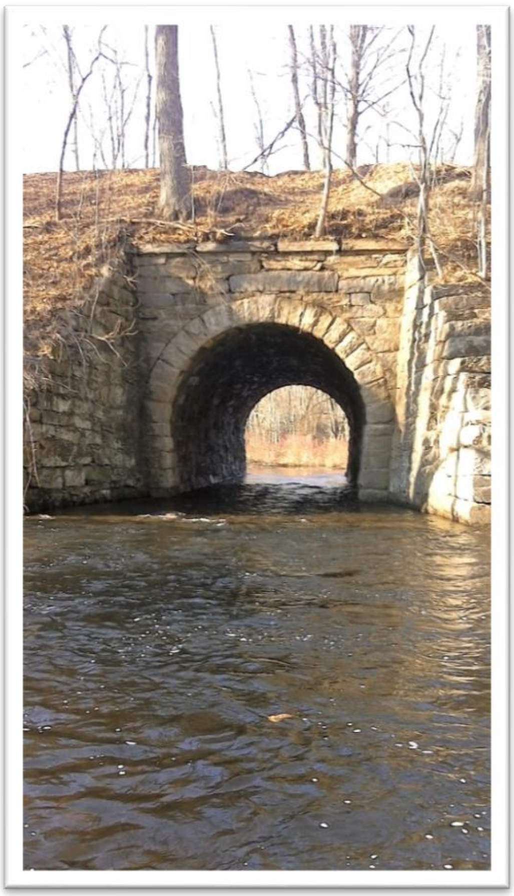
Planning for Flood Resilient and Fish-Friendly Road-Stream Crossings in the Naugatuck Valley

Towns of Oxford and Seymour, Connecticut

Final Grant Report



Prepared by the Housatonic Valley Association for the Town of Oxford

December 2018

Sponsored by grants from the Connecticut Institute for Resilience and Climate Adaptation and the Connecticut Community Foundation

The mission of the Connecticut Institute for Resilience and Climate Adaptation (CIRCA) is to increase the resilience and sustainability of vulnerable communities along Connecticut's coast and inland waterways to the growing impacts of climate change on the natural, built, and human environment. More information about CIRCA can be found at circa.uconn.edu

The mission of the Connecticut Community Foundation is to foster creative partnerships that build rewarding lives and thriving communities. More information about the Connecticut Community Foundation can be found at conncf.org

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EXECUTIVE SUMMARY

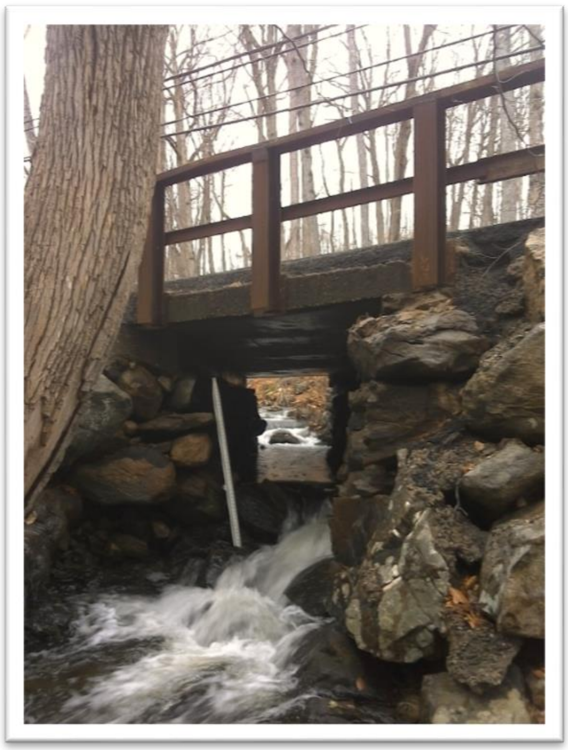
As climate change contributes to increasing temperatures and more frequent flood events in the Northeast, it is crucial to adapt local management strategies to ensure resilient infrastructure and biodiversity. The Towns of Oxford and Seymour, in partnership with the Housatonic Valley Association (HVA) and the University of Connecticut, worked toward reducing flood damage risk and improving stream habitat connectivity in the Naugatuck Valley by integrating climate change resiliency into the management of road-stream crossings. Project partners worked to assess all road-stream crossings in each town, identify the structures most at risk, and develop Road-Stream Crossing Inventory and Management Plan documents for both Oxford and Seymour. These documents will be adopted as an annex to each town's Natural Hazard Mitigation Plan, and position both Seymour and Oxford to take advantage of every opportunity to reduce flood risk at road-stream crossings. This includes but is not limited to capital planning and regular maintenance, hazard mitigation and habitat restoration grant programs, and recovery operations in the wake of the next flood.

PROJECT BACKGROUND AND CONTEXT

The Connecticut towns of Oxford and Seymour are located in a region known as the Naugatuck River Valley. In this area, historic and routine exposure to flooding hazards is a major concern[1] and these towns are particularly vulnerable due to their geography. Seymour is characterized by hills and steep slopes and is divided between the two major drainage basins of the Housatonic and Naugatuck rivers. Oxford contains several North-South trending ridges (e.g., Hulls's Hill, Mount Pisgah Ridge, Bowers Hill, Fivemile Hill, Jacks Hill, Towantic Hill, and Hunters Mountain), many parallel valleys, and is adjacent to large water bodies, such as Lake Zoar and the Housatonic

River.[1] Other major water bodies include the Little River, a tributary of the Housatonic, which flows parallel to a major road (Route 67) through the center of Oxford and into Seymour, crossing the road several times. Buildings along the Little River have historically experienced regular flooding in both towns.[2] In total, there are 125 miles of streams and rivers in these two towns; these waterways are overlaid with 234 miles of road. At every intersection between these two long, linear networks, there is a bridge, culvert, or some other mechanism for carrying the road over the stream. Flood risk at these road-stream crossings is increased when structures change stream shape and process, most commonly because they are undersized and/or misaligned.

Climate change is contributing to increased occurrences of intense rainfall and extreme precipitation events in northeastern U.S. towns, such as Oxford and Seymour. The most recent NOAA Precipitation Atlas for the Northeastern United States[3] shows a roughly 2-inch increase in the amount of rain expected during the 24-hour, 1% annual chance storm from Technical Paper Number 40[4]. Many road-stream crossings in Connecticut were designed and sized using data from this paper and now are undersized for current storm events. Increasing intense rainfall events in this region contribute to increased flooding of the Housatonic and Naugatuck Rivers, a situation exacerbated from December to April due to frozen ground and snowmelt contributing to greater volumes of run-off. Between 1900 and 2006, only six major floods had occurred in Oxford with the worst being the flood of 1955.[1] However, since 2006 the Housatonic and Naugatuck Rivers have experienced four federally-declared flood



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[1] Town of Oxford, Council of Governments of the Central Naugatuck Valley, and DELTA Environmental Services, Inc. (2006). Town of Oxford Hazard Mitigation Plan. Oxford, Connecticut.

[2] Seymour Planning and Zoning Commission. (2016). Town of Seymour, Connecticut: Plan of Conservation and Development.

[3] Perica, Sanja, Sandra Pavlovic, Michael St Laurent, Carl Trypaluk, Dale Unruh, Deborah Martin, and Orlan Wilhite. (2015). Precipitation-Frequency Atlas of the United States: Volume 10 Version 2.0: Northeastern States. Silver Spring, Maryland: National Oceanic and Atmospheric Administration.

[4] Hershfield, D. M. (1961). Rainfall frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from I to 100 Years (p. 65). Washington D.C.: U.S. Department of Commerce, Weather Board.

events[5]: the April 2007 Nor'Easter, 2011 Hurricane Irene, 2011 Tropical Storm Lee, and 2012 Superstorm Sandy. Oxford and Seymour residents that live along the Housatonic and Naugatuck River banks are particularly at risk of flood damage.

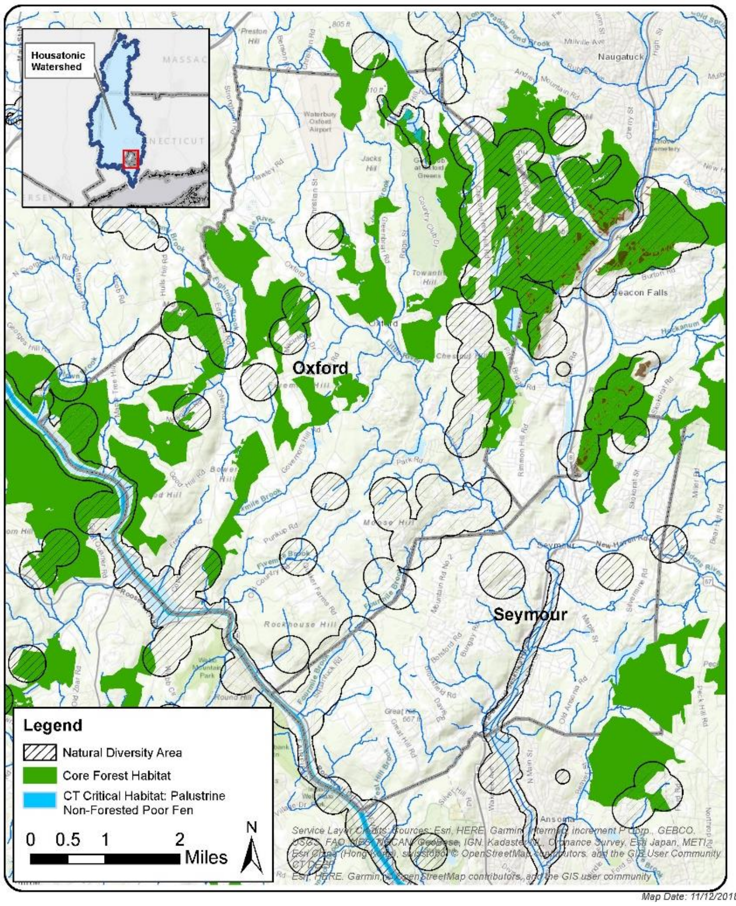


Figure 1 Protected space and areas of conservation interest in Oxford and Seymour (CT)

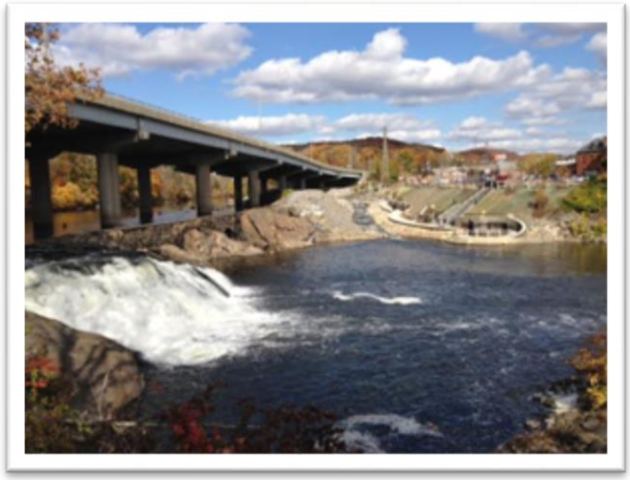
In addition to abundant water resources, each town contains open spaces and wildlife habitat that have been recognized and protected at both a town and state-level. Both towns contain multiple areas designated as core forest habitat and areas designated as Connecticut Natural Diversity Database (NDDB) areas (Figure 1). The Naugatuck State Park occurs in the northeast corner of Oxford and two areas designated as Connecticut Critical Habitat (Poor Fen) lie just north of the park. In Connecticut's State Wildlife Action Plan, unrestricted, free-flowing streams and cold headwater streams are identified as habitats of Greatest Conservation Need (GCN), home to important species such as eastern brook trout (*Salvelinus fontinalis*). The headwater streams of western Connecticut provide some of the best examples of these habitats in the state.

The Naugatuck River empties into the Housatonic River approximately 11 miles up from the Housatonic's confluence w

ith the Long Island Sound. This proximity to marine habitat makes the Naugatuck an important waterway for diadromous fish, those that spent part of their lives in freshwater and part in saltwater. The 2014 installation of a fish bypass channel at the Tingue Dam in Seymour opened up many miles of spawning habitat in the Naugatuck River to diadromous fish species such as, American shad (*Alosa sapidissima*), American eel (*Anguilla rostrate*), blueback herring (*Alosa aestivalis*), and alewife *(Alosa pseudoharengus*). Now that the Naugatuck River is open to

[5] According to FEMA, a significant flood event is one with 1,500 or more paid loses. Data retrieved from: https://www.fema.gov/significant-flood-events

downstream aquatic species, we can turn our focus to removing barriers to fish passage from tributaries of the Naugatuck, allowing these fish even greater access to high-quality headwater streams.



Tingue Dam Fish Bypass (Photo Credit: NOAA Fisheries)

This outstanding natural heritage is threatened by transportation infrastructure. Road-stream crossings that change the natural shape of a stream (most commonly because they are undersized and/or misaligned) can be more vulnerable to flood damage and can also block the movement of fish and wildlife along the stream corridor. There are approximately 226 road-stream crossings in the project area, and a large proportion of those are managed by the towns.

The results of HVA's ongoing research to identify flood risk and habitat barriers at road-stream crossings indicate that a significant proportion of these structures are management issues. In Oxford and Seymour, approximately 54% of the non-bridge structures that were assessed act as seasonal or year-round barriers to fish and wildlife movement (Table 1).

Table 1. Proportions of all non-bridge structures that were assessed in Oxford and Seymour (*n* = 164) in each Barrier category

Barrier Evaluation	Number of Culverts	Percentage
Severe barrier	27	16%
Significant barrier	17	10%
Moderate barrier	44	27%
Minor barrier	64	39%
Insignificant barrier	12	7%
No barrier (full passage)	0	0%

This proportion is consistent with the proportion of barrier structures observed in other towns, as well as at a regional level. We are also seeing interesting overlap between culverts that act as barriers to fish and wildlife and those that are likely to fail in a relatively short flood interval; research conducted by HVA at a regional level indicates that approximately half of all assessed barrier culverts in New York and Connecticut towns are likely at risk of failure (water on the road) in the 25-year recurrence interval flood (Figure 2; see Map on page 19 for other project towns).

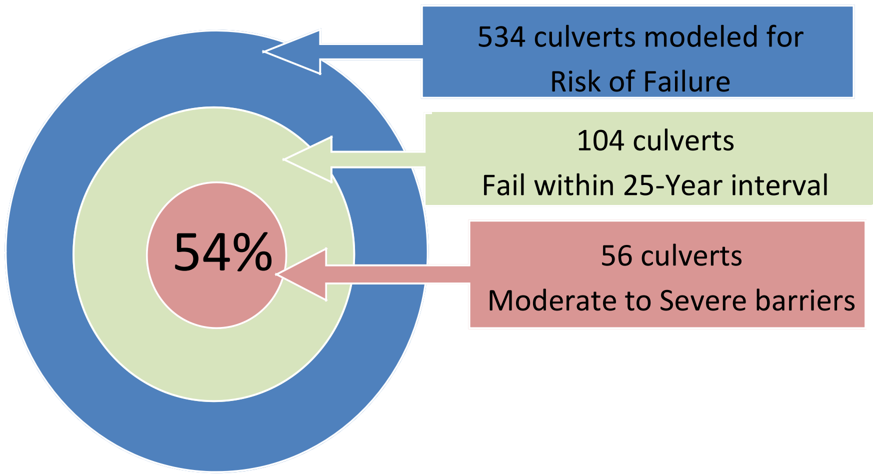


Figure 2 Regional results for all culverts modeled to-date for risk of failure in Connecticut and New York; these numbers show the overlap between culverts that act as barriers and that are likely to fail in relatively short flood intervals.

Given the large number of problem culverts and the fact that resources available for management are limited, a strategic approach that identifies structures where both flood risk and habitat restoration priorities can be addressed with a single intervention is essential.

Equally important, given the ubiquity of barrier road-stream crossings, is empowering local highway managers to address stream habitat connectivity issues with every road-stream crossing replacement. There is generally overlap between flood risk and habitat barrier issues at undersized/misaligned culverts, which presents an opportunity to help communities adopt Best Management Practices (BMPs) that address both issues as a matter of course in every replacement project. A piecemeal approach that focuses only on regionally important priorities is inadequate to comprehensively restoring stream habitat connectivity within the Housatonic Valley Watershed. We need to leverage work at these high-priority structures to demonstrate design techniques that allow natural stream processes to operate through a crossing structure, reducing flood risk and the need for regular maintenance in addition to restoring fish and wildlife passage. Furthermore, we need to leverage these projects to demonstrate to highway managers and local decision-makers that using these BMPs will be cost-effective over the life of the structure. The Town-Scale Road-Stream Crossing Management Planning process was developed by HVA to accomplish these goals.

PROJECT DESCRIPTION

The towns of Oxford and Seymour partnered with HVA to conduct field assessments of all road-stream crossings in each town and develop town-specific Road-Stream Crossing Inventory and Management Plan documents. In 2017, HVA began to conduct field assessments of all the road-stream crossings in each of these towns. Assessments were completed in June 2018, with a total of 131 assessed crossings in the Town of Oxford and 95 assessed crossings in the Town of Seymour. During these field surveys, HVA staff and volunteers collected information about the stream channel and the crossing structure itself, which help in determining if crossings are barriers to fish and wildlife. Road-stream crossings were evaluated using the protocol developed by the North Atlantic Aquatic Connectivity Collaborative (NAACC); a partnership of universities, conservation organizations, and state and federal agencies focused on improving aquatic connectivity across a region spanning West Virginia to Maine.[6] Field data was logged into a region-wide database and an algorithm is used to assign a barrier evaluation ranking to each structure, based on how much of a barrier the structure is to aquatic organism passage (i.e., none, insignificant, minor, moderate, significant, severe). Based on initial results for the Towns of Seymour and Oxford, 52% of all non-bridge structures (e.g., culverts) in Oxford and 56% of non-bridge structures in Seymour are ranked as moderate or worse barriers.

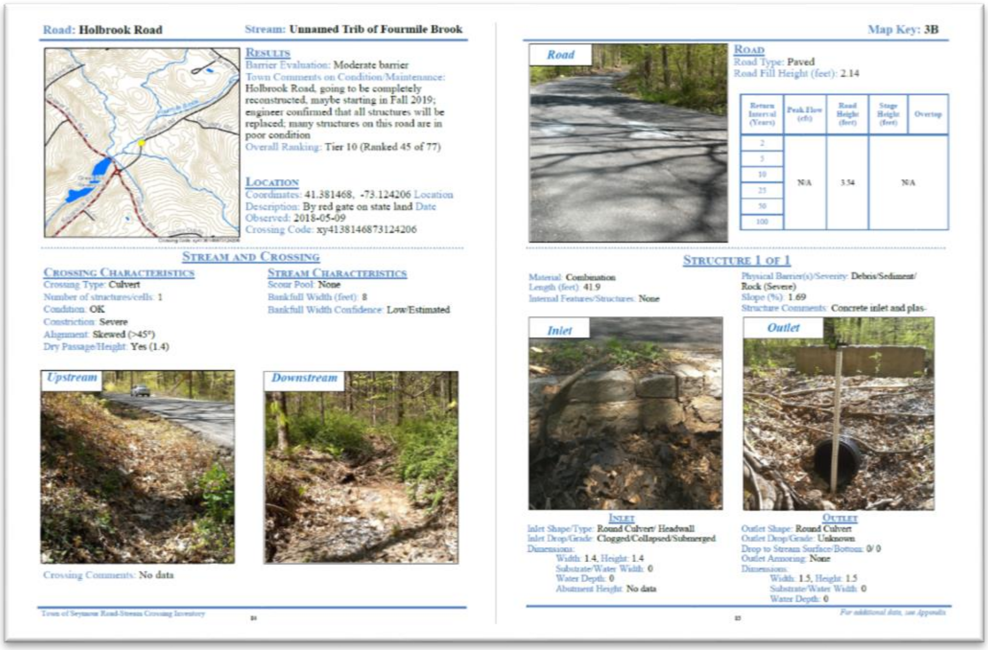
Next, the field data for each assessed culvert was packaged and sent to partners at the University of Connecticut's Civil and Environmental Engineering Department (UCONN) for flood risk modeling. Using a surface water runoff model developed by Dr. Emmanouil Anagnostou and Dr. Xinyi Shen[7] in combination with HVA's field data, this analysis predicts when a culvert will fail (indicated by water overtopping the road) during floods of different magnitudes. UCONN's runoff model provides peak flows for the 2-, 5-, 10-, 25-, 50-, and 100-year flood events at each culvert, which are then combined with HVA's field data in a hydraulic model. The hydraulic model is used to determine stage height for each peak flow, which is then compared with road fill height to determine whether the culvert would pass water or fail, for the flows of each flood interval.

Using the field data collected during NAACC assessments and the risk-of-failure modeling results, comprehensive Road-Stream Crossing Inventory documents were assembled for both the Towns of Seymour and Oxford. These documents contained photos and field data of every

[6] NAACC (North Atlantic Aquatic Connectivity Collaborative). (2014). https://www.streamcontinuity.org/ (Accessed April 2018).

[7] Shen, X., & Anagnostou, E. N. (2017). A framework to improve hyper-resolution hydrological simulation in snow-affected regions. Journal of Hydrology, 552, 1–12.

structure in town, as well as results of the risk of failure modeling (if applicable) and the NAACC barrier evaluation for each structure (Figure 3).


Road: Holbrook Road   Stream: Unnamed Trib of Fourmile Brook   Map Key: 3B

RESULTS
Barrier Evaluation: Moderate barrier
Town Comments on Condition/Maintenance: Holbrook Road, going to be completely reconstructed, maybe starting in Fall 2019; engineer confirmed that all structures will be replaced; many structures on this road are in poor condition
Overall Ranking: Tier 10 (Ranked 45 of 77)

LOCATION
Coordinates: 41.381468, -73.124206 Location Description: By red gate on state land Date Observed: 2018-05-09
Crossing Code: xy4138146873124206

ROAD
Road Type: Paved
Road Fill Height (feet): 2.14

Return Interval (Years)	Peak Flow (cfs)	Road Height (feet)	Stage Height (feet)	Overtop
2	N/A	3.54	N/A	
5				
10				
25				
50				
100				

STREAM AND CROSSING

CROSSING CHARACTERISTICS
Crossing Type: Culvert
Number of structures/cells: 1
Condition: OK
Constriction: Severe
Alignment: Skewed (>45°)
Dry Passage/Height: Yes (1.4)

STREAM CHARACTERISTICS
Scour Pool: None
Bankfull Width (feet): 8
Bankfull Width Confidence: Low/Estimated

Upstream   Downstream

Crossing Comments: No data

STRUCTURE 1 OF 1
Material: Combination
Length (feet): 41.9
Internal Features/Structures: None
Physical Barrier(s)/Severity: Debris/Sediment/ Rock (Severe)
Slope (%): 1.69
Structure Comments: Concrete inlet and plas-

Inlet   Outlet

INLET
Inlet Shape/Type: Round Culvert/ Headwall
Inlet Drop/Grade: Clogged/Collapsed/Submerged
Dimensions:
Width: 1.4, Height: 1.4
Substrate/Water Width: 0
Water Depth: 0
Abutment Height: No data

OUTLET
Outlet Shape: Round Culvert
Outlet Drop/Grade: Unknown
Drop to Stream Surface/Bottom: 0/ 0
Outlet Armoring: None
Dimensions:
Width: 1.5, Height: 1.5
Substrate/Water Width: 0
Water Depth: 0

Town of Seymour Road-Stream Crossing Inventory
For additional data, see Appendix

Figure 3 Sample road-stream crossing two-page spread from the Seymour Inventory document

In the Fall/Winter of 2018, HVA conducted a workshop meeting for each town with town officials, highway superintendents, and emergency services employees. Each of these parties were asked to review the Inventory document prior to the meeting and incorporate any local knowledge (e.g., which structures have to be regularly cleared of debris or experience high beaver activity). After the municipal meetings, all culverts in each town were ranked and prioritized, using a process that accounts for conservation/habitat value, flood risk, barrier status, and condition/management priority (as understood through local knowledge). Finally, one or two of the highest priority structures per town (i.e., severe barriers in high conservation value areas that are town priorities) were selected to prioritize for replacement.

The following section details how we achieved each the project objectives:

Objective 1: Develop comprehensive inventory documents of road-stream crossings in Seymour and Oxford using North Atlantic Aquatic Connectivity Collaborative (NAACC) method (July 2017 – July 2018)

HVA assessed all road-stream crossings in Oxford and Seymour using the North Atlantic Aquatic Connectivity Collaborative[8] method. During these assessments, data related to the stream

[8] Please see www.streamcontinuity.org for more information about the NAACC.

channel (e.g., bankfull, dominant substrate, alignment with the structure) and the actual structure (e.g., type, length, width, height, outfall drop height) were recorded and the upstream and downstream areas, structure inlet and outlet, and the roadway over the structure were all photographed. Each road-stream crossing assessment was uploaded to the NAACC database so that the data could be accessed by fellow researchers, as well as the general public. In addition to pinpointing where barriers to fish and wildlife movement are located, information collected during the NAACC assessments served as the backbone of a comprehensive inventory of road-stream crossings in Seymour and Oxford. During these assessments, additional data (e.g., slope, angles, weir crest length) was collected so that our project partners at UCONN could conduct the risk of failure analysis.

Deliverables Objective 1:

- Approximately 226 crossings assessed using the NAACC protocol
- Data for assessed crossings, including physical measurements, photos and ground-verified mapping collected into Road-Stream Crossing Inventory documents for Oxford and Seymour

Objective 2: Determine hydraulic capacity of culverts and identify undersized structures (May 2018 to November 2018)

Under this objective, we partnered with researchers at the University of Connecticut Civil and Environmental Engineering department (UCONN) to identify culverts that are at risk of failing in various flood interval, using a model. The surface water runoff model determined peak flows for the 2-, 5-, 10-, 25-, 50-, 100-, and 200-year recurrence-interval events at each culvert in target sub-watersheds. These flows were then combined with additional field data, in a hydraulic model that is used to calculate an overtopping height and will determine if a given culvert overtops and floods the roadway during a flood of each recurrence interval.

Deliverables Objective 2:

- Data to support hydraulic capacity determination for non-bridge structure in Oxford and Seymour
- Maps for each Town showing vulnerable crossings
- Capacity information (i.e., failing in 2-, 5-, 10-, 25-, 50-, 100-, or 200-year flood, or Passing) added to Inventory documents for Oxford and Seymour

Objective 3: Prioritize road-stream crossings for replacement (November 2018)

Undersized road-stream crossings represent a nexus of threats to both human and ecological communities of Oxford and Seymour. The large number of undersized crossings throughout the Housatonic Watershed presents a significant challenge, but the potential to achieve both flood resilience and conservation benefits by intervening at a single crossing makes them an excellent place for us to focus our efforts. Given the scale of the problem and the cost of replacement projects, it is essential that resources be targeted to provide the greatest possible community and ecological benefit. The prioritization approach that HVA developed and utilizes maximizes the value of resources allocated to increasing flood resilience and restoring stream habitat continuity at road-stream crossings in both Oxford and Seymour. This process can also help towns access funding sources aimed at habitat restoration to address flood risk at road-stream crossings.

Town staff and officials worked collaboratively with HVA to conduct a detailed prioritization process for each town. Crossings were prioritized based on: 1) risk of failure (as identified by the vulnerability assessment conducted under Objective 2 and local knowledge, including both vulnerability to direct damage from flood events as well as potential to impede flood disaster response); 2) crossing condition and maintenance need, and; 3) habitat restoration value of a potential replacement project (based on quality of the stream, proximity to major rivers [i.e., Housatonic and Naugatuck Rivers], as an indication of the potential to restore diadromous fish runs, and Critical Linkage status[9] of each barrier). The Critical Linkages project was developed by the University of Massachusetts, in collaboration with The Nature Conservancy, to evaluate and prioritize habitat connectivity projects (i.e., dam removals, culvert upgrades/replacements, and wildlife passage structures). Based on a variety of parameters, road-stream crossings are assigned a score to represent their importance to regional habitat connectivity, with a greater

[9] Critical Linkages Project. (2013). Conservation and Assessment Priority System. University of Massachusetts. Amherst, MA.

score indicating greater importance of that particular point on the map to stream network connectivity.[10]

Local knowledge was incorporated into the prioritization process through municipal prioritization workshops. Oxford's municipal workshop took place in November 2018 and included town staff (department of public works and department of emergency management employees) and HVA staff. Seymour's municipal workshop took place in December 2018 and included town staff (a representative from the first selectman's office, department of public works staff, and emergency services staff) and HVA staff. Prior to each of these meetings, all attendees reviewed the town Road-Stream Crossing Inventory document. During each meeting, town priority crossings were identified using the following questions:

- Which structures regularly flood the road?
- Has water over the road or other crossing failure blocked access for Town residents to essential services, such as Fire/EMS?
- Which structures require regular sediment, debris, and/or ice removal?
- Are you aware of structures that are in poor condition and need to be repaired or replaced?

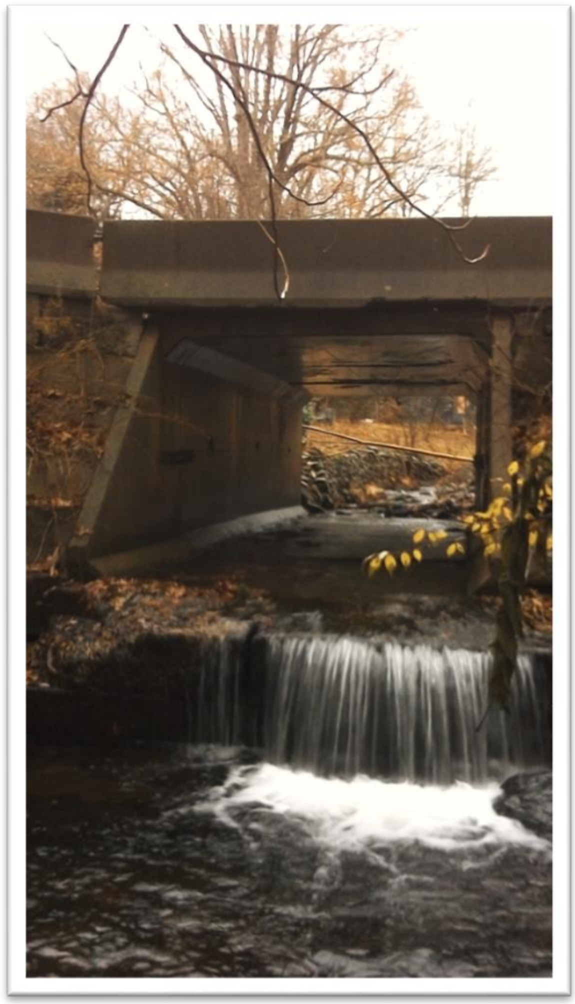


Figure 4 Highest ranked structure in Oxford, CT, based on a prioritization rubric

The outcomes of each of these town meetings was the incorporation of valuable local knowledge back into the final Road-Stream Crossing Management Plans and the identification of 8-15 structures that the town would like to prioritize for replacement. In Oxford, several structures were identified as ones that flood relatively frequently and structures with alignment issues were noted. In Seymour, structures that have flooded in the past were noted and it was pointed out that some structures are downstream of several new residential developments, which may be contributing to increase runoff and water volumes. These areas may benefit from stormwater

[10] For more information, visit: www.umasscaps.org/applications/critical-linkages.html

management best management practices.

The final ranking is a composite of flood risk severity, barrier evaluation as it pertains to the passage of fish and wildlife, town priority, consonance with local highway infrastructure maintenance plans, and conservation value. Based on the prioritization ranking rubric, the highest ranked structure in Oxford (Figure 4) is one that is a severe barrier to the passage of fish and wildlife, is a town priority based on past flooding, and is of high conservation value (i.e., it is the first barrier up from the Housatonic River, on the Fivemile brook). Based on the same rubric, the highest ranked structure in Seymour (Figure 5) is one that is a severe barrier to the passage of fish and wildlife, will likely fail in a 25-year flood interval, is in poor condition, and is of high conservation value (i.e., it is the second barrier up from the Housatonic River).

Deliverables for Objective 3:

- Lists and maps of crossings ranked by a composite of flood damage risk, conservation value, and town maintenance priority

Objective 4: Create Road-Stream Crossing Inventory and Management Plan Documents for each town and facilitate municipal adoption (August 2018 - December 2018)

To facilitate future fundraising and integration of this work into each town's highway management and hazard mitigation planning, the final task was to assemble all of the information collected and generated during this project into a document suitable for inclusion as an annex to each town's Natural Hazard Mitigation Plan. Final drafts of the Road-Stream Crossing Management Plan documents for Oxford and Seymour were completed in December 2018. These documents include:

Figure 5 Highest ranked structure in Seymour, CT, based on a prioritization rubric

- Supporting information including common problems with road-stream crossings and Best Management Practices;
- Town-wide Road-Stream Crossing Inventory including ground-verified mapping, photo documentation, and physical measurements for each structure (Deliverables Objective 1), and documentation of flood risk (Deliverables Objective 2);
- Results of prioritization ranking of all non-bridge structures in each town.

Links to the Road-Stream Crossing Management Plans can be found in the appendices. These documents will aid the Town of Oxford and the Town of Seymour in opportunistically taking advantage of grant programs in the wake of a flood event and when budgeting capital planning. The prioritization process will allow each town to strategically choose high-priority structures, in order to make the best use of limited resources to address flooding, condition, and ecological issues.

Deliverables Objective 6:

- Creation of Road-Stream Crossing Inventory and Management Plan documents for Oxford and Seymour
- Formal adoption of Road-Stream Crossing Inventory and Management Plan by each Town.

HOW PROJECT ADVANCED CIRCA MISSION AND PRIORITY AREAS

This project advanced the mission of CIRCA by increasing the climate resilience of communities who have already been affected by extreme storm events and who remain vulnerable to future flooding. As climate change contributes to more intense and frequent storm events, we can expect to experience more flood disasters like we saw in Hurricane Sandy. By focusing on the resilience of road-stream crossings, the communities of Oxford and Seymour were able to identify priorities that reduced flood risks and maintained the integrity of our transportation network. This project set the groundwork for both towns to plan for culvert replacement that will have the most impact, in terms of both flood resilience and habitat connectivity. Utilizing this approach placed each town in a better position to take advantage of funding opportunities aimed at habitat that might have not been previously available.

Moving forward, we intend to strategically mitigate the flood risk presented at undersized crossings through smarter infrastructure planning and management that incorporates the best available science. In doing this we will reduce burdens on the communities caused by flood disasters. Utilizing approaches such as the United States Forest Services' Stream Simulation Design[11] in the planning and replacement of road-stream crossings will reduce damages related to high-impact storm events that overwhelm and undermine infrastructure, and reduce the frequency of required maintenance to address debris and sediment accumulations.

The U.S. Forest Service's Stream Simulation Design protocol recommends the following[12] :

- Structure width is equivalent to or exceeds the bankfull width of the natural channel. (In Connecticut, the Department of Energy and Environmental Protection recommends that culvert width should span at least 1.2 times the bankfull width of the stream.[13])
- Structure substrate should have similar mobility and stability properties to that of the natural bed material of the stream channel.
- Structure should provide sufficient hydraulic capacity and passage of debris during a 100-year flood.
- Structure should provide adequate space between 100-year flood water level and top of the structure utilizing a head-water-to-depth ratio less than 0.8, allowing room for debris to pass without clogging the structure.
- The stream within the structure should have the capability to adjust dimensions in response to a wide range of floods and sediment or wood inputs without compromising the movement needs of aquatic organisms or the hydraulic capacity of the structure.

These principles will generally allow for the conveyance of flood-level flows, natural sediment transport patterns, and the passage of fish and wildlife. Stream simulation channels, like that of a natural stream channel, are able to adjust dimensions through substrate movement and accommodate a wide range of flows as well as sediment and debris inputs.

There are many examples of Stream Simulation Design structures proving their flood resiliency. In the summer of 2011 Tropical Storm Irene dramatically impacted the Northeast, rising rivers

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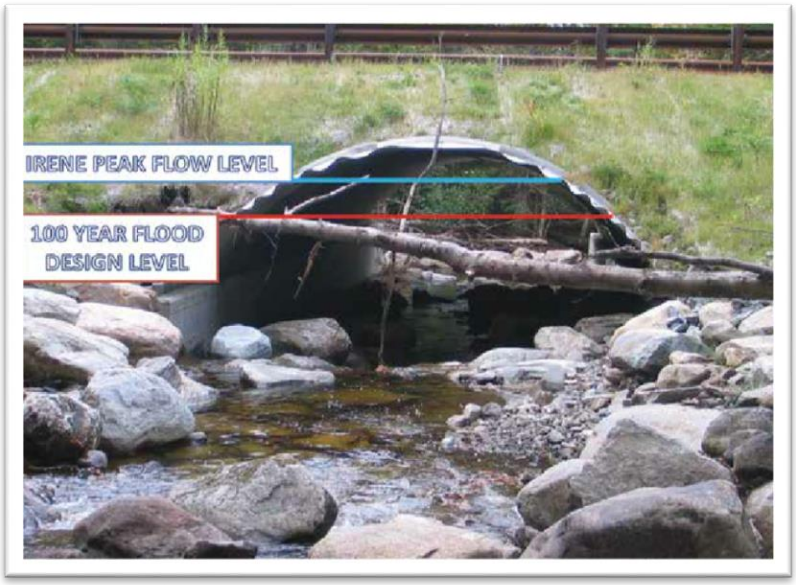
[11] Stream Simulation Working Group. (2008). *Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings*. San Dimas Technology and Development Center: U.S. Department of Agriculture, Forest Service.

[12] Stream Simulation Working Group. (2008). *Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings*. San Dimas Technology and Development Center: U.S. Department of Agriculture, Forest Service, page 3-2.

[13] Connecticut Department of Environmental Protection Inland Fisheries Division. (2008). *Stream Crossing Guidelines.* Retrieved from: https://www.ct.gov/deep/lib/deep/fishing/restoration/StreamCrossingGuidelines.pdf

to record levels and causing considerable infrastructure damage. The upper White River watershed of Vermont was hit particularly hard during the storm and 15 road-stream crossings in this watershed failed. According to stream assessments conducted prior to the storm, each of those structures provided either reduced or no Aquatic Organism Passability (AOP) and had culvert widths less than stream bankfull.[14] Nearby, in the Green Mountain National Forest, two Stream Simulation Design crossings had been installed before the 2011 storm. These culverts not only provided fish and wildlife passage, but survived Tropical Storm Irene and needed no follow-up maintenance. Similarly, in the summer of 2003 an undersized double box culvert catastrophically failed on Bronson Brook (Worthington, Massachusetts) and was replaced with an arch-design structure that allowed for free passage for aquatic organisms.[12] This replacement structure and adjacent roadway has survived several major storms without damage, including Irene. The survival of the replacement structures designed for fish and wildlife passage highlights the dual benefit of stream simulation principles as compared to that of the traditional hydraulic design approach. In short, road-stream crossings built with the intention of restoring stream connectivity also provide flood resiliency.



Stream simulation design culvert at Jenny Coolidge Brook, installed in June 2010, showing height of 100-year design discharge in red and height of Tropical Storm Irene flood level in blue.[14] Photo credit: Brian Austin, Green Mountain National Forest

Resilient road-stream crossings that persist through storm events will also maintain transportation networks crucial in times of crisis. By establishing resilient infrastructure, we will reduce the likelihood that citizens will be cut off from essential services and their daily needs. As the towns of Oxford and Seymour adopt practices outlined in the Road-Stream Crossing Inventory and Management Plan documents, they will set the bar for resilient and sustainable management of road-stream crossings in the state. Access to these resources for future planning and in response to the next flood will prove invaluable.

[14] Gillespie, N., et al. (2014). Flood Effects on Road–Stream Crossing Infrastructure: Economic and Ecological Benefits of Stream Simulation Designs. *Fisheries*, 39(2), 62–76.

The Road-Stream Crossing Inventory and Management Plan documents are powerful tools for adapting to a changing climate and the storms of the future. This process taught decision-makers and planners in the towns of Oxford and Seymour about management practices that can help reduce the vulnerability of highway infrastructure town-wide. Incorporating Stream Simulation Design principles into future culvert replacements will provide the greatest benefit to Oxford and Seymour. This approach to road-stream crossing management allows for long-term savings, setting up a sustainable course to systematically addressing infrastructure issues. Finally, this road-stream crossing management planning process is replicable and can be utilized throughout the state. Other towns likely share the undersized road-stream crossing problem observed in Seymour and Connecticut, and we welcome the opportunity to share this approach for addressing this issue with other communities.

DESCRIPTION OF HOW APPLICABLE CIRCA RESEARCH TOOLS WERE UTILIZED

We partnered with CIRCA researchers, Dr. Manos Anagnostou and Dr. Xinyi Shen of the University of Connecticut's Department of Civil and Environmental Engineering to complete a crucial step in the planning process. This research group developed an integrative hydrologic and flood inundation modeling system[15] in a previous CIRCA project and used that methodology to conduct risk of failure analysis for the culverts in Oxford and Seymour. HVA has previously worked with this research group to successfully model climate vulnerability of culverts in the Northwest Hills of Connecticut. Therefore, utilizing this same approach in Oxford and Seymour will keep the process of culvert prioritization throughout the Housatonic watershed consistent, making it easier for other communities in the region to replicate this work and allowing for the use of this data in regional level watershed plans. The results of this modeling indicated that approximately 5% of non-bridge structures assessed in Oxford and Seymour are likely to fail in a 25-year flood interval or less (Table 2). It is important to note that these results are *not* consistent with what we are seeing at a regional level, where approximately 20% of non-bridge structures are likely to fail in this same flood interval or less (Table 3).

[15] Shen, X., & Anagnostou, E. N. (2017). A framework to improve hyper-resolution hydrological simulation in snow-affected regions. Journal of Hydrology, 552, 1–12.

Table 2. Proportions of the non-bridge structures in Oxford and Seymour for which Uconn flood risk analysis was performed (*n* = 154) that fail at the given flood intervals

Recurrence of Interval Failure	Number of Culverts	Percentage
2-Year	1	1%
5-Year	0	0%
10-Year	3	2%
25-Year	2	1%
50-Year	5	3%
100-Year	8	5%
200-Year	12	8%
Passing	123	80%

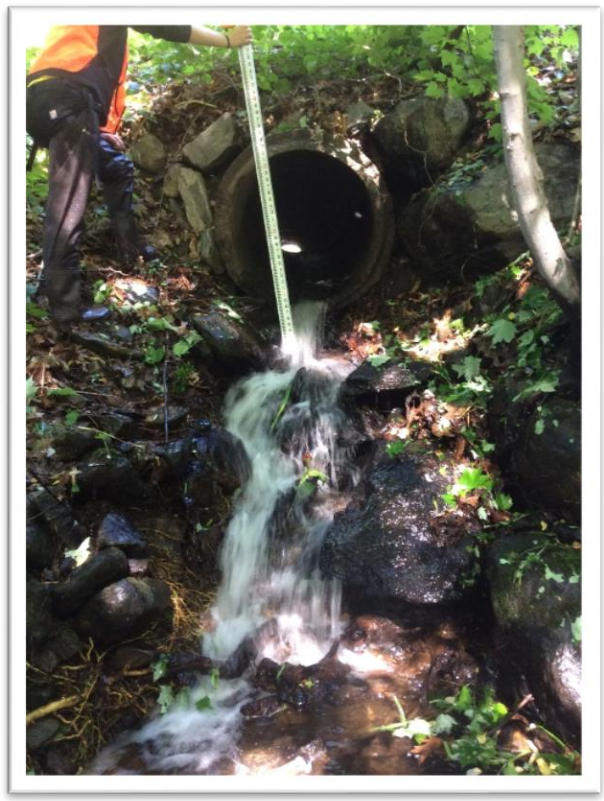
Table 3. Proportions of the non-bridge structures in the Housatonic Watershed for which UConn flood risk analysis was performed (*n* = 534) that fail at the given flood intervals.

Recurrence of Interval Failure	Number of Culverts	Percentage
2-Year	13	2%
5-Year	10	2%
10-Year	22	4%
25-Year	59	11%
50-Year	43	8%
100-Year	44	8%
200-Year	50	9%
Passing	293	55%

PROJECT OUTCOMES AND LESSONS LEARNED

The Road-Stream Crossing Management Plans for the towns of Oxford and Seymour will aid each town in strategically managing bridges and culverts to reduce flood risk and restore stream habitat continuity. These documents are invaluable in identifying the highest priority projects for culvert replacements in each town, in order to most efficiently allocate limited resources. However, a limitation of each of these particular projects is that it only got each town up to the Road-Stream Crossing Management Plan phase. In order to broadly advertise the benefits of resilient road-stream crossing planning, each town would have an actual culvert replacement demonstration project. Ideally, the towns of Oxford and Seymour would acquire funding to replace a barrier culvert in each town with a Stream Simulation Design structure. With such a demonstration project in place, we could much more effectively conduct regional education to decision-makers and the general public.

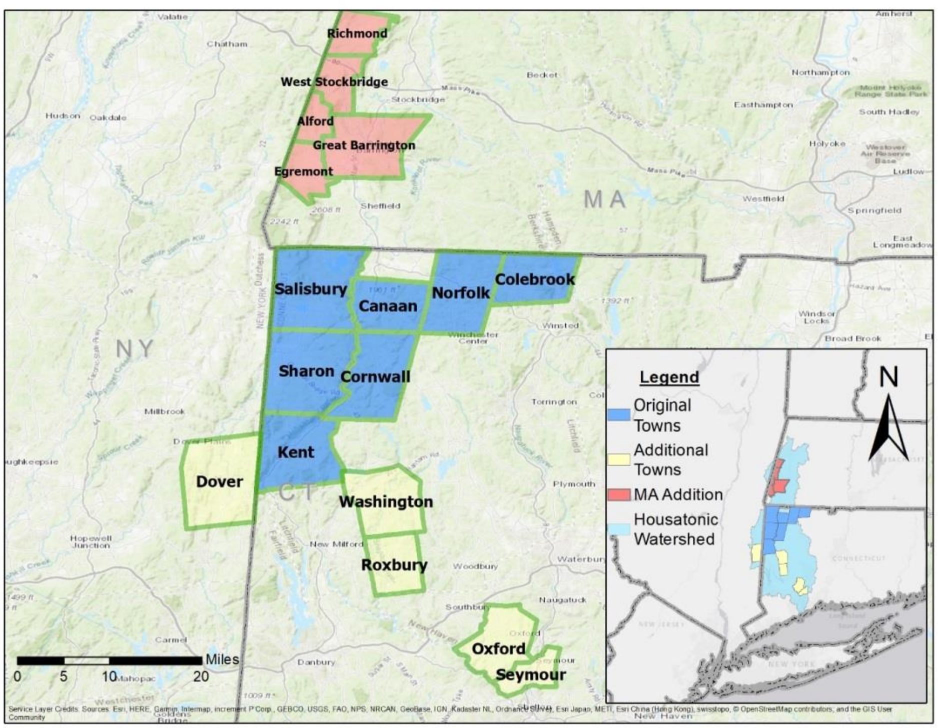
The original partnership between HVA and their first seven project towns (in Connecticut's Northwest Hills) allocated funding for the preliminary design stage for a high priority replacement project in each town. Because we did not receive a grant for this project that was initially expected, the preliminary design step was cut from this project due to lack of funds. Ideally, future road-stream crossing management planning projects would include funding for such designs. Having preliminary designs in hand and an initial plan for the replacement of a barrier culvert can greatly aid in funding requests to see the project through to the final stage.



In both Oxford and Seymour, there is generally enthusiasm for installing projects that will save the towns money over the lifetime of the structure and an eagerness to apply for funding to acquire preliminary designs for the replacement of a priority structure. However, once we have the preliminary designs in hand, there is still a major roadblock to overcome. It is often more expensive on the front end to install stream simulation style structures and both towns have limited resources for infrastructure upgrades. Therefore, a crucial next step in the development stage of this process is finding ways to reduce the costs of installing multiple Stream Simulation Design structures in the region.

HVA is exploring shared services for the stream channel design elements of replacement projects. Many towns (or regional associations of towns) already have existing relationships with engineering firms that specialize in highway infrastructure and can complete design/permitting/construction management elements of road-stream crossing replacement projects relatively inexpensively. The downside is that these firms generally are focused on designing for the road rather than considering both the road and the stream. Conversely, firms like the project engineer that HVA uses are focused on designing for the stream generally cannot get the highway infrastructure elements of these projects done as cheaply. One option that HVA is considering is an "engineering team" approach, whereby a firm that specializes in stream channel design and restoration is paired with a civil engineering firm that specializes in highway infrastructure. The intention is that each member of the team will be able to focus on what they do best and most efficiently, and collaborate on a design that meets the specifications of the stream and the road while minimizing engineering fees.

This project was really just the beginning of a comprehensive effort to restore and protect stream habitat continuity throughout the Housatonic Watershed, that will include assessment and replacement planning, construction of demonstration projects, and most importantly education and capacity-building at the local level that leads to a fundamental change in management philosophy. The ultimate vision behind road-stream crossing management planning is for municipal highway managers to officially adopt Stream Simulation Design methods for all future repairs and replacements of road-stream crossings. HVA is currently working with eleven towns in Connecticut, one in New York, and five in Massachusetts to conduct road-stream crossing assessments and prioritize one or two culverts per town for replacement. HVA'S long-term goal is to get each of these initial project towns to replace the highest priority barrier culvert in their town.



The Housatonic Valley Association is currently collaborating with 17 towns in Connecticut, New York, and Massachusetts to create Road-Stream Crossing Management Plans

Looking forward, we encourage the application of this road-stream crossing management planning process elsewhere; more communities taking on projects such as this one can only strengthen regional transportation systems. HVA has spent several years developing and streamlining this road-stream crossing planning and management process and they are willing to share methodology and all the tools and resources that they have developed and acquired. For our outcomes to be replicated in neighboring communities, the benefits of managing for resilient road-stream crossings must be communicated effectively and widely. The primary audience for this type of communication is municipal highway managers and decision makers in the Housatonic River watershed, because they manage the majority of road-stream crossings. Our recommendation for a communication strategy to other municipalities is to focus on how these structures can most benefit communities, especially small towns with limited operating budgets. As extreme precipitation events become more frequent, repairing damaged culverts can become extremely costly. FEMA funds for repairing or replacing a damaged crossing are limited and also are subject to certain restriction and limitations, making it potentially difficult for towns to access these funds. While replacing ineffective crossing structures with Stream Simulation Design methods may appear to be more expensive when only construction costs are considered, studies have shown that Stream Simulation Design structures actually cost less in the long-term, due to the consistent higher maintenance costs and shorter lifespans of undersized culverts.[16, 17] Another way to effectively reach municipalities is through Council of Governments (COG) organizations. HVA has a working partnership with several COGs in the area, including the Northwest Hills COG and Naugatuck Valley COG. COGs often hold regular regional meetings related to transportation and infrastructure; attending and presenting at these meetings would allow us to share the benefits of this Road-Stream Crossing Management process with representatives from multiple municipalities. Furthermore, partnering with COGs may aid in finding ways to reduce the costs of the implementation stage of this process (i.e., culvert construction).

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[16]Levine, J. (2013). An Economic Analysis of Improved Road-Stream Crossings. Keene Valley, NY: The Nature Conservancy, Adirondack Chapter.

[17] Massachusetts Division of Fish and Game, Division of Ecological Restoration. (2015). Economic & Community Benefits from Stream Barrier Removal Projects in Massachusetts.

FINAL PROJECT SCHEDULE

	2018			2019			
Objectives	**Summer**	**Fall**	**Winter**	**Spring**	**Summer**	**Fall**	**Winter**
Develop comprehensive inventory of road-stream crossings in Seymour and Oxford using North Atlantic Aquatic Connectivity Collaborative (NAACC) method.	**X**	**X**	**X**	**X**	**X**		
Determine hydraulic capacity of culverts and identify undersized structures				**X**	**X**	**X**	
Hold Municipal Prioritization Workshops for each town						**X**	**X**
Prioritize road-stream crossings for replacement						**X**	**X**
Create Road-Stream Crossing Inventory and Management Plan Documents for each town and facilitate municipal adoption						**X**	**X**

July 2017 to July 2018: Completed field assessments of all road-stream crossing structures in the towns of Oxford and Seymour.

May 2018 to July 2018: The field data for both towns was packaged and sent to UCONN for risk of failure modeling.

August 2018: HVA received Town of Oxford risk of failure results from UCONN partners

September 2018: Using the data above, HVA finalized the Oxford Road-Stream Crossing Inventory document and sent it to town staff and officials for their review.

November 2018: HVA received Town of Seymour risk of failure results from UCONN partners. HVA finalized the Seymour Road-Stream Crossing Inventory document and sent it to town staff and officials for their review. Municipal workshops meetings were conducted for each town, with town staff and officials, to identify the priority culverts based on flood risk, conservation value, and condition/maintenance need.

December 2018: Notes from each town prioritization workshop were incorporated back into the respective Road-Stream Crossing Inventory documents and final Road-Stream Crossing Management Plans were prepared for each town. Final CIRCA grant report was prepared and submitted.

PROJECT BUDGET

Expenditures	Total Project Budget (including matching funds)	CIRCA Municipal Resilience Grant	Match amount	Other Funding Source(s)
Salaries				
Town Engineer	$750	$0	$750	In-kind services
Emergency Services Director	$750	$0	$750	In-kind services
Public Works Director	$750	$0	$750	In-kind services
Wetland Officer	$750	$0	$750	In-kind services
SUBTOTAL SALARIES	**$3,000**	**$0**	**$3,000**	
Program				
Contracted Services: Town of Seymour	$3,000	$0	$3,000	Town of Seymour (In-Kind Services)
Contracted Services: Flood Risk Modeling by University of Connecticut Department of Civil & Environmental Engineering	$20,000	$20,000	$0	
Contracted Services: Housatonic Valley Association	$13,600	$13,600	$0	
SUBTOTAL PROGRAM	**$35,544**	**$33,600**	**$3,000**	
TOTAL EXPENDITURES	**$39,600**	**$33,600**	**$6,000**	

Income	
Source	**Amount**
CIRCA Municipal Resilience Grants Program	**$33,600**
In-kind staff time Town of Oxford	**$3,000**
In-kind staff time Town of Seymour	**$3,000**
TOTAL INCOME	**$39,600**

Appendix

Appendix A: Maps

Attachments (Project Products)

Access all project products at this DropBox link: Oxford and Seymour Road-Stream Crossing Management Plans

Attachment A: Town of Oxford Road-Stream Crossing Management Plan: Volume 1

Attachment B: Town of Oxford Road-Stream Crossing Management Plan: Volume 2

Attachment C: Town of Oxford Reference Map

Attachment D: Town of Seymour Road-Stream Crossing Management Plan: Volume 1

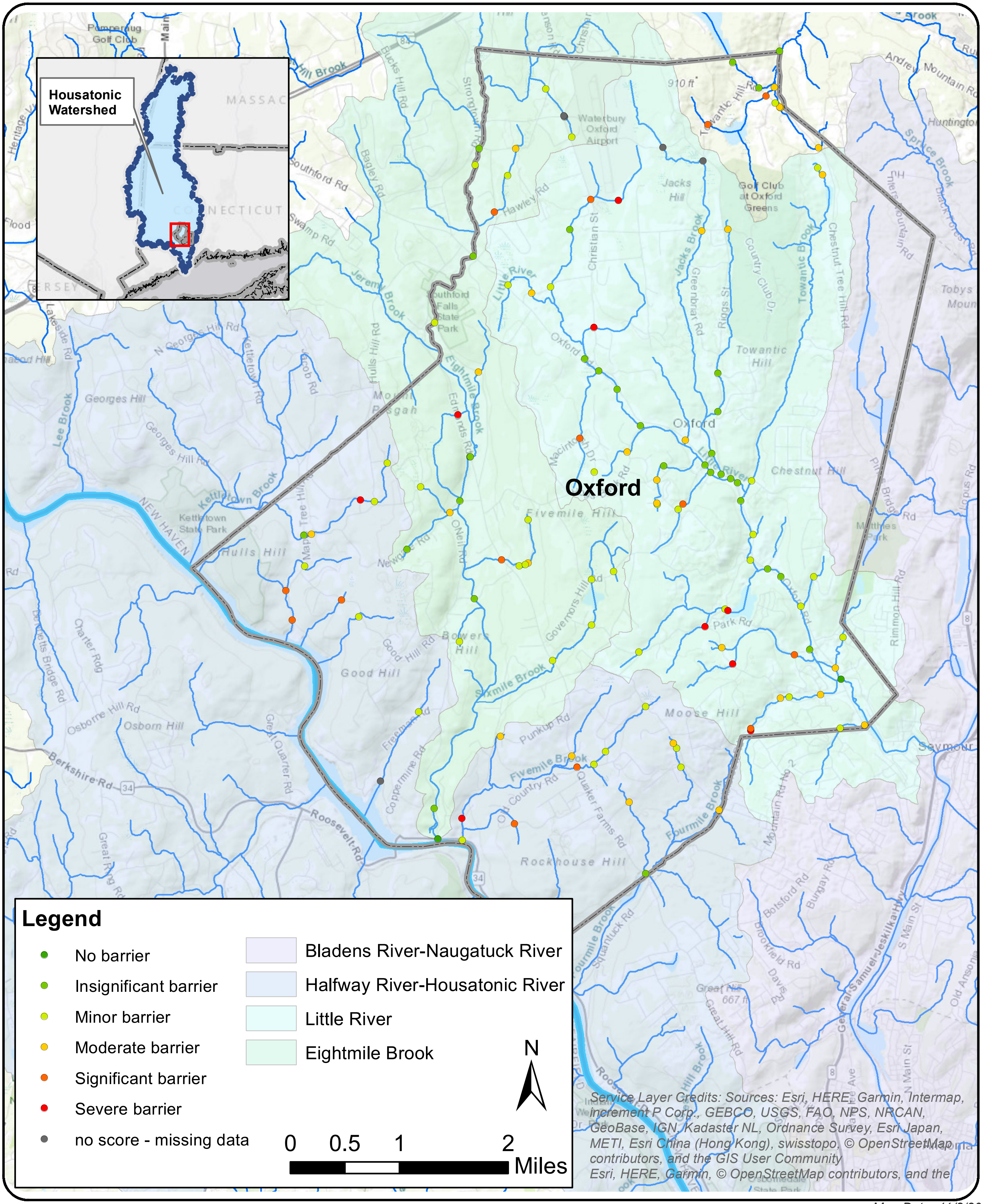
Attachment E: Town of Seymour Road-Stream Crossing Management Plan: Volume 2

Attachment F: Town of Seymour Reference Map

Appendix A: Maps

CIRCA Grant Area

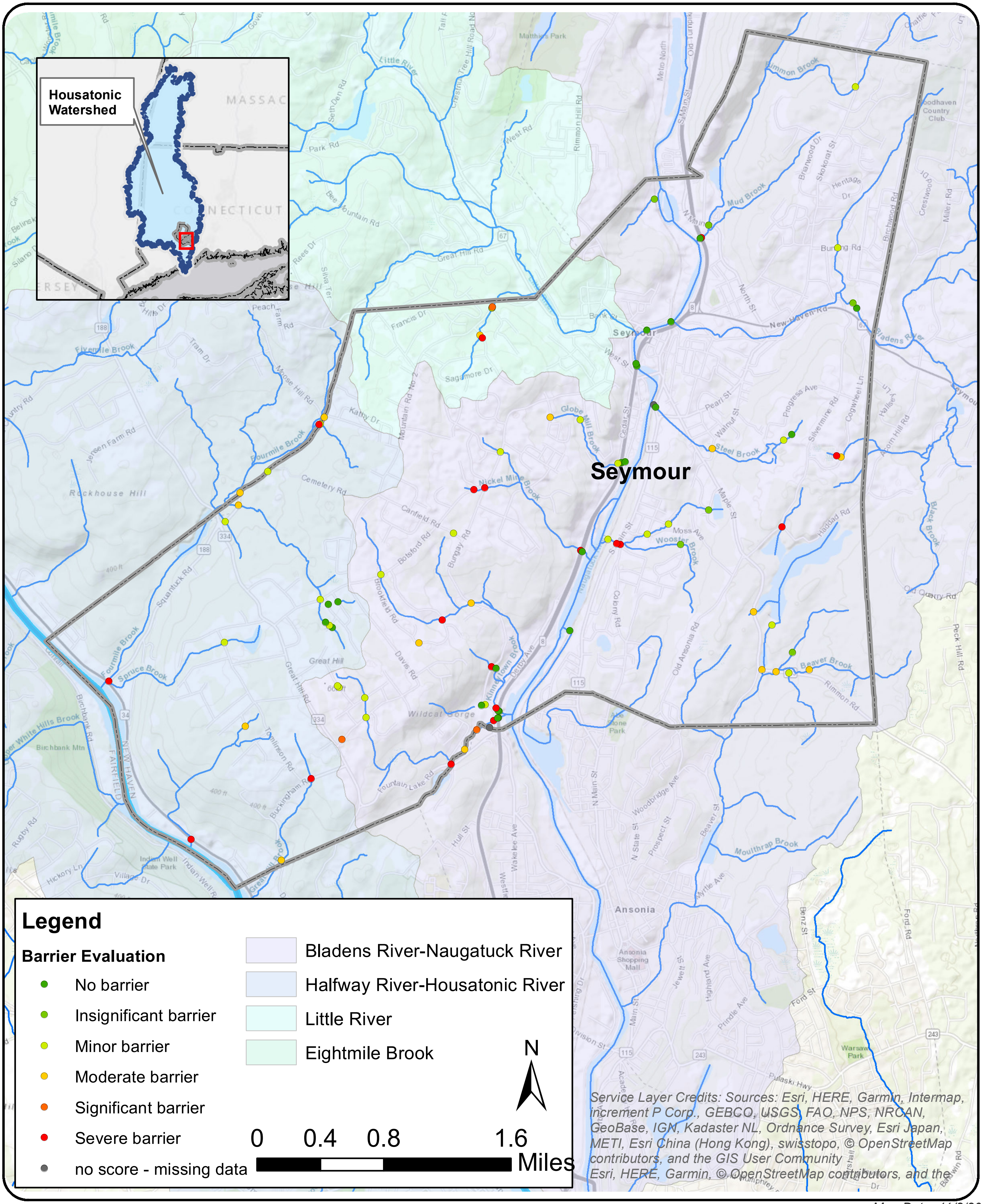
Town of Oxford



Map Date: 11/8/2018

CIRCA Grant Area

Town of Seymour



Map Date: 11/8/2018