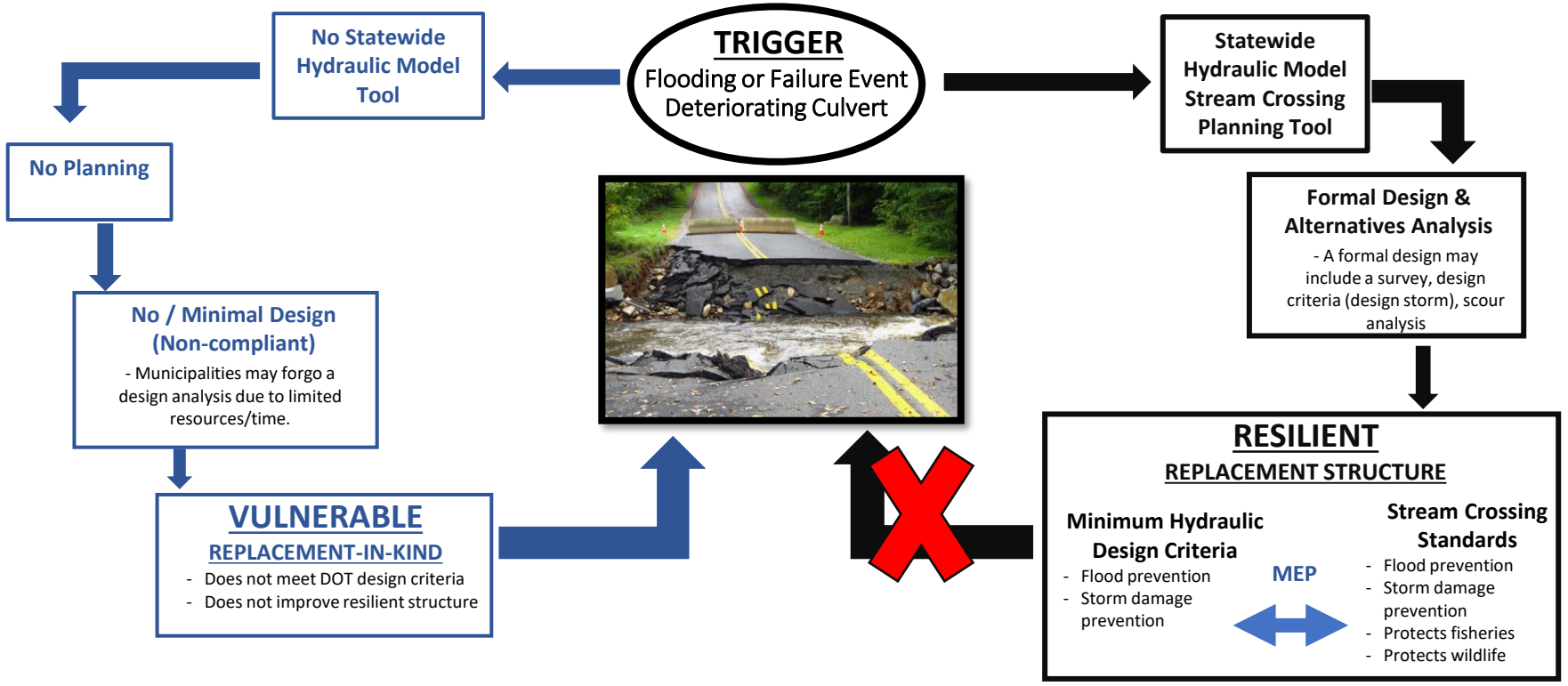
Statewide Hydraulic Model as a Stream Crossing Planning Tool



USGS science for a changing world

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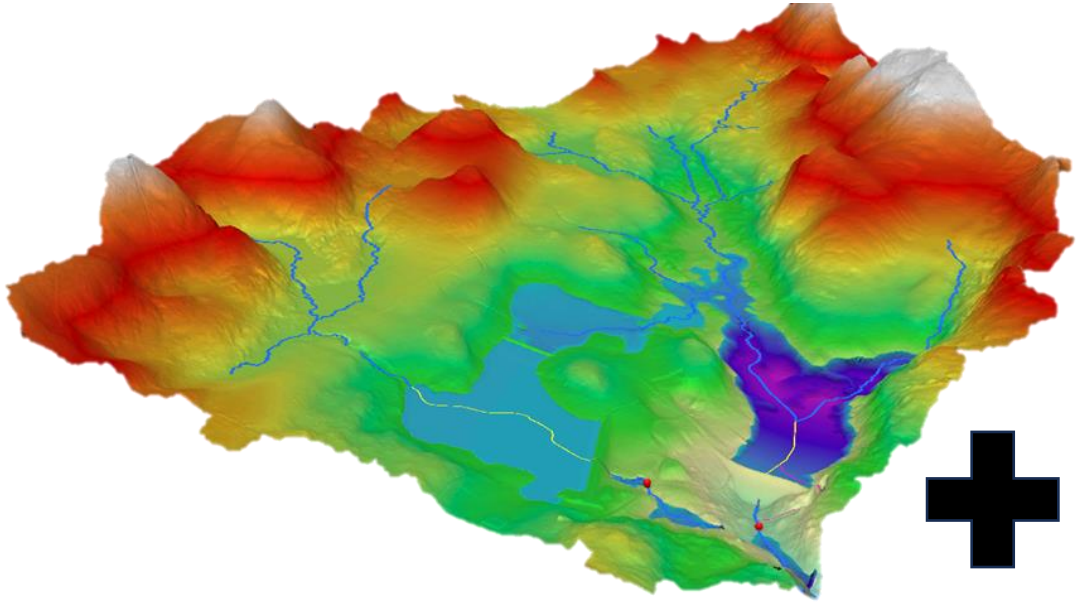
UMass Amherst

GIS-BASED Hydraulic Model Development



+

python™

+Arcpy functions

+

RAS

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GIS-Based Hydraulic Model Development

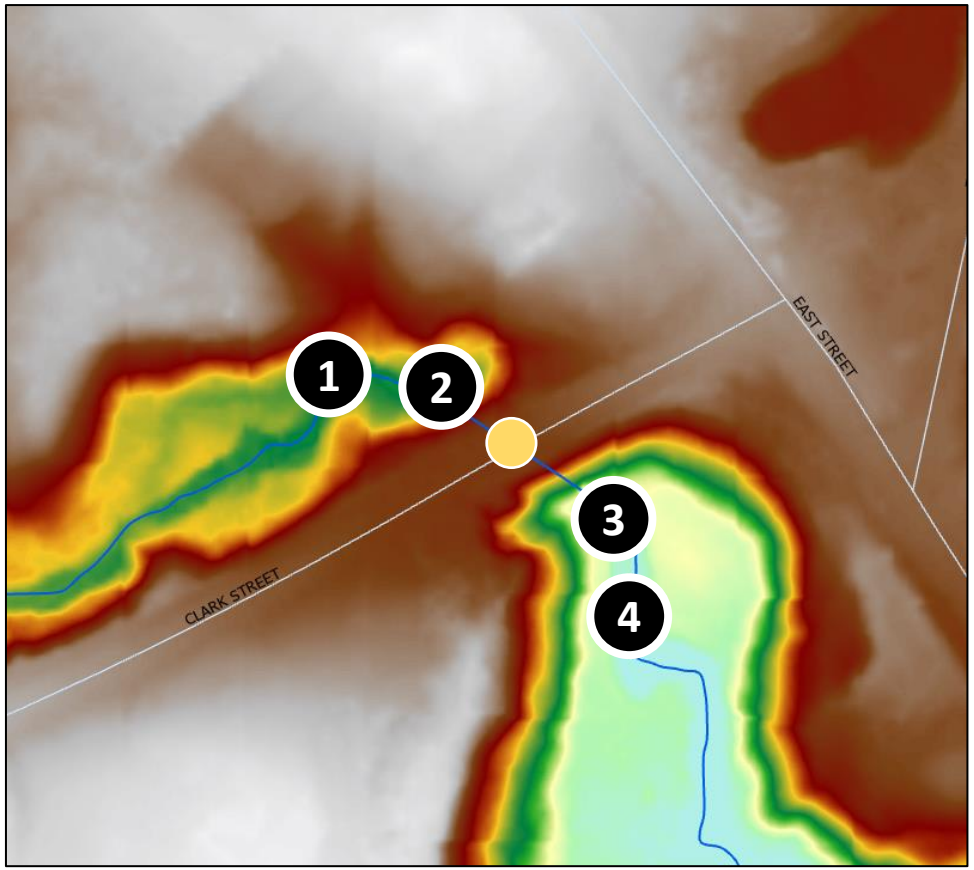
Looking Upstream

Upstream Face

Downstream Face

Looking Downstream

Unnamed Tributary to Manhan River, Southampton, MA



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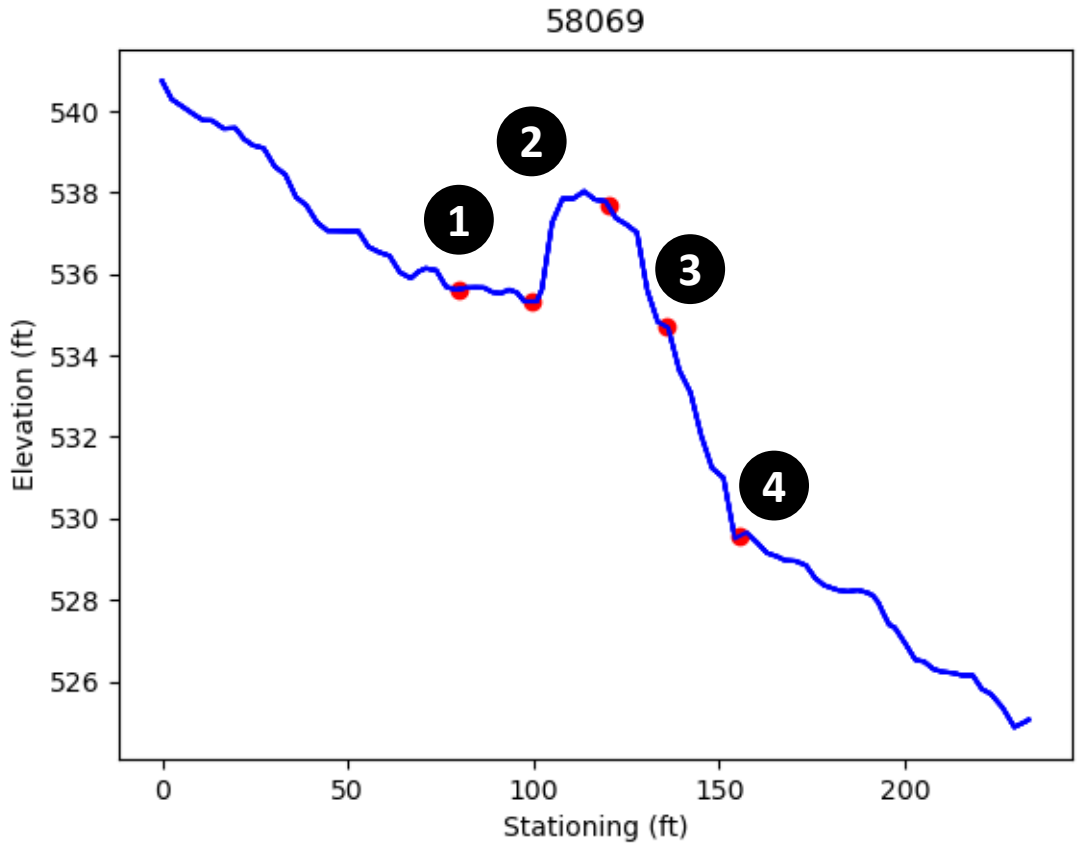
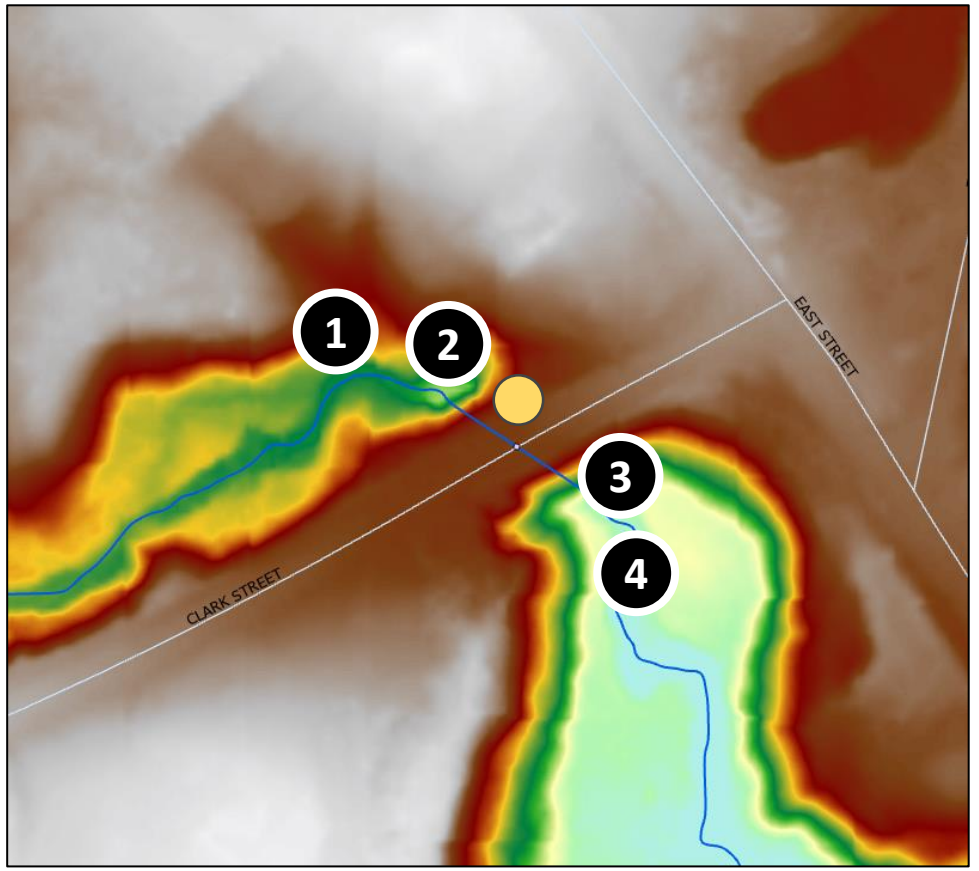
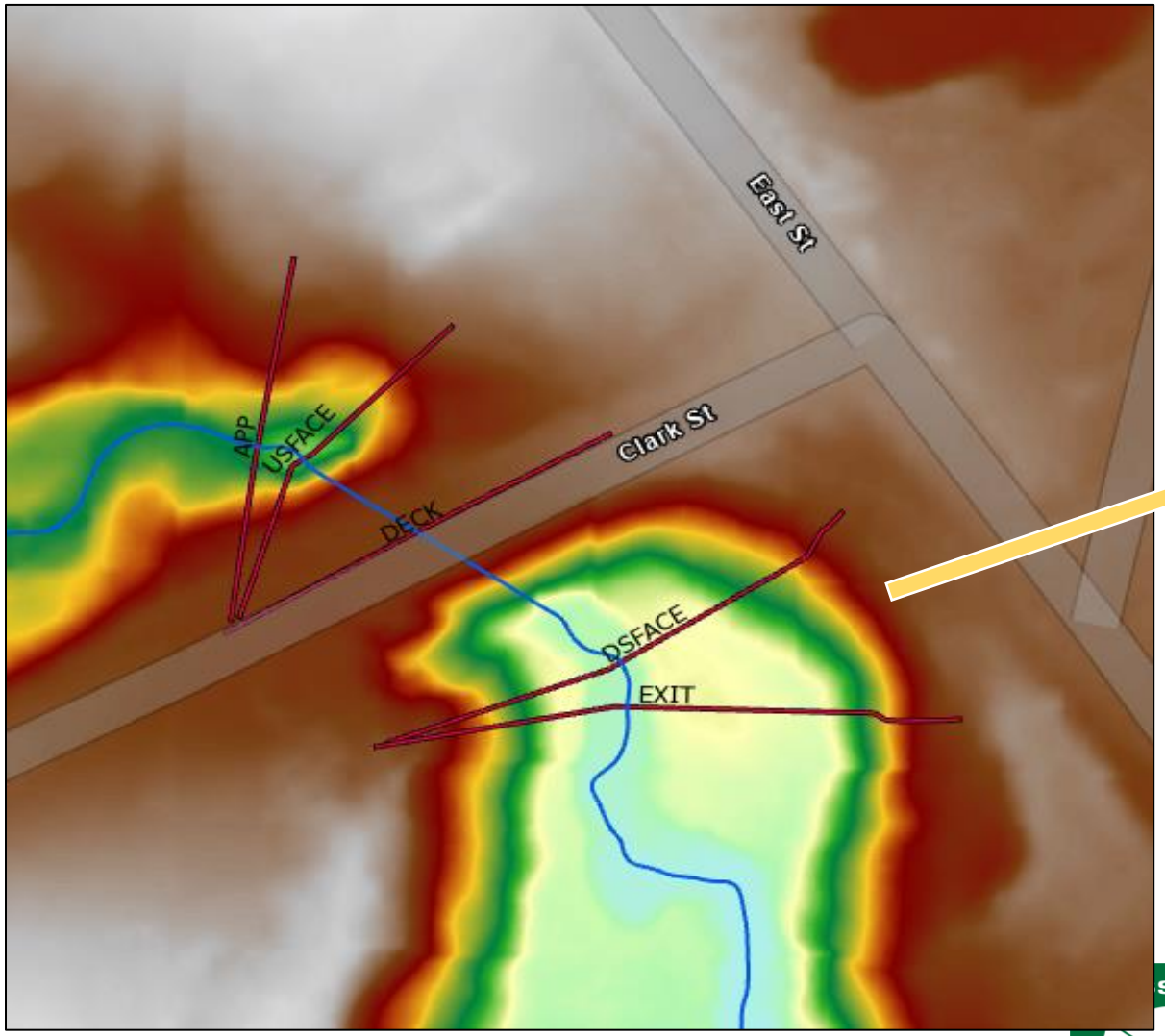
GIS-Based Hydraulic Model Development – Lidar Derived Elevation Data

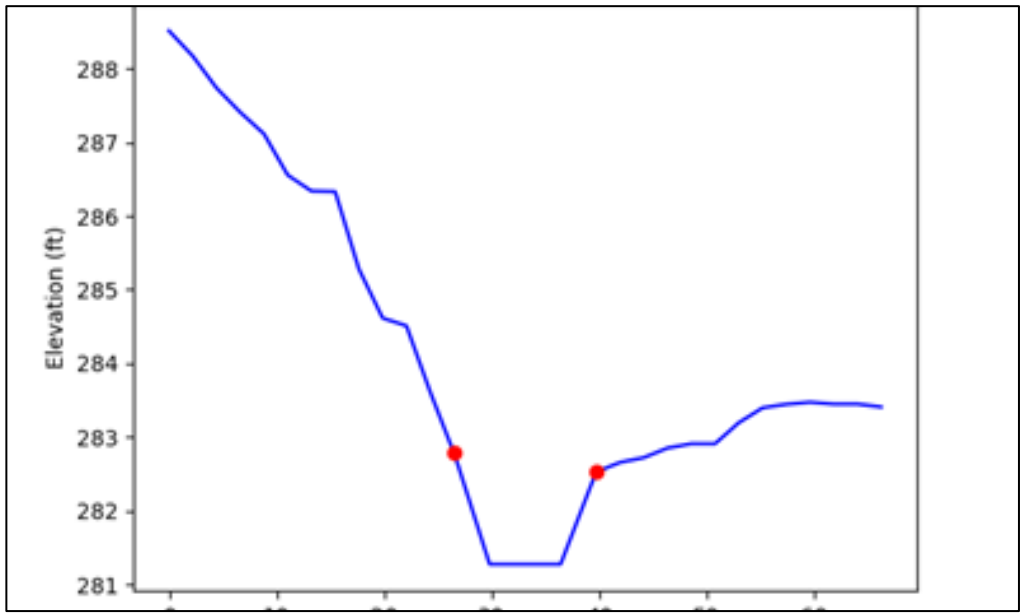
Unnamed Tributary to Manhan River, Southampton, MA





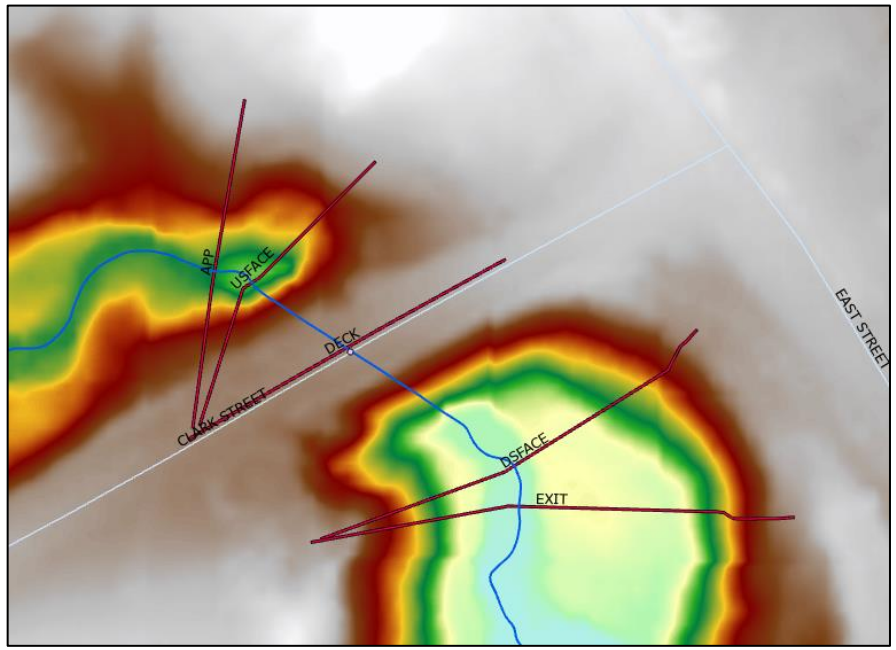
GIS-Based Hydraulic Model Development – Cross Sections

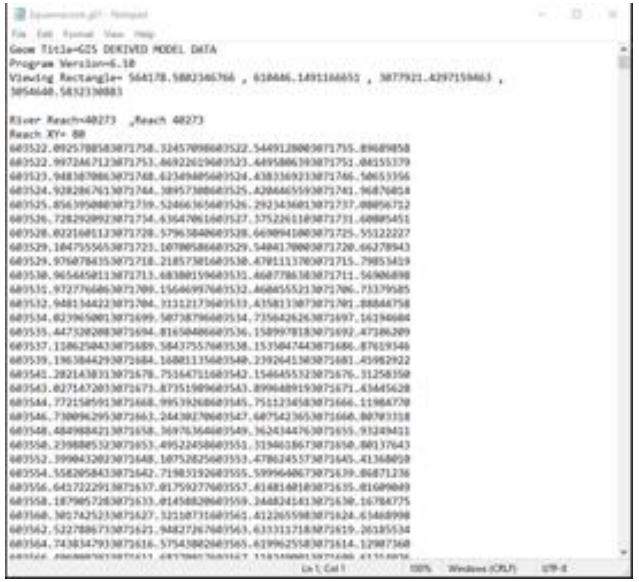




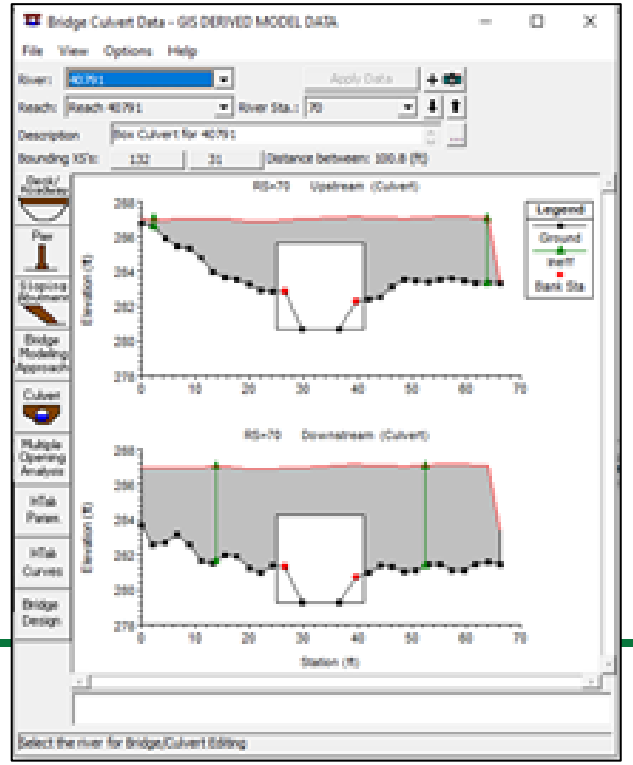
- Channel <u>width</u> and <u>depth</u> determined by Massachusetts Bankfull Channel Geometry Equations (Bent and Waite, 2013)

Creation of HEC-RAS Model Files



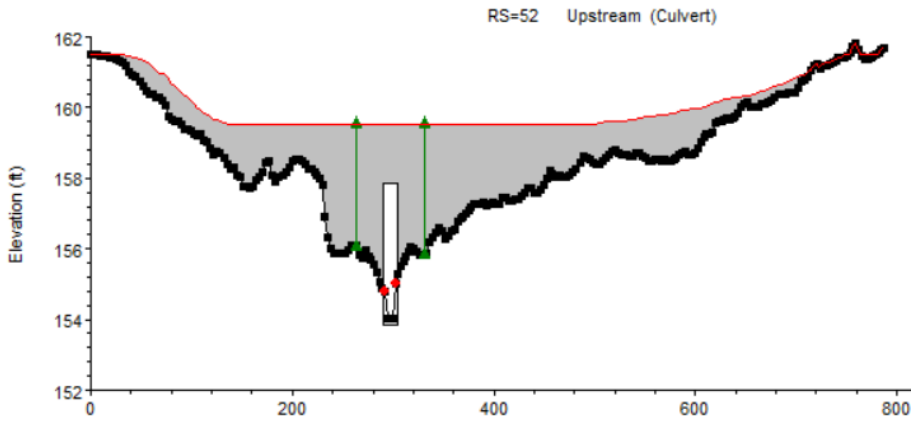


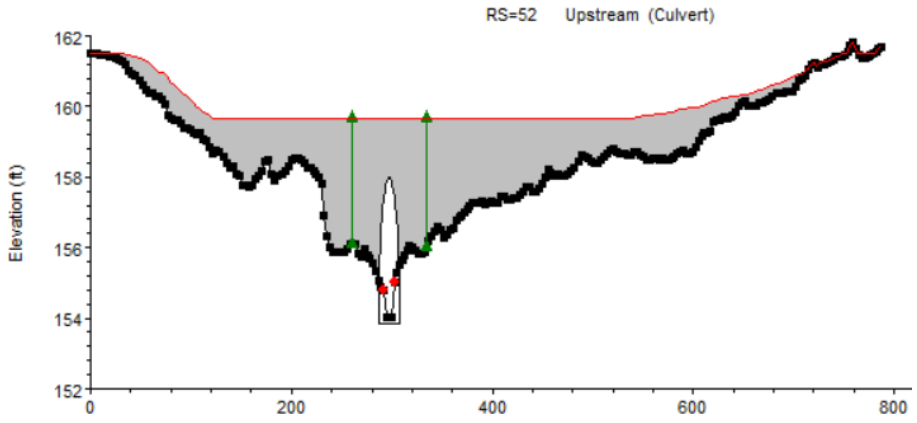
- Geometry file
- Plan file
- Flow file [Massachusetts regional regression equations for estimating peak flows (Zarriello, 2017)]

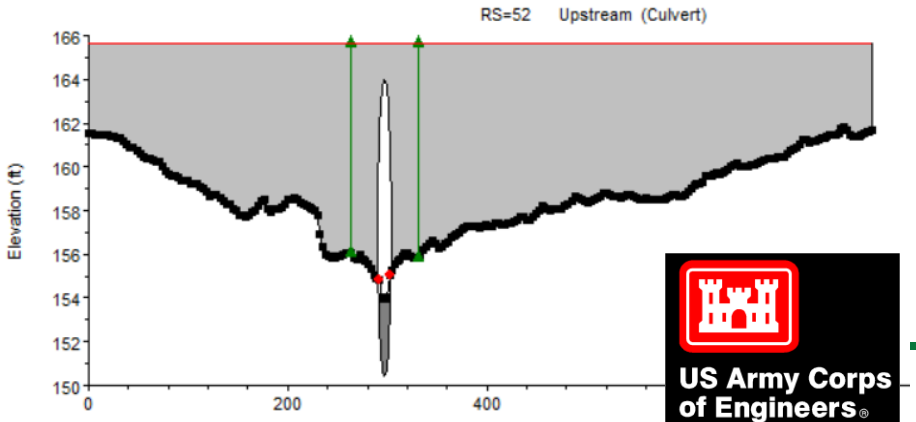


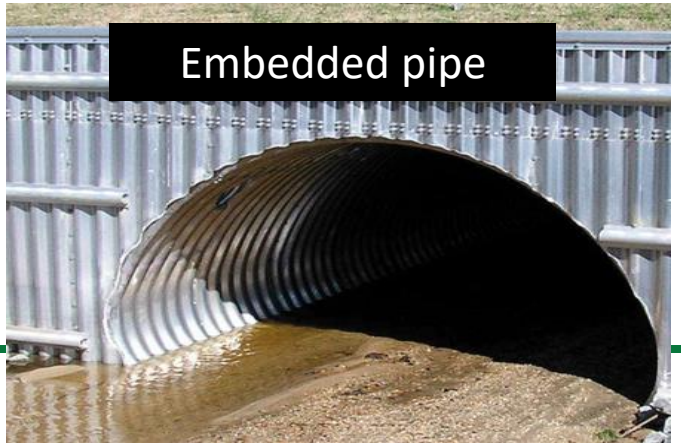
Preliminary Culvert Designs

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









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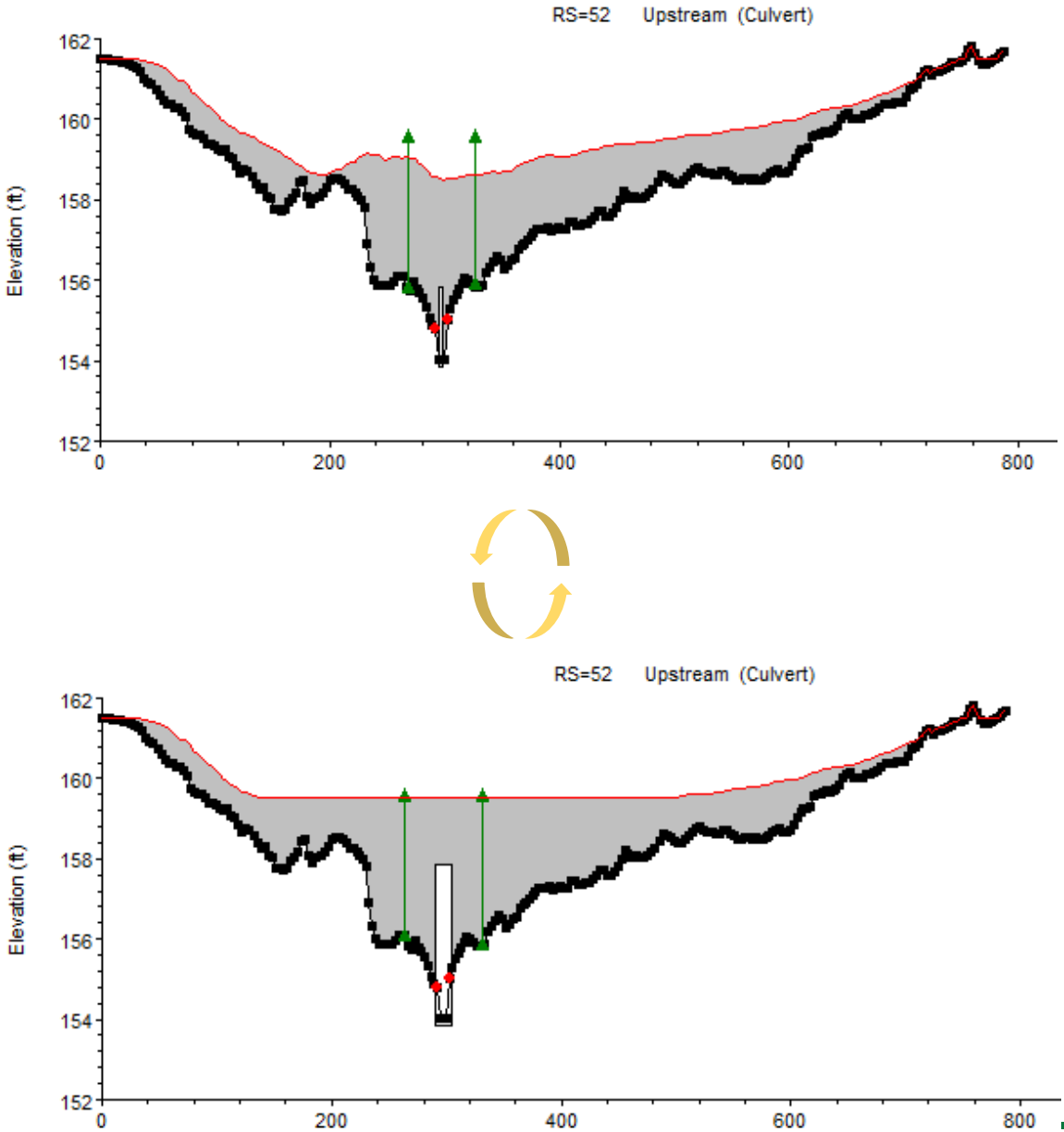
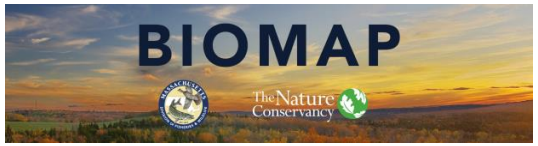
Hydraulic Models

- 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 < or = 2 mi^2 and < 20% impervious area
- Minimum spans:
  - 10% AEP = 0.8 x BFW
  - 4% AEP = 0.9 x BFW
  - 2% and 1% AEP = 1.0 x BFW
  - SCS = 1.2 x BFW



Habitat Quality and stream connectivity



BioMap Aquatic

Coldwater Fisheries Resource

Diadromous Fish Run

Critical Linkages and Coldwater Critical Linkages

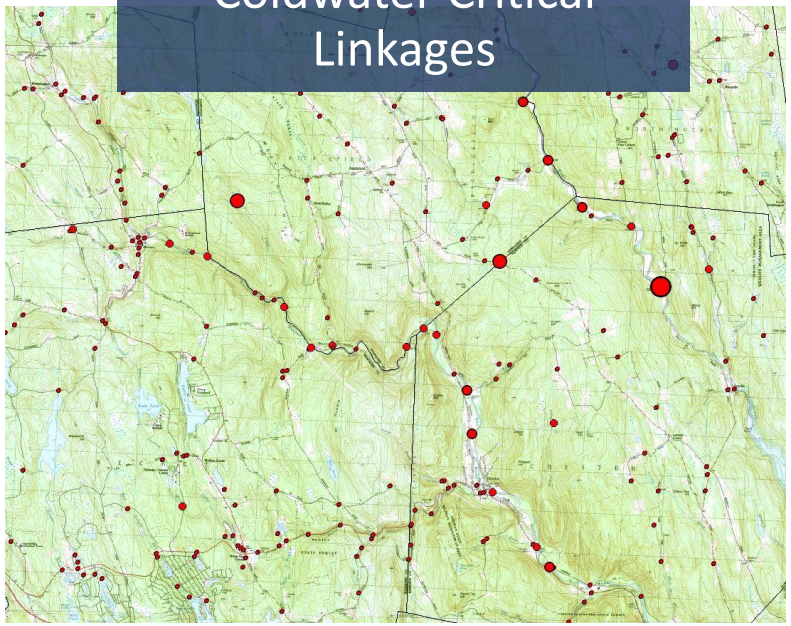


Photo courtesy of *University of Massachusetts at Amherst, Conservation Assessment and Prioritization System*

Area of Critical Environmental Concern

Wild & Scenic River

Photos courtesy of *MA DFW, USFS, MA EOEEA, Kenneth Zirkel*

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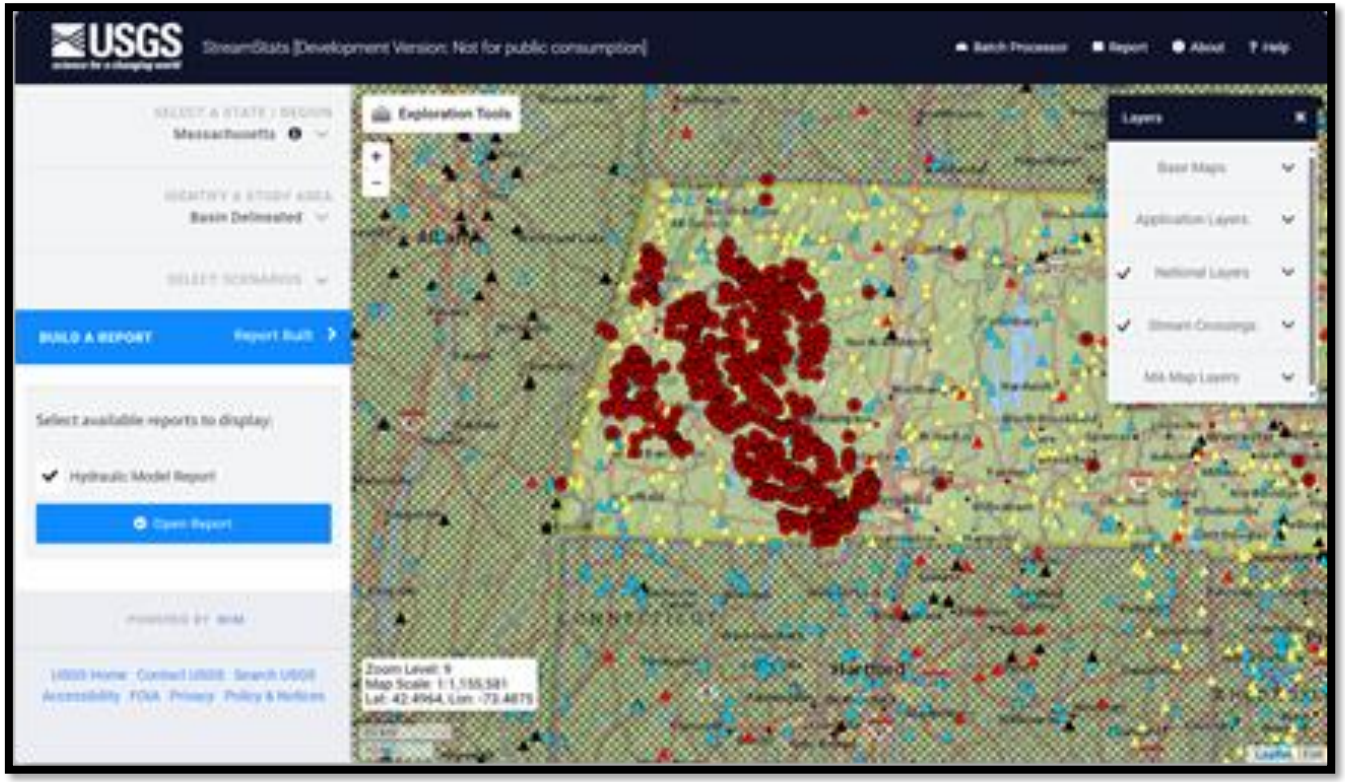
1. USGS StreamStats is an Existing Website with Various Applications



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

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

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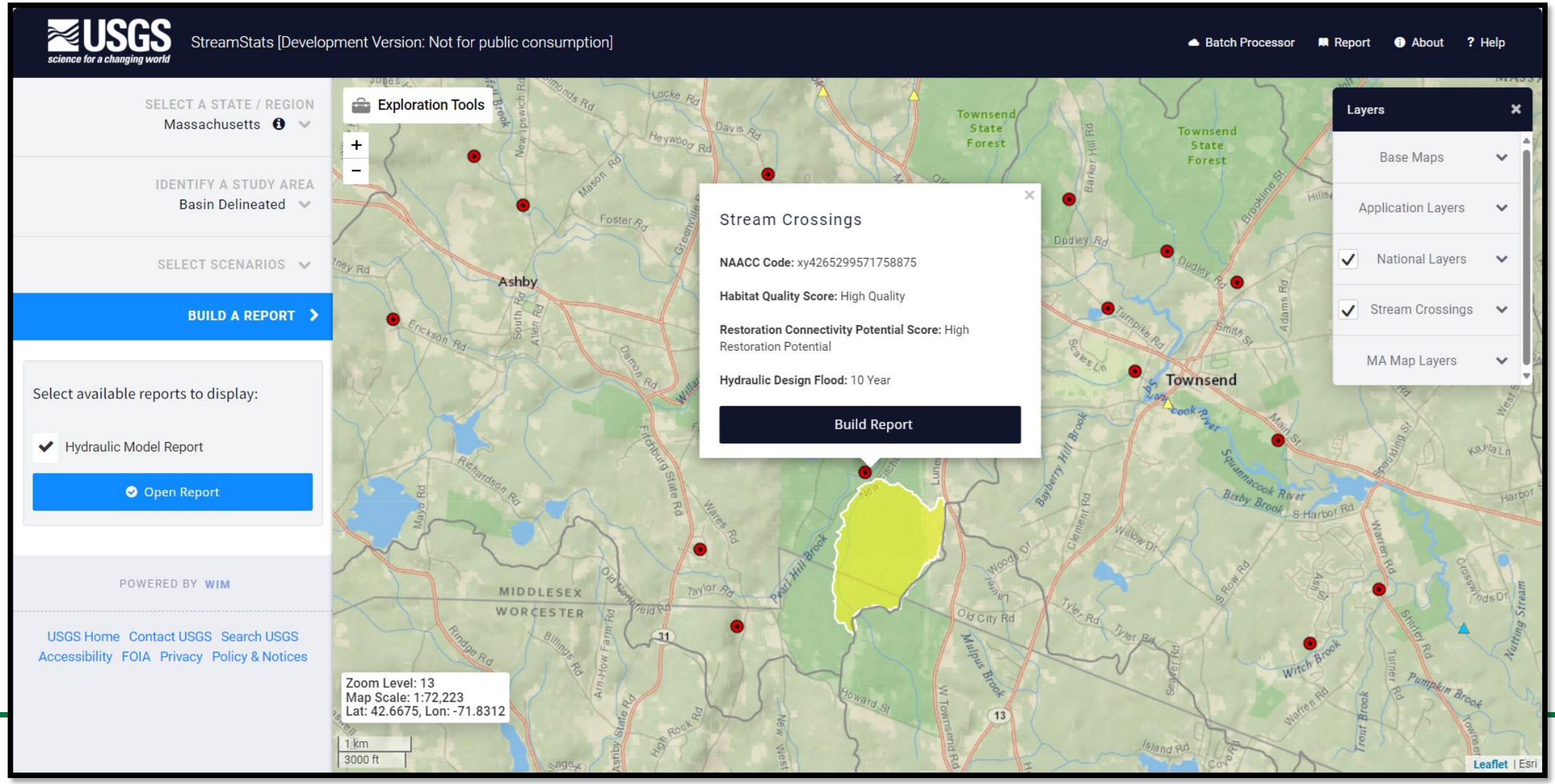
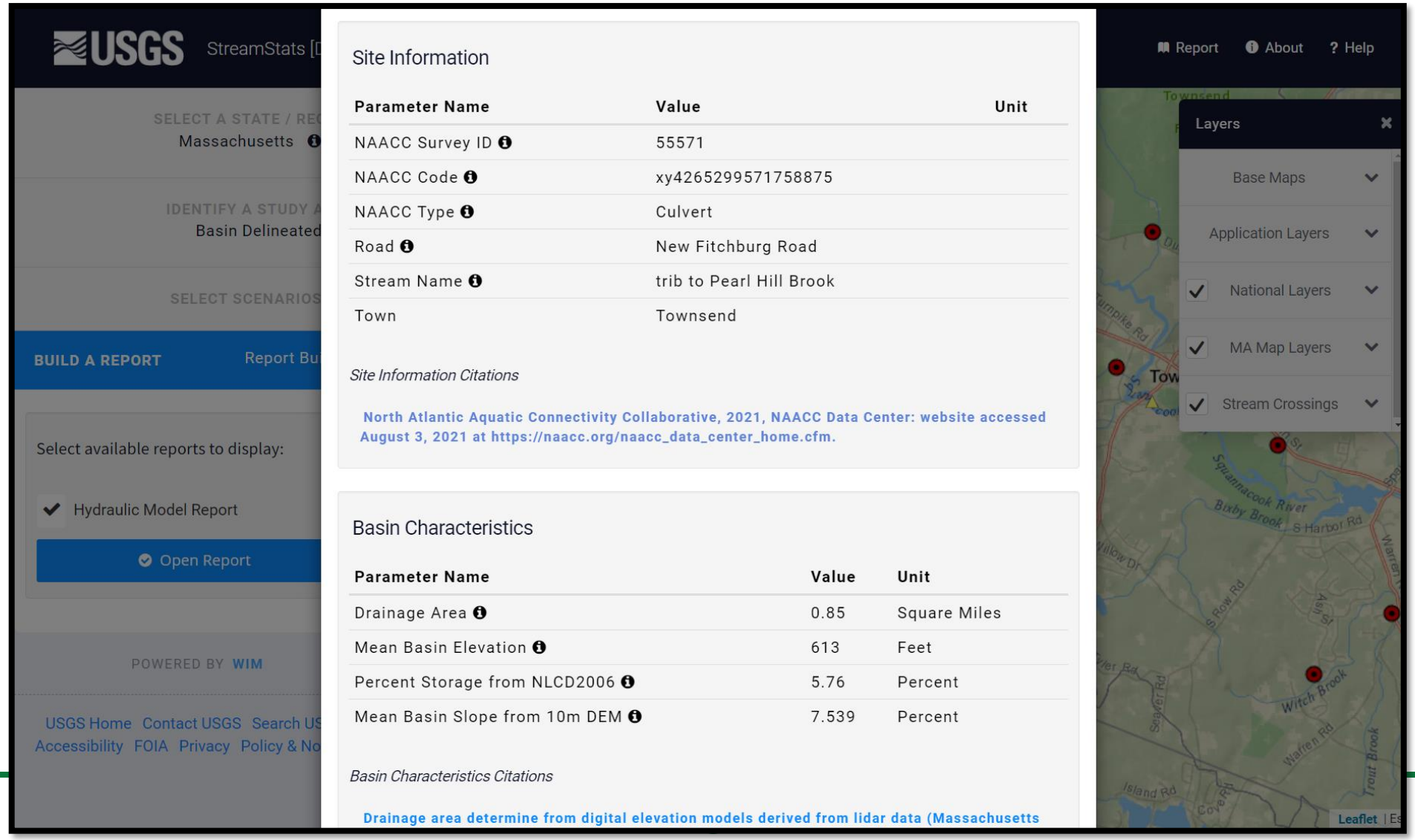
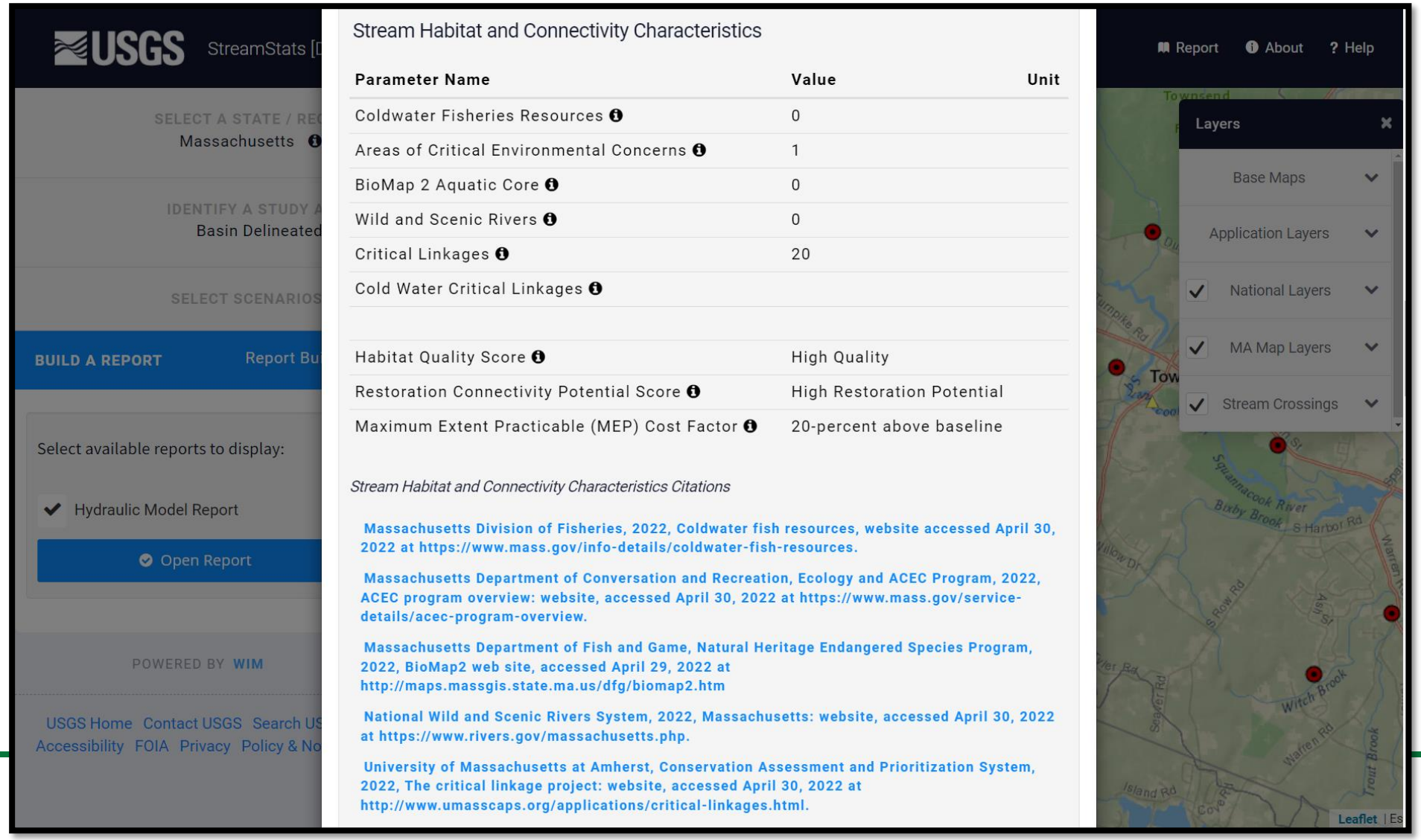
2. Choose the Crossing



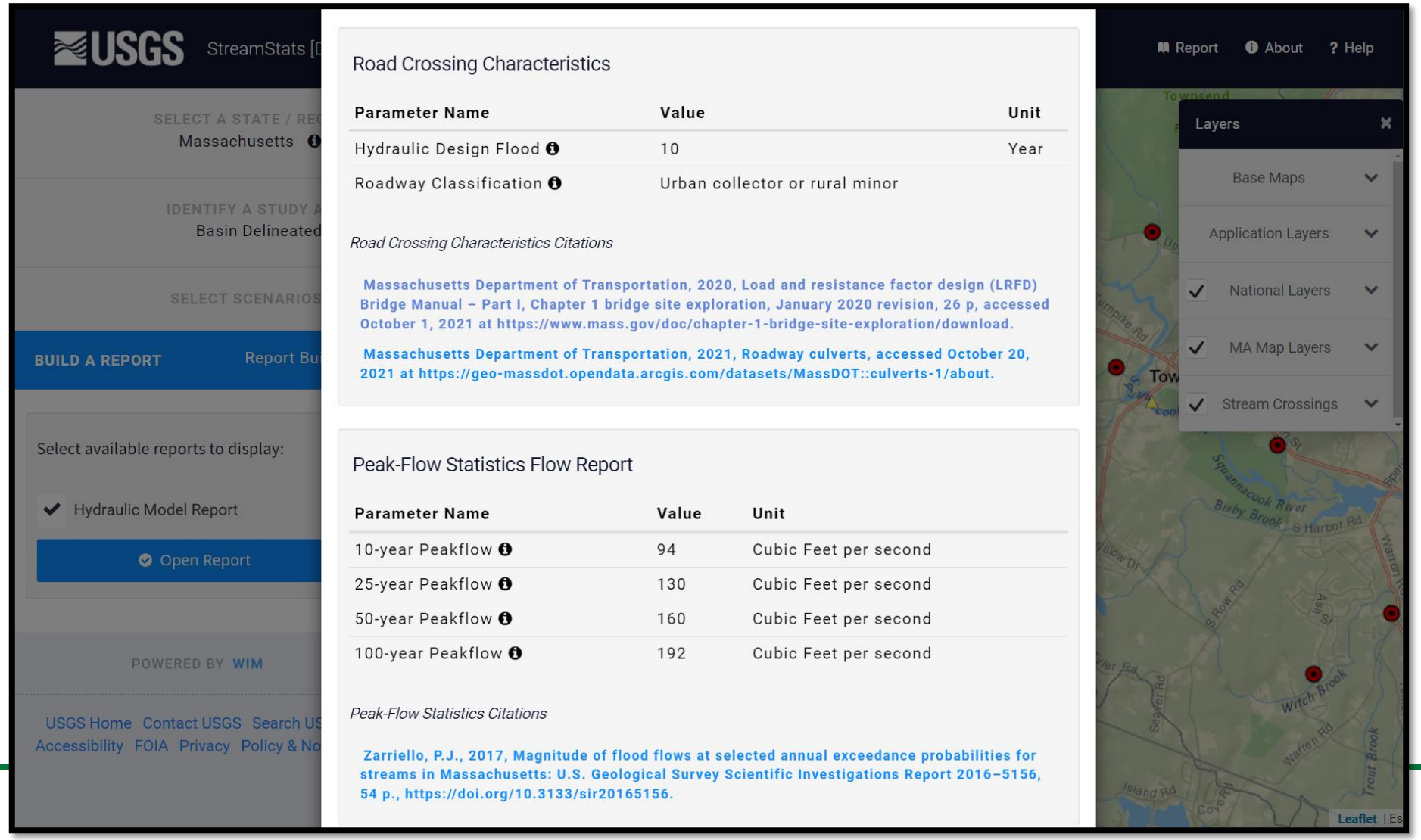
3. Report Provides Prior Assessments and Watershed Details



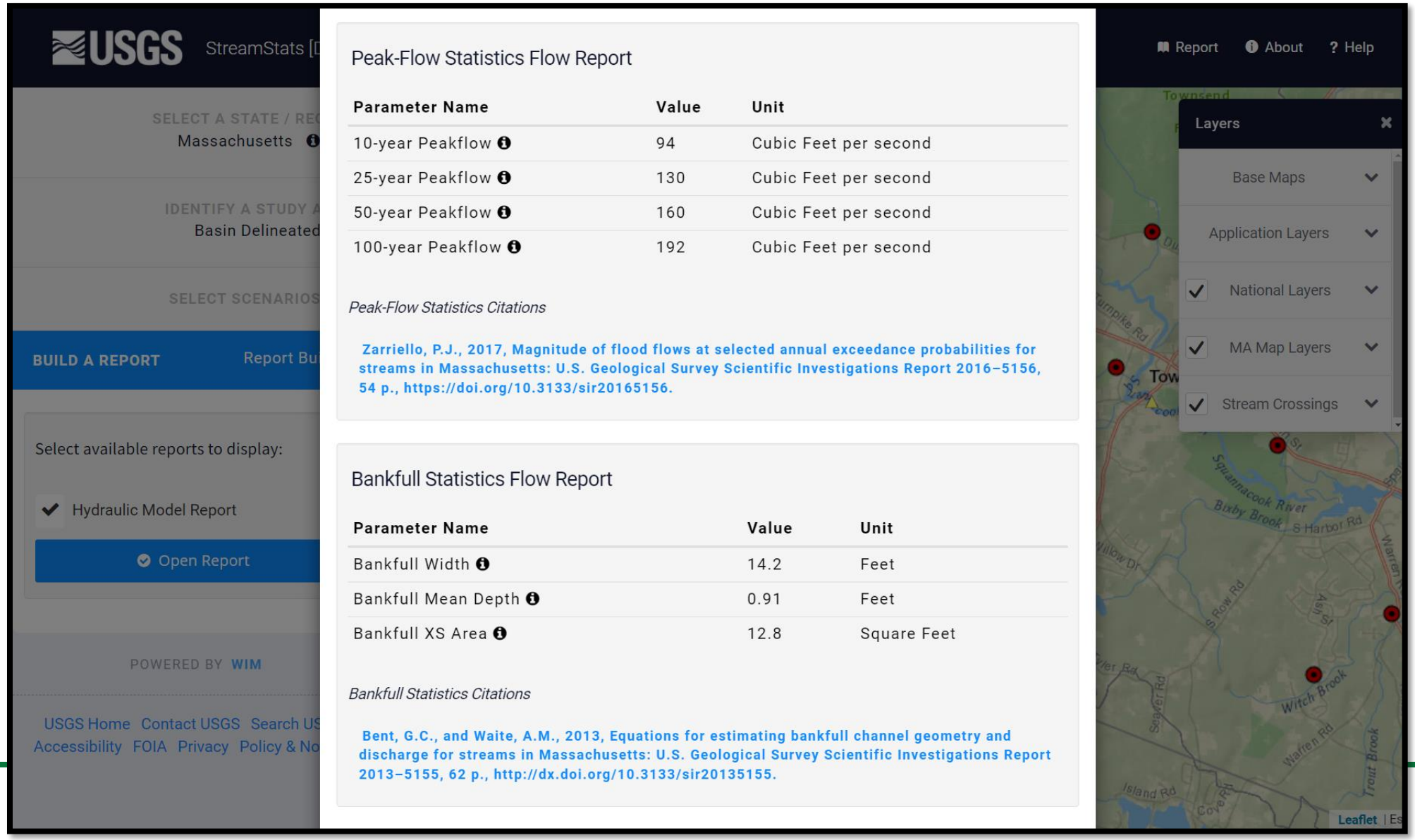
4. Report Provides Habitat Connectivity and Restoration Potential



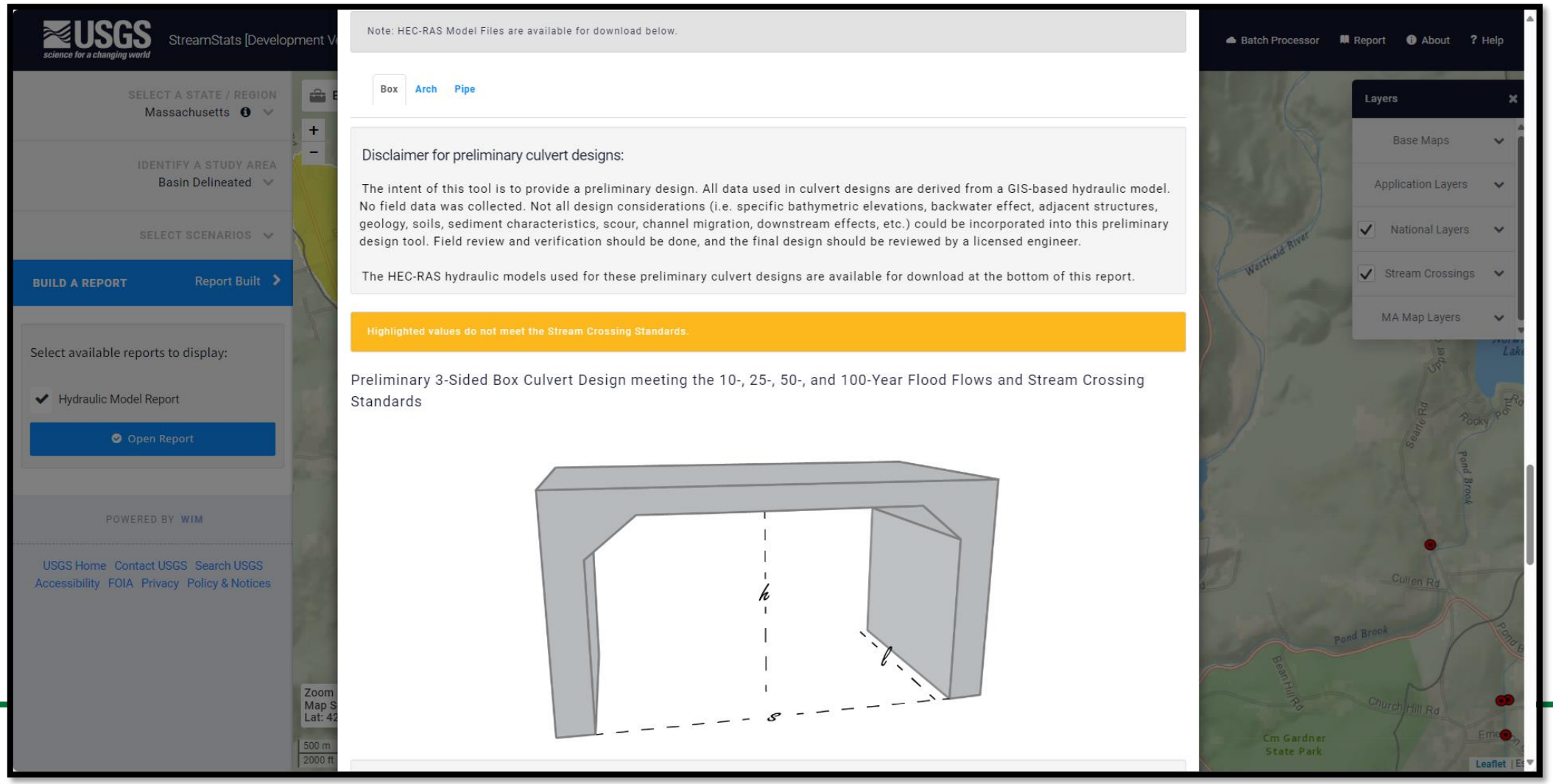
5. Report Provides DOT Road Classification and Design Flow



6. Report Provides Bankfull Width



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



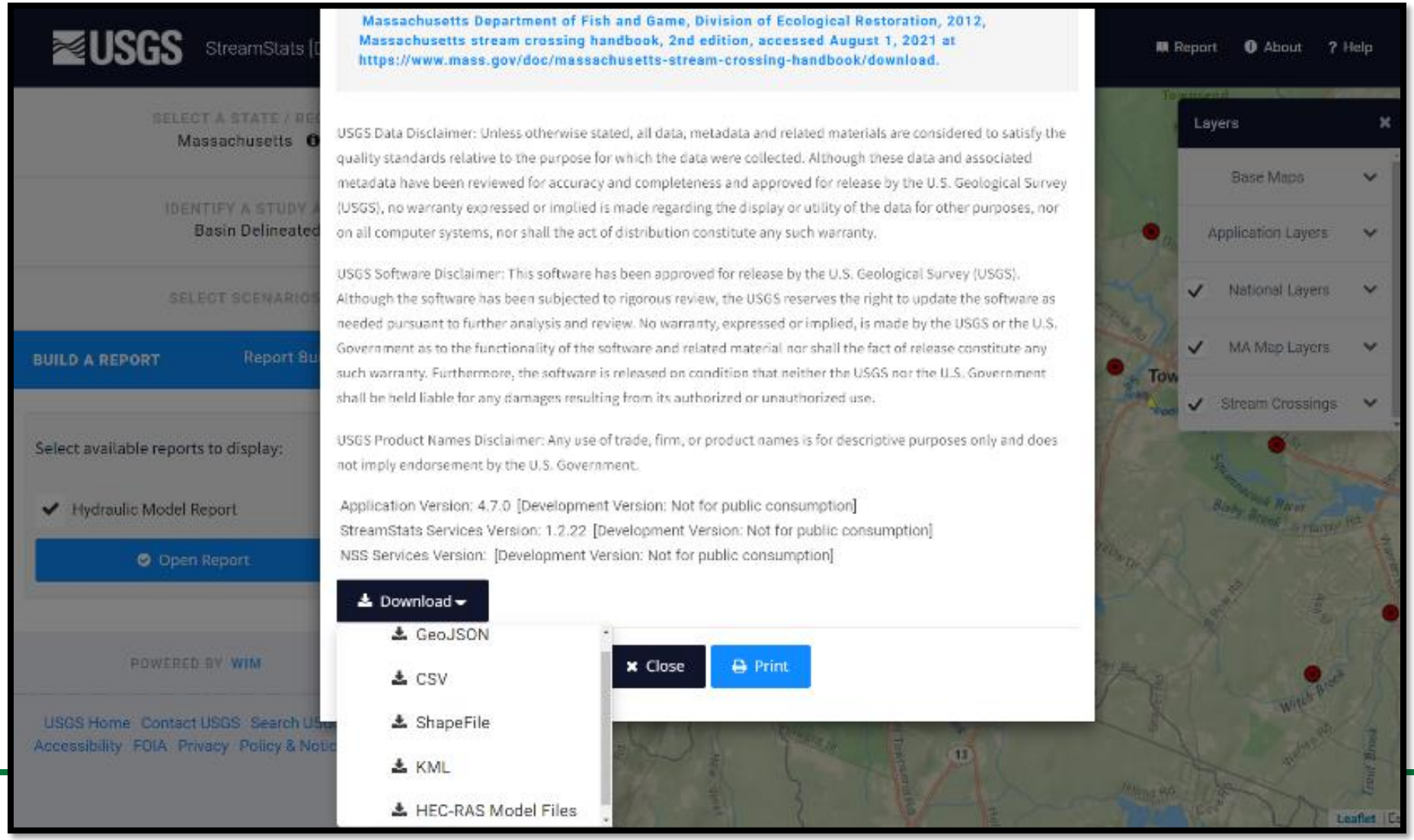
8. Report Provides 3 Sizes for Each (15 Designs Total)

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	

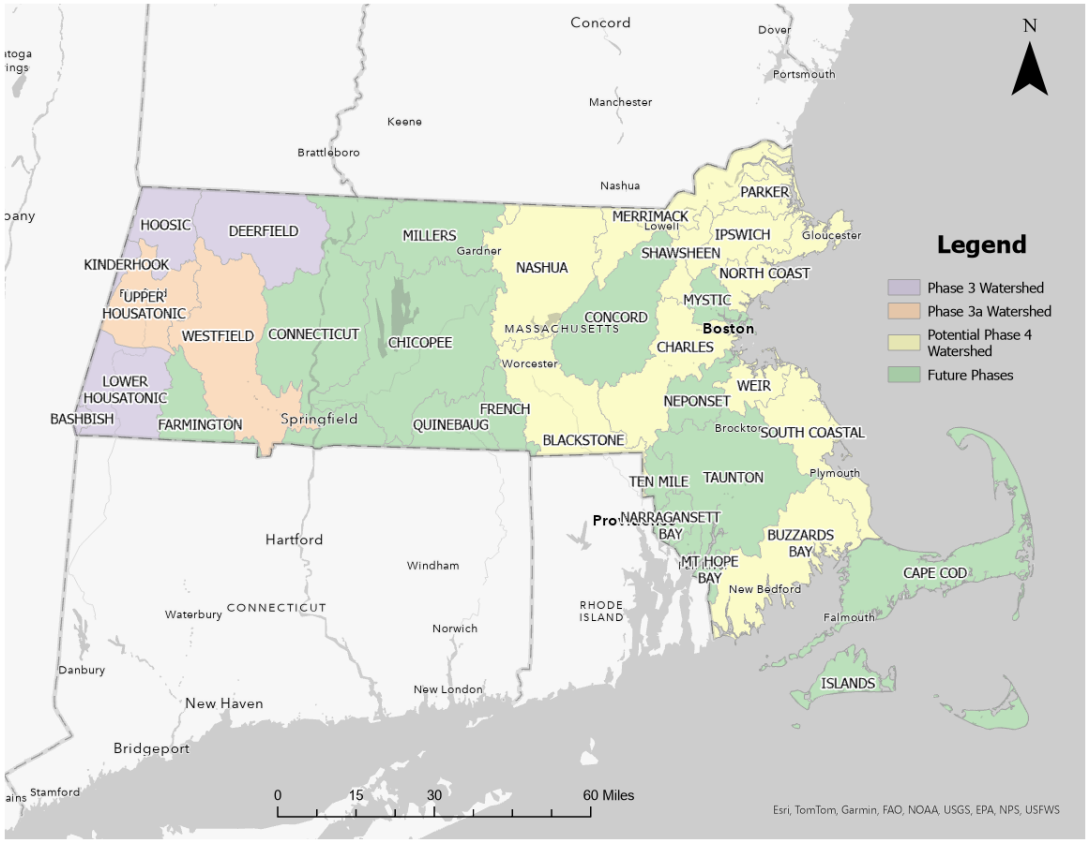
9. Output Also Provides Preliminary Model Results for Use by Engineer in Final Design



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



A Statewide Hydraulic Modeling Tool for Stream Crossing Projects in Massachusetts | U.S. Geological Survey (usgs.gov)

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

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USGS StreamStats and WIM Teams

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

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Project Webpage