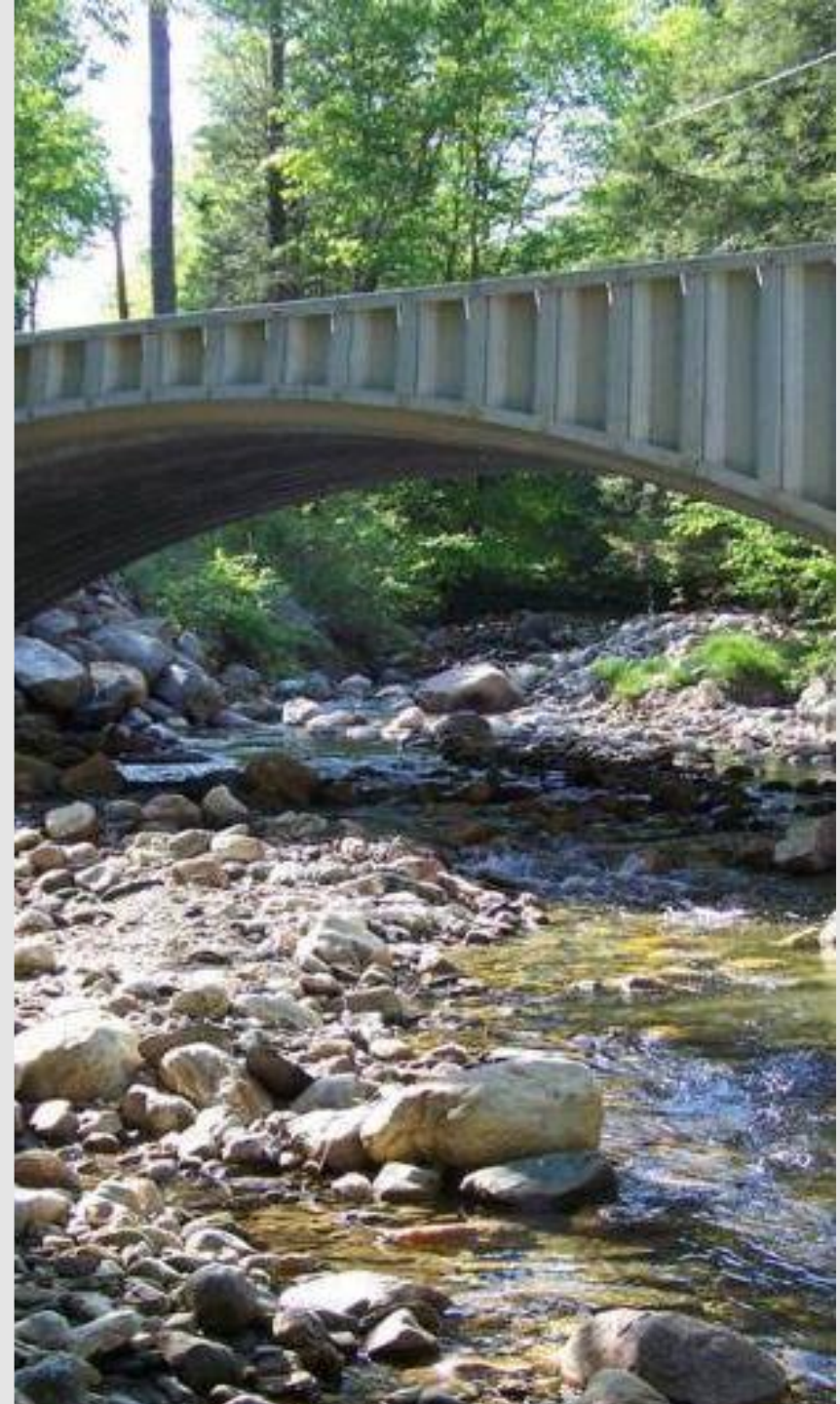


A GIS-BASED HYDRAULIC MODELING TOOL FOR MASSACHUSETTS STREAM CROSSING REPLACEMENT PROJECTS IN USGS STREAMSTATS

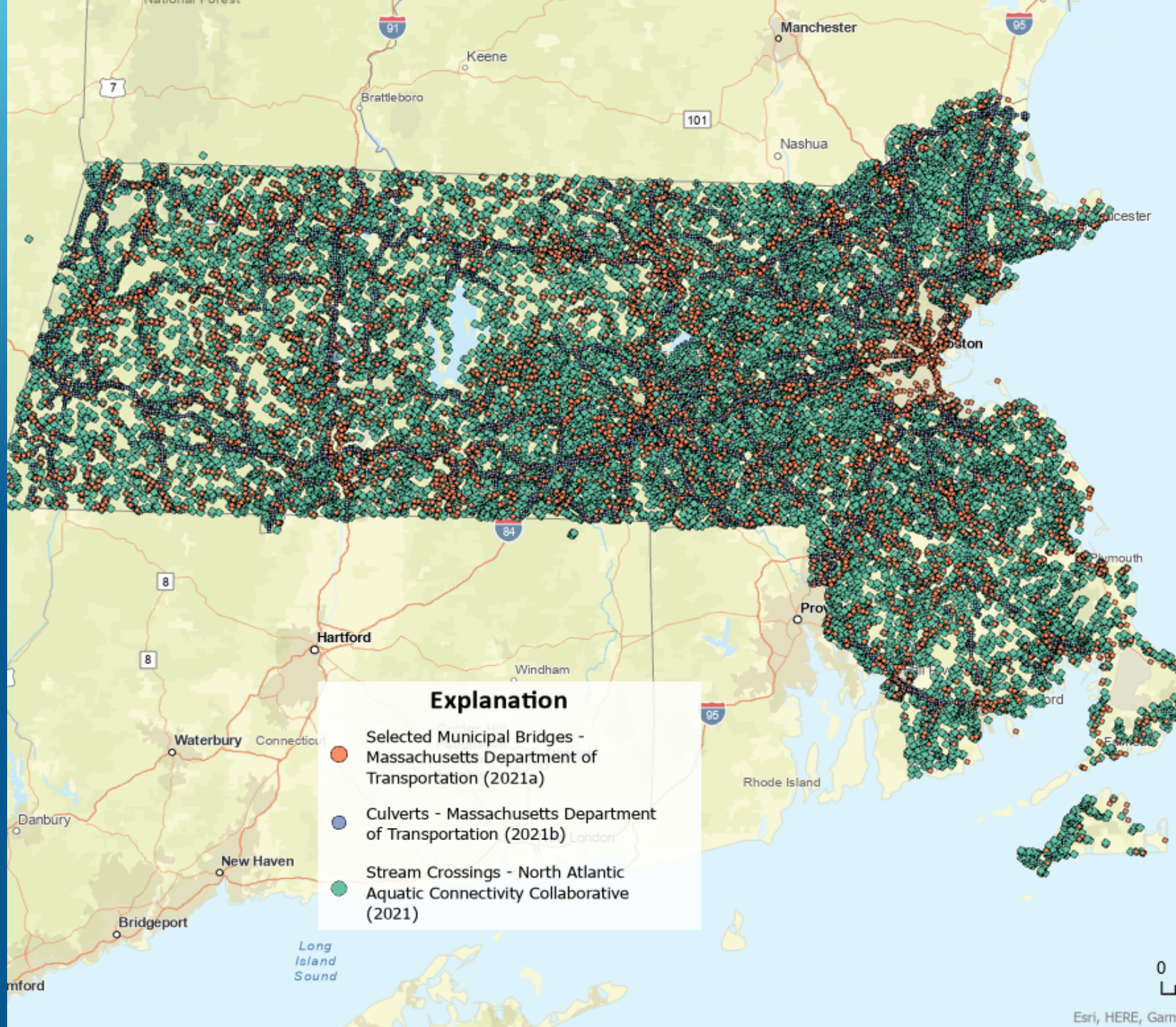
Gardner Bent
U.S. Geological Survey
New England Water Science Center



MASSACHUSETTS STREAM CROSSINGS

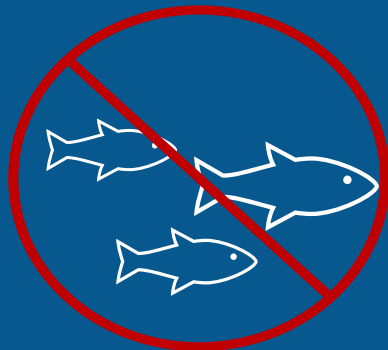


Photo courtesy of MassDOT, Massachusetts Culverts and Small Bridges Working Group



Undersized Culverts

- Outlet drops
- Restrict aquatic organism passage (AOP) to spawning, feeding, and cold-water habitat
- Restrict wildlife passage
- Reduce stream connectivity
- Extreme low flow
- Restrict sediment transport



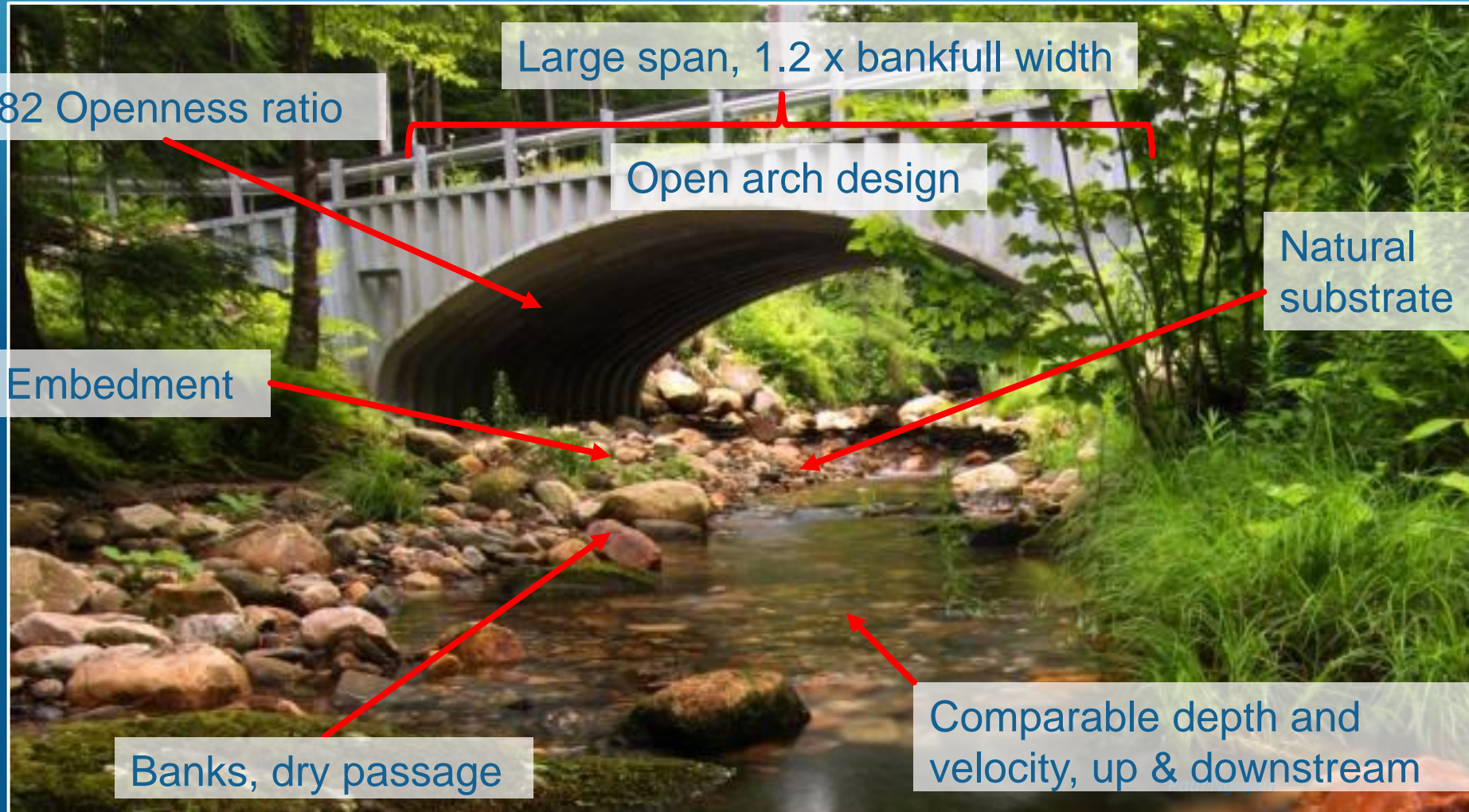
Undersized Culverts

- Create high flow velocities
- Cause road flooding
- Clogging/debris
- Create significant backwater during flooding events
- Cause road washouts
- Create scour and erosion
- Create extreme low flows



Photos courtesy of
University of Massachusetts
at Amherst, River Smart
Communities

MASSACHUSETTS STREAM CROSSING STANDARDS



Project Goals and Objectives

- Create hydraulic models for about 20,000 stream crossing sites in Massachusetts
- Develop culvert designs to convey flood flows and meet the Massachusetts Stream Crossing Standards
- Publish culvert designs on USGS StreamStats
- Assist MassDEP in facilitating stream crossing replacement projects



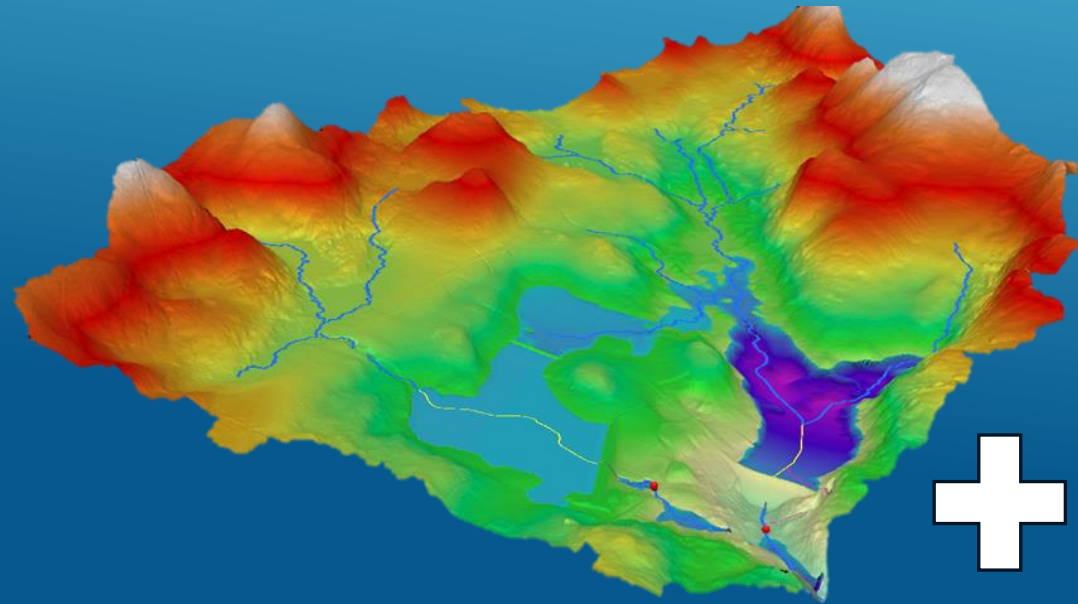
	10-Yr Flow	25-Yr Flow	Meets SCS	Unit
Water	12.6	17	17	Feet
Invert Elevation	2.0	2	2	Feet
Stream Channel Invert Elevation	42.6	42.6	42.6	Feet
Deck Elevation	26.0	26	26	Feet
Material	Concrete	Concrete	Concrete	Material
Stream Channel Invert Elevation	478.2	478.2	478.2	Feet
Stream Channel Invert Elevation	477.2	477.2	477.2	Feet
Deck Elevation	481.7	481.7	481.7	Feet
Material	Concrete	Concrete	Concrete	Material
Stream Channel Invert Elevation	10	10	10	Feet
Material	3-sided Box	3-sided Box	3-sided Box	Material
Material	Natural	Natural	Natural	Material



	10-Yr Flow	25-Yr Flow	Meets SCS	Unit
Water	5.5	5.8	14.75	Feet
Invert Elevation	66.2	66.2	66.2	Feet
Stream Channel Invert Elevation	16.0	17.9	137.2	Sp
Material	Concrete	Concrete	Concrete	Material
Stream Channel Invert Elevation	414.5	414.5	412.8	Feet
Stream Channel Invert Elevation	412.6	412.6	410.9	Feet
Deck Elevation	429.0	429.0	429	Feet
Material	10	25	500	Feet
Material	Pipe	Pipe	Pipe	Material
Material	2.0	2.0	3.7	Feet
Material	0.4	0.4	1	Feet
Material	Natural	Natural	Natural	Material
Material	0.20	0.30	2.1	Material



GIS-BASED HYDRAULIC MODEL DEVELOPMENT



+Arcpy
functions



GIS-Based Hydraulic Model Development

Looking Upstream



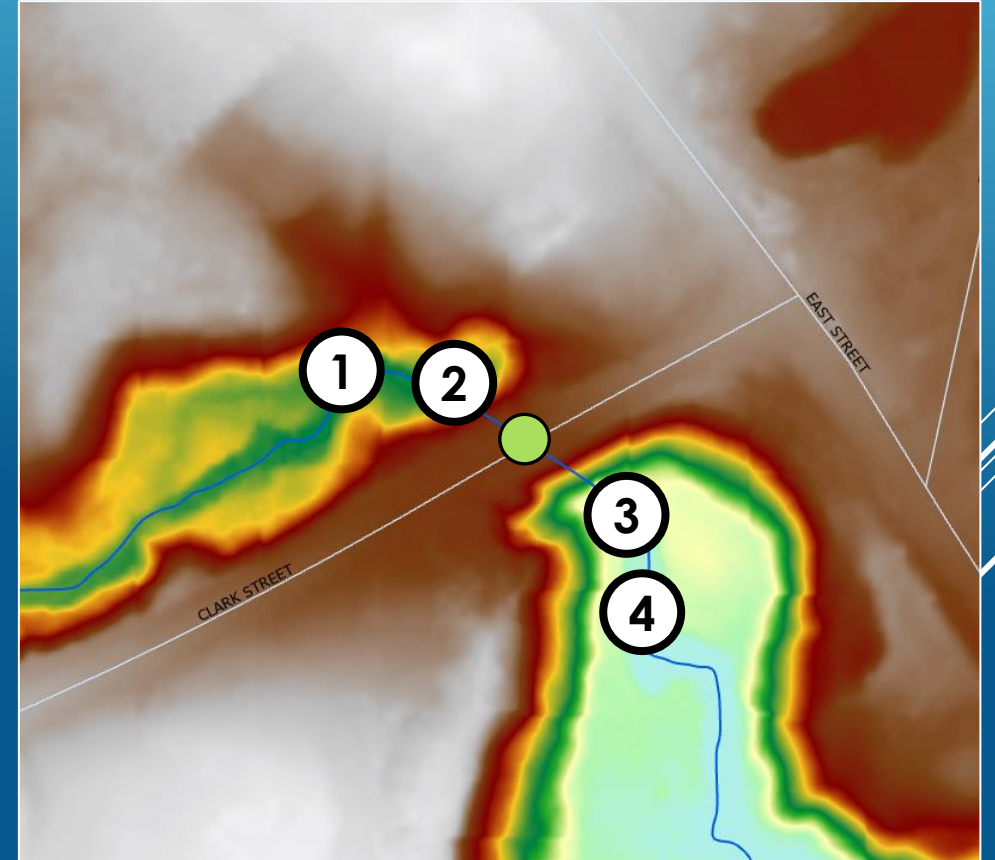
Upstream Face



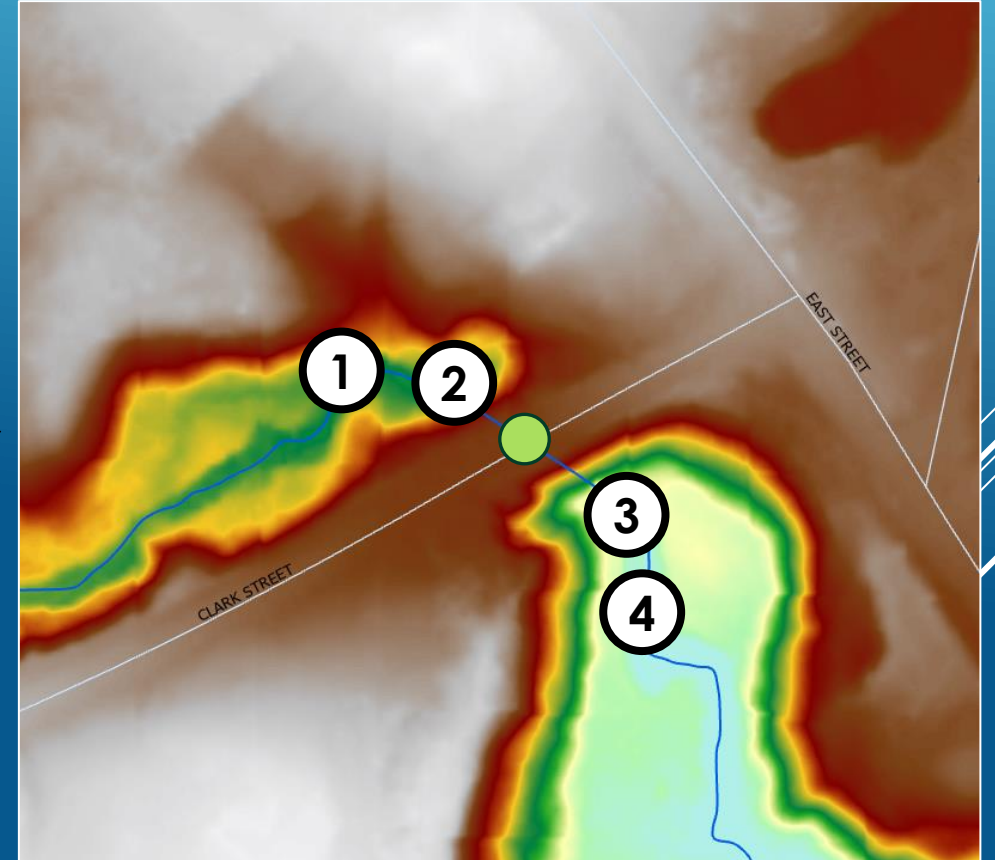
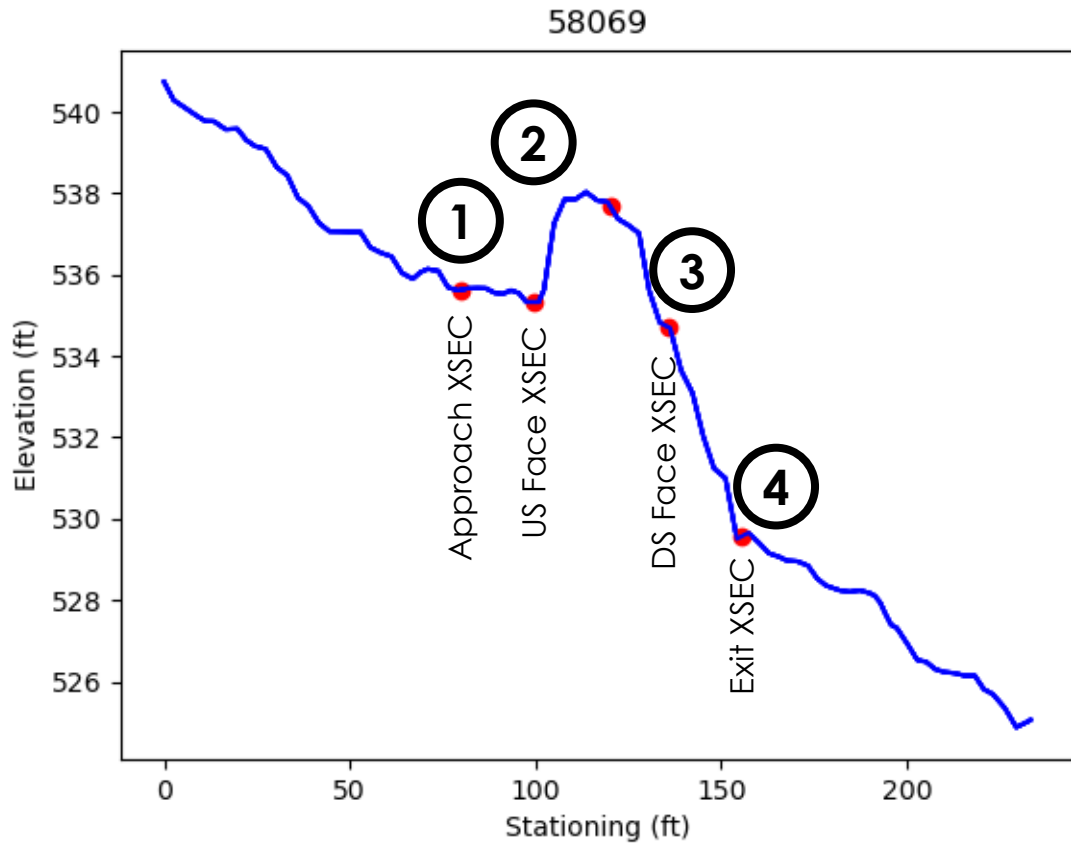
Downstream Face



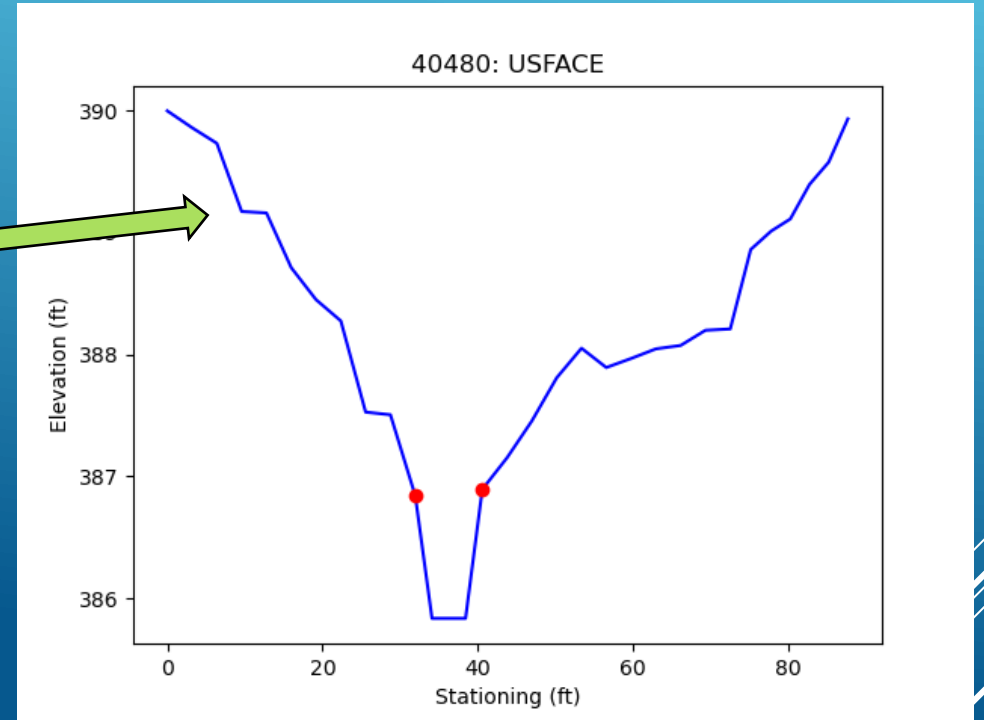
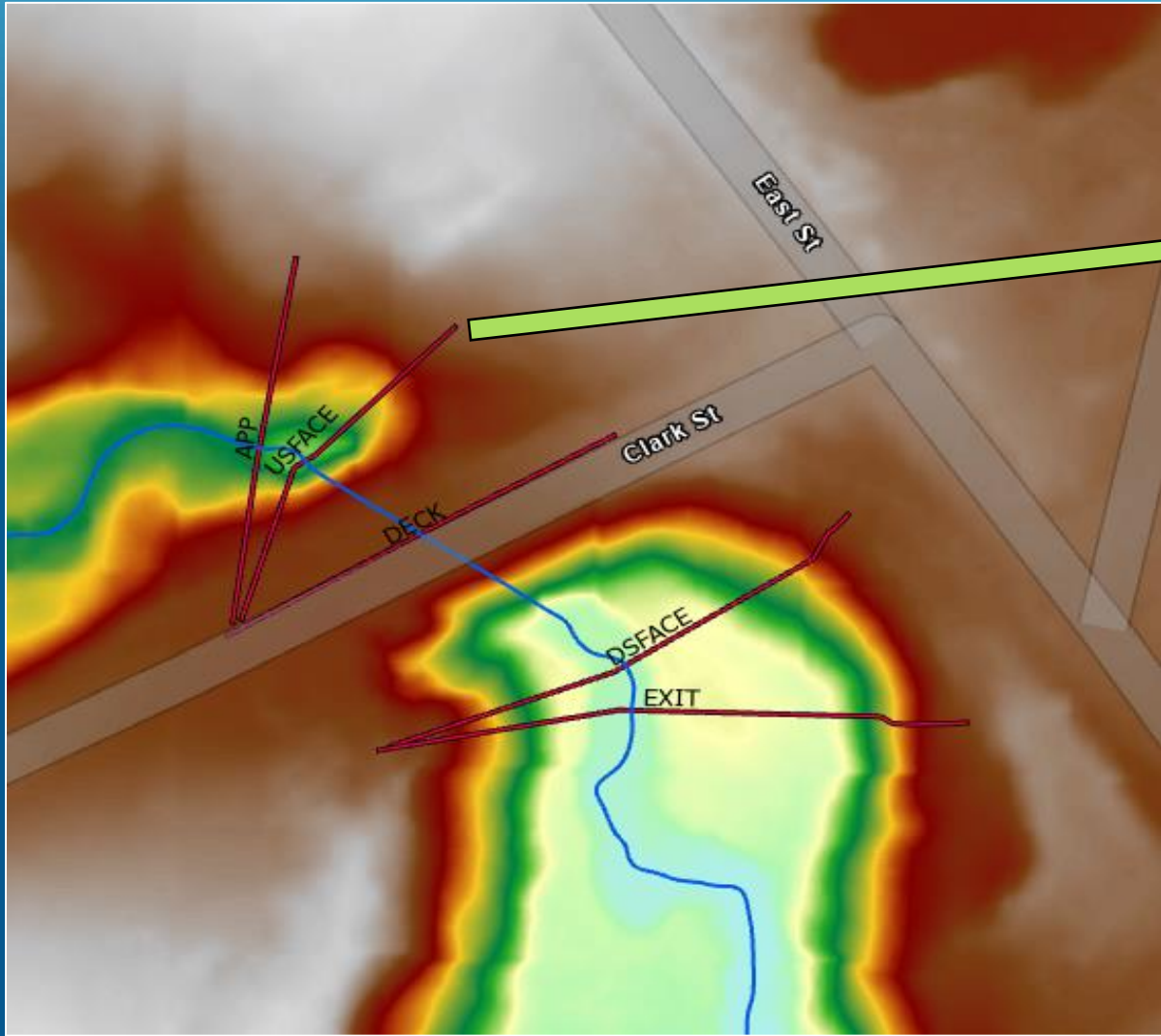
Looking Downstream



GIS-Based Hydraulic Model Development – Lidar Derived Elevation Data



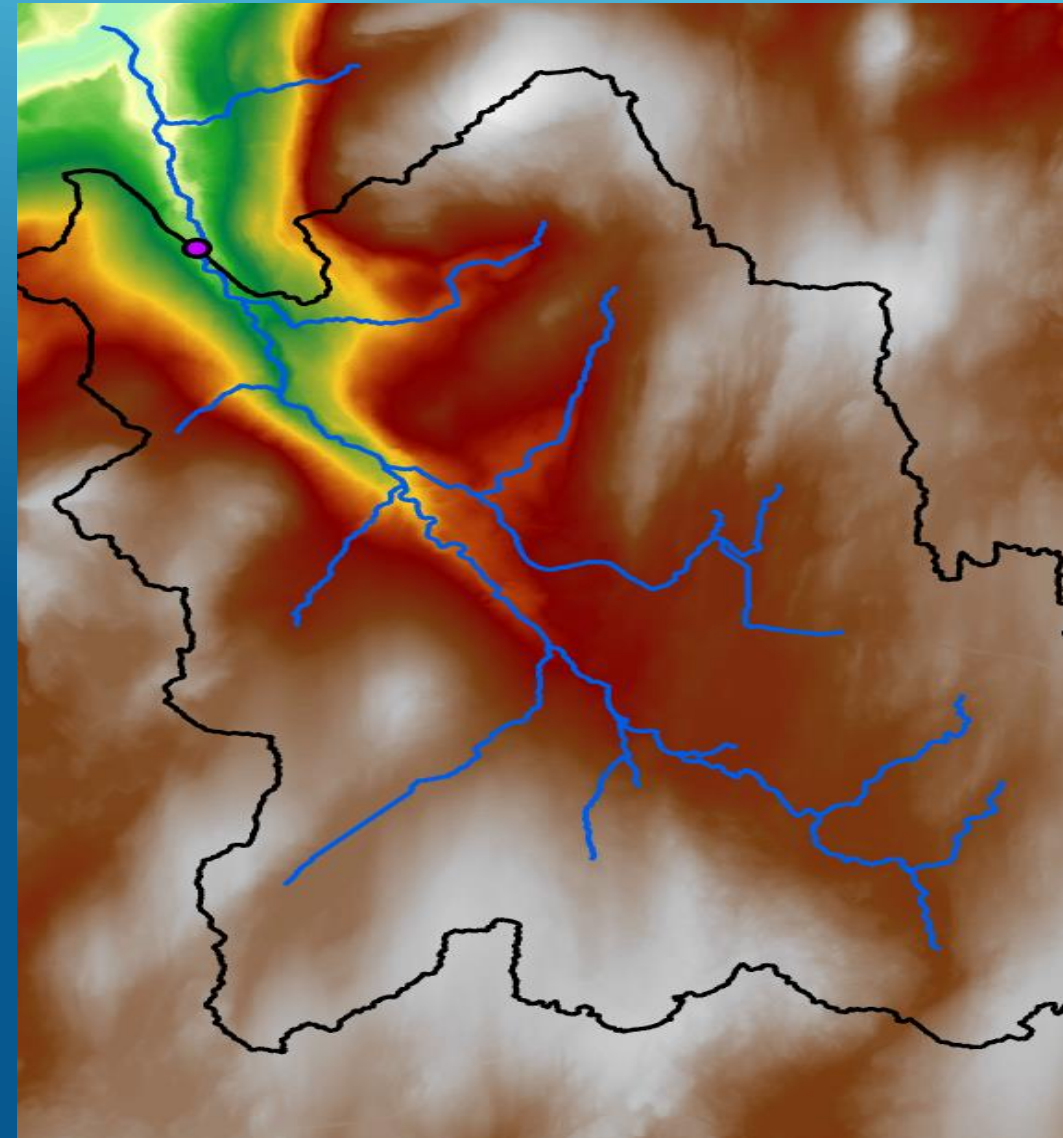
GIS-Based Hydraulic Model Development – Cross Sections



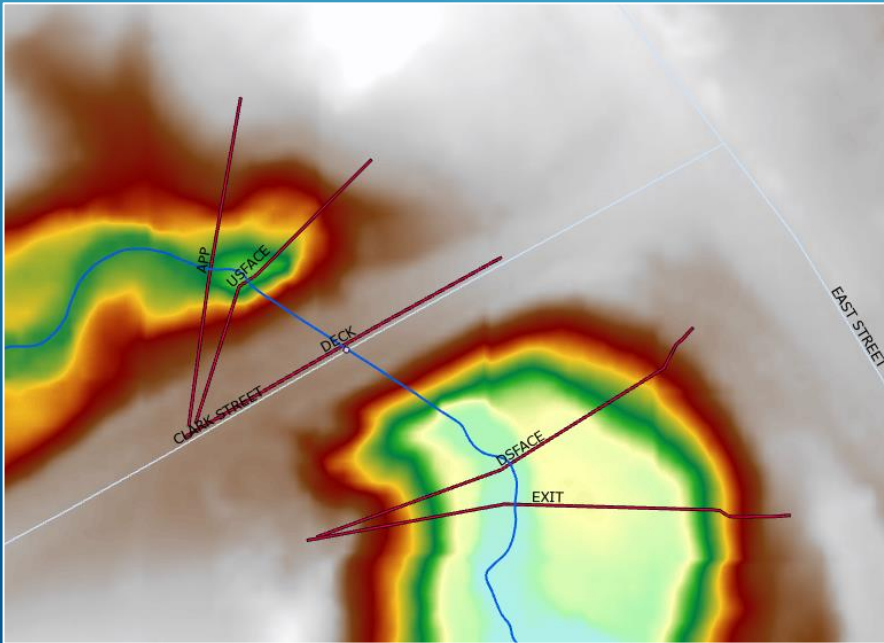
- Channel width and depth determined by Massachusetts Bankfull Channel Geometry Equations (Bent and Waite, 2013)

GIS-Based Hydraulic Model Development – Flood Flows

- Massachusetts regional regression equations for estimating peak flows (Zarriello, 2017)
- Estimate 10-, 4-, 2-, and 1-percent annual exceedance probability (AEP) flood flows (10-, 25-, 50-, and 100-, and recurrence intervals)
- Equations based on drainage area, mean basin elevation, and storage (water bodies and wetlands)



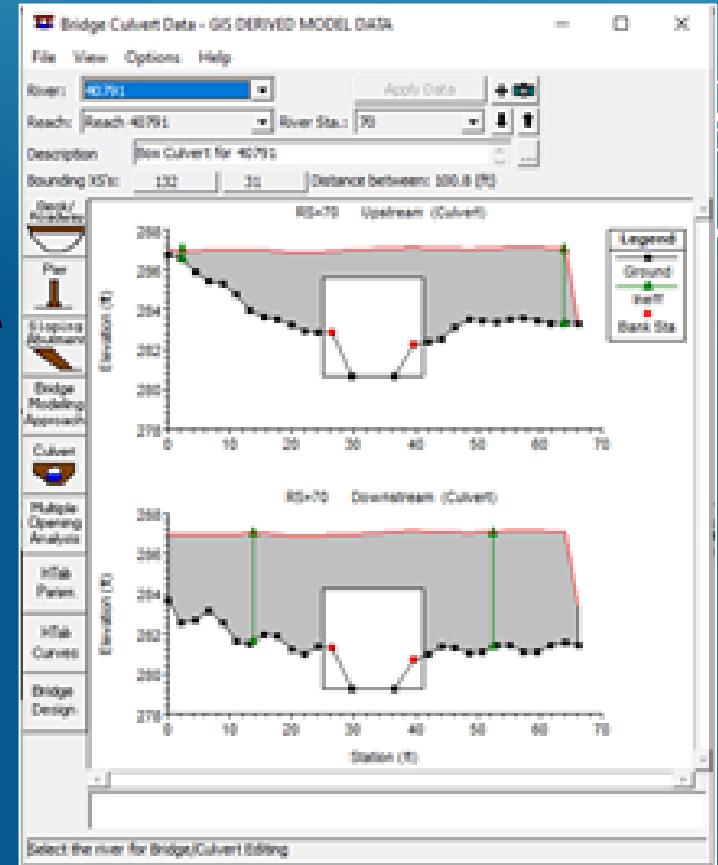
Creation of HEC-RAS Model Files



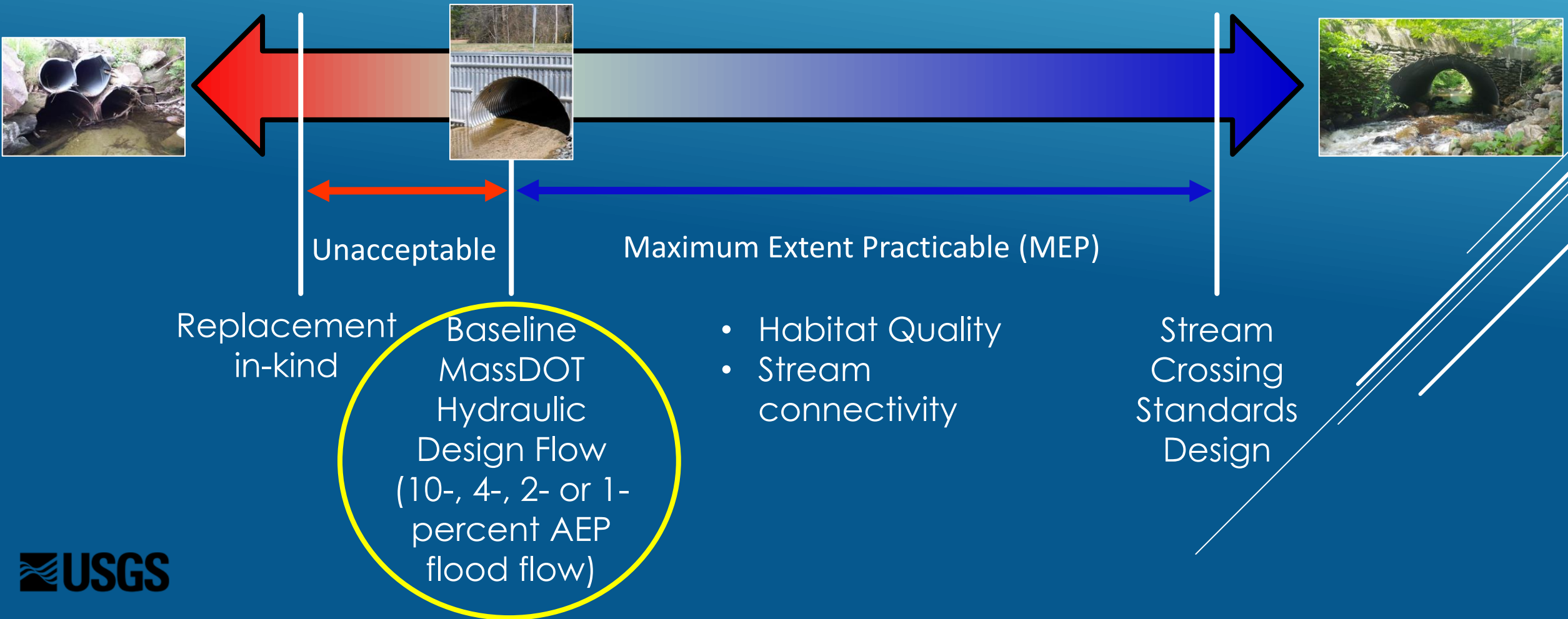
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Program Version=6.1B
Viewing Rectangle= 566178.588236766 , 618866.1491166652 , 3877921.4297158663 ,
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```

```
# Creating string of 48 structure coordinates
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    for pt in seg:
        if seg < 4:
            str = format_struct[typel].format('00', 1)
            seg += 1
            n = 1
        else:
            seg += 1
            n = 1
        if type == '001':
            str = format_struct[typel].format('00', 1, format(pt, 8), pt, 2, 4)
        if type == '010':
            B13 = pt, X, Y, C1[1016]
            while len(str) < 16:
                str += '0'
            B13 = pt, X, Y, C1[1016]
            while len(str) < 16:
                str += '0'
            str = format_struct[typel].format('00', 1, format(pt, 8), pt, 2, 4)
        if type == '010001':
            if len(str) < 16:
                str = str + '0'
            str = format_struct[typel].format('00', 1, format(pt, 8), pt, 2, 4)
            str = str + format_struct[typel].format('00', 1, format(pt, 8), pt, 2, 4)
            str = str + format_struct[typel].format('00', 1, format(pt, 8), pt, 2, 4)
            str = str + format_struct[typel].format('00', 1, format(pt, 8), pt, 2, 4)
            str = str + format_struct[typel].format('00', 1, format(pt, 8), pt, 2, 4)
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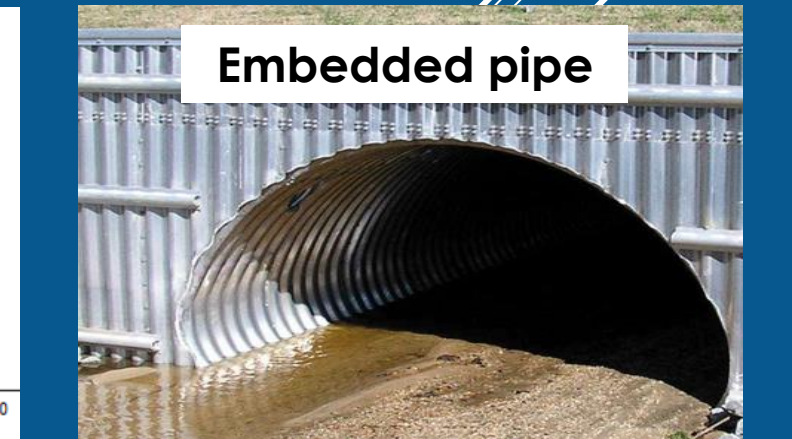
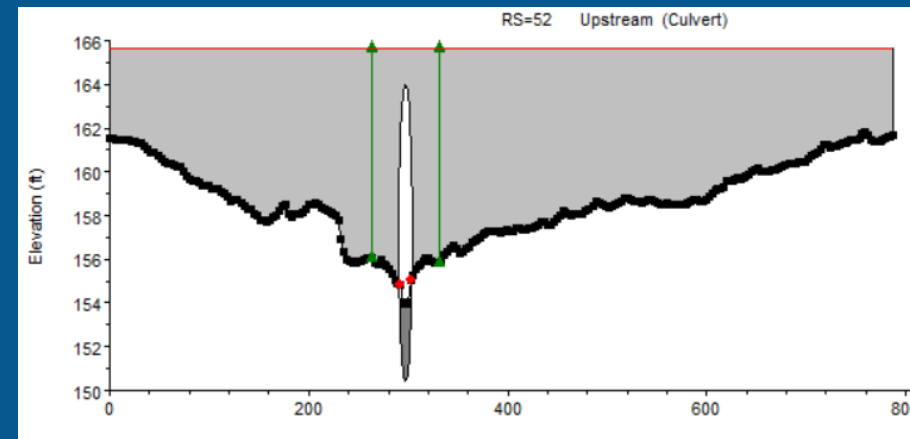
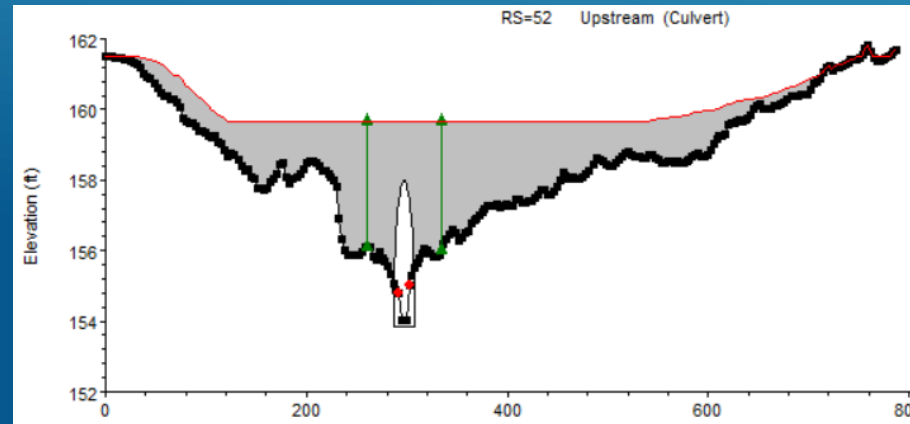
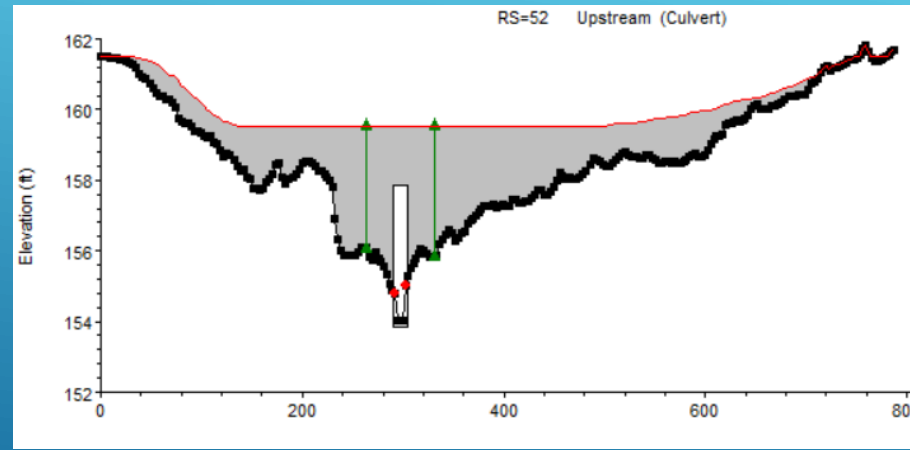


CULVERT - HYDRAULIC DESIGN FLOW



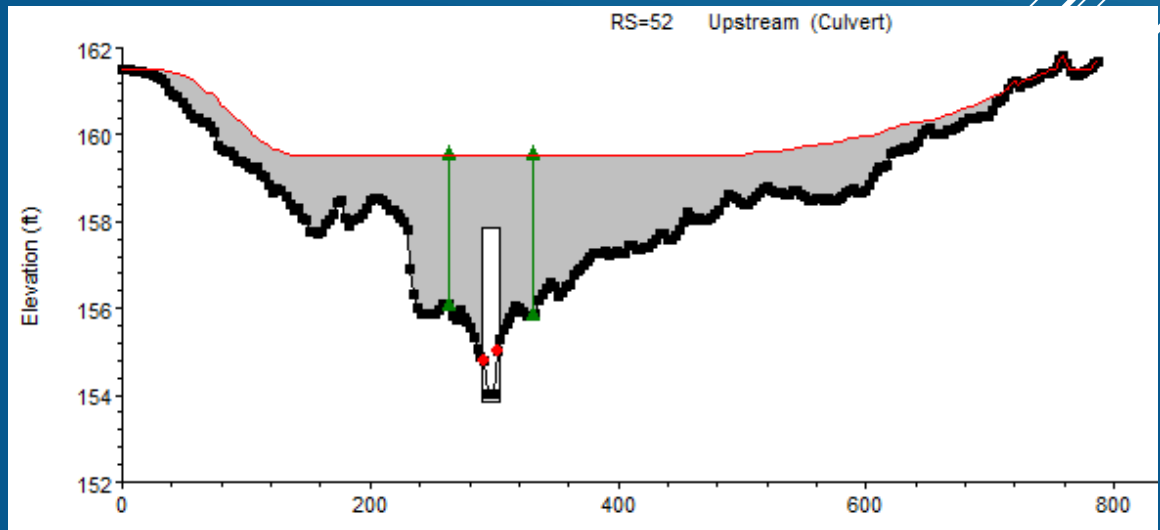
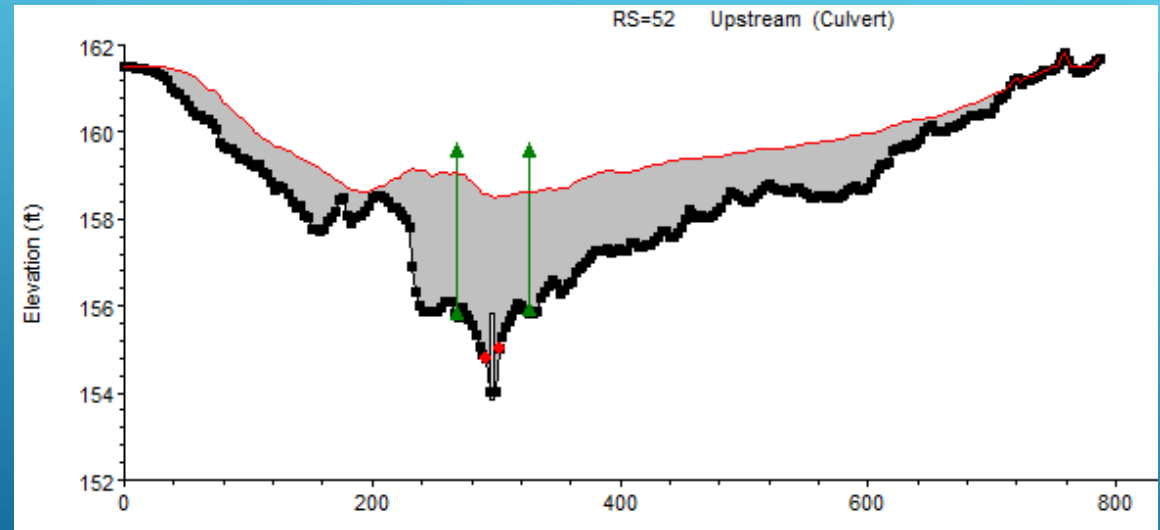
Preliminary Culvert Designs

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

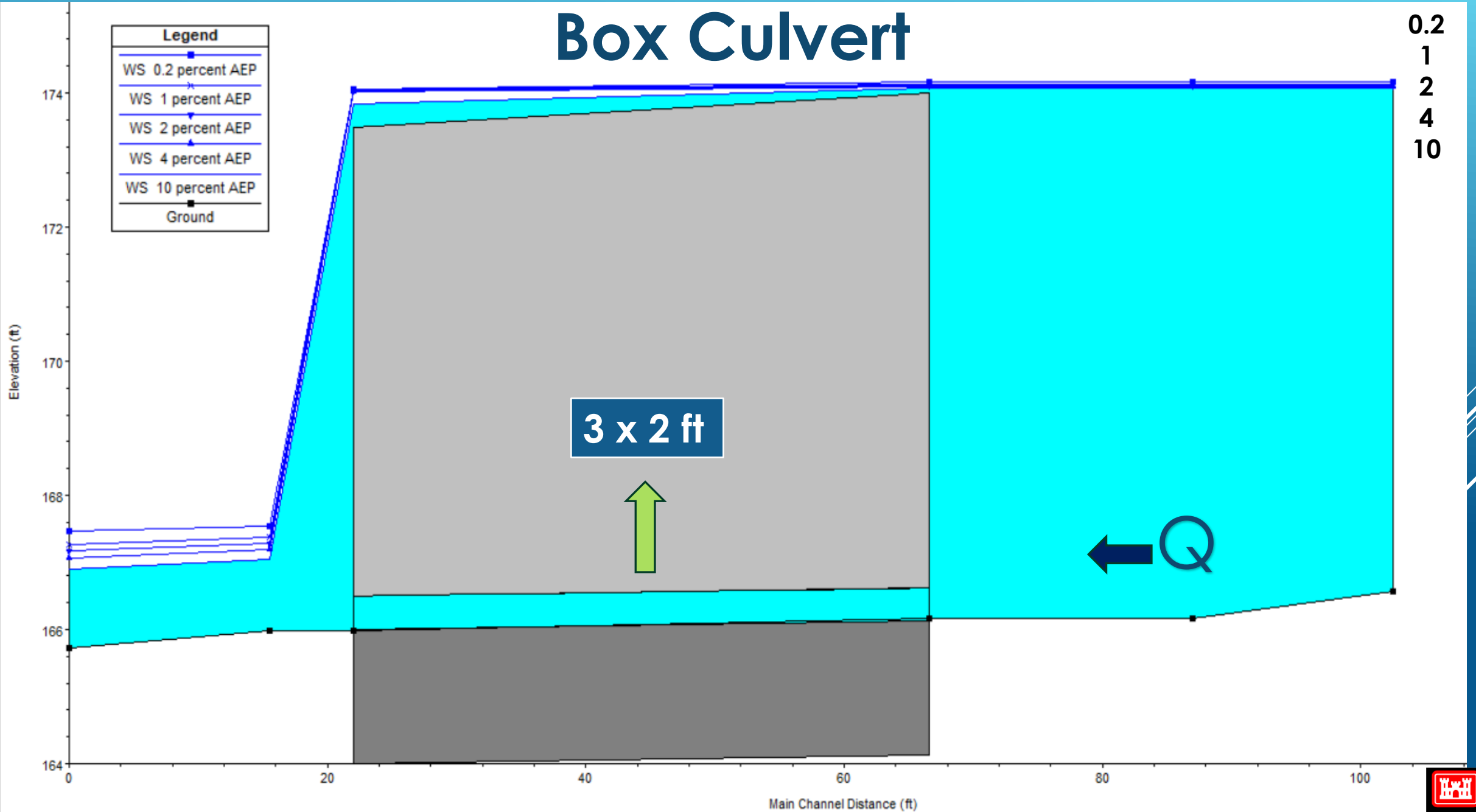


Hydraulic Models

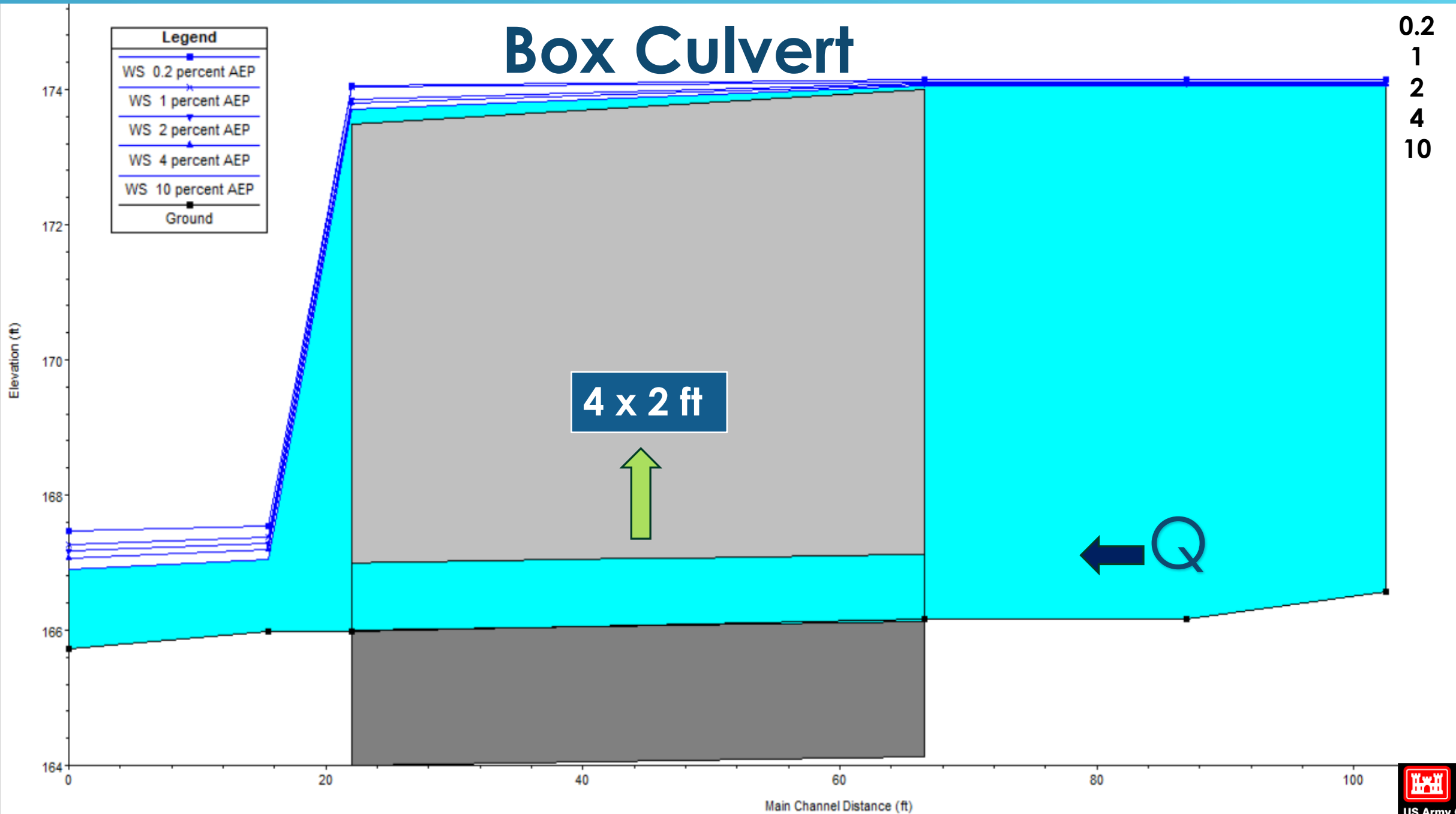
- Manning's n-values of 0.045 for channel and 0.10 for overbank
- Freeboard of at least 1 ft, and 2 ft if specified by MassDOT Chap. 85 Section 35
- Precast concrete sizes for box and pipe culverts
- Arch sizes limited to those in HEC-RAS
- Stream crossing sites with drainage areas ≤ 2 mi² and $< 20\%$ 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



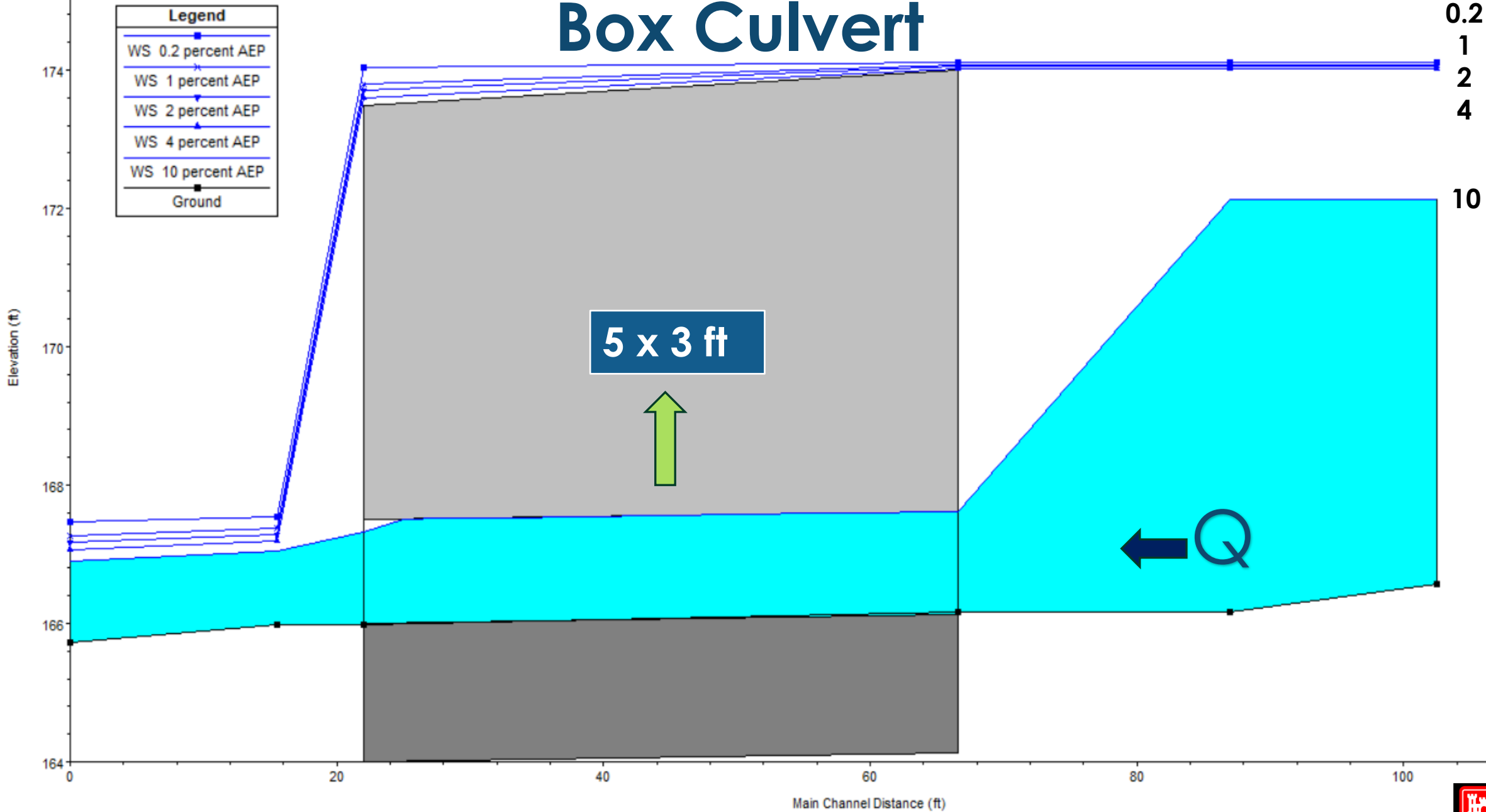
Box Culvert



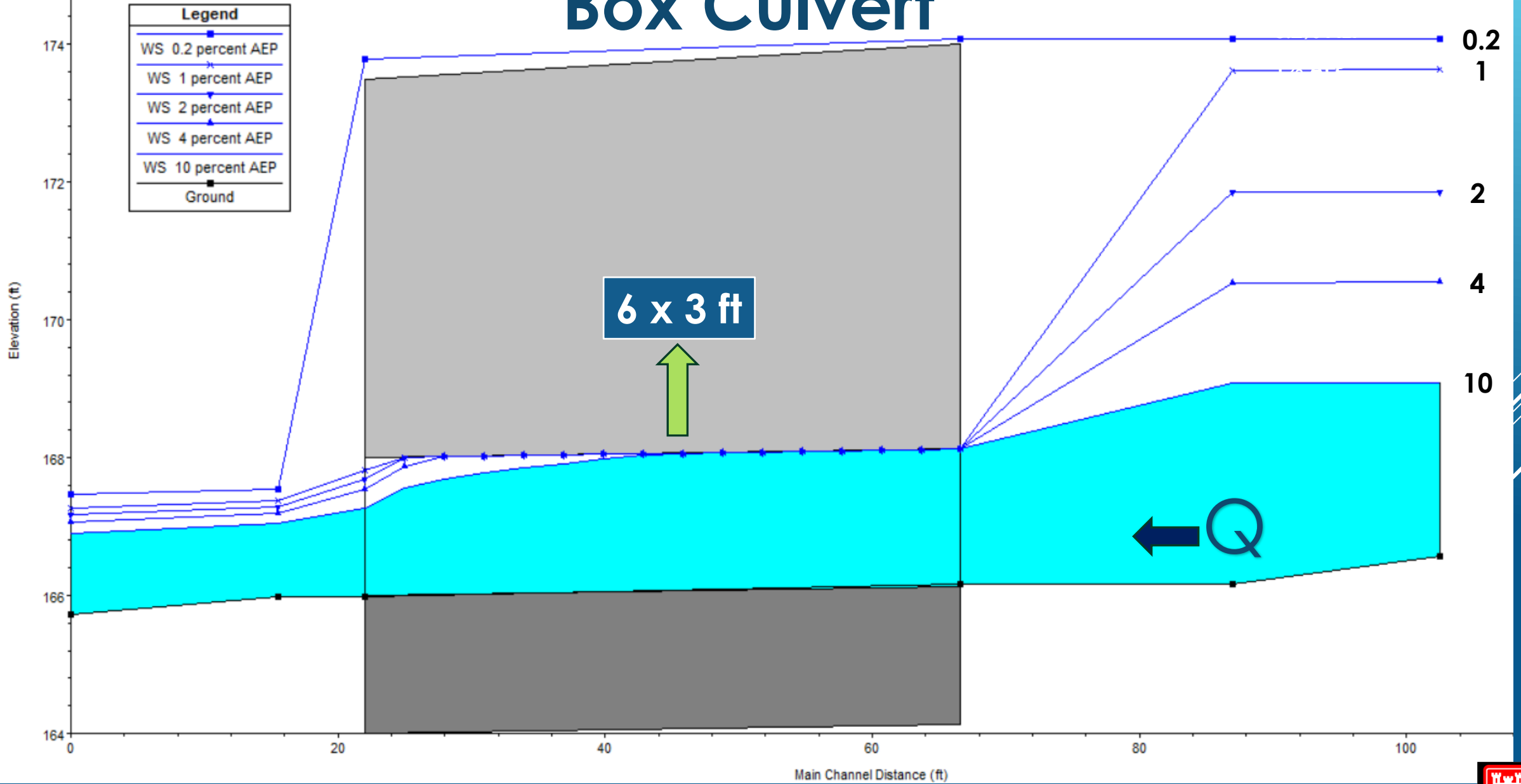
Box Culvert

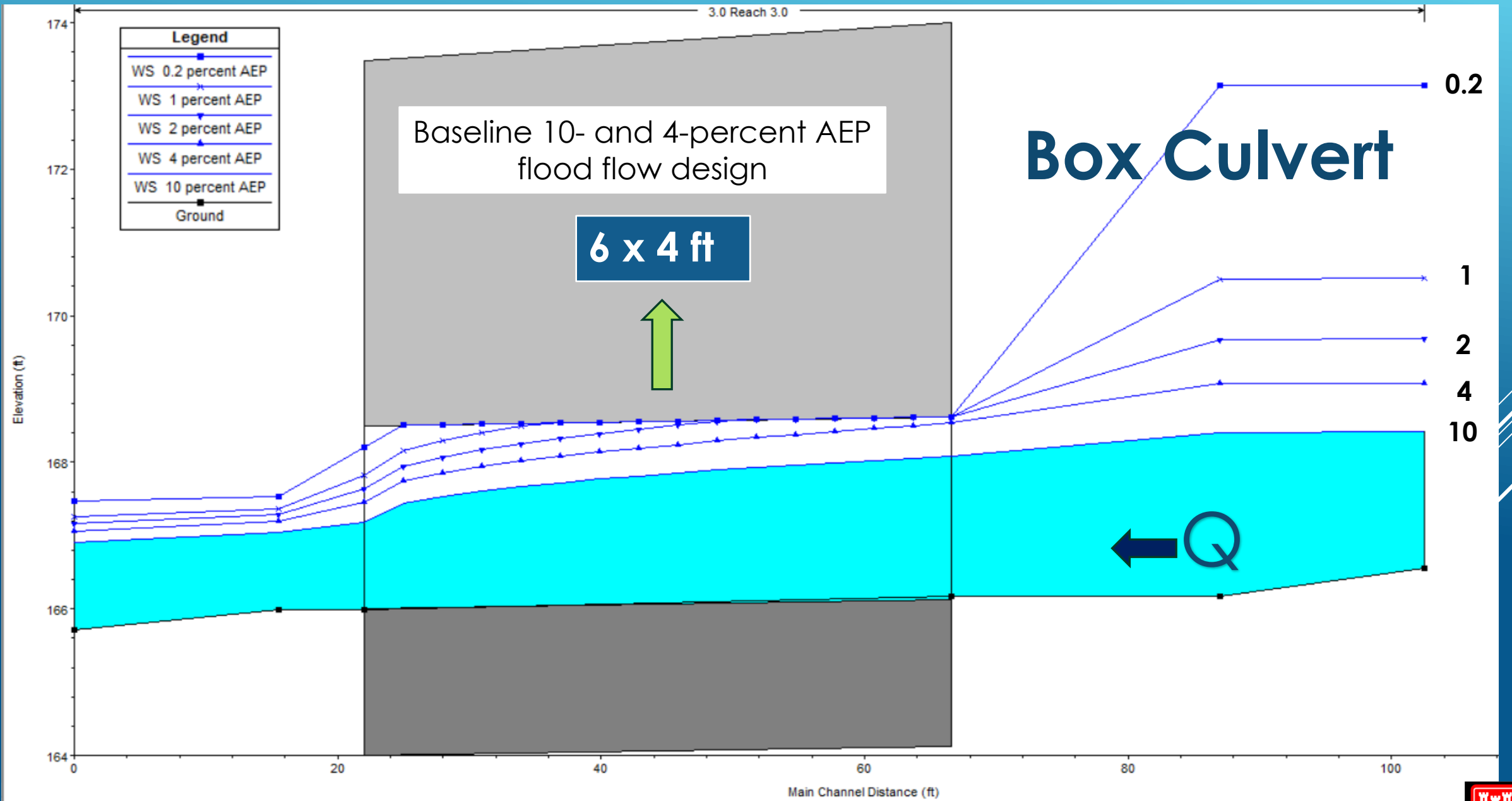


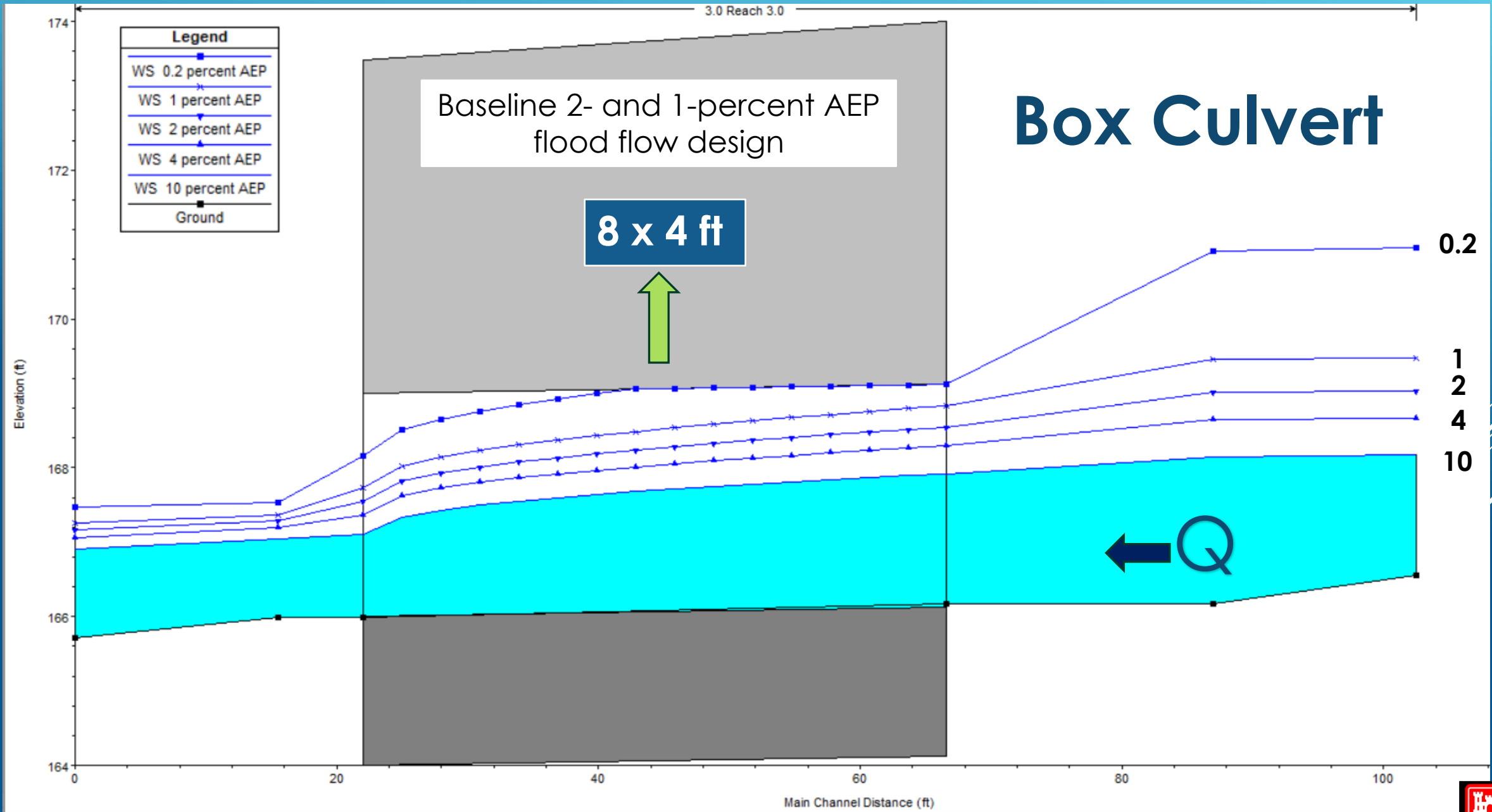
Box Culvert



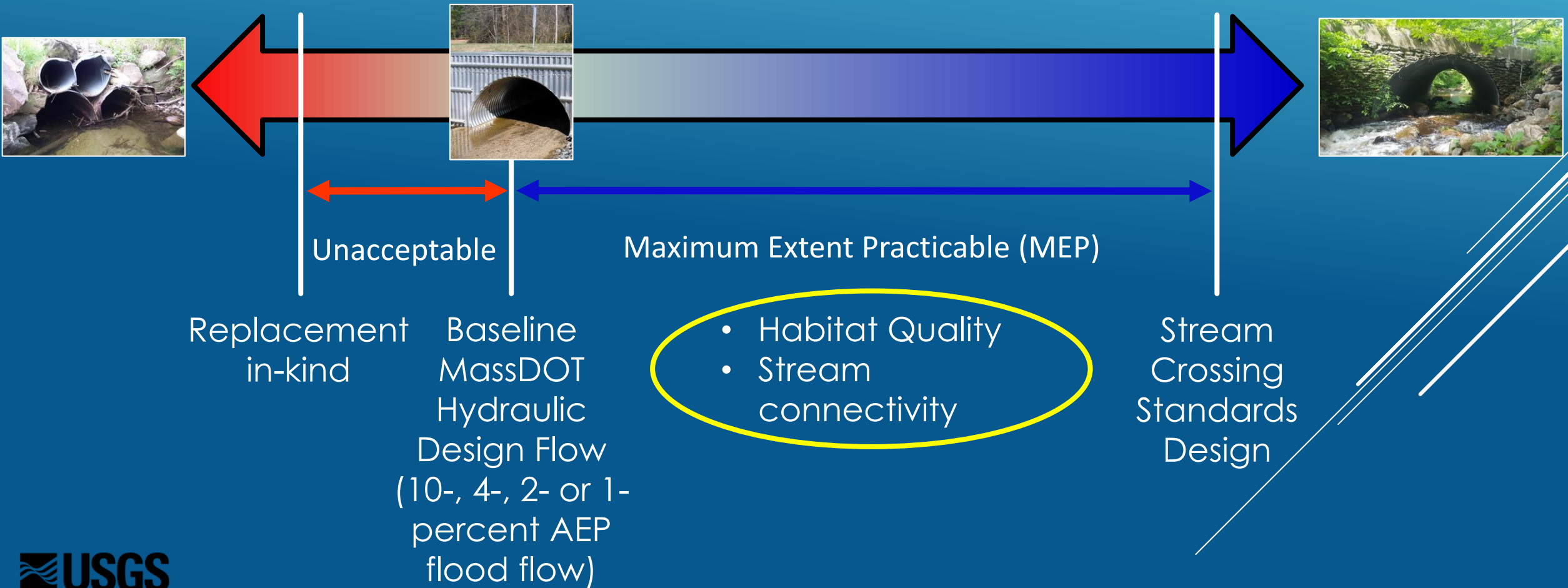
Box Culvert







STREAM HABITAT QUALITY AND CONNECTIVITY CHARACTERISTICS



HABITAT QUALITY



BioMap Aquatic Score



Coldwater Fisheries Resource



Diadromous Fish Run



Area of Critical Environmental Concern



Wild & Scenic River



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

STREAM CONNECTIVITY RESTORATION POTENTIAL

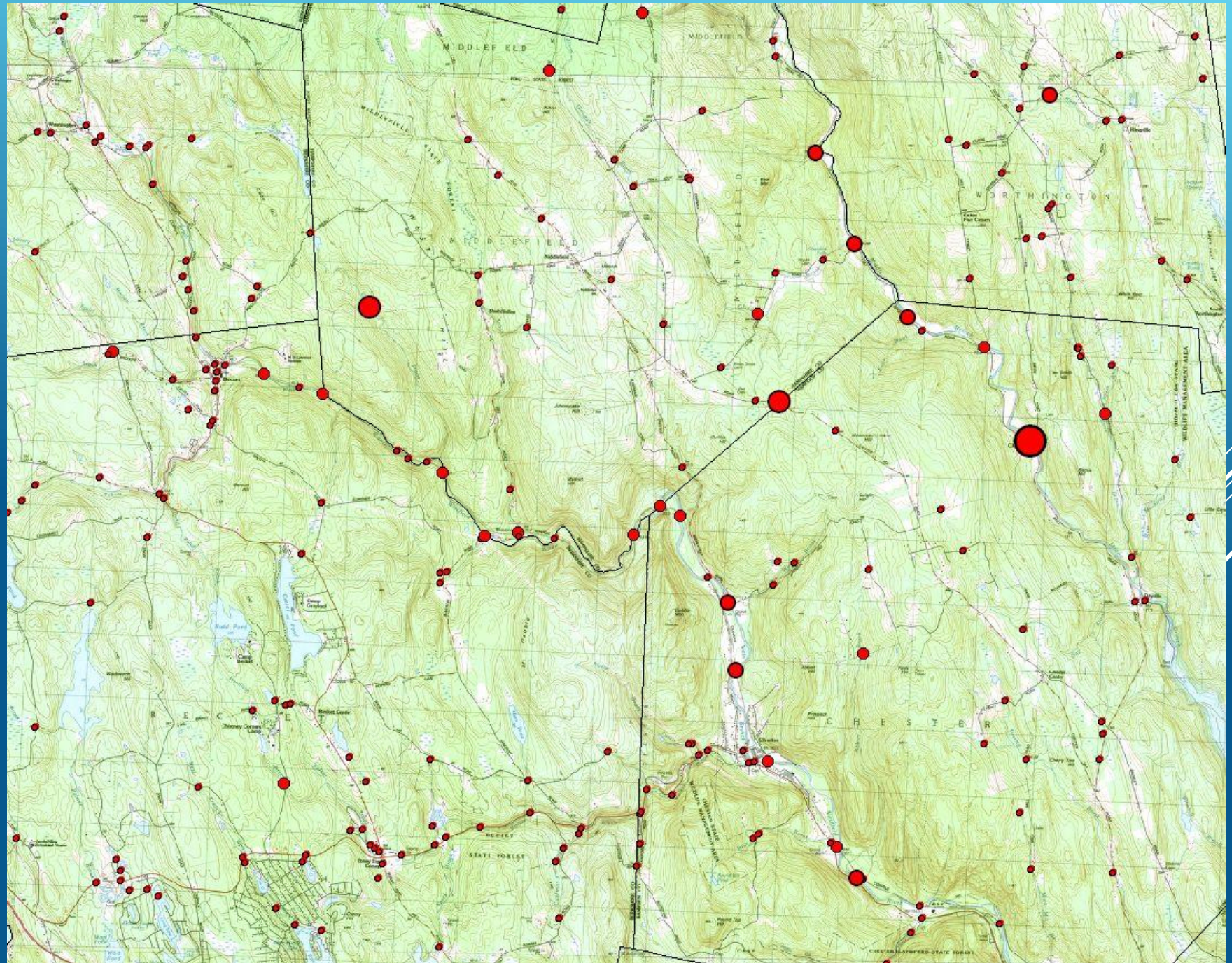
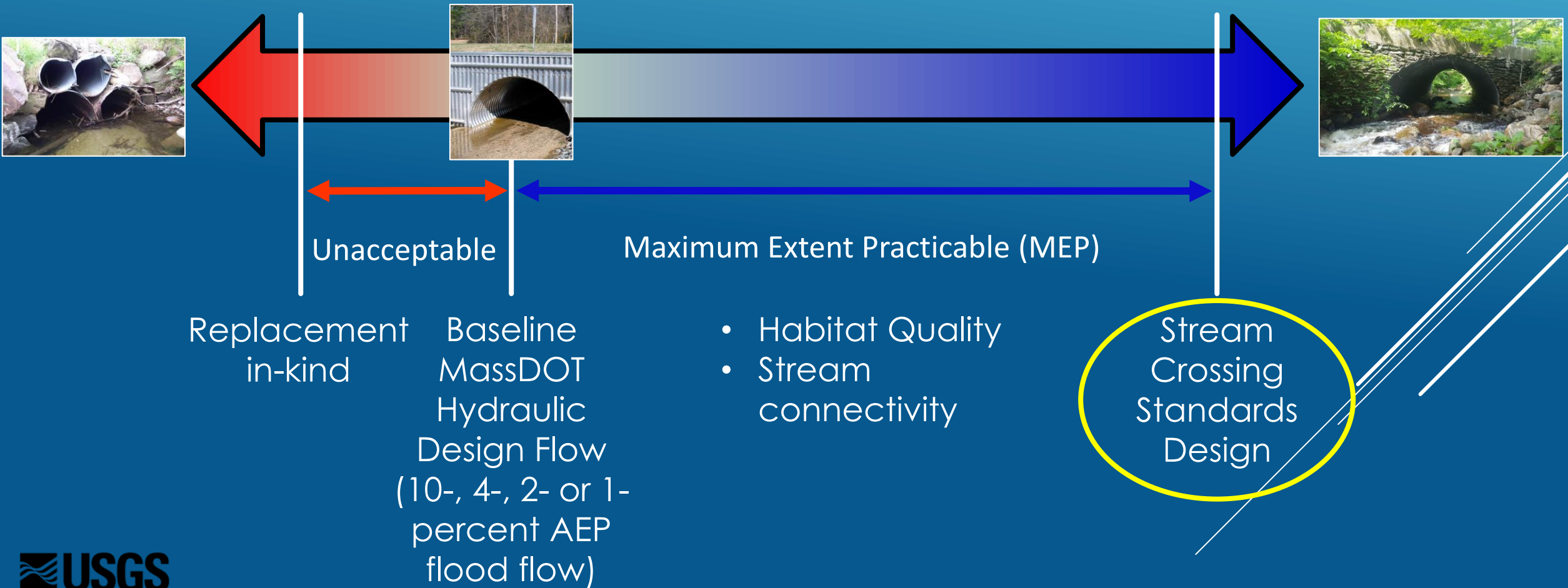
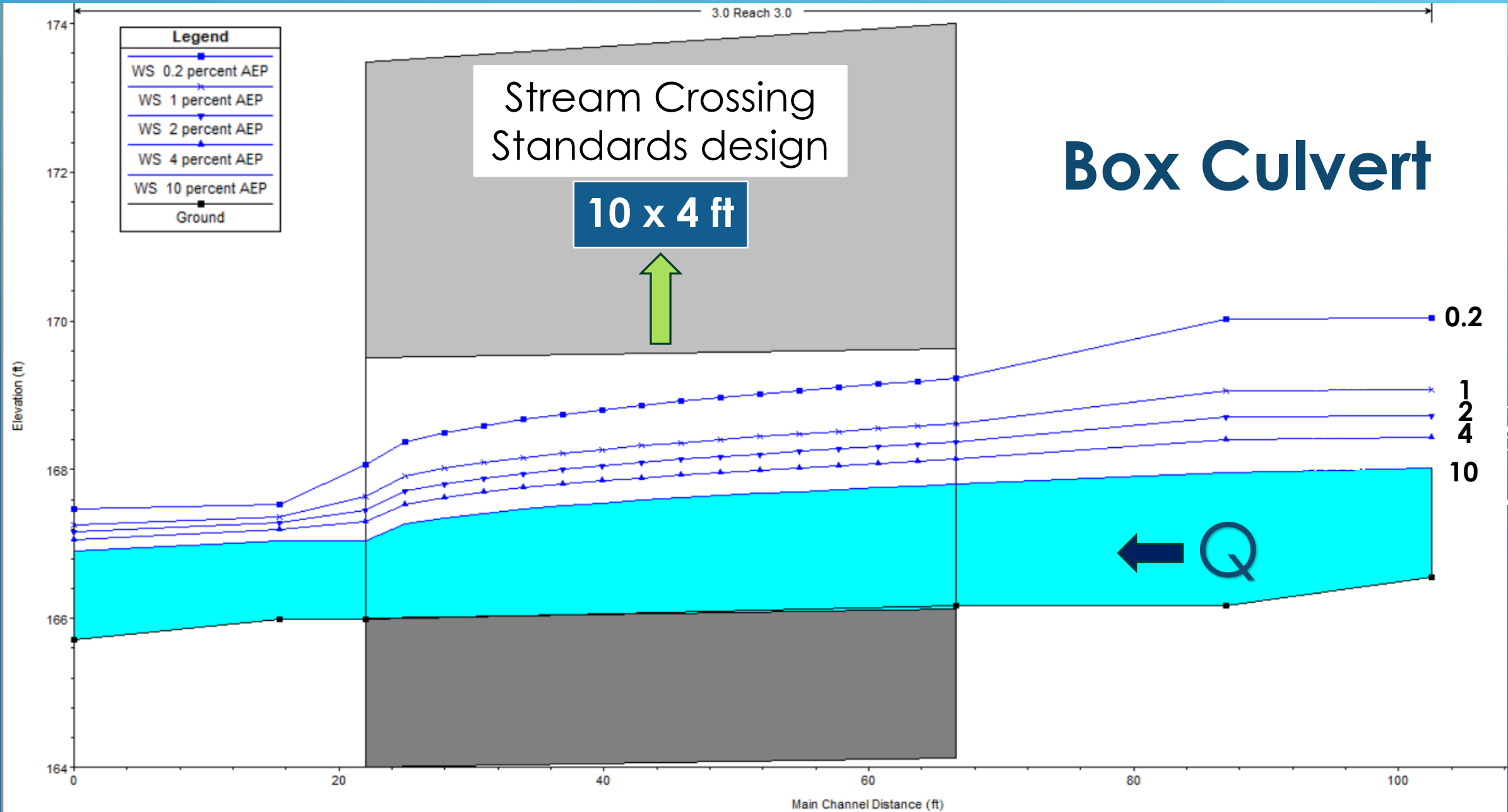


Photo courtesy of
University of
Massachusetts at
Amherst, Conservation
Assessment and
Prioritization System



STREAM CROSSING STANDARDS DESIGN





STREAMSTATS WEB APPLICATION

The screenshot displays the USGS StreamStats web application interface. The top left features the USGS logo and the text "StreamStats science for a changing world". The top right contains navigation links: "Batch Processor", "Report", "About", and "Help".

On the left side, there is a sidebar with the following elements:

- "SELECT A STATE / REGION" dropdown menu set to "Massachusetts".
- "IDENTIFY A STUDY AREA" button.
- "Step 1: Zoom in to level 15 or greater to enable the delineation tool" instruction.
- "Delineate" button.
- "SELECT SCENARIOS" dropdown menu.
- "BUILD A REPORT" dropdown menu.
- "POWERED BY WIM" text.
- Links for "USGS Home", "Contact USGS", "Search USGS", "Accessibility", "FOIA", "Privacy", and "Policy & Notices".

The main area is a map of Massachusetts showing stream networks. A popup window titled "Stream Crossings" is open over a specific location, displaying the following information:

- NAACC Code: xy4268702471724536
- Habitat Quality Score: High Quality
- Restoration Connectivity Potential Score: High Restoration Potential
- Hydraulic Design Flood: 10 Year
- A "Build Report" button.

On the right side, there is a "Layers" panel with the following options:

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

At the bottom left of the map, a status box shows:

- Zoom Level: 13
- Map Scale: 1:72,223
- Lat: 42.6721, Lon: -71.6788

The map includes a scale bar (1 km / 3000 ft) and the Leaflet/Esri logo in the bottom right corner.



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

STREAMSTATS WEB APPLICATION

The interface includes a sidebar with the following sections:

- USGS StreamStats** logo and tagline: "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
 - Open Report
- POWERED BY WIM**
- Footer: USGS Home, Contact USGS, Search USGS, Accessibility, FOIA, Privacy, Policy & Notices

Disclaimer for preliminary culvert designs:
The intent of this tool is to provide a preliminary design. Not all design consideration (i.e. specific bathymetric elevations, backwater effect, freeboard, adjacent structures, soil type, scour, channel migration, etc.) could be incorporated into this preliminary design tool. Field review and verification should be performed, and the final design should be reviewed by a licensed engineer.

Highlighted values do not meet the Stream Crossing Standards

Preliminary 3-Sided Box Culvert Design meeting the 10- and 25-Year Flood Flows and Stream Crossing Standards

Parameter Name	10-Yr Flow	25-Yr Flow	Meets SCS	Unit
Box Culvert Span	6.0	7.0	11.0	Feet
Box Culvert Height	2.0		2.0	Feet
Box Culvert Length	45.5	45.5	45.5	Feet
Box Culvert Area	12.0	14.0	22.0	Square Feet
Box Culvert Material	Concrete	Concrete	Concrete	
Box Culvert Upstream Channel Invert Elevation	385.8	385.8	385.8	Feet - NAVD88
Box Culvert Downstream Channel Invert Elevation	384.4	384.4	384.4	Feet - NAVD88
Box Culvert Road Deck Elevation	389.3	389.3	389.3	Feet - NAVD88
Box Embedment	None	None	None	Feet
Box Substrate	Natural	Natural	Natural	
Box Span Ratio	0.7	0.8	1.3	
Box Openness Ratio	0.26	0.31	0.48	

Hydraulic Model Citations

Massachusetts Stream Crossing Citation
Sturtevant, L.P., and McCarthy, B.A., 2024, Massachusetts stream crossing project data web map service: U.S. Geological Survey data release, <https://doi.org/10.5066/P9BL9CW4>.

The map interface includes a top navigation bar with "Batch Processor", "Report", "About", and "Help". A "Layers" panel on the right shows the following layers:

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

Download HEC-RAS files

Download

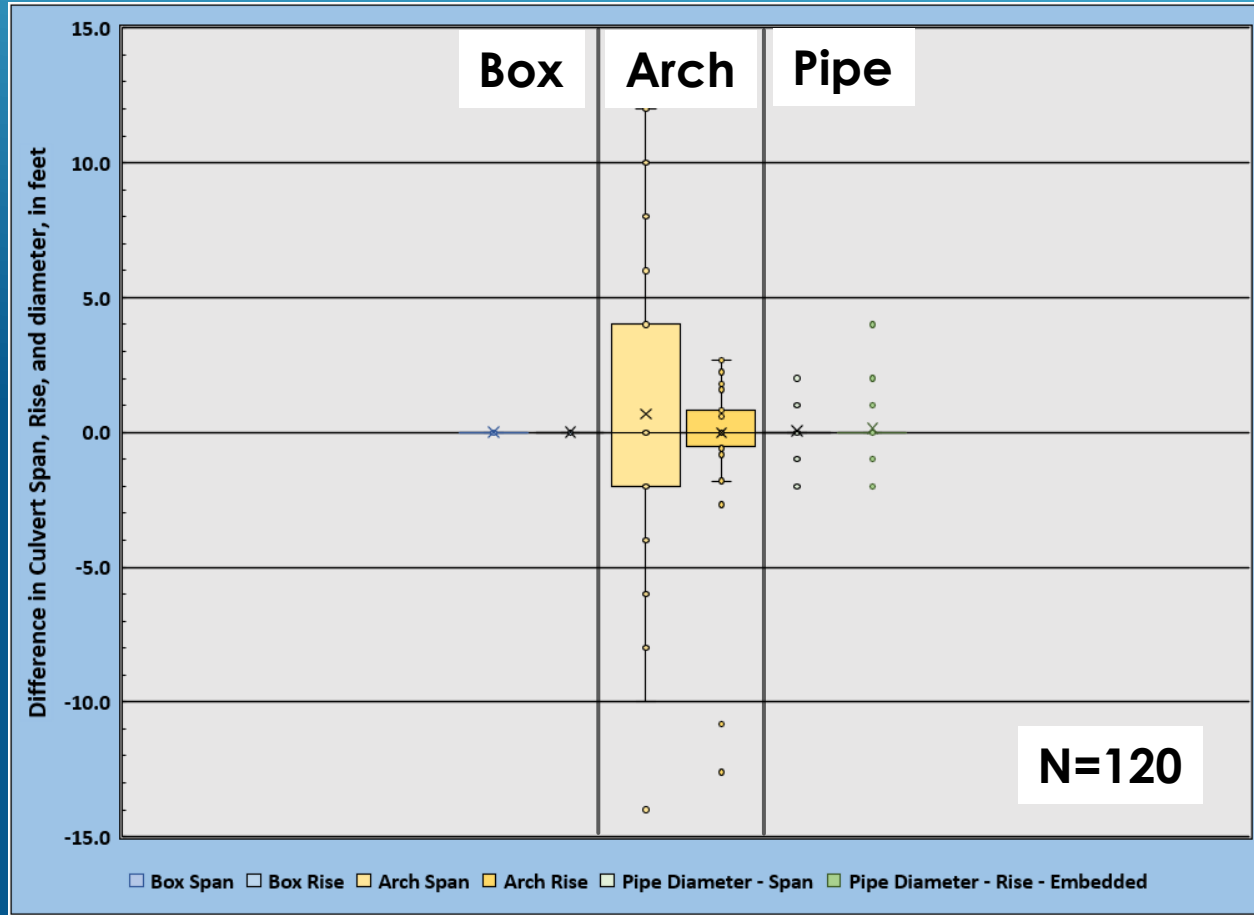
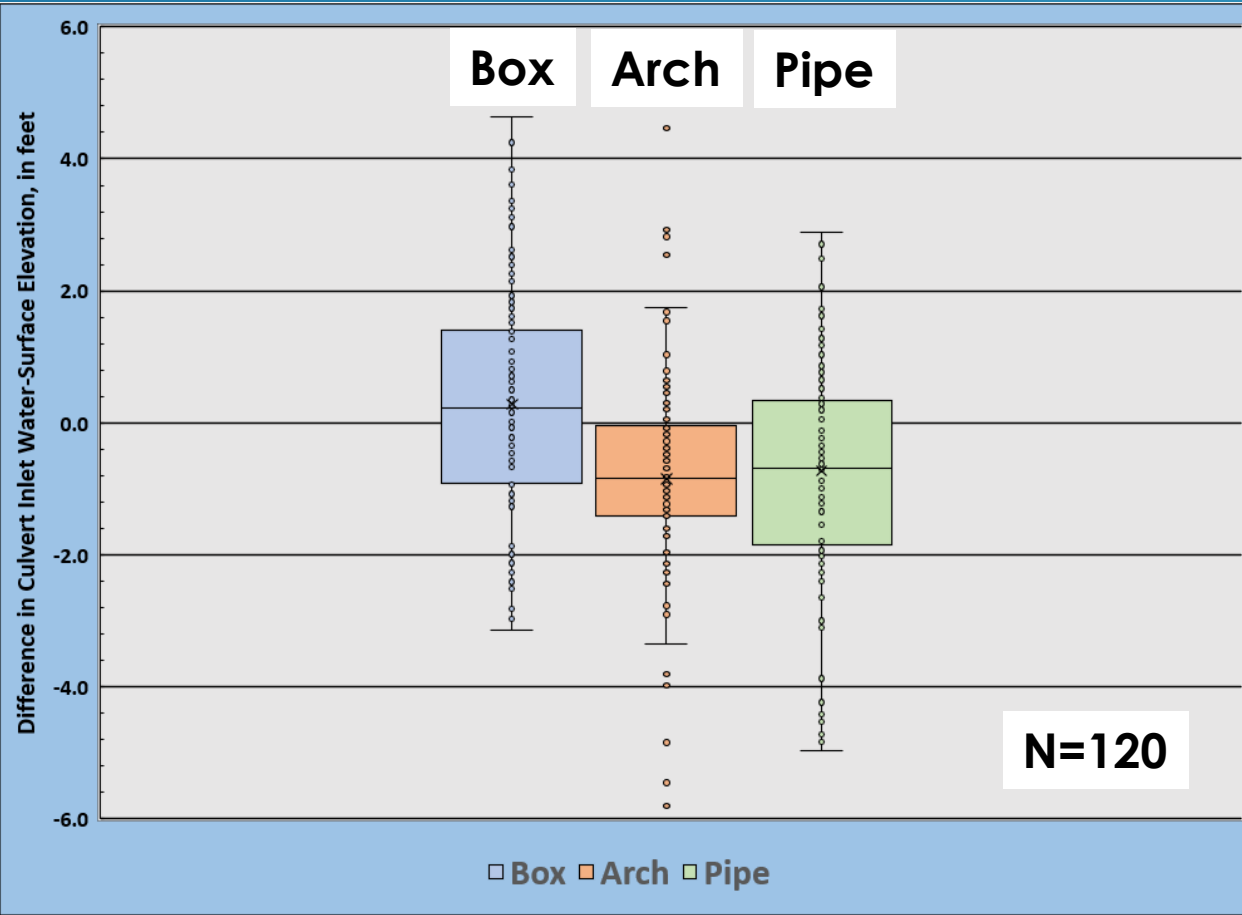
- GeoJSON
- CSV
- ShapeFile
- KML
- HEC-RAS Model Files



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

Comparison of GIS- and Field-Based Hydraulic Models

- Have 46 comparison sites with both GIS- and field-based hydraulic models across Massachusetts
- Comparing selected model inputs and outputs, such as thalweg elevations, water-surface elevations, velocities, culvert dimensions, etc.



Questions

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, Hans Vraga, Pete McCarthy, and Pete Steeves

Mass DEP and UMass Teams

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



Project Webpage

