VULNERABILITY ASSESSMENT OF ROAD / STREAM CROSSINGS IN THE DEERFIELD WATERSHED

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GOALS OF STUDY

To develop an innovative systems-based approach to improve the assessment, prioritization, planning, protection and maintenance of roads and road-stream crossings that:

1. **Is proactive with respect to upgrading structures to account for climate change;**
2. **Complements existing MassDOT project development and bridge design processes; and**
3. **Provides a decision-support tool that can be used during project planning and development phases**

PROJECT PARTICIPANTS

- **Massachusetts Department of Transportation**
  - **Highway Division: Environmental Section, Districts One and Two, Bridge Section**
  - **Planning / GIS**
- **UMass Amherst**
  - **Water Resources Research Center**
  - **Massachusetts Geological Survey**
  - **Department of Environmental Conservation**
  - **Department of Geosciences**
  - **Northeast Climate Science Center**
  - **School of Computer Science**
  - **The Center for Agriculture, Food and the Environment**
- **USGS**
- **Trout Unlimited**
- **Milone & MacBroom**

FHWA FRAMEWORK

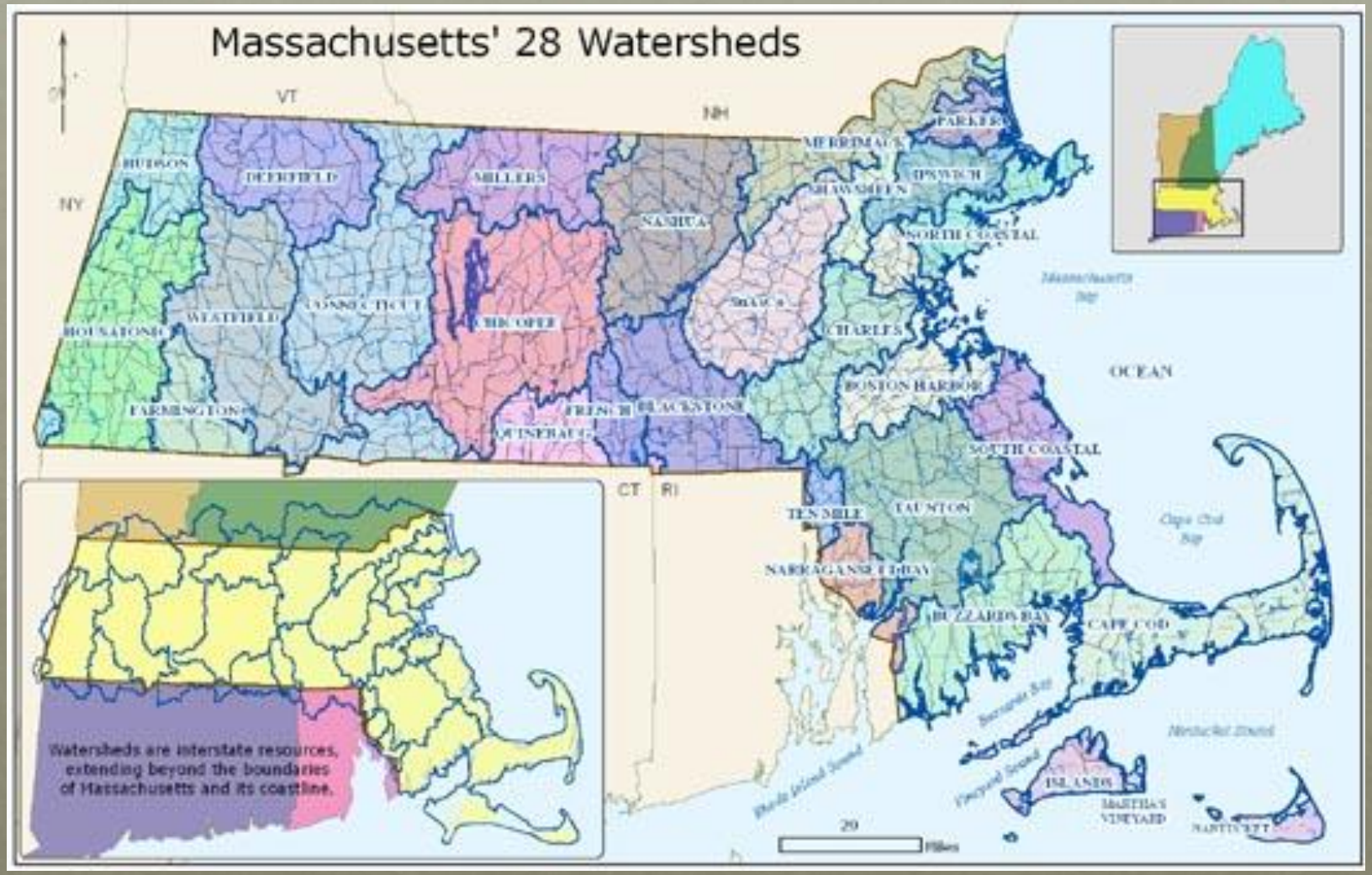
- **Climate change & extreme weather vulnerability assessment framework**
- **Vulnerability made up of an asset's exposure (will its location be impacted?) sensitivity (how will it handle the impacts?) and adaptive capacity (can it adjust to handle changes)**
- **Risk made up of the likelihood that an asset will be impacted and the severity of the impact**

MASSACHUSETTS AND ADAPTATION

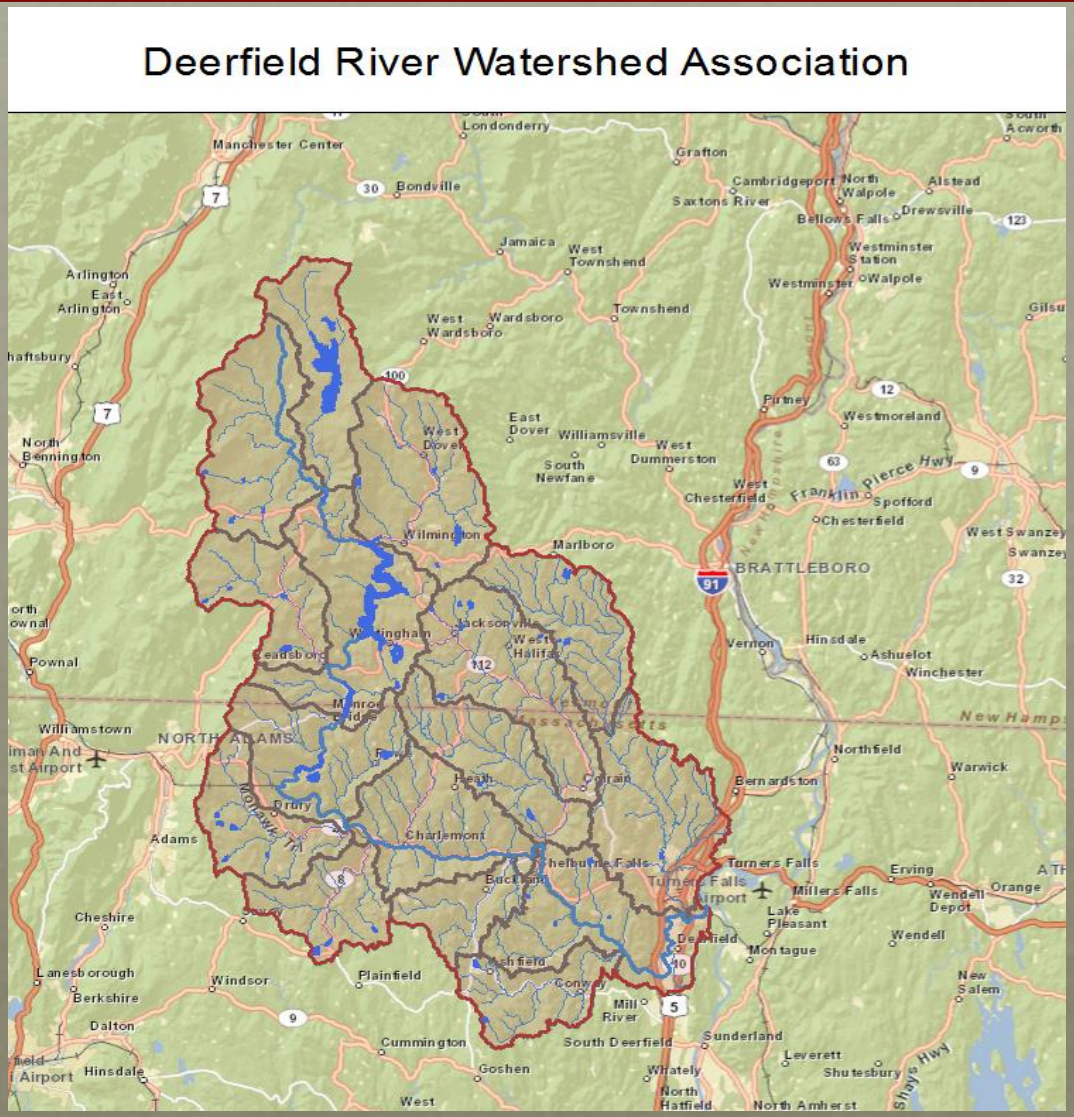
- **2008: Global Warming Solutions Act required a climate change adaptation report**
- **2011: Massachusetts Climate Change Adaptation Report – included suggested actions for MassDOT**
- **2014: Gov. Patrick announces $50 million for climate change preparedness**
- **Gubernatorial directive: MassDOT must do a statewide climate vulnerability assessment for all facilities & adopt a Climate Adaptation Plan by 2015**
- **This project is looking ahead to next steps after that**

FOCUS AREA

Deerfield River Watershed



DEERFIELD RIVER WATERSHED



IRENE

AN INTEGRATED APPROACH

Develop an integrated approach which reduces uncertainties and improves prioritization schemes by including:

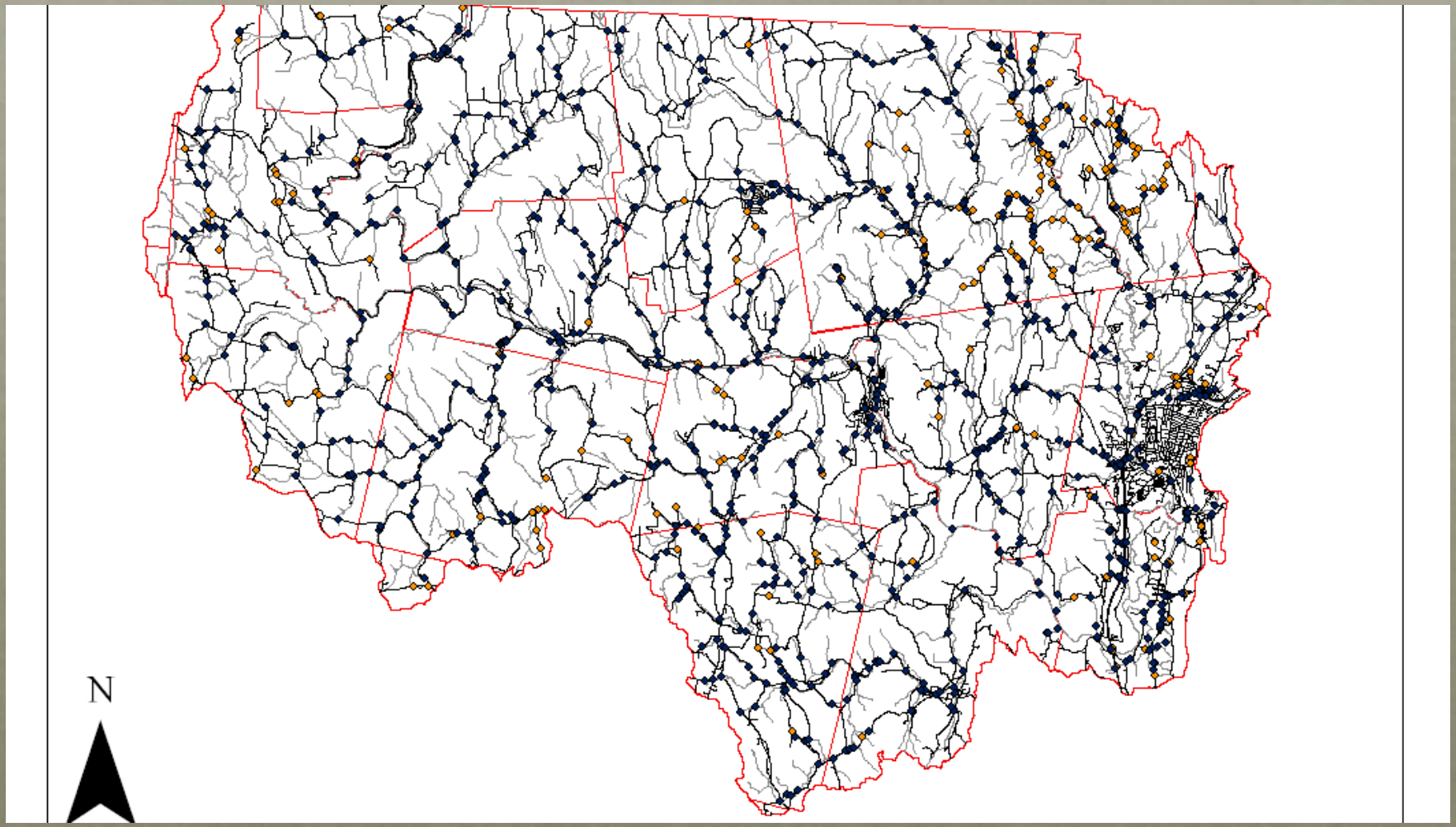
Hydrologic/hydraulic risk

Geomorphic risk

Ecological services

Potential disruption of local services

DEERFIELD WATERSHED CROSSINGS



DATA COLLECTION

TASK 1 – Collection of existing relevant data

- **MassDOT and district data**
- **USGS data**
- **Modeling data**
  - **Hydrologic data**
  - **Hydraulic data**
  - **Reservoir operations data**
- **Literature/Other Studies**
  - **i.e., FEMA policies and precedents**

PASSABILITY AND CONDITION

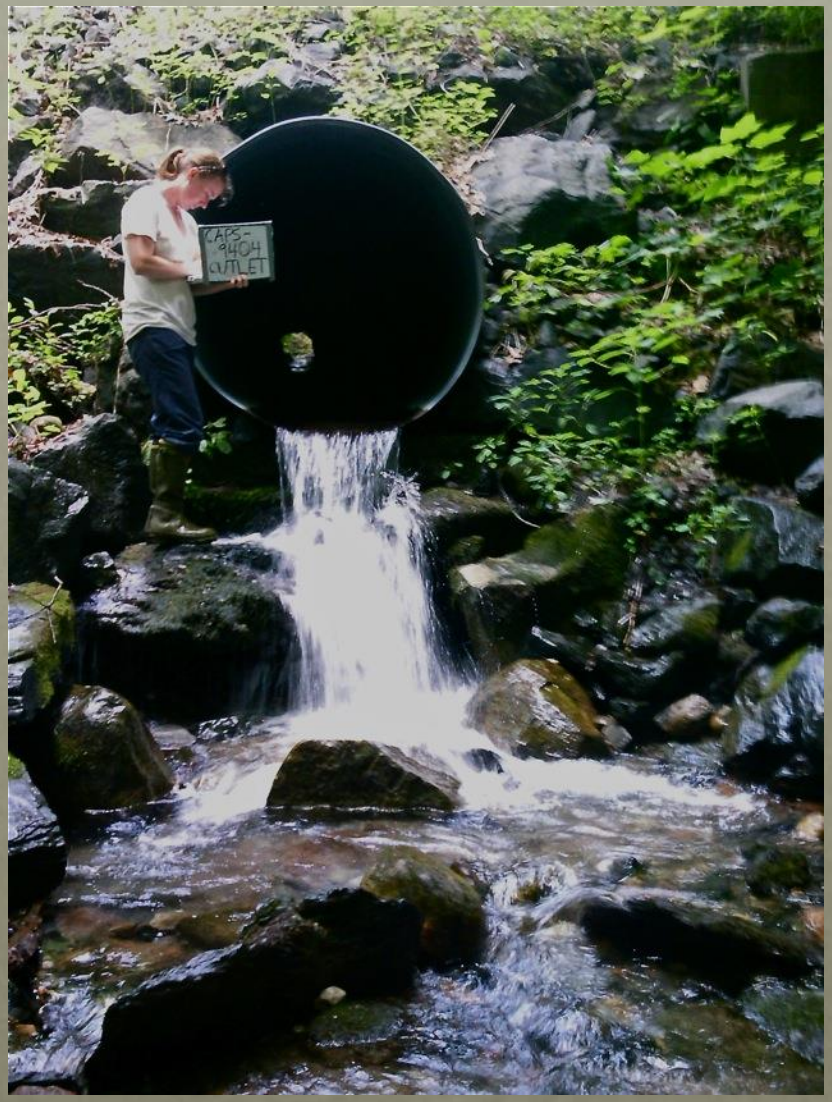
TASKS 2 & 3 – Stream crossing passability and condition assessment

- **Comprehensive aquatic passability & rapid condition assessment of an estimated 850 state and local stream crossing structures in MA**
- **Trout Unlimited (TU) trained technicians are collecting data**
- **Milone & MacBroom, Inc. (MMI) – licensed PEs – will field check data at 10 percent of the higher risk culvert sites**

FIELD ASSESSMENTS

3 Field Forms

- **UMass-Amherst River and Stream Continuity Project Database Form**
- **MassDOT Culvert Crossing Condition Form**
- **Trout Unlimited Field Form – truncated to reduce redundancy**



FIELD ASSESSMENT FOR AOP SCORES

- AOP passability based on:*
  - Outlet drop
  - Inlet drop
  - Physical barriers
  - Water velocity
  - Water depth
  - Crossing constriction
  - Crossing embedment
  - Crossing substrate
  - Tailwater scour pool
  - Tailwater armoring
  - Structure height
  - Structure openness
- Additional metrics for
  - Structure type and dimensions
  - % bankfull constriction
  - Culvert slope
  - Sediment erosion and deposition

* River & Stream Continuity Project Road-Stream Crossing Assessment protocol

Culvert Condition Survey

- **Rapid Condition Assessment developed by the River & Stream Continuity Project for use by lay observers**
- **Culverts only (no bridges)**
- **Multiple uses (asset management)**
- **'Ends Only' assessment**
- **Non-technical, visual assessment of condition**
  - **Assessment at inlet and outlet**
  - **Culvert barrel integrity**
  - **Condition of culvert appurtenances**
  - **Tentative identification of 'poor' or 'critical' conditions**
  - **Intended to draw attention to structures that need further investigation**

ADDITIONAL FIELD DATA COLLECTION

- **Qualitative survey based on all organizations' interests**
  - **bank stability**
  - **scour around structure**
  - **physical structural deterioration**
  - **dominant substrate**
  - **sediment transport**
  - **wildlife and forest characteristics**

- **Pebble counts and substrate photos with scale**

CRITICAL LINKAGES

TASK 4 – Conduct Aquatic Critical Linkages Analysis

- **Utilize the Conservation Assessment and Prioritization System (CAPS) to rerun the Critical Linkages analysis for the Deerfield River**
- **Critical Linkages involves scenario analysis to assess the potential for restoring functional connectivity via culvert and bridge replacement/upgrade**
- **Crossings will be rated based on restoration potential for aquatic connectivity**
- **Critical Linkages presentation on Wednesday**

FLUVIAL GEOMORPHIC ASSESSMENT (FGM)

TASK 5 – Fluvial Geomorphic Assessment

- **Goal: Create Screening Tool to Assess Culvert Vulnerability to Erosion and Deposition**
- **Procedure:**
  1. **Compute Stream Power with GIS, Watershed Scale**
  2. **Identify Critical Thresholds**
  3. **Rank Channel Vulnerability**
  4. **Verify Field Data at High Risk Culverts**
  5. **Detailed Assessment at High Risk Culverts**
  6. **Culvert Vulnerability Ranking**

FGM PHASE I

Coarse Screening

EROSION RISK (COARSE SCREEN)			
Specific Stream Power (W/m^2)	0-60	60-300	>300
Natural confinement by valley (no.)	>10	6-10	<6
Percent (%) increase in confinement by existing permanent structure	<10	10-25	>25
Level of Risk	**LOW**	**MODERATE**	**HIGH**
DEPOSITION RISK (COARSE SCREEN)			
Specific Stream Power (W/m^2)	>300	60-300	0-60
Number of 5% or larger slope decrease areas	0	1	≥2
Number of 3rd order or larger confluence areas	0	1	>1
Number of road crossings	0	1-2	>2
Level of Risk	**LOW**	**MODERATE**	**HIGH**

FGM CULVERT VULNERABILITY

Characteristic	Low	Medium	High
Invert	Structural	Cobbles/riprap	Soil/sediment
Bed Material	Bedrock	Riprap	Silt/Sand/Gravel
Flow Capacity	>50 year	10-50 year	<10 year
Slope	Matches Channel	Channel ±50%	Channel< >50%
Culvert width / channel bankfull width	>1.2	0.75 - 1.2	<0.75
Culvert Material	Concrete	Corrugated Steel	Masonry
Culvert Condition	Good	Fair	Poor

D50, bankfull and flood prone width, allowable headwater depth, entrance geometry, presence and type of wing wall or end walls, floodplain width to culvert width ratio, bankfull width to culvert width ratio, eccentricity, skewness, substrate size and channel resistance.

FGM CROSSING VULNERABILITY

	Culvert Vulnerability		
Channel Vulnerability	**Low**	**Medium**	**High**
Low	1	2	3
Medium	2	4	5
High	3	6	7

CULVERT CAPACITY

TASK 6 – Culvert Capacity Calculations

- **Determine the design flow capacity of road-stream crossings within the Deerfield Watershed, focusing on culverts**
  - **May be available from MassDOT or Districts**
  - **Other will be based on Hydraulic Design Series 5 (HDS-5) methodologies**
  - **Data collected for tasks focusing on aquatic organism passage, culvert condition, and FGM vulnerability will be used in the calculations**

FUTURE CLIMATE

TASK 8 – Future Climate Assessment

- **Will leverage air temperature and precipitation data archived under the North American Regional Climate Change Assessment Program (NARCCAP)**
- **Climate data to be utilized:**
  - **NRCC (present)**
  - **NOAA Atlas 14 – not yet available (present)**
  - **NARCCAP predictions (present, mid-century)**
  - **PRECIS model predictions (2100)**

CLIMATE METHODS

TASK 8 CONT.– Future Climate Assessment

- **NARCCAP "micro" overview**
  - **Dynamical downscaling - high computational cost but results in high spatial-resolution data (50 km)**
  - **Daily and 3-hourly data for two 30-year periods, 1971 – 2000 (present) and 2041 – 2070 (mid-century)**
  - **Available statistically downscaled data will be used to compliment the NARCCAP data**
- **PRECIS "micro" overview**
  - **Developed by researchers at the UK Met Office Hadley Centre**
  - **Used previously to study impacts of climate change across Central America and Mexico**

VULNERABILITY ASSESSMENT

TASKS 7, 9, 10 – Assessment of Current and Future Vulnerability due to Extreme Flows

- **Evaluate risk of failure due to hydrologic conditions under current, mid-, and end-century climate conditions**
- **Focus on the shift of a culvert to risk from one category to another (moderate to high) rather than specific Q numbers**
- **Risk will be based on comparing predicted flows to the culvert capacity**
- **Utilize a range of methodologies to identify strengths, weaknesses and sensitivities**

VULNERABILITY ASSESSMENT

TASKS 7, 9, 10 cont. – Assessment of Current and Future Vulnerability due to Extreme Flows

- **Discharge estimation methodologies**
  - **NRCS TR-55**
  - **USGS MA RPFE system**
  - **Statistical stream flow models (adapting methods of CRUISE and StreamStats)**
  - **Advanced (physically based) discharge estimation methods / models**
  - **All methods not applicable to all locations**

VULNERABILITY ASSESSMENT

Task 10 – Advanced Discharge Estimation Methods

- Assessment of the most applicable more advanced hydrologic-hydraulic models to implement
  - PRMS
  - HEC-HMS
  - HEC-ResSim
- Implementation of the model(s) at a subset of locations
- Categorization of culvert vulnerability under current and future climate based on these model results

METHODS COMPARISON

TASK 10 – Advanced Discharge Estimation Methods

Advanced Estimation Method Questions

- **Impact of model choice on outcomes**
- **Usability of previously performed work**
- **Impact of incorporating climate change**
- **Value of more specific information / results**

ECOLOGICAL SERVICES

TASK 11 – Impact of Future Climate on Ecological Services

- **Stream Temperature Model**
  - **Determine how air and stream temperature are synchronized**
  - **Utilized as input to…**
- **Brook Trout Occupancy Model**
  - **Used to identify important habitat areas in watershed**
  - **Compare to location of culverts in relation to areas of poor, high quality, and refugia aquatic habitat**

LOCAL DISRUPTION

TASK 12 – Potential Disruption of Local Services

- **Map "first responder" services (e.g., police stations, hospitals) and major utility locations (e.g., electrical substations, water treatment facilities)**
- **Use scenario analysis to assess the interconnected network under current conditions and compare it to a scenario with a failure**
- **Ranking of road-stream crossings and road segments based on disruption potential**
- **Development of more efficient computer algorithms that will allow for more powerful optimization modeling**

DECISION SUPPORT

TASK 13 – Ranking and decision support matrix

- **Simple single scoring system (e.g., 0 to 9) similar to that used by MassDOT in bridge inspection reports**
- **Metrics and cutoffs between categories for each linked consideration to be developed to meet MassDOT needs**
- **Final product a decision support matrix that can be used to:**
  - **Prioritize structures for upgrade or other remedial action**
  - **Identify potential sources of funding**
  - **Lend itself to planning (transportation improvement, climate change mitigation, development of policies)**

EXAMPLE SCORING SYSTEM MATRIX

Score	Aquatic Connectivity Restoration Potential	Condition Hazard	Risk of Failure	Disruption of Services
1.0	Critical	Critical	Critical	Critical
0.9 – 0.99	Very High	Very High	Very High	Very High
0.8 – 0.89	High	High	High	High
0.7 – 0.79	Moderately High	Moderately High	Moderately High	Moderately High
0.6 – 0.69	Moderate	Moderate	Moderate	Moderate
0.5 – 0.59	Moderately Low	Moderately Low	Moderately Low	Moderately Low
0.4 – 0.49	Low	Low	Low	Low
0.3 – 0.39	Very Low	Very Low	Very Low	Very Low
0.2 – 0.29	Insignificant	Insignificant	Insignificant	Insignificant
0.1 – 0.19				
0.0 – 0.09				

EXAMPLE DECISION SUPPORT MATRIX

Crossing #	Aquatic Connectivity Restoration Potential	Condition Hazard	Risk of Failure	Disruption of Services
1	0.33	0.12	0.11	0.88
2	0.78	0.96	0.67	0.90
3	0.54	0.28	0.29	0.22
4	0.51	0.14	0.58	0.65
5	0.22	0.55	0.31	0.41
6	0.43	0.37	0.71	0.18
7	0.89	0.70	0.92	0.93
8	0.92	0.66	0.97	0.33
9	0.08	0.44	0.08	0.26
10	0.76	0.05	0.66	0.70

FINAL PRODUCTS

- **GIS layer rating potential vulnerabilities for roads and road-stream crossings under current climate conditions**
- **GIS layer rating potential vulnerabilities for roads and road-stream crossings under future climate conditions**
- **GIS layer showing high threat sites based on vulnerability and the potential to disrupt local services or emergency response routes**
- **GIS layer ranking road-stream crossings based on potential to restore river and stream connectivity via road-stream crossing rehabilitation or upgrade**

FINAL PRODUCTS

- **A decision support matrix - ranking each road-stream crossing based on condition, exposure, sensitivity, ecological passage, and transportation/emergency service disruption potential**
- **Recommendations focusing on the challenges, opportunities, and further work necessary for potentially applying this pilot program statewide**

QUESTIONS & DISCUSSION?

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