Developing a Statewide Hydraulic Modeling Tool

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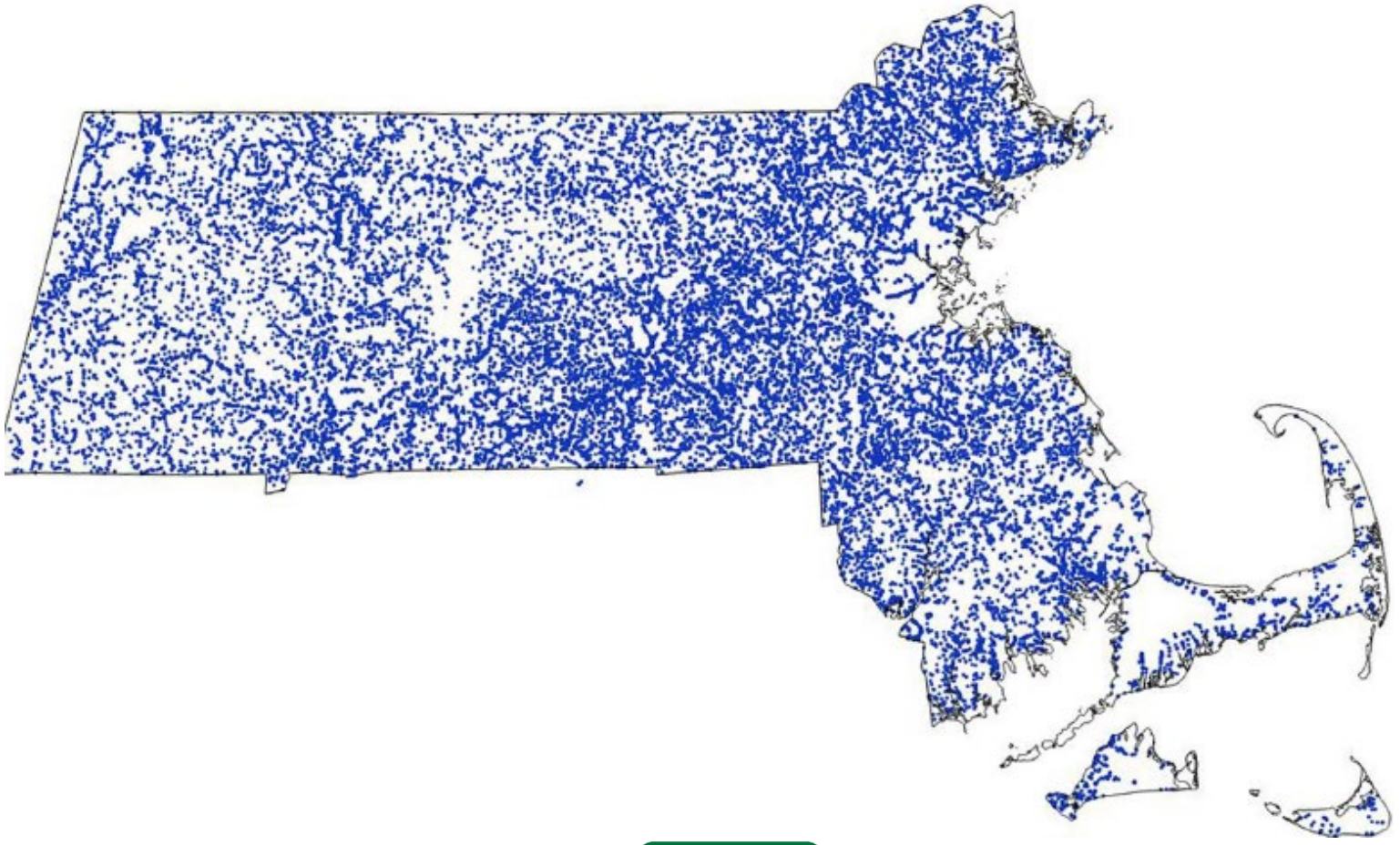
Agenda

- Massachusetts Regulations (310 CMR 10.00)
- Stream Crossing Standards
- Statewide Policy and Guidance under Development for Maximum Extent Practicable
- Statewide Hydraulic Modeling Tool Development

Thousands of culverts in MA, many undersized and need replacement over the next two decades



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Poorly Designed Culverts Disrupt Aquatic Organism Passage

Undersized culverts create high water velocities, scour, and outlet drops that impede the upstream movements of fish and other aquatic organisms.

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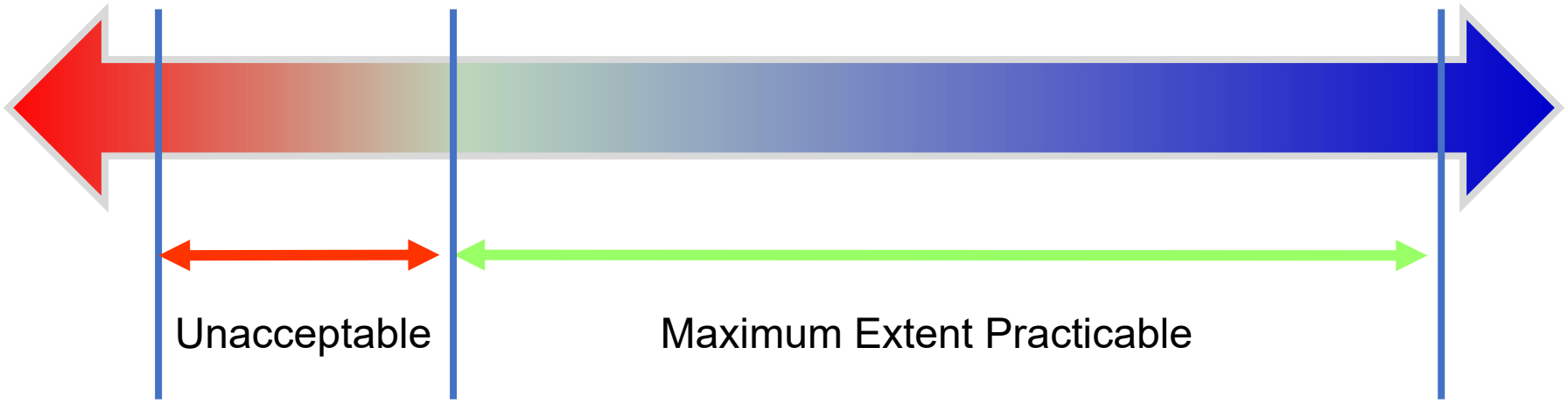
Massachusetts Stream Crossing Regulations

- New Stream Crossings - 310 CMR 10.54(4)(a)6 & 10.56(4)(a)(5)
  - *Massachusetts River and Stream Crossing Standards* developed by the River and Stream Continuity Partnership

- Replacement Stream Crossings - 310 CMR 10.53(8)(a)
  - Maximum Extent Practicable Standard requires evaluation of 12 metrics including engineering design constraints, stream stability, and cost.

Massachusetts Stream Crossing Standards (SCS)

Maximum Extent Practicable (MEP)



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MassDOT
Hydraulic Design Flow Requirements

Highway Functional Classification	Hydraulic Design Flow
Interstate, or limited access highways	100-year
Rural principal arterial	50-year
Rural minor arterial	50-year
Rural collector, major	25-year
Rural collector, minor	10-year
Rural local road	10-year
Urban principal arterial	50-year
Urban minor arterial street	25-year
Urban collector street	10-year
Urban local street	10-year

MassDOT, 2013, LRFD Bridge Manual, Part I, Chapter 1, Table 1.3.4-1

Maximum Extent Practicable

Cost-Benefit Analysis

- How much additional cost is “practicable”
  - Relative to crossings built to hydraulic design criteria
  - Based on
    - Habitat quality
    - Connectivity restoration potential

- Still Need to maximize aquatic organism passage when it is not physically possible to meet the Stream Crossing Standards, Examples:
  - Maximize crossing width
  - Rock or log weirs to backwater the outlet and/or reduce velocities
  - Roughened channel within the crossing structure to reduce velocities and ensure adequate water depth

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Habitat Quality

- Biomap aquatic core
- Cold water fisheries resource
- Diadromous fish run (Mass F&W development)
- Area of Critical Environmental Concern (ACEC)
- Wild and scenic river

Highest Quality: two or more of the above categories apply

High Quality: one of the above categories apply

General Quality: All other stream and river segments

Connectivity Restoration Potential

Highest Restoration Potential: Top 5% of statewide Critical Linkages or top 10% of Coldwater Critical Linkages Effect scores for crossings on streams with a projected mean summer temperature ≤ 16C

Very High Restoration Potential: 5-10% of statewide Critical Linkages or top 10-20% of Coldwater Critical Linkages Effect scores for crossings on streams with a projected mean summer temperature ≤ 16C

High Restoration Potential: 10--20% of statewide Critical Linkages or top 20-30% of Coldwater Critical Linkages Effect scores for crossings on streams with a projected mean summer temperature ≤ 16C

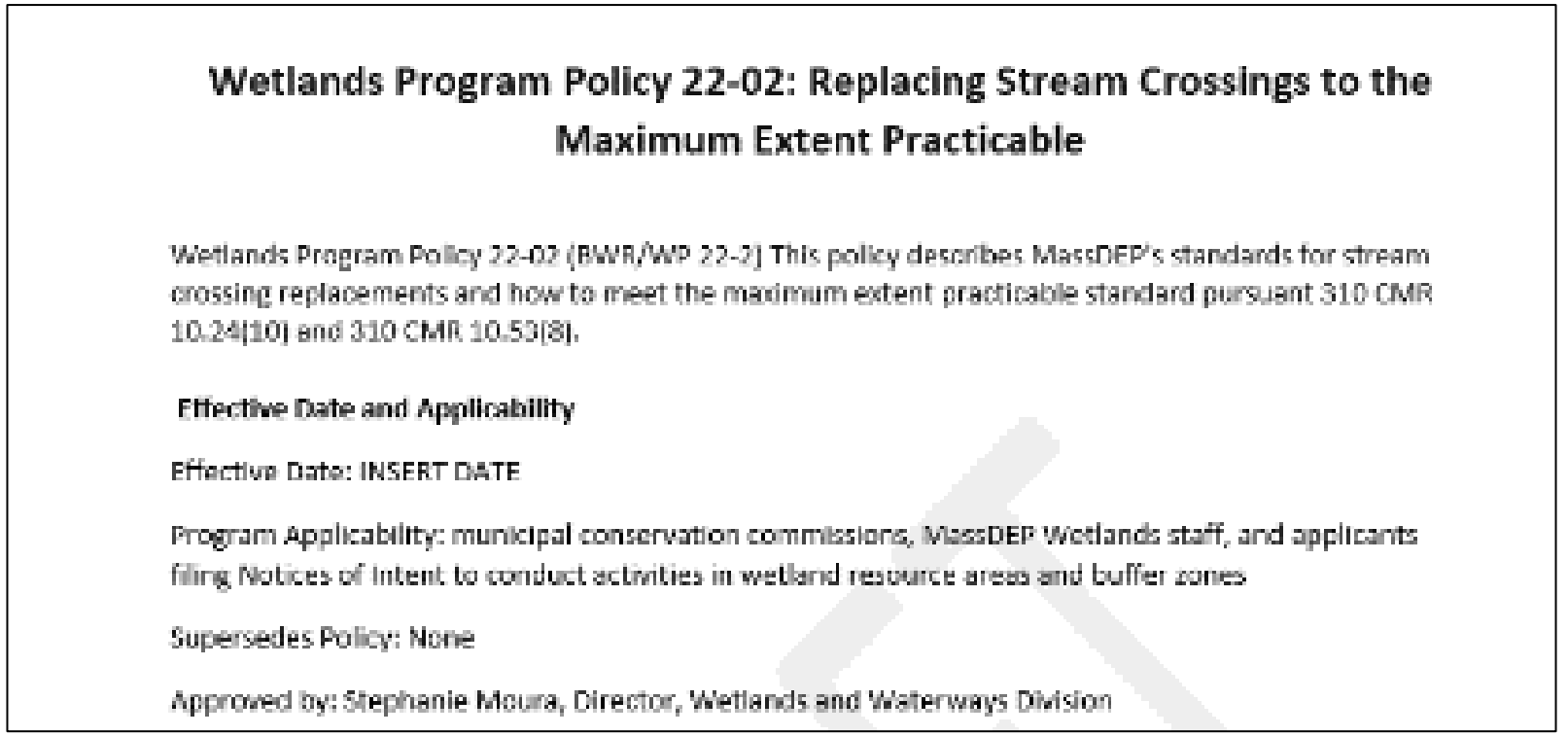
Medium Restoration Potential: 20-25% of statewide Critical Linkages or top 30-40% of Coldwater Critical Linkages Effect scores for crossings on streams with a projected mean summer temperature ≤ 16C

Other: All other crossings (below top 25% for Critical Linkages; below top 40% for Coldwater Critical Linkages)

Maximum Extent Practicable Cost Factors

Connectivity Restoration Potential	Highest Habitat Quality	High Habitat Quality	General Habitat Quality
Highest restoration potential	50% above baseline	30% above baseline	25% above baseline
Very high restoration potential	40% above baseline	25% above baseline	20% above baseline
High restoration potential	30% above baseline	20% above baseline	15% above baseline
Medium restoration potential	20% above baseline	15% above baseline	10% above baseline
Other	10% above baseline	10% above baseline	Baseline

MassDEP Draft Policy and UMass Guidance under Development



Wetlands Program Policy 22-02: Replacing Stream Crossings to the Maximum Extent Practicable

Wetlands Program Policy 22-02 (BWR/WP 22-2) This policy describes MassDEP's standards for stream crossing replacements and how to meet the maximum extent practicable standard pursuant 310 CMR 10.24(10) and 310 CMR 10.53(8).

Effective Date and Applicability

Effective Date: INSERT DATE

Program Applicability: municipal conservation commissions, MassDEP Wetlands staff, and applicants filing Notices of Intent to conduct activities in wetland resource areas and buffer zones

Supersedes Policy: None

Approved by: Stephanie Moura, Director, Wetlands and Waterways Division

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Project Goals and Status

Goal:

- Provide communities a preliminary design for small (<10’) stream crossing infrastructure.
- Streamline permitting review in certain scenarios.

Status:

- Phase 1 – Feasibility (7/19 – 9/22) USGS Geonarrative published
- Phase 2 (7/21 – 6/23) – Pilot Watershed and MEP Guidance
- Phase 2A (7/22 – 6/24) – Ground Comparison, Statewide 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 and Westfield watersheds

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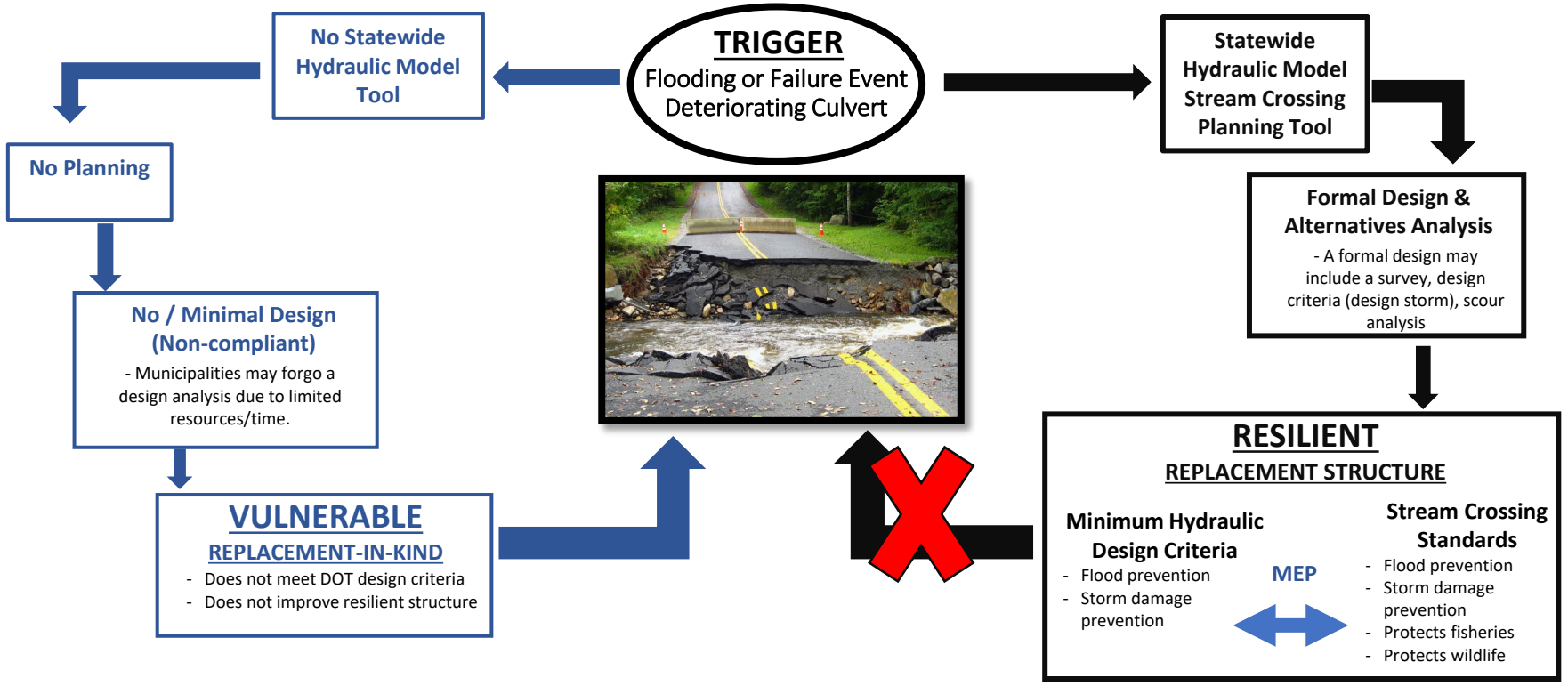
Statewide Hydraulic Model as a Stream Crossing Planning Tool



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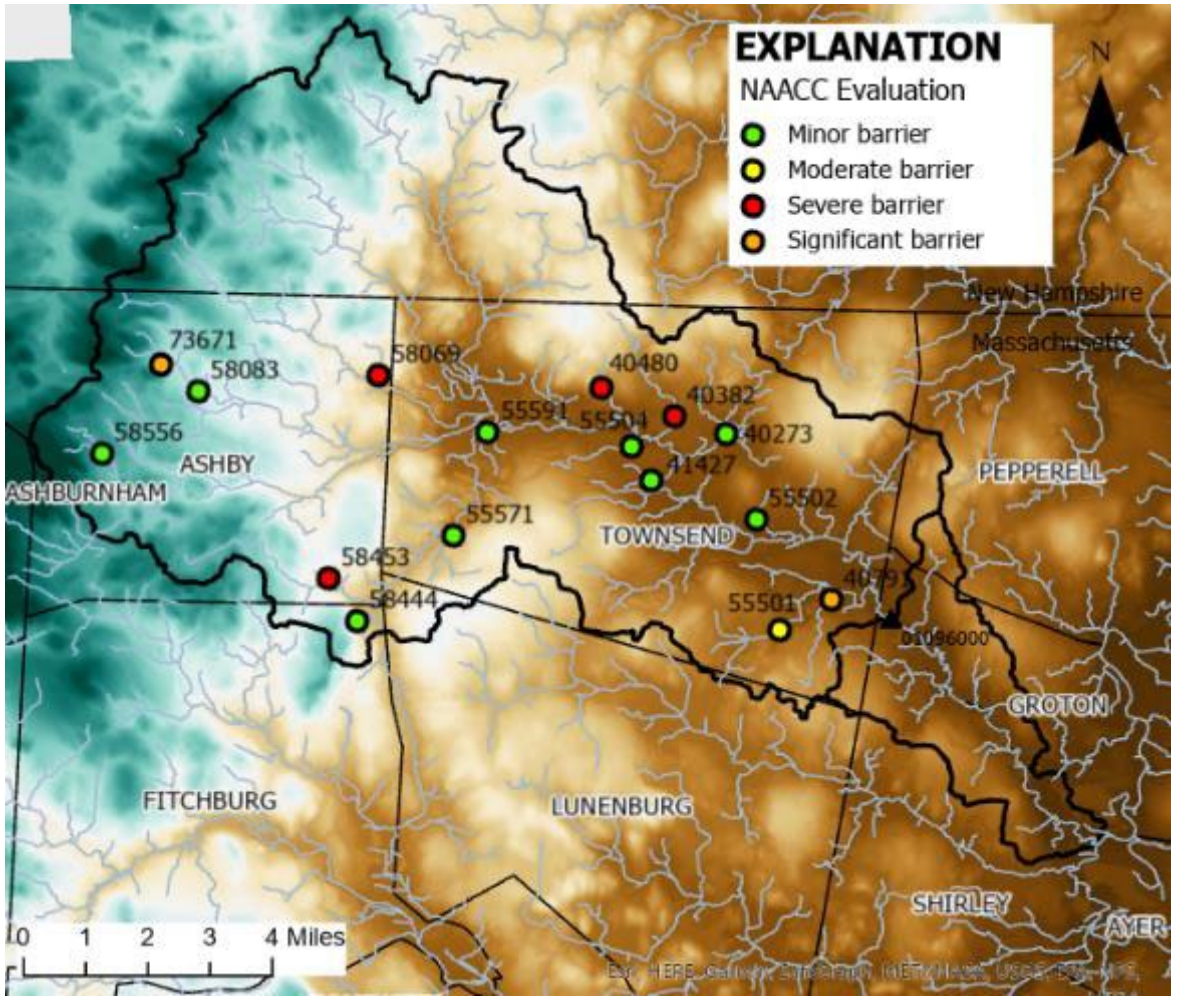
Pilot –Squannacook Watershed – North Central MA

- Field surveyed 16 stream crossing sites in Sept 2021
  - drainage area from 0.1 to 2.0 mi^2
  - varied basin slope
  - stream crossing assessment of minor, moderate, or severe barrier)
- Remainder of stream crossings with no NAACC assessment were completed by UMass and the Nashua WS Association



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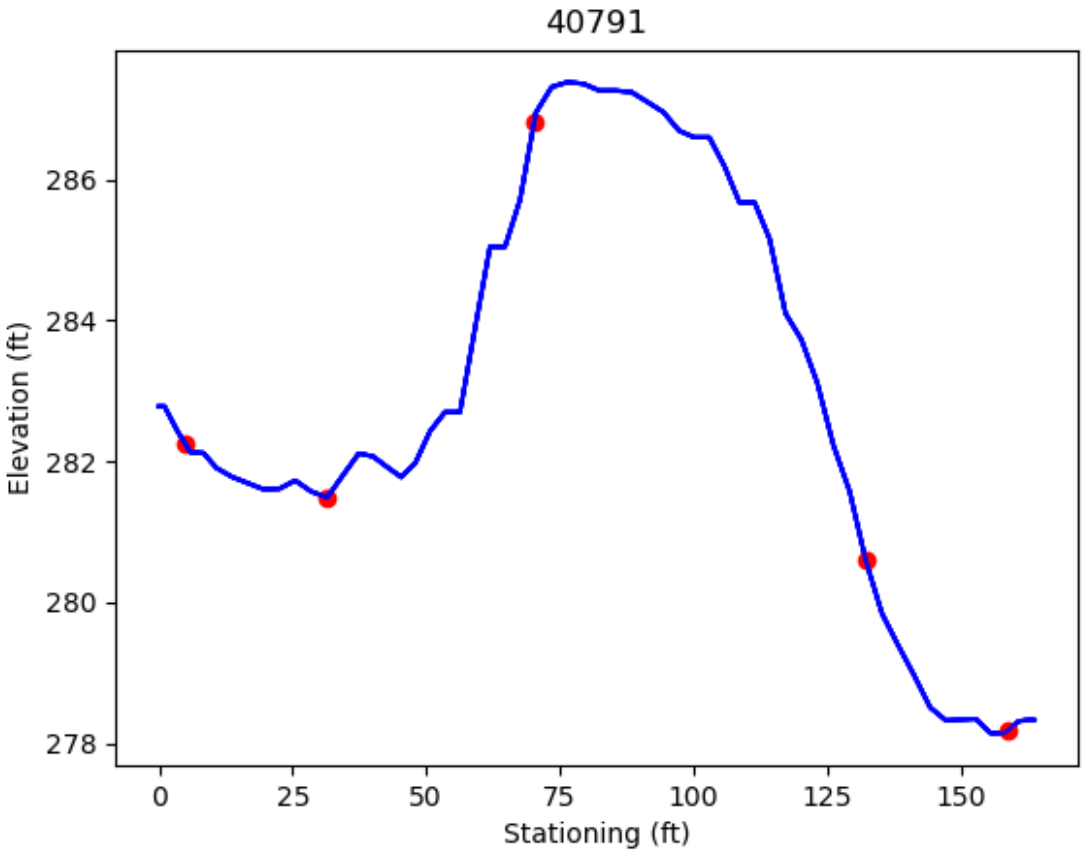
GIS Derived Elevation Data



Example: Trout Brook, Shirley Road, Townsend, MA

- XSEC locations are selected along a profile from elevation changes and inflection points
- An inflection point algorithm is also used to determine embankment width and estimate culvert length
- Approach and exit XSEC are spaced from the structure faces by a certain number of bankfull widths

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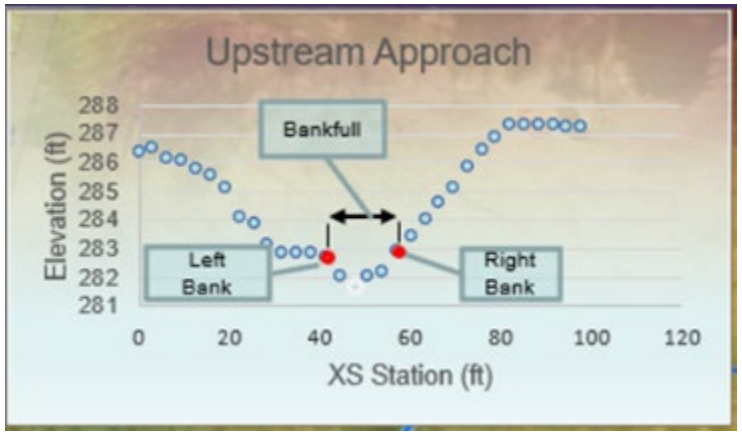
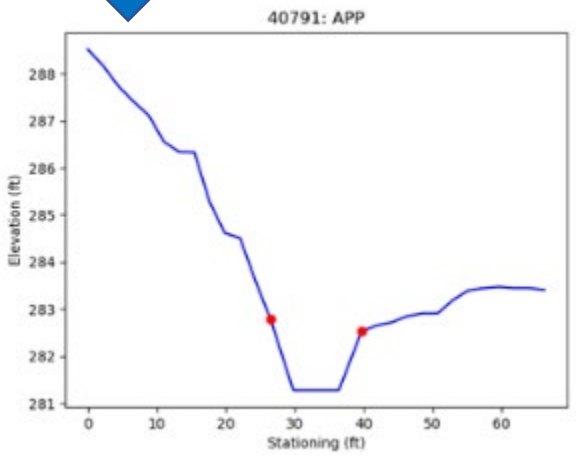
Burned Channel Geometry



Bankfull Depth Equation
(Bent and Waite, 2013)



- Lidar does not capture channel geometry
- Bankfull Depth equations are used to approximate channel geometry by 'burning' in a new channel
- Currently using a trapezoid to approximate shape, plan to use a parabola for more realistic geometry. (Bjerklie and others, 2020)

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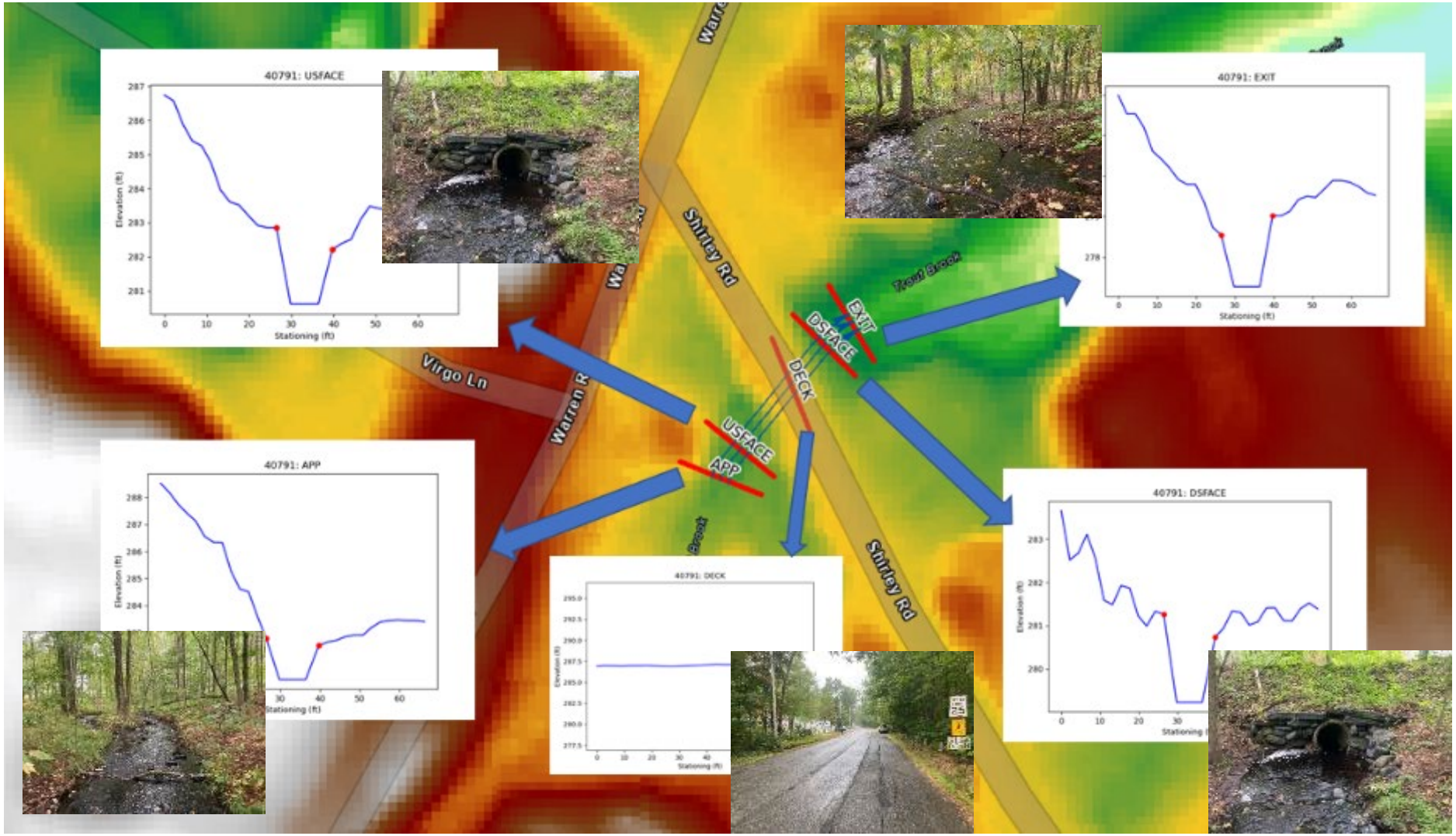
GIS Derived Elevation Data



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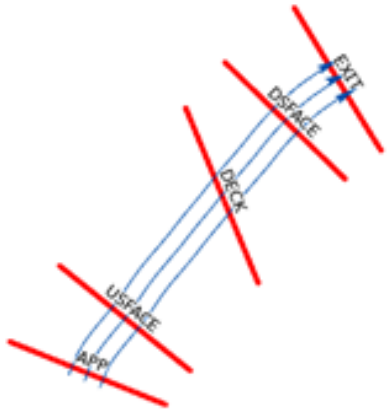
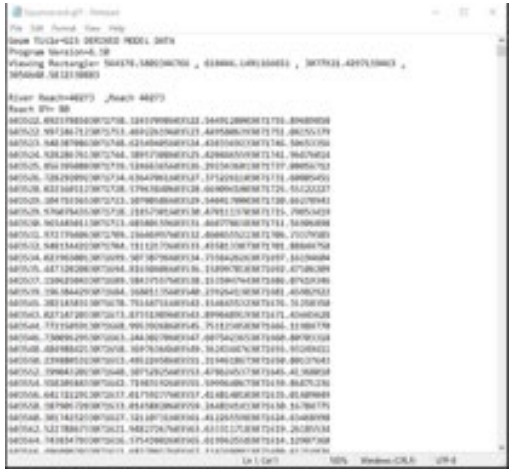
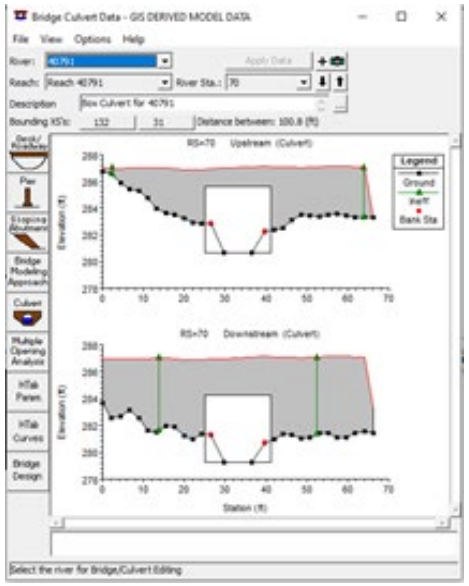
Creation of Geometry File for HEC-RAS







- Features created by automation script are broken down into points and translated into a HEC-RAS geometry file.
- Dimensions of initial structures derived from channel geometry using standards defined by the modeling team

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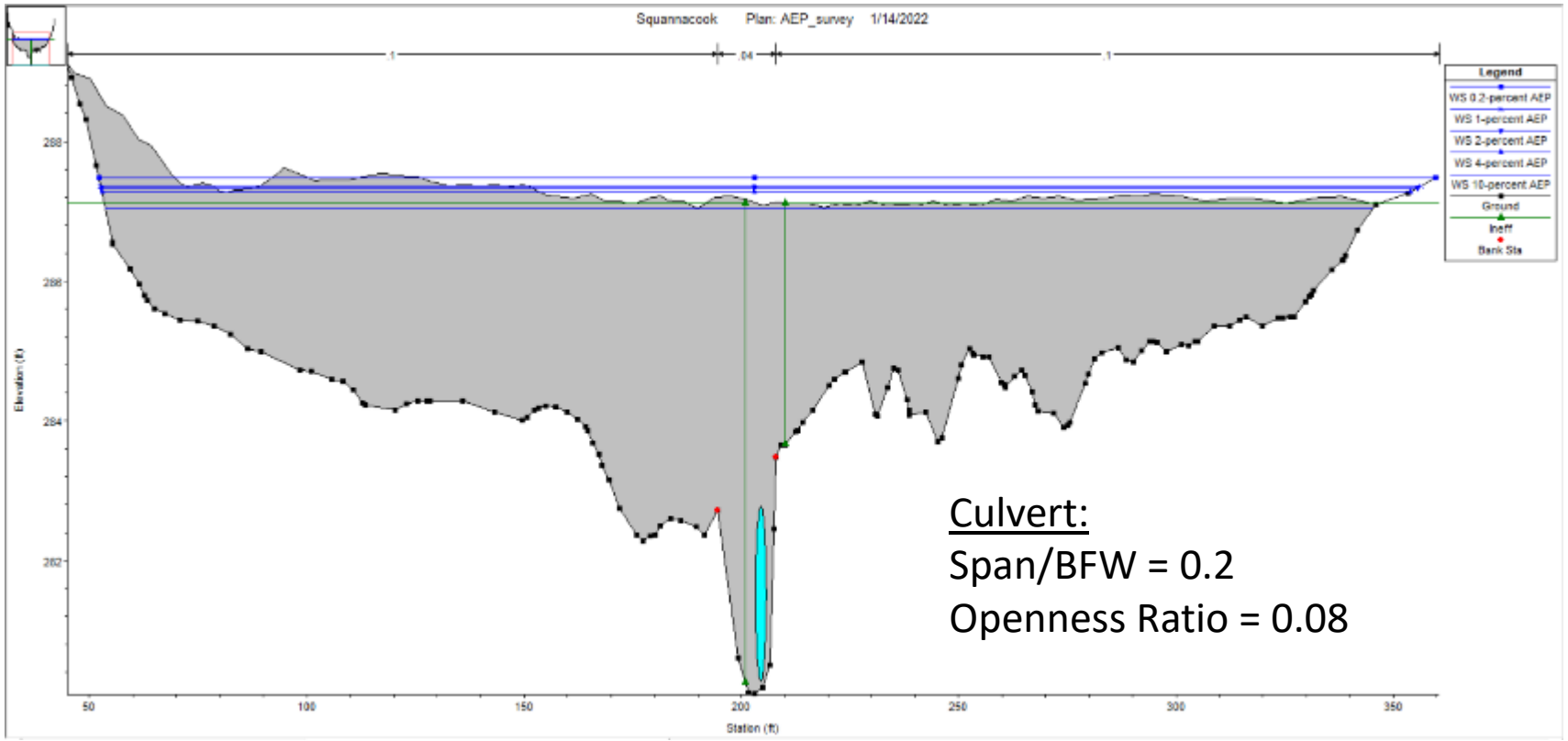
HEC-RAS Model for “Current” Culvert Design

- Culvert is a 2.5 ft diameter concrete pipe
- Current culvert design: weir flow for all flows except, the 10-percent AEP



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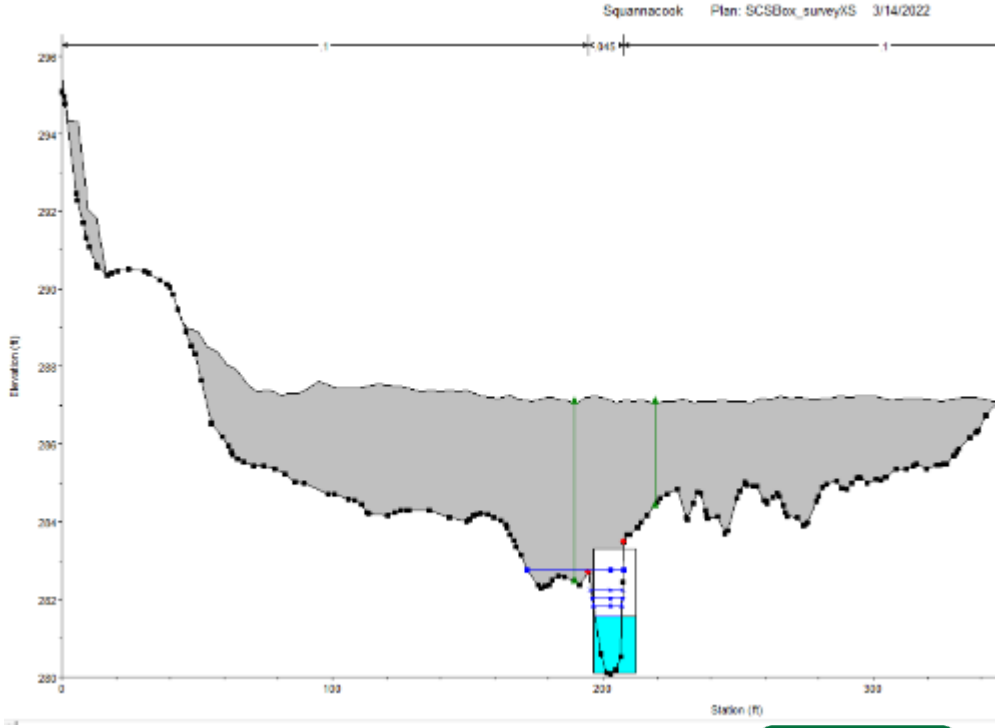
HEC-RAS Model for Preliminary Design

- Box (3-sided) culvert: span ratio = 1.2 x BFW, height = (0.82 x length)/span
- Natural bottom based on SCS
- Current culvert design with 10- to 0.2-percent AEP WSE
- Length estimated from embankment width



Culvert meets SCS:

- Span Ratio = 1.2
- Openness Ratio = 0.82

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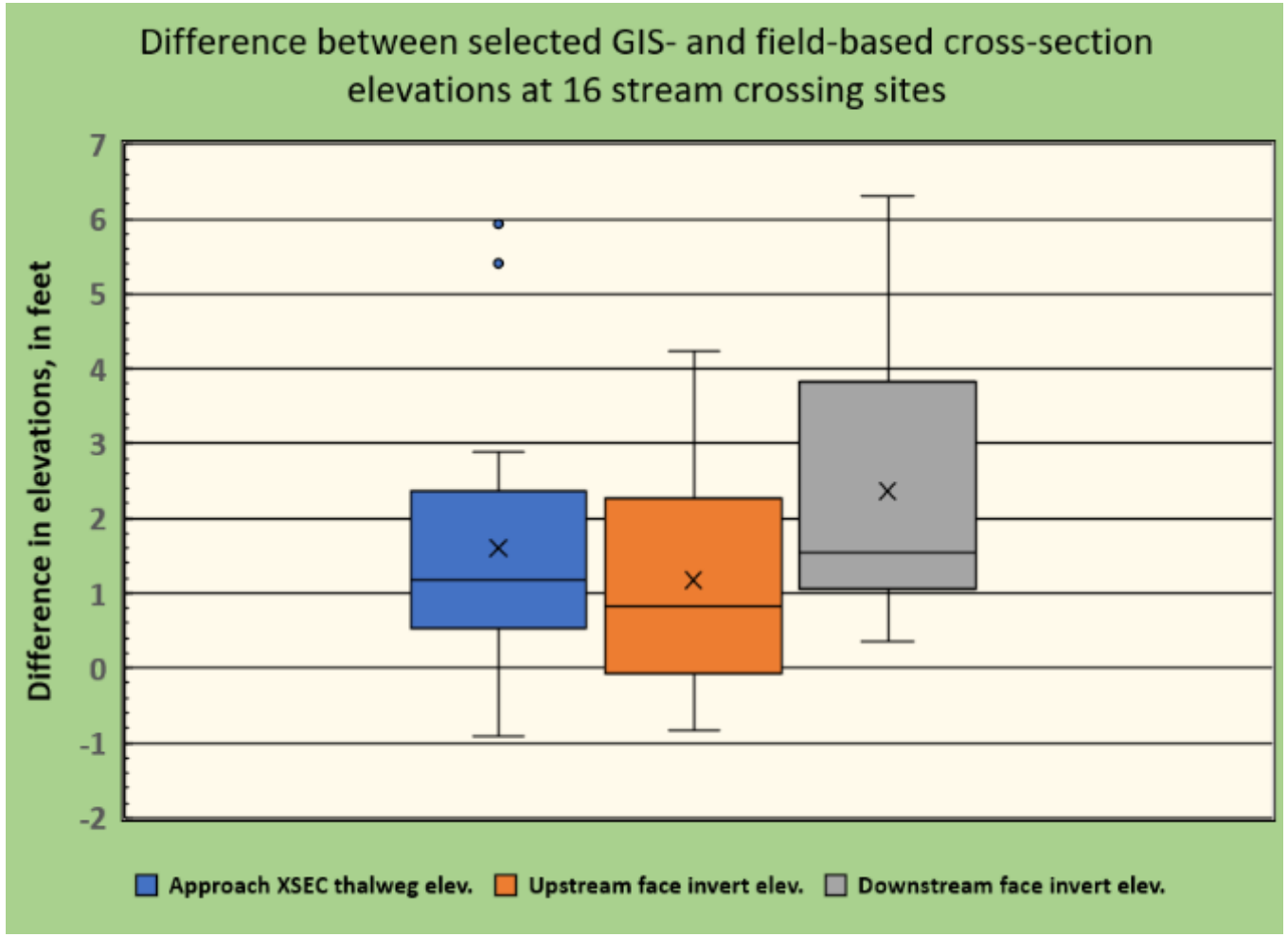
Comparison between GIS- and Field-Based Elevations



Note, the locations of the field- and GIS-based cross sections do not necessarily coincide

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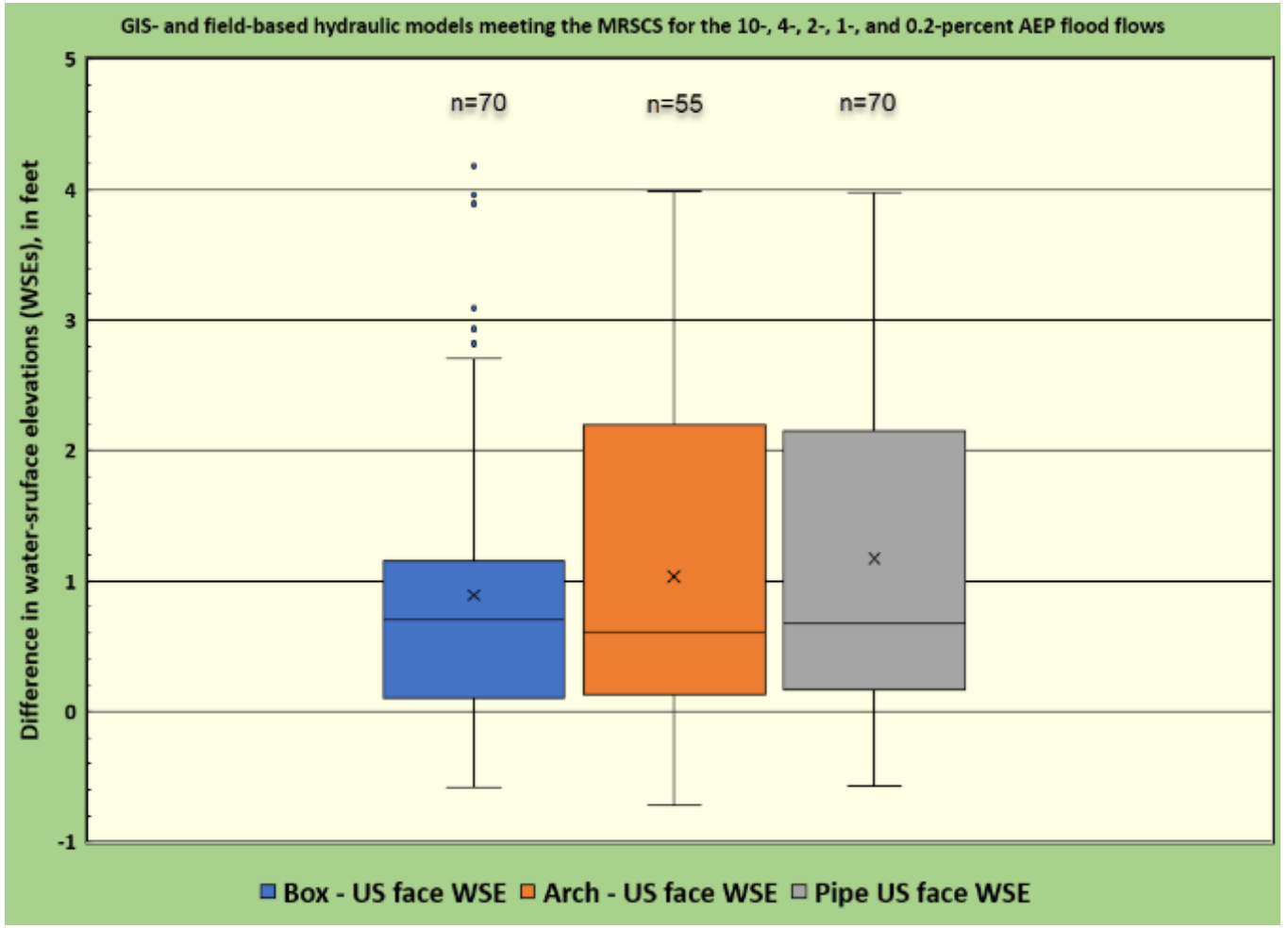
Comparison between Field- and GIS-Based Modeled WSEs



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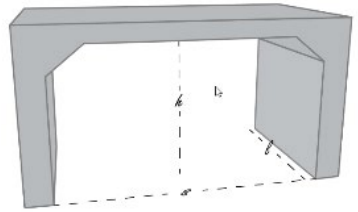
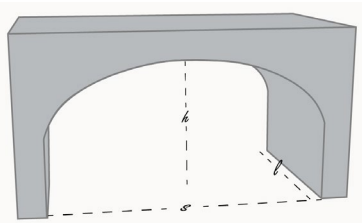
Comparison between Field- and GIS-Based Culvert Dimensions

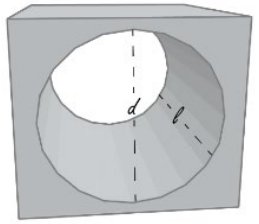
- Box culvert (14 of 16 sites)
  - Median “span, height, and cross-sectional area” difference = 0.0 ft



- Conspan arch culvert (12 of 16 sites)
  - Median “span, height, and cross-sectional area” difference = 0.0 ft



- Pipe culvert (14 of 16 sites)
  - Median “diameter” difference = -1.0 ft
  - Median “cross-sectional area minus SCS embedded area” = -8.7 ft^2



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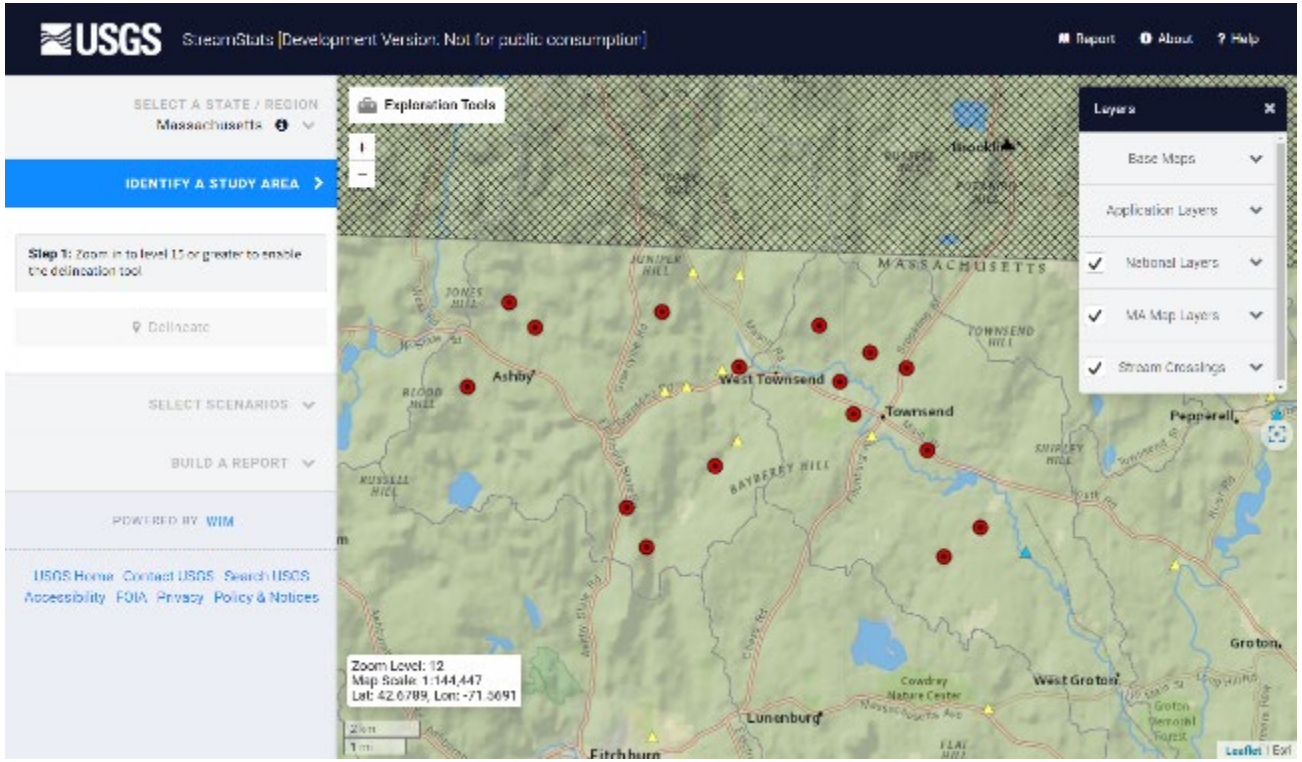
USGS StreamStats Hydraulic Modeling Tool Web Application

Information presented:

- Site location
- North Atlantic Aquatic Connectivity Collaborative (NAACC)
- Aquatic habitat quality, stream connectivity restoration potential, and Maximum Extent Practicable (MEP) scores
- MassDOT highway functional classification and hydraulic design flow
- USGS peakflow and bankfull channel geometry equations
- Preliminary 3-sided box and conspan arch, and pipe culvert dimensions and relation to Mass SCS



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

SHM Web Application: https://dev.streamstats.usgs.gov/ma-culverts/
*SHM will be on public StreamStats this summer/fall

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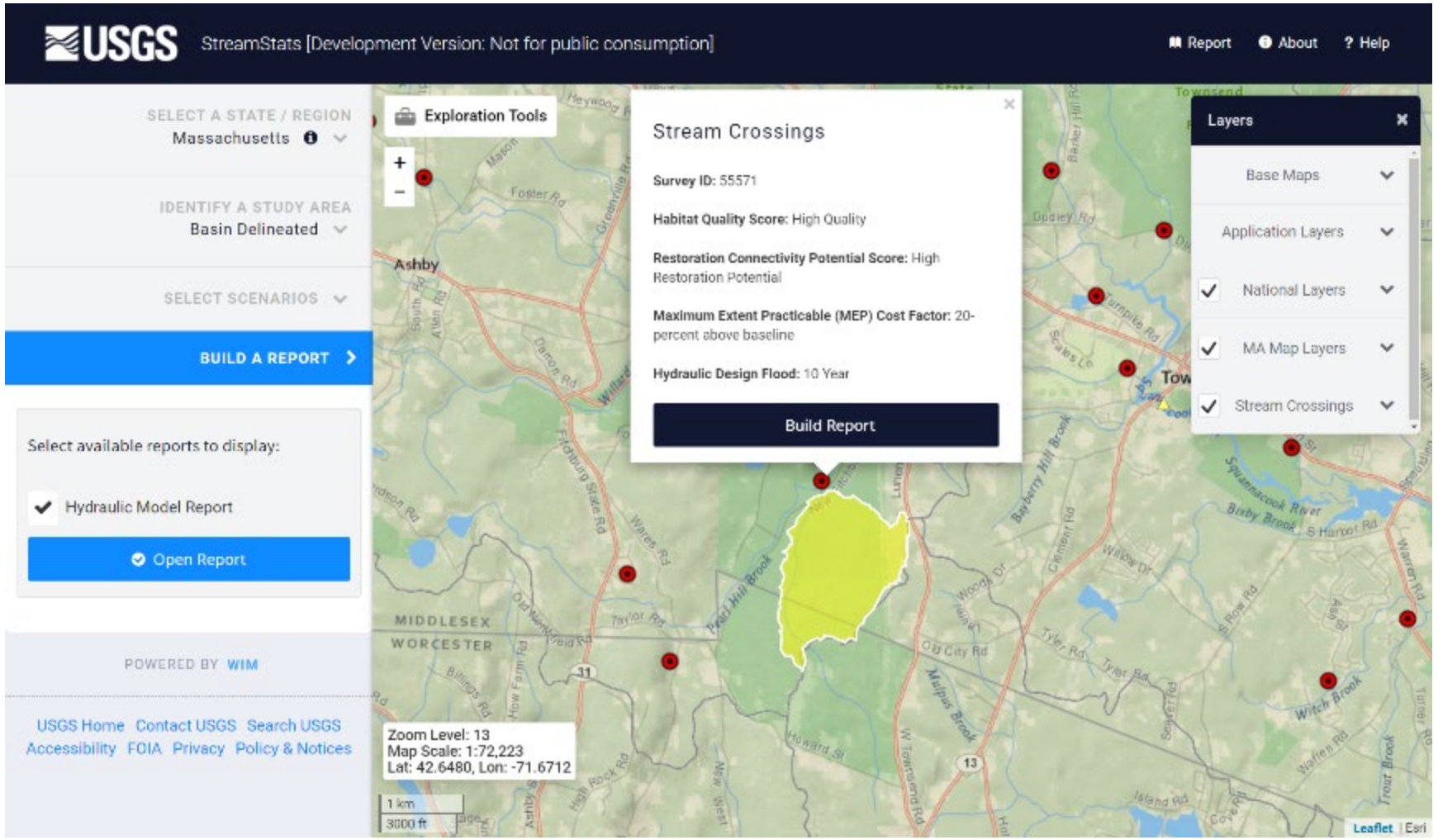
Hydraulic Modeling Tool Web Application – 1

- Click on your stream crossing of interest
- Tool draws drainage area to that stream crossing and builds report
- Click on blue “Open Report” button on left to view report



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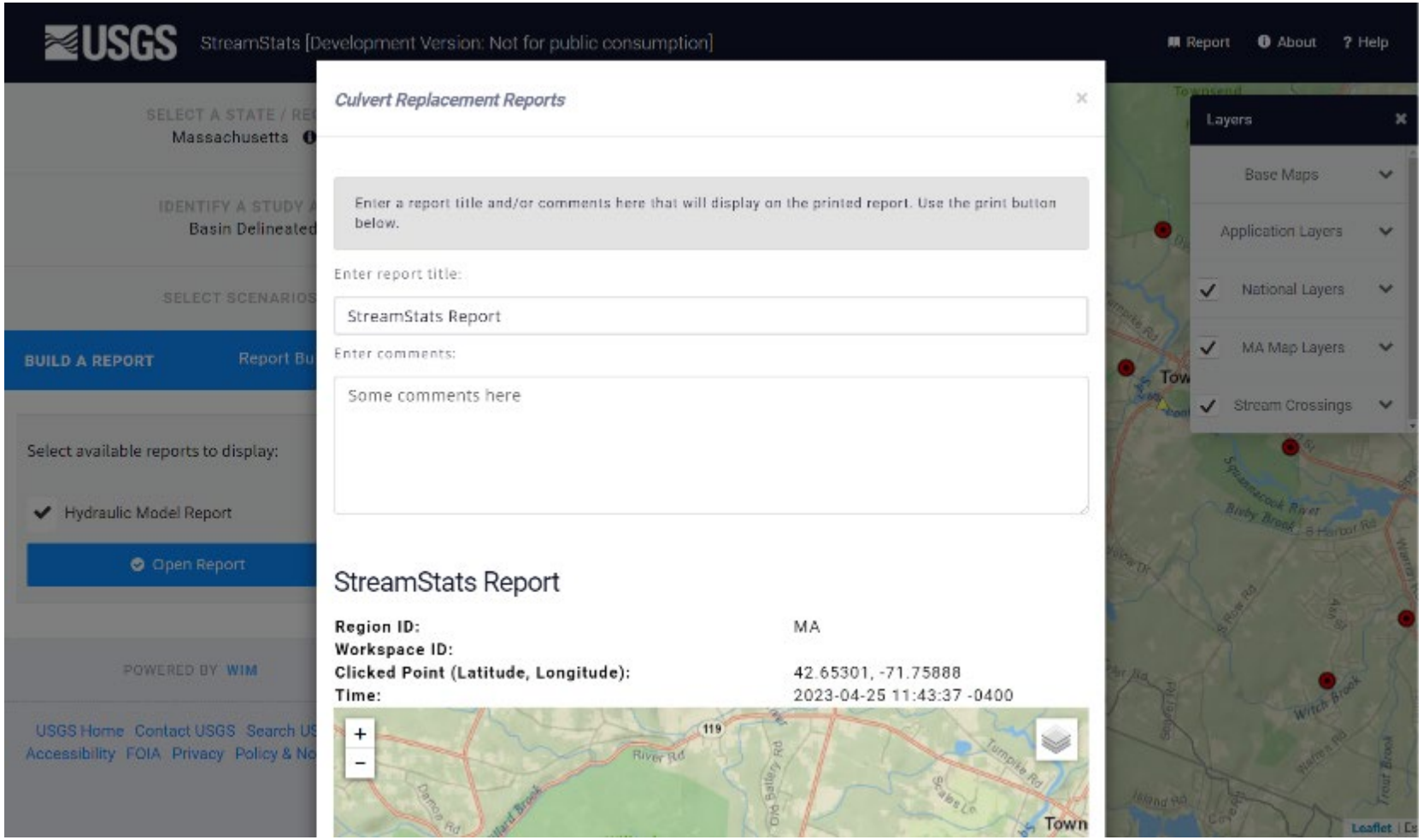
Hydraulic Modeling Tool Web Application – 2

Culvert Replacement Report

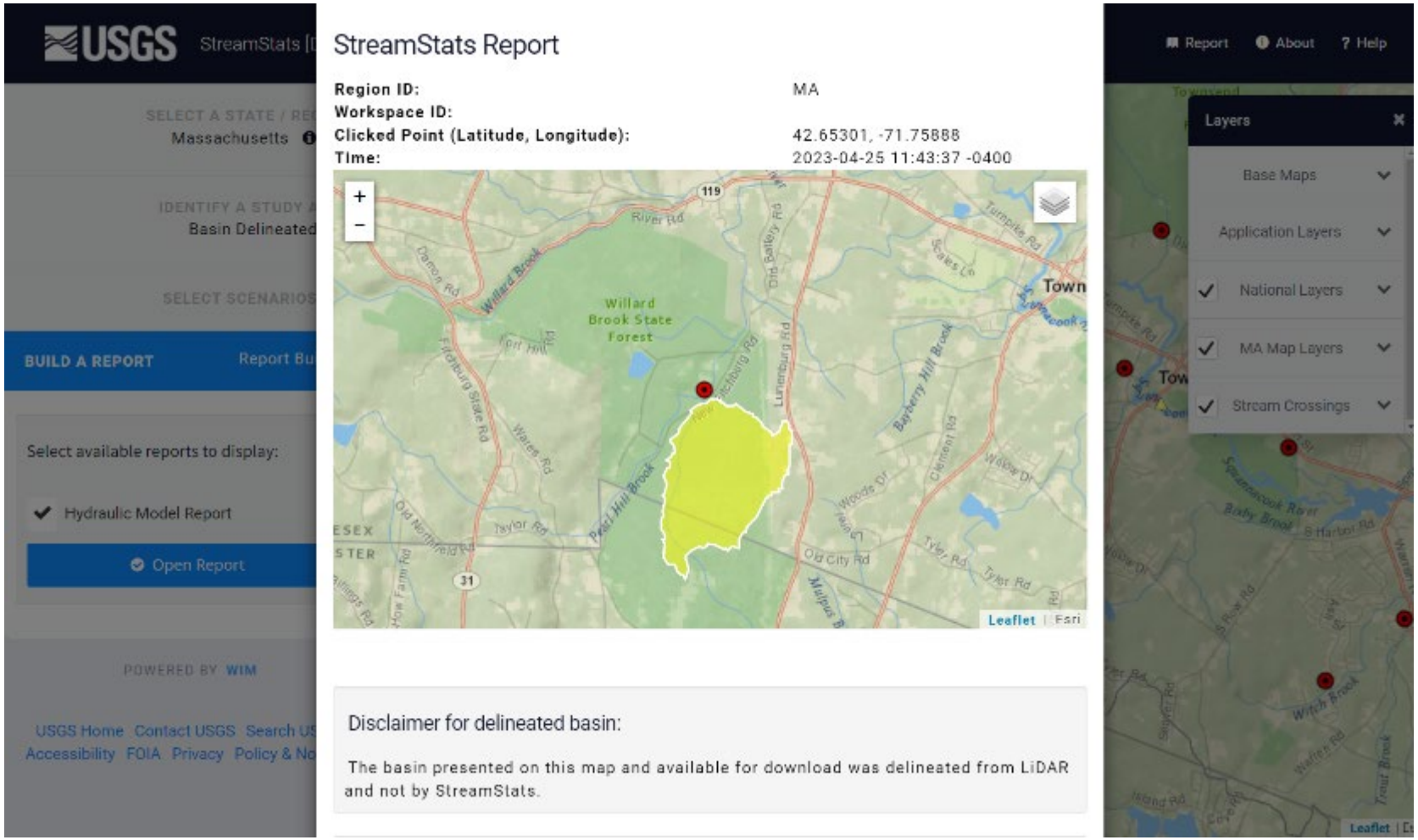
- User can enter a report title and add comments



Hydraulic Modeling Tool Web Application – 3

Culvert Replacement Report

- Latitude and longitude of location
- User can zoom in and out on the map
- Drainage basin boundary is delineated from high-resolution elevation data derived from lidar



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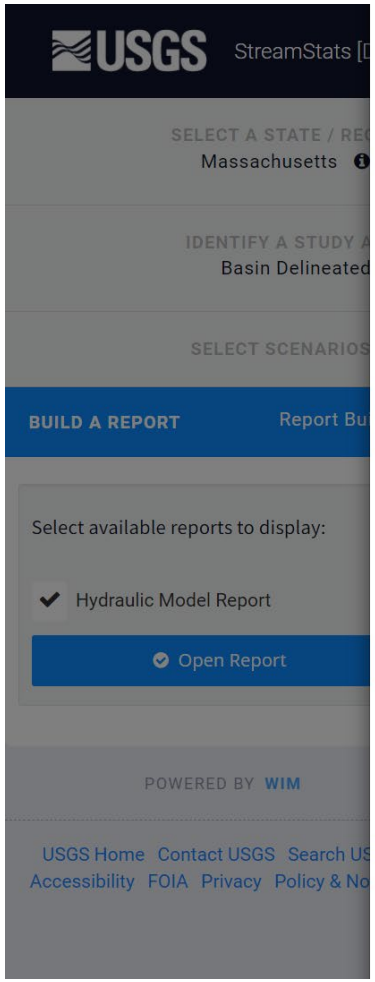
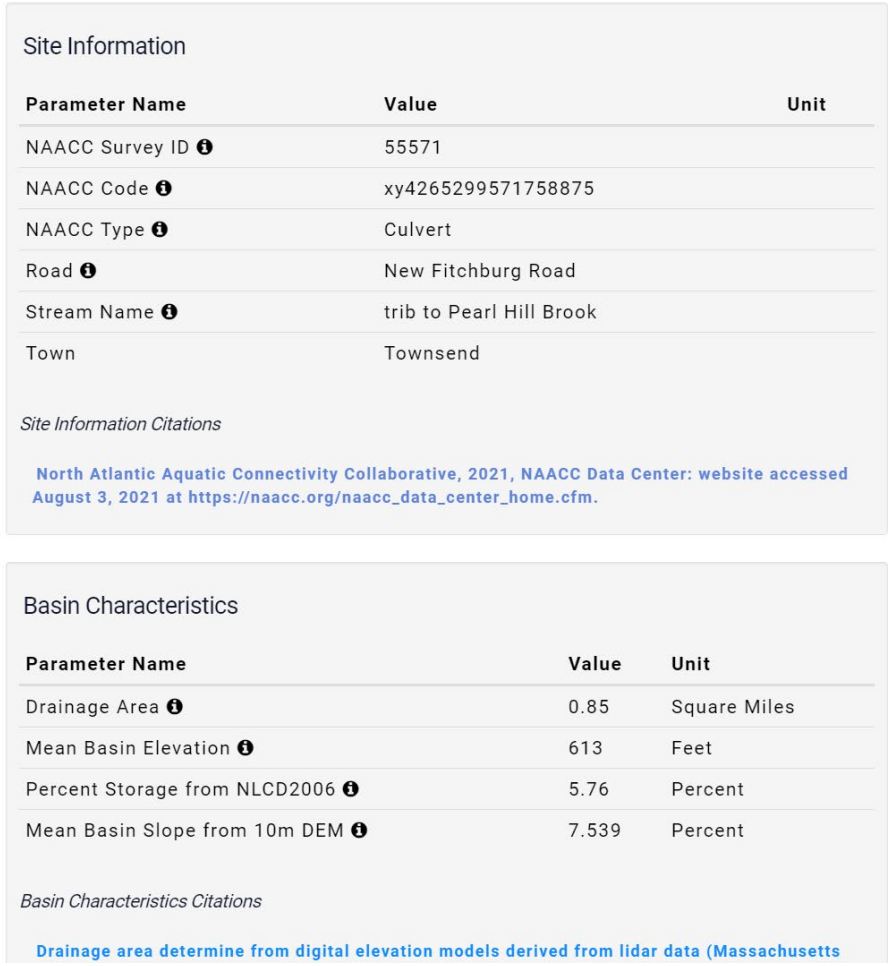
Hydraulic Modeling Tool Web Application – 4

Culvert Replacement Report

- Site information
- Basin characteristics used to solve the Massachusetts peakflow and bankfull channel geometry equations
- User can hover over the black ⓘ button next to the parameter name to get a description





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

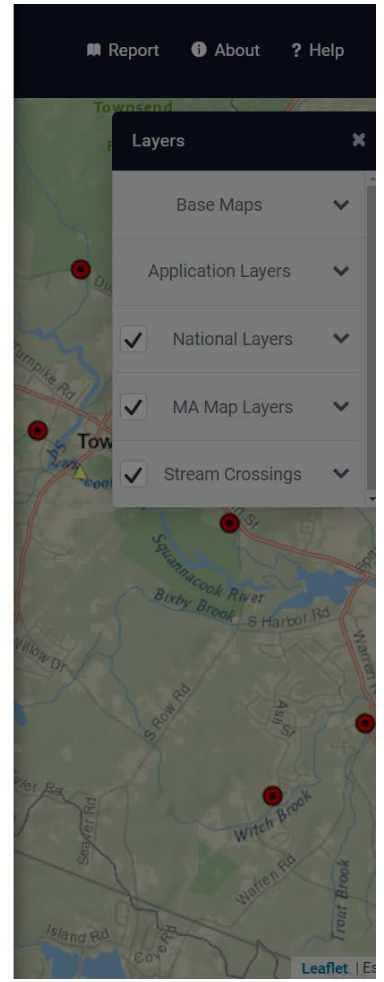
North Atlantic Aquatic Connectivity Collaborative, 2021, NAACC Data Center: website accessed August 3, 2021 at https://naacc.org/naacc_data_center_home.cfm.

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

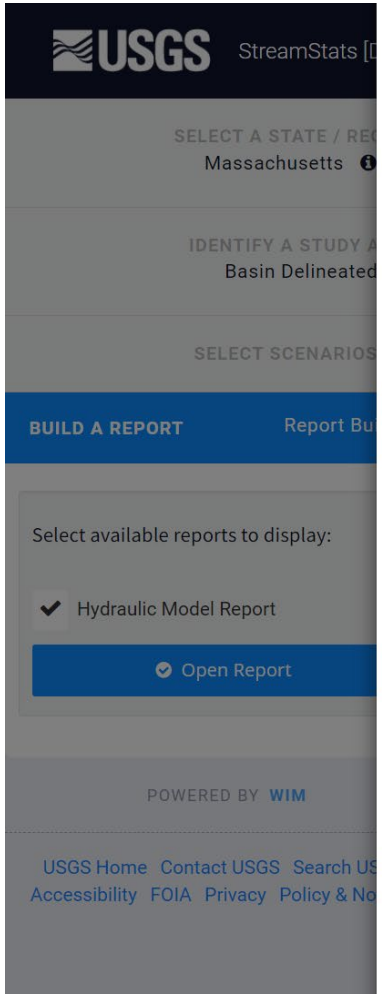
Drainage area determine from digital elevation models derived from lidar data (Massachusetts



Hydraulic Modeling Tool Web Application – 5

Culvert Replacement Report

- Stream Habitat and Connectivity Characteristics
- Habitat Quality and Restoration Connectivity Potential Scores
- Maximum Extent Practicable (MEP) Cost



Stream Habitat and Connectivity Characteristics

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	

Stream Habitat and Connectivity Characteristics Citations

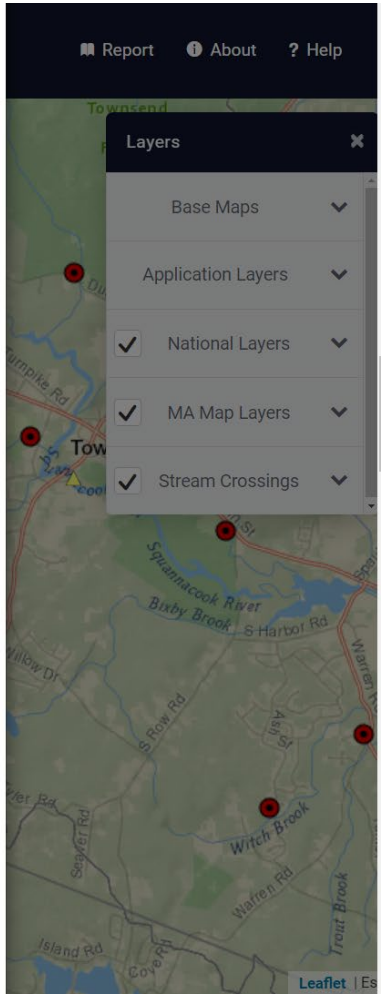
Massachusetts Division of Fisheries, 2022, Coldwater fish resources, website accessed April 30, 2022 at https://www.mass.gov/info-details/coldwater-fish-resources.

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.

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

National Wild and Scenic Rivers System, 2022, Massachusetts: website, accessed April 30, 2022 at 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.



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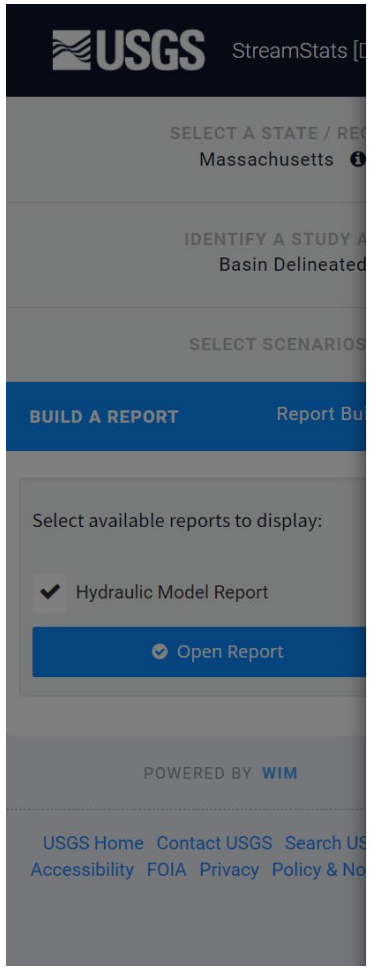
Hydraulic Modeling Tool Web Application – 6

Culvert Replacement Report

- MassDOT roadway classification and associated hydraulic design flood
- USGS Massachusetts peakflow recurrence interval and magnitude



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.

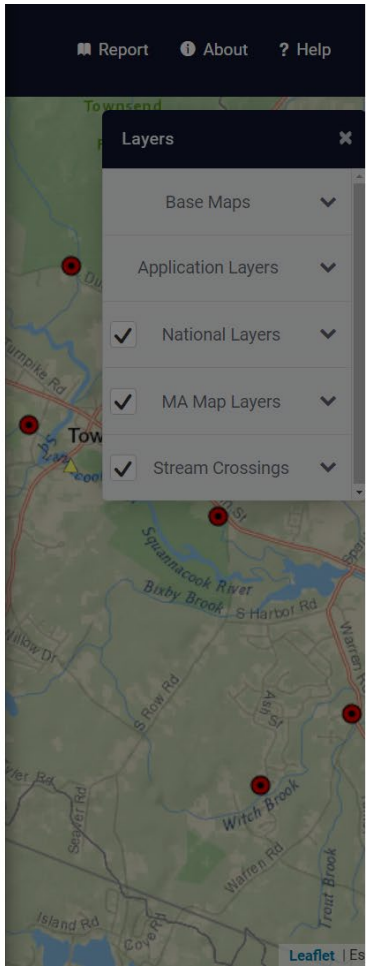
Massachusetts Department of Transportation, 2021, Roadway culverts, accessed October 20, 2021 at https://geo-massdot.opendata.arcgis.com/datasets/MassDOT::culverts-1/about.

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.



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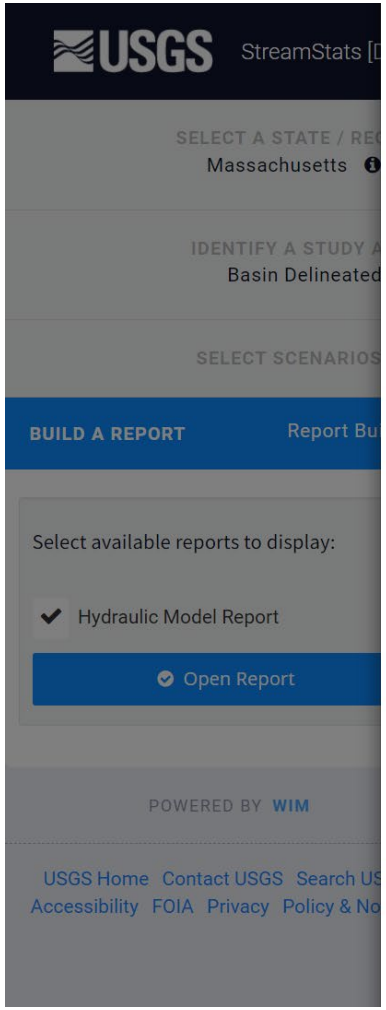
Hydraulic Modeling Tool Web Application – 7

Culvert Replacement Report

- USGS Massachusetts peakflow recurrence interval and magnitude
- USGS Massachusetts bankfull width, mean depth, and cross-sectional area



Peak-Flow Statistics Flow Report

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Peak-Flow Statistics Citations

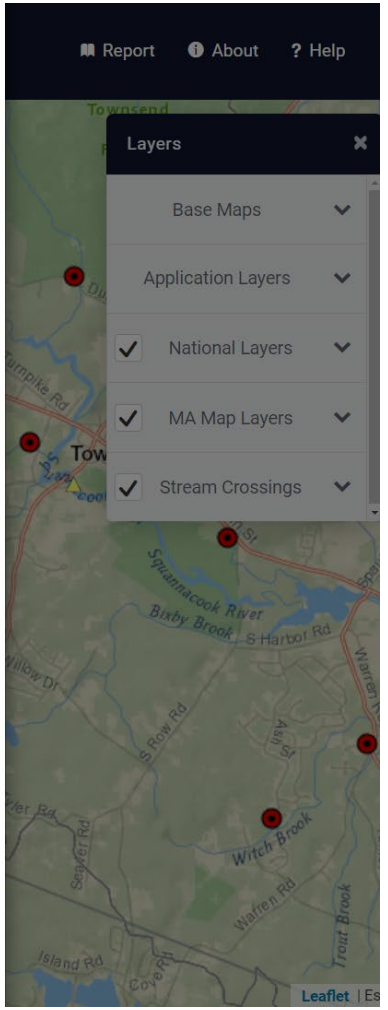
Zarriello, P.J., 2017, Magnitude of flood flows at selected annual exceedance probabilities for streams in Massachusetts: U.S. Geological Survey Scientific Investigations Report 2016–5156, 54 p., https://doi.org/10.3133/sir20165156.

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.



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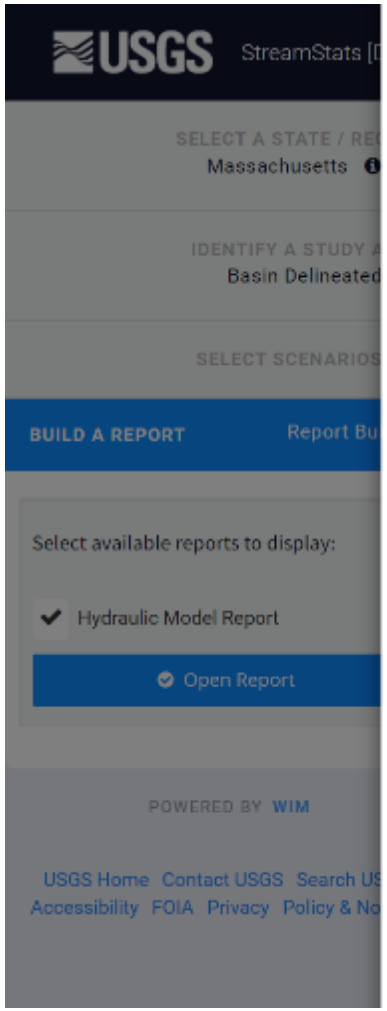
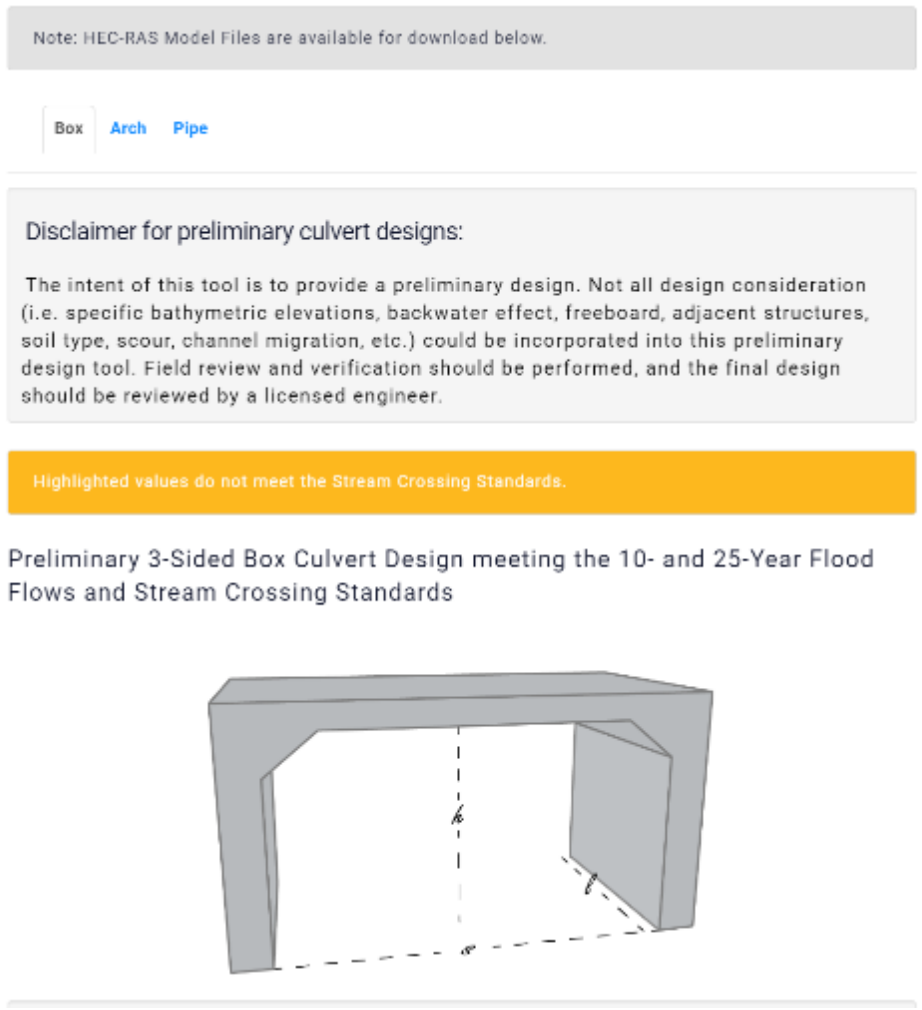
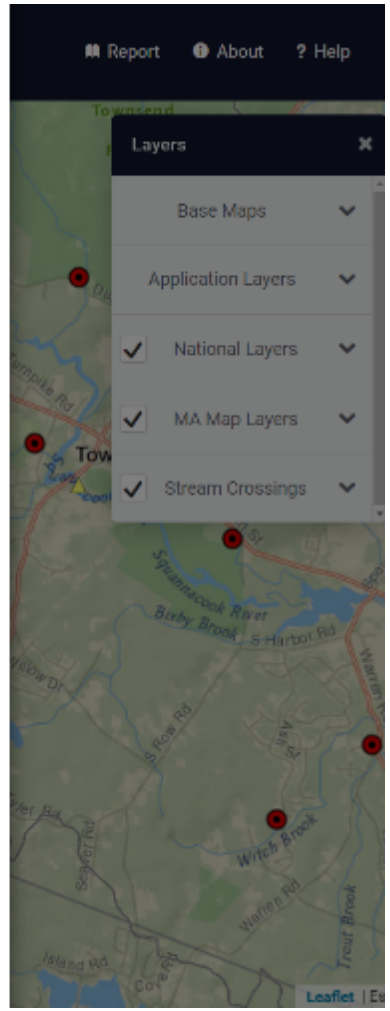
Hydraulic Modeling Tool Web Application – 8

Culvert Replacement Report

- User can select culvert design: Box, Arch, or Pipe
- This example will be for a 3-side box
- Preliminary culvert designs to convey the 10- and 25-yr flood flow with no backwater and to meet the Stream Crossing Standards







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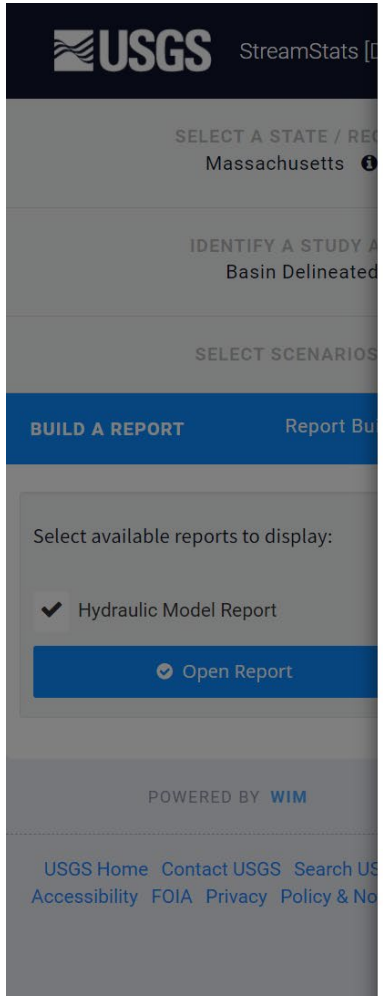
Hydraulic Modeling Tool Web Application – 9

Culvert Replacement Report

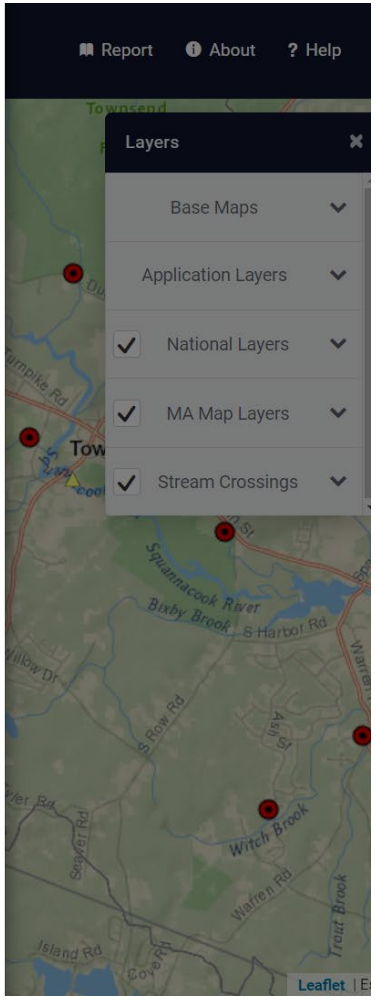
- Culvert information: span, height, diameter, length, XSEC area, material, invert and road deck elevations, and maximum recurrence interval flood flow passed without flowing over the road deck
- Stream Crossing Standard results



Parameter Name	10-Yr Flow	25-Yr Flow	Meets SCS	Unit
Box Culvert Span	5.0	5.0	18	Feet
Box Culvert Height	4.0	5.0	8	Feet
Box Culvert Length	66.2	66.2	66.2	Feet
Box Culvert Area	20.0	25.0	144	Square Feet
Box Culvert Material	Concrete	Concrete	Concrete	
Box Culvert Upstream Channel Invert Elevation	416.5	416.5	416.5	Feet - NAVD88
Box Culvert Downstream Channel Invert Elevation	414.6	414.6	414.6	Feet - NAVD88
Box Culvert Road Deck Elevation	429.0	429.0	429	Feet - NAVD88
Box Culvert Maximum Flow to Pass Through	10	25	500	Year
Box Culvert Type	3-sided Box	3-sided Box	3-sided Box	
Box Embedment	None	None	None	Feet
Box Substrate	Natural	Natural	Natural	
Box Span Ratio	0.4	0.4	1.3	
Box Openness Ratio	0.30	0.40	2.2	

Hydraulic Model Citations

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.



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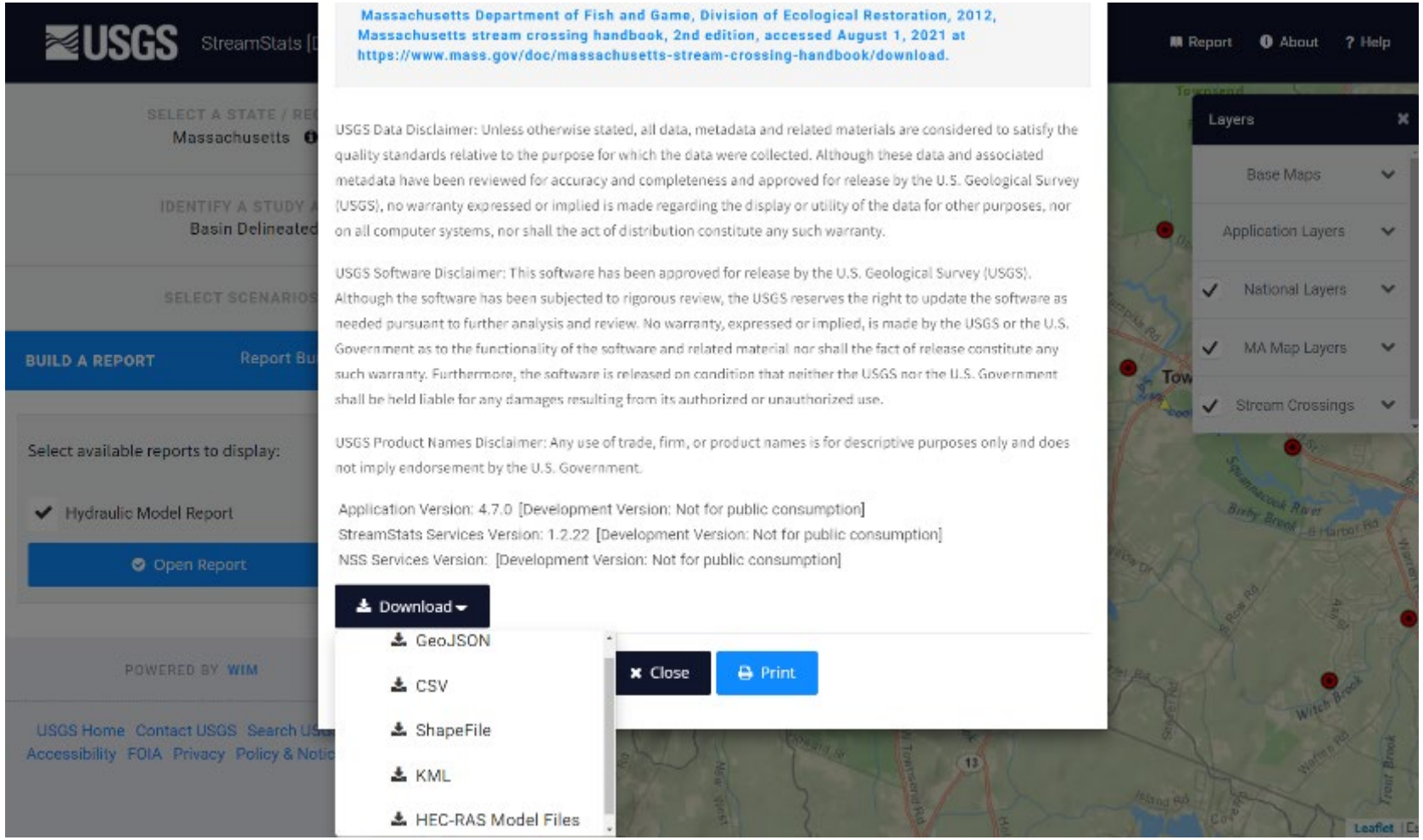
Hydraulic Modeling Tool Web Application – 10

Culvert Replacement Report

- User can print the report
- User can download the HEC-RAS hydraulic modeling files (input and output files) associated with this stream crossing and culvert design



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Questions

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