Town of Grafton Road Stream Crossing Management Plan

Project Partners:

Town of Grafton

Trout Unlimited

NEIWPCC

NYS Hudson River Estuary Program

NYS DEC Region 4 Fisheries Department

Rensselaer County Soil and Water Conservation District

Cornell Cooperative Extension of Columbia and Greene County

NYS Water Resources Institute at Cornell University

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Glossary of Terms

Aquatic organism – An aquatic organism living in water for at least a portion of their life.

Bankfull– Bankfull is an established height at a given location along a river or stream, above which a rise in water surface will cause the river or stream to overflow the lowest natural stream bank somewhere in the corresponding reach.

Bankfull discharge – Bankfull discharge is the dominant channel forming flow with a recurrence interval seldom outside the 1 to 2-year range.

Bankfull width- The wetted width of the stream occurring at Bankfull.

Clear Span-The maximum inside width of a non-circular pipe or bridge. Cover height - The amount of fill material above a road stream crossing structure.

Design Load- The sum of all vertical forces (i.e. soil weight, passing vehicles, etc.) applied to a buried culverts or bridge.

Flood resiliency – Flood resiliency is the ability for the Town to withstand and recover from flood crisis.

Freeboard - The distance between normal water level and the bottom of the road stream crossing structure.

Geomorphic –Response of river and stream channels to various types of natural and human-caused disturbances including floods.

Head cut - A head cut in stream geomorphology, is an area of instream instability and erosional feature of streams with an abrupt vertical drop that can be perpetuated through the river system until equilibrium of channel dimensions and slope is attained.

Hydraulic capacity - The amount of water that can pass through a structure or watercourse.

Intermittent stream – An intermittent stream is a stream which normally ceases to flow for weeks or months each year.

Perennial stream – A perennial stream is a stream or river (channel) that has continuous flow in parts of its stream bed all year-round during years of normal rainfall.

Recurrence Interval - Statistical techniques, through a process called frequency analysis, are used to estimate the probability of the occurrence of a given precipitation event. The recurrence interval is based on the probability that the given event will be equaled to or exceeded in any given year. Ten or more years of data are required to perform a frequency analysis for the determination of recurrence intervals. Of course, the more years of historical data the better—a hydrologist will have more confidence on an analysis of a river with 30 years of record than one based on 10 years of record.[1]

[1] https://water.usgs.gov/edu/100yearflood.html

Recurrence Intervals and Probabilities of Occurrences

Recurrence interval, in years	Probability of occurrence in any given year	Percent chance of occurrence in any given year
100	1 in 100	1
50	1 in 50	2
25	1 in 25	4
10	1 in 10	10
5	1 in 5	20
2	1 in 2	50

Regional regression – Regional regression equations are based on statistical relations between (1) streamflow statistics of interest computed from applicable records of the stations and (2) basin and climatic characteristics, for which data are typically readily available.

Road Stream Crossing – Road stream crossings are locations where a road, paved or unpaved, crosses over a body of water within the physical extents of all supporting infrastructure (i.e. the proposed crossing infrastructure, wingwalls, etc.)

StreamStats - StreamStats is a USGS Web application that queries an assortment of Geographic Information Systems (GIS) analytical tools to calculate peak discharges for certain recurrence intervals. The calculations were established from publicly available US Geological Service research (USGS SIR 2006-5112 "Magnitude and Frequency of Floods in New York") which established a relationship between watershed characteristics and peak discharges. StreamStats also is a USGS web application hat calculates bankfull dimensions from publicly available US Geological Service research (USGS SIR 2009-5144 "Bankfull Discharge and Channel Characteristics of Streams in New York State") which established a relationship between watershed characteristics and bankfull dimensions.

Stormwater - Stormwater is water that originates during precipitation events and snow/ice melt that either soak into the soil (infiltrate), evaporates, or runs off and ends up in nearby streams, rivers, or other water bodies.

Wetland - A wetland is a distinct ecosystem that is inundated by water, either permanently or seasonally, where oxygen-free processes prevail.

1.0 Project Overview

The Town of Grafton Road Stream Crossing Management Plan is designed to improve community and ecosystem resiliency by identifying high priority road stream crossing replacement projects that reconnect high quality aquatic habitat and improve community flood resiliency and road infrastructure condition within the Town of Grafton. The scope of the Project included:

i) an inventory of all state, county, town road stream crossing,
ii) hydraulic modeling,
iii) evaluation of aquatic organism passage,
iv) prioritization of results using multiple objectives, and
v) the development of final conceptual and shovel ready designs and cost estimates for highest priority projects.



Eastern brook trout is New York's state fish and a native species of the Eastern U.S. Brook trout need access to cold, clean water to survive (Photo TU).

Inadequately sized or incorrectly installed culverts can be a seasonal or year-round barrier to aquatic species, fragmenting habitat and disconnecting the natural flow of organisms, material, nutrients and energy along river systems. This loss of stream connectivity is a critical threat to valuable and already vulnerable species such as the native Eastern brook trout (*Salvelinus fontinalis*), the American eel (*Anguilla rostrata*) and river herring (*Alosa spp*). The Grafton Road Stream Crossing Project has identified opportunities to reduce habitat fragmentation by prioritizing replacement barrier removal projects that provide the greatest improvement for these vulnerable species as well as other aquatic organisms.

In addition to habitat fragmentation caused by inappropriately sized culverts, flood risks and infrastructure damage are also a concern. Damage caused by flooding can be reduced if local decision-makers are aware of current infrastructure conditions to proactively plan and implement restoration strategies at high priority locations. The Grafton Road Stream Crossing Project has identified at-risk infrastructure, so the Town can prioritize their upgrades with hydraulically appropriate and geomorphologically ally compatible designs.

2.0 Project Steps

Step 1: Road Stream Crossing Inventory

At the request of the Town, a North Atlantic Aquatic Continuity Collaborative (NAACC) survey was completed by Rensselaer County Soil and Water Conservation District in the summer of 2022.

The NAACC is a participatory network of practitioners united in their efforts to enhance aquatic connectivity. The collaborative efforts of NAACC have so far:

1. developed unified protocols for road-stream crossing assessments that can help identify bridges and culverts that are problematic from an aquatic connectivity perspective,
2. launched an online assessment training program,
3. created an online database that serves as a common repository for crossing assessment data,

4. developed a tool to identify high priority watersheds and crossings for assessment, and
5. are supporting efforts to conduct assessments throughout the region.

The survey includes a variety of measurements that include structure type and condition, flow condition in and out of the structure, structure alignment and many other measurements that will provide the needed data to generate an aquatic passage score for each surveyed crossing. The standardized protocol can be found on the NAACC website.[2]

In the Town of Grafton 74 road stream crossings were surveyed. Of those crossings surveyed 46 were located on town roads. Only Town crossings were included in the prioritization process; however, county and state crossings were surveyed, and the data are publicly available.

The data from the survey can be accessed by the public through the NAACC online database.[3] Within the database a town specific map with survey can be accessed by the Town and the community.

In addition to the culverts surveyed, the TU team also reviewed all dams within the Town of Grafton to evaluate the impact of each dam on both the ecosystem and the community. According to the NYS DEC, "the state is concerned with the protection of the health, safety and welfare of the people of the State of New York and the conservation and protection of its natural resources. Water stored behind a dam represents potential energy which can create a hazard to life and property located downstream of a dam. For a dam to safely fulfill its intended function, it must be constructed, operated and maintained properly." Each known dam in NYS has been given a hazard classification (Table 1). The classification of a dam is driven by potential impacts to the downstream community if a dam were to fail. The owner of the dam is responsible for all potential impacts and for the maintenance and upkeep needed to keep a dam safe.

There are 11 registered dams in the Town, 7 have a hazard classification of "A" which is the lowest hazard risk classification. The remaining four are high hazard dams (C) owned by the state parks for recreation. Martin Dunham Reservoir Dam should be considered for removal if the deficiencies and safety cannot be maintained by the state. A summary of the dam details can be found in Appendix A: Map 3 and Table A2.

[2] https://www.streamcontinuity.org/pdf_files/NAACC_Instructions%20for%20Field%20Data%20Form%205-22-16.pdf
[3] https://www.streamcontinuity.org/cdb2/naacc_search_crossing.cfm

Table 1: New York State Dam Hazard Classification[4]

Class A	A dam failure is unlikely to result in damage to anything more than isolated or unoccupied buildings, undeveloped lands, minor roads such as town or county roads; is unlikely to result in the interruption of important utilities, including water supply, sewage treatment, fuel, power, cable or telephone infrastructure; and/or is otherwise unlikely to pose the threat of personal injury, substantial economic loss or substantial environmental damage.
Class B	A dam failure may result in damage to isolated homes, main highways, and minor railroads; may result in the interruption of important utilities, including water supply, sewage treatment, fuel, power, cable or telephone infrastructure; and/or is otherwise likely to pose the threat of personal injury and/or substantial economic loss or substantial environmental damage. Loss of human life is not expected.
Class C	A dam failure may result in widespread or serious damage to home(s); damage to main highways, industrial or commercial buildings, railroads, and/or important utilities, including water supply, sewage treatment, fuel, power, cable or telephone infrastructure; or substantial environmental damage; such that the loss of human life or widespread substantial economic loss is likely.
Class D	A dam that has been breached or removed, or has failed or otherwise no longer materially impounds waters, or a dam that was planned but never constructed. Class "D" dams are considered to be defunct dams posing negligible or no hazard. The department may retain pertinent records regarding such dams.

Step 2: Aquatic Organism Passage Modeling

The survey data was entered into the Aquatic Organism Passage (AOP) model developed by University of Massachusetts at Amherst and other NAACC partners. The model is not species specific but instead uses criteria on a variety of different life forms and life histories to assess the passage potential of each structure. The results from the model classify each structure based on “No AOP”, “Reduced AOP” and “Full AOP”. No AOP means that most species will not be able to pass through the structure. Reduced AOP means that some species may be able to pass under certain flows, but others may or may not be able to pass through the structure. Full AOP means that all species can pass through the structure. Within the No AOP and Reduced AOP category, the severity of the barrier is determined and classified as,“Severe”, “Significant”, “Moderate”, “Insignificant” and “Minor”. The results of the AOP modeling for the Town of Grafton are summarized below in Table 2 and highlighted in Appendix A: Map 1.

Table 2: Town of Grafton Aquatic Organism Passage Survey Results

AOP Severity Evaluation	Percent of Total Crossings Surveyed
Severe	**11%**
Significant	**7%**
Moderate	**22%**
Insignificant	**9%**

[4] https://www.dec.ny.gov/docs/water_pdf/togs315.pdf

Minor	**22%**
No Barrier	**15%**

*Remaining 15% are missing data or inaccessible.

Step 3: Hydraulic Capacity Modeling

The survey data is also used to determine the resiliency and flow capacity of each crossing structure. Cornell University Water Resource Institute, in partnership with the Northeast Regional Climate Center and Hudson River Estuary Program, developed the Cornell Resiliency Model to identify undersized culverts vulnerable to flooding under current and future climate conditions. [3] Using a combination of culvert inventory field data and peak discharge predictions for current and future climate scenarios, the model determines culvert flow capacity and highlights the flow event at which the structure will fail. A diagram of the model can be found in Appendix A: Figure A1.

This model consists of four main components: 1. watershed delineation, 2. peak discharge calculation, 3. capacity calculation, and 4. return period assignment. The watershed component of the model is conducted using ArcGIS, while the peak discharge calculation, capacity calculation and return period assignment are executed using Python scripts.

A detailed description of the steps in the Cornell Resiliency model are as follows:

1. The watershed delineation component of the model is conducted on ArcGIS using custom tools created by Rebecca Marjerison for her PhD dissertation. The tools first delineate the watershed of each culvert. Next, all culvert watersheds being evaluated are aggregated into a single shapefile. Finally, the area, weighted Curve Number (CN) and Time of Concentration (Tc) are computed for each watershed.

2. The second component of the model is the peak discharge calculation. The watershed data compiled in the initial phase of the model is used as the input for this component. The procedure set in the USDA Natural Resources Conservation Service (NRCS) Technical Release 55 (TR-55) graphical method is used to determine peak discharge for various return period storms for each delineated watershed.

3. The third component of the model is the calculation of culvert capacity. Using field data, the capacity of each culvert is modeled using the inlet control equation set forth by the Federal Highway Administration Hydraulic Design Series 5. In this model, the headwater ponding height was assumed to be the height of the road surface above the culvert invert.

4. In the final component of the model, the assigned capacity of each culvert is compared against the peak discharges calculated for the culvert in order to determine the maximum return period storm that the culvert can safely pass.[5]

The model looks at flow conditions for the 2, 5, 10, 25, 50 and 100-year storm events. A detailed projection of future climate conditions for Columbia County can be found at the NYS DEC website[6] that confirms that future conditions should be considered before developing a new culvert replacement plan to ensure the new structure is able to pass floodwaters of the future. Hydraulic capacity data from the Resiliency Model was generated for the Town of Grafton road stream crossings. The results are summarized below in Table 3. Site

[5] https://wri.cals.cornell.edu/sites/wri.cals.cornell.edu/files/shared/CornellCulvertsModelInstructions_RevisedAug2018.pdf
[6] http://www.dec.ny.gov/docs/remediation_hudson_pdf/cphv.pdf

specific information on hydraulic capacity can be cross referenced in the inventory document or on the online TU prioritization map tool.

The results show that of those road stream crossings modeled, 100% of the surveyed structures will be a flood issue under current climatic conditions.

Table 3: Town of Grafton Hydraulic Capacity Results[7]

Flow Event	% of Structures that fail this event under current climatic conditions
< = 2-year flow	**100%**
< = 5-year flow	-
< = 10-year flow	-
< = 25-year flow	-
< = 100-year flow	-
< =200-year flow	-

Step 4: Prioritization Process

Following the review of survey and model results, the data was separated into ownership to complete the prioritization process. Only the Town-owned or -maintained structures were included in the prioritization process. The prioritization process was a collaboration between the TU team and the Town. Prioritization metrics consider both infrastructure and ecosystem vulnerability. Infrastructure vulnerability metrics include hydraulic capacity, geomorphic compatibility, crossing condition, age of structure, maintenance issues and other concerns identified by the Town highway supervisor. Ecosystem vulnerability metrics considered stream type, aquatic passage ranking and severity, location of structure in the watershed to include the number of stream miles upstream and the number of barriers identified downstream. Additional metrics included presence of aquatic species of concern (e.g., threatened, endangered, or of conservation concern), stream classification and species composition upstream and downstream of the structure. A summary of the prioritization metrics and the data sources used in the analysis can be found in Appendix A: Table A1.

Each crossing was ranked for each of the prioritization metrics (HIGH, MEDIUM, LOW). The goal of the ranking efforts was to identify three priority replacement structures that could then undergo further study and design development. It was determined that the top priority projects would focus on those structures that were located on perennial streams, [8] that represent barriers to aquatic organisms and are a priority for the Town. The first step in the prioritization process was to determine which Town crossings were a severe or significant barrier to aquatic organism. The next step was to determine if the crossing was located on perennial, intermittent stream or whether the crossing was over a wetland or used for stormwater conveyance. There are 25 (33% of the crossings) severe or significant barriers in the Town. A summary of severe and significant crossings that have a “HIGH” ecological value can be found in Appendix: Table A3.

7 Data is based on modeling results from Cornell Water Resource Institute and include only 140 road stream crossings.

8 A perennial stream is one that flows year-round under normal rainfall conditions. Perennial streams are ecologically important for the life histories of many species.

Table 4: Town of Grafton Road Stream Crossing Freshwater Type

Freshwater Type	Total # Road Stream Crossing
Perennial Stream	93%
Intermittent Stream	7%
Wetland	-
Stormwater	-

There are 8 road stream crossings that are located on perennial streams in the Town of Grafton with severe or significant barriers to aquatic organisms. Four Priority sites were identified, and site visits were completed with the town. Results will provide the needed information to the town on ensure an appropriate replacement. Results from the prioritization process and the site visits are summarized below in Table 5. Entire prioritization results for town structures can be found in Appendix A: Table A2-A6.

47746	**Cranberry Pond Rd**	**42.76010**	**-73.44104**

Table 5: Top 4 Priorities for the Town of Grafton

Ranking	NAACC Survey ID	Road	Latitude	Longitude
1	46490	Claus Road	42.735200	-73.495442
2	47739	Jay Hakes Road	42.759581	-73.51164
3	47738	Roark Road	42.768928	-73.517758
4				

Step 5: Conceptual and Final Design Development

Following the prioritization process and site visits, the TU team and the Town determined the four highest priorities. Of those, the top priority was identified. A summary of these results can be found in Table 5 above. Conceptual level effort was completed for the identified priorities. Permit ready packets were created for each, but all designs should be reviewed once funding is secured.

The conceptual level design effort presents a complete permit packet of the project sites showing the location of the desired stream crossing, its orientation, and proposed dimensions (clear span, rise) and supportive features to be built in the stream to protect the crossing. An estimated cost estimate was also developed. Due to the generalities in development of the conceptual level alternatives, there is a higher level of uncertainty of the amount of work needed to construct that may be determined during final design development. The goal of the conceptual level design process is to prepare the Town for future planning and budgeting.

3.0 Planning for the Future: Best Management Practices for Road Stream Crossing Designs

Understanding how best to design and install a flood resilient and wildlife friendly culvert is the ultimate outcome of the road stream crossing management planning exercise. The examples identified and designed during the project highlight the types of structures and design criteria needed to ensure that the structure meets these goals.

A well-designed culvert should avoid constricting the stream channel, consider the width and skew of the river as well as be appropriately sized to pass the largest storm feasible - ideally, the 100-year storm (plus 20% for preparing for climate changes). The structure should maintain the continuity of the natural stream substrate, slope, and water velocity through the structure. Non-constricting culverts installed with a similar natural slope will normally provide water depths, velocities, bottom substrates, and channel characteristics that are comparable to the natural stream.[9]

NYS DEC has compiled stream crossing standards that can be used to guide all road stream crossing construction projects. Project permits are required for projects that are located on perennial streams with a water quality classification of A, B, C(T) or C(TS). NYS DEC should also be consulted for all Class C streams if they flow into a higher classification stream. Information on water quality classification on perennial streams can be found in Appendix A: Map A1.

NYS Stream Crossing Standards

The following recommended standards and permit requirements are provided on the NYS DEC website[10] and are effective for reducing stream barriers and impediments to fish and wildlife.

Structure Type:

A. Bridges and bottomless arches are preferred and should be used whenever possible.

B. Box and Pipe culverts, if used, must be:

- Embedded into the streambed to at least 20 percent of the culvert height at the downstream invert
- Used only on "flat" streambeds (slopes no steeper than 3 percent)
- Installed level.

Structure Width:

- The crossing opening (whether open arch, bridge, or culvert) should be at least 1.25 times the width of the stream channel bed. This width is measured bank to bank at the ordinary high-water level (OHW) or edges of terrestrial, rooted vegetation.
- An average of three measurements, (project location and straight sections of the stream upstream and downstream) should be used to determine the channel bed width.

Depth and Velocity:

- At low flows, water depths and velocities should be the same as they are in natural areas upstream and downstream of the crossing.

Substrate:

- Natural substrate should be used within the crossing, and it should match the upstream and downstream substrates. It should resist displacement during floods and should be designed so that appropriate material is maintained during normal flows.

9 https://www.streamcontinuity.org/aquatic_connectivity/crossing_design/stream_simulation.htm
10 http://www.dec.ny.gov/permits/49060.html

Additional Design Criteria:

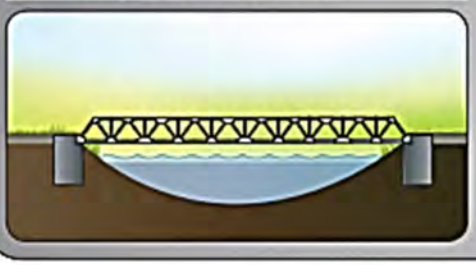
- The size of the structure is large enough to pass a 100-year flow event or the largest storm event feasible considering future climatic conditions (20% increase). If there are constrictions to sizing, the town should consider the largest possible structure feasible under considering site and budget restraints.
- Placement of the structure is in line with the stream to reduce skew.
- Instream passable, grade control structures are installed to prevent channel head cuts[11] from causing additional erosion and instability within the stream.

11 Head cut in stream geomorphology, is an area of instream instability and erosional feature of streams with an abrupt vertical drop that can be perpetuated through the river system until equilibrium of channel dimensions and slope is attained.

Design Considerations

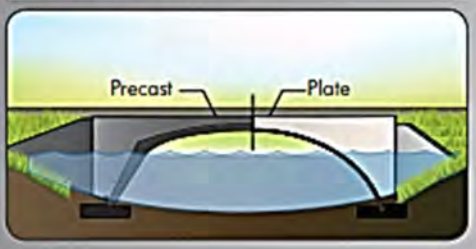
- AESTHETICS
- COST
- CLEAR SPAN
- DEBRIS BLOCKAGE
- DISTURBANCE
- FREEBOARD
- HYDRAULICS
- LIFE CYCLE
- MAINTENANCE
- ORDINARY HIGH WATER
- PERMITTING
- SCOUR
- SOIL CONDITIONS
- TEMPORARY IMPACT
- WETLANDS
- FISH PASSAGE (AOP)
- STREAM BIOLOGY
- STREAM ECOLOGY

BRIDGE AT-GRADE



- Long clear span required
- No stream impact allowed
- High span to rise ratio required
- Minimal freeboard clearance available
- Desire to reduce permitting requirements

BURIED BRIDGE



- Clear span required
- Minimal or no stream impact allowed
- Desire to reduce permitting requirements
- Life cycle/maintenance costs a primary concern
- Design considerations balanced between stream impact, cost and permitting

CULVERT w/Engineered Natural Invert



- Hydraulics are primary design consideration
- Temporary stream disturbance allowed
- Minimal debris or maintenance concerns
- Stream ecology/fish passage are key design consideration

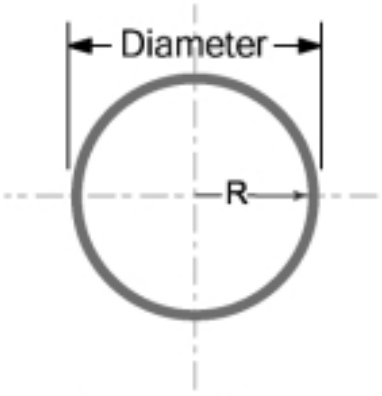
CULVERT



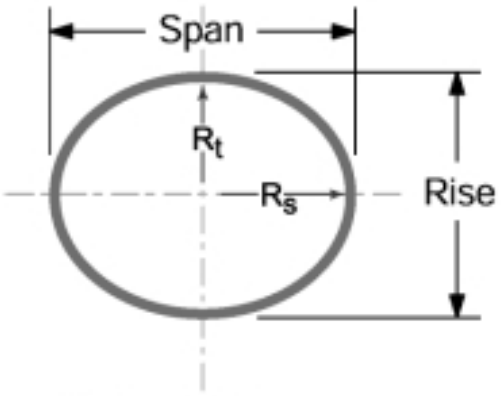
- Hydraulic design considerations only
- Clear span not required
- Stream disturbance allowed
- Minimal debris or maintenance concerns
- Cost more critical than stream considerations

Traditional culverts are typically designed to pass flood discharge without consideration for stream ecology impacts.

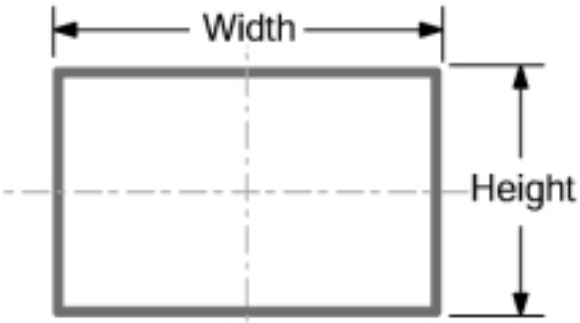
Culvert Shapes



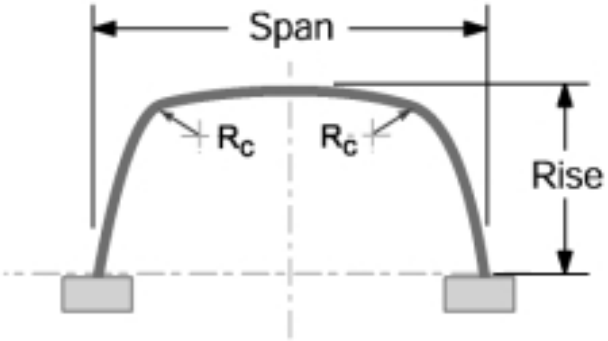
Circular Culvert



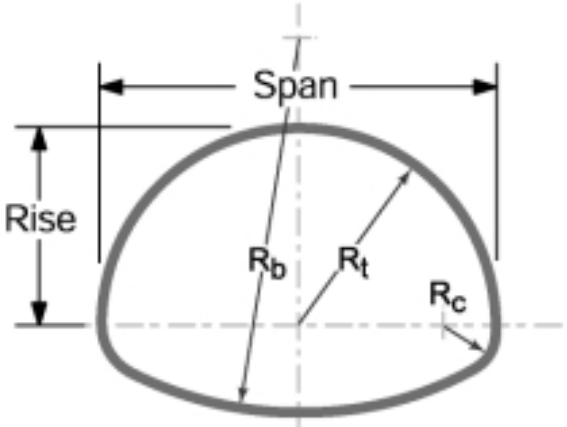
Horizontal Ellipse



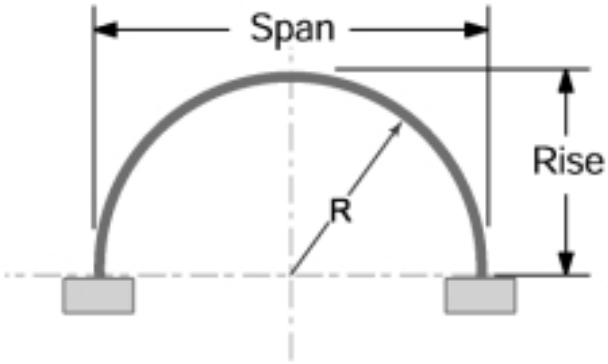
Box Culvert



Metal Box



Pipe-Arch
(Multiple Radius)



Open Bottom Arch
(Single Radius)

https://www.fs.fed.us/biology/nsaec/fishxing/index.html

Table 6: Recommended Non-Bridge Culvert Structure

Option 1: Three-Sided Concrete Box



Material – Steel-reinforced concrete

Usage Summary – Good structure to use if looking for a natural bottom, simple solution; should be considered on perennial streams	**Life Span –** 50-75 years
Benefits – Open bottom; may require some instream work to ensure stream stability, however this is a good solution for aquatic passage projects; can accommodate minimal road fill over top.	
Disadvantages – Can be higher profile; weight of concrete structures may limit installation options and require some towns to contract out work increasing cost; required installation of footers.	
Cost Comparison – Higher cost depending on the size and weight of the structure.	

Option 2: Aluminum Box Culvert with or without Invert

<table>
<tr><td></td><td>Considerations –
- Strict cover requirements.
- Can be installed with prefabricated or poured in place concrete footers or with full invert on prepared bed.
- Potential extended road closure for footer installation.
- If using full invert contractor must ensure that natural material is added to the structure to mimic natural stream bed and depending on the size of the structure this can be challenging.
- Open bottom structure may require instream work to ensure channel stability.</td></tr>
<tr><td>Material - Aluminum</td><td>Life Span – 50-75 years</td></tr>
<tr><td colspan="2">Usage Summary - Good structure to use if looking for a natural bottom, low profile solution</td></tr>
<tr><td colspan="2">Specifications –
- Open bottom or full invert
- Spans to 35 ft
- Wide-span, low-rise structures
- Ideal for small bridge replacements
- Light weight; variety of shapes and sizes</td></tr>
<tr><td colspan="2">Cost Comparison – Low-cost solution as the town may have the equipment to install these structures in house and may be a less expensive option because of transport and installation savings. Should balance cost savings with the reduced life span of the structure and the potential for extended road closure depending on footer design. Site specific needs and funding limitations should be considered.</td></tr>
</table>

Option 3 - Structural Plate (ALSP) Single Radius Arch



Material - Galvanized steel or aluminum	Life Span – **50-75 years**
Usage Summary – Wide span, low rise structures typically at lower material cost compared to concrete arches or aluminum box culverts.	
Benefits – Lower structure cost compared with concrete or aluminum box culvert alternatives. Offers a wide range of sizing options.	
Disadvantages – Requires concrete footers which can increase the duration of road closure. Requires a crew of laborers to fabricate plates. Typically requires at least 2.5’ of cover for HS25 loading.	
Cost Comparison – While material costs are comparatively low, labor costs tend to be higher.	

Option 4 - Embedded or at Stream Grade Round or Elliptical Culvert



**Structure can be buried to accommodate natural channel bottom. [12]

Material - Galvanized steel, steel reinforced concrete.	**Life Span –** 20-75 years
Usage Summary – Low-cost solution for small intermittent streams, wetland crossings and stormwater infrastructure.	
Benefits – Embedded pipe provided natural bottom; good for bankfull widths of less than 12'. Can be quickly installed; doesn't require footers.	
Disadvantages – Depending on size of the pipe it may be difficult to embed pipe and provide natural bottom; in both scenarios the culvert must span creek width, stream grade structure rarely adequate for fish passage at less than stream width. Requires 30" of cover.	
Cost Comparison – Lower cost solution	

[12] https://www.fs.fed.us/biology/nsaec/fishxing/index.html

Information from Contech - https://www.conteches.com/bridges-and-structures/plate/aluminum-box-culvert

Option 5 – Prefabricated Bridge



Material - Galvanized steel, wood decking	**Life Span –** 50-75 years; paving over decking will preserve deck life.
Usage Summary – Variable lengths – 20 Ft, 25 ft, 30 ft**;**	
Benefits – Can be quickly installed; budget friendly option for sites that do not have adequate cover.	
Disadvantages – Depending on the **size** of the span it may require a crane to lift into place. Hinged or hybrid designs for longer spans available.	
Cost Comparison – Lower cost solution for a single span option.	

Other Design Considerations

The prioritization exercise highlighted in this report is just one way the road stream crossing data can be used to benefit the Town. Our example prioritization effort outlined in the report focuses on improving Town's natural resources. However, the results from the prioritization effort also demonstrate the benefit of consolidating the large dataset into smaller components to highlight opportunities for other priorities beyond aquatic organism passage.

To better facilitate the use of the data to achieve multiple prioritization efforts an online map resource was developed to be used by town and highway personnel. The map is accessible to the public with sign in credentials for those that are qualified to update and modify the data. The map resource supports the development of the inventory document that was provided to the town as part of this project. The inventory document is a printed version of the dataset by crossing that can be referenced to as needed. The online map can be found at https://trout.maps.arcgis.com/apps/webappviewer/index.html?id=4e9b2e8b23c64ce99e3f4df147285c83.

The dataset can be used in a variety of other ways to benefit the town. Here are a few ways the data can be used:

- Provide specific data for each structure surveyed.
- Provide data to help with planning and budgeting.
- Prioritize structures based on flood potential (Appendix A: Table A5)
- Identify structures that will require permitting for replacement.
- Identify stormwater infrastructure.
- Prioritize structures based on structure condition.

By using the strategies and design examples outlined in the report, the Town can ensure that all replacements are adequately sized and designed to pass the 100-year flow, preparing for future extreme weather. Adequately sized and appropriately designed culverts will result in a flood resilient community with connected and healthy aquatic habitat.

4.0 Project Results

The results from the design process are four replacement opportunities reviewed and vetted by the town that will pass the 100-year flow event as well as ensure aquatic passage. During the design process, alternative structures were compared to consider both the site-specific requirements and town concerns and budget. The structures considered were only those determined to be ecologically and hydraulically appropriate. Since in most cases the existing structures are greatly undersized, comparing the costs to replace a structure with an in-kind inadequately sized structure to save money is not recommended. It may be detrimental to the process to consider short-term budgets only. Instead, the goal of the planning process was to identify high priority sites where it makes the most sense for the town to invest resources. The cost comparison and vetting process weighed the up-front, one-time costs against the future and ongoing maintenance and replacement costs of replacing smaller, inadequately sized structures.

In New York storm frequency and magnitude are predicted to increase. With the potential for more intense storms, the town's strategy for road stream crossing infrastructure replacements should consider the economic and public safety benefits achieved through properly sized road stream crossing structures. In

addition, inadequately sized and inappropriately designed structure fragment stream systems impacting the organisms that need healthy and connected streams to survive. Although this cost is difficult to calculate and easy to ignore, considering these impacts with support the goals of the project and result in real ecological benefits. If the goal of the Town is to improve their road infrastructure to withstand future flood and eliminate aquatic barriers, there are grant opportunities that may help reduce the higher upfront costs (Table 7) for replacement projects. The results of the prioritization efforts and selection of the top priority projects are summarized in Table 8. Each of the three priority design details are presented as separate documents. These designs documents were developed to provide a resource for planning, fundraising, and permitting the projects. Additionally, the TU team is available to support the Town on future grant proposals and permitting as needed.

As part of the project, the Team developed an inventory document with printed forms for each road stream crossing. In addition, an online mapping resource was also developed to help with the planning and management of the Town's Road stream crossings. The application is an interactive map which can be zoomed, panned, and searched. Individual crossings can be inspected by clicking on the point in the map. A view of the list of layers, a legend, basemap collection or the glossary of terms are also presented. In order to find a crossing of interest, you can search by place names, address or by NAACC survey identification number. You can also use the query 'stream crossing function' to select stream crossing rankings by town or by various prioritization metrics. Those crossings that meet your search criteria will be highlighted on the map. You can then export or save your searches. The map can be found here:

https://trout.maps.arcgis.com/apps/webappviewer/index.html?id=4e9b2e8b23c64ce99e3f4df147285c83

Figure 1: Road Stream Crossing Online Decision-Making Tool

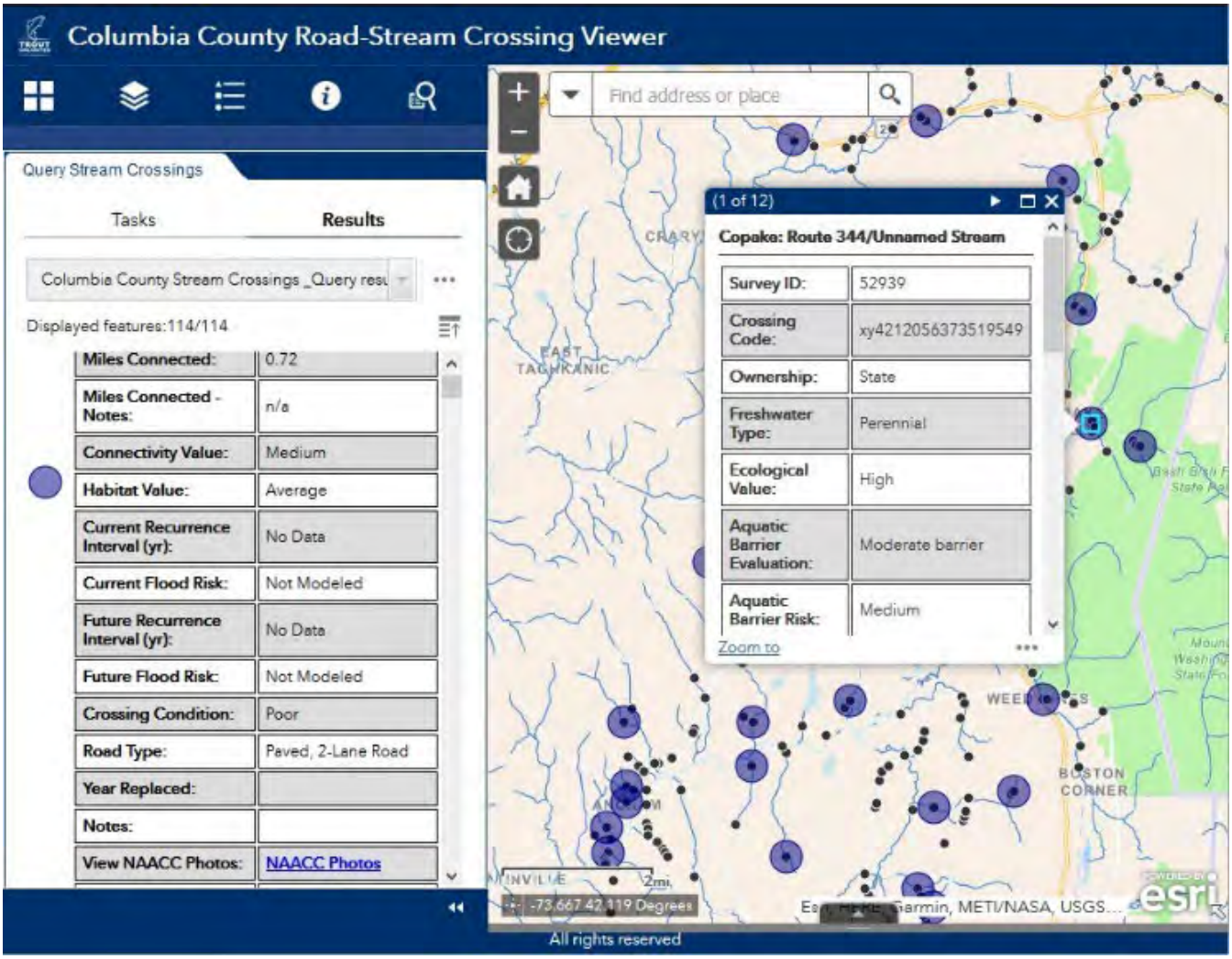


Table 7: Grants Available for Culvert Replacement Projects

Granting Agency	Grant	Project Type
NYS DEC (Department of Environmental Conservation)	Hudson River Estuary Program, Local Stewardship Planning Grants	Grant funds planning and design work for water infrastructure to improve resiliency for flooding.
NYS DEC Hudson River Estuary Program in partnership with NEWIPCC	Restoration of Watershed Connectivity	Funding for restoration of aquatic connectivity for herring and eels.
NYS DEC	Climate Smart Communities Grant	Funding provided for culvert replacement and nature- based shoreline restoration projects.
NYS DEC	Water Quality Improvement Project: Non-Agricultural Nonpoint Source Abatement and Control	Funding for streambank stabilization and riparian buffers as well as culvert repair and replacement projects.
NYS DEC	Water Quality Improvement Project: Aquatic Connectivity Restoration	Restoration of aquatic connectivity with a maximum grant of $250,000.
NYS DEC	Non-Agricultural Nonpoint Source Planning Grant	Planning funds for streambank stabilization and culvert repair or replacement.
NYS DEC	Trees for Tribs	Trees from the Saratoga Tree Nursery to re-establish/restore riparian buffers using native vegetation. First come-first served, tree stock is quickly exhausted.
NYS DOS (Department of State)	Local Waterfront Revitalization Program	Funding to prepare a Local Waterfront Revitalization Plan (LWRP) or implement a component of an approved LWRP.
NYS EFC (Environmental Facility Corporation)	Clean Water State Revolving Fund	CWSRF can provide various forms of project finance for certain habitat restoration and protection projects in national estuary program areas. Short and long-term loans are available at no interest and low interest rates.

Granting Agency	Grant	Project Type
FEMA (Federal Emergency Management Agency)	Hazard Mitigation Assistance	Triggered by a disaster, funding can be made available for projects to mitigate future damages and can include culvert right sizing and stream stabilization; pre-disaster funding may also be available
HUD (US Department of Housing and Urban Development)	Community Development Block Grant Program	Programs can potentially fund improvements in public infrastructure.
NYS Hudson River Valley Greenway	Greenways Communities Grant Program	Small projects that can fund natural resource protection initiatives.
NYS Department of Transportation (DOT)	BRIDGE program	The BRIDGE NY program provides enhanced assistance for local governments to rehabilitate and replace bridges and culverts.
NYS DOT	CHIPs: Consolidated Highway Improvement Program	CHIPS provides State funds to municipalities to support the construction and repair of highways, bridges, highway-railroad crossings, and other facilities that are not on the State highway system. Note that PAVE NY is closely related to CHIPs and may help finance resurfacing efforts.

Table 8: Proposed Priority Crossing Replacements for the Town of Grafton

NAACC	Road	Stream	AOP/Ecological	Flooding	Maintenance - Public Safety	Replacement	Cost (materials only)
47746	Cranberry Pond Rd	UNT	Significant barrier/HIGH	HIGH	HIGH	ABC Shell 44, 19’5”X 6’11’’x 30’	$99,800
47739	Jay Hakes Road	UNT Quaken Kill	Severe barrier/HIGH	Moderate	HIGH	ABC Shell 20, 13’3”x 6'9"x30'	$112,300
46490	Claus Road	Bonesteel Brook	Severe barrier/HIGH	Moderate to High	Moderate	Shell 6 ABC, 10’11”x6’4”x30’	$63,900
47738	Roark Road	UNT Quaken Kill	Significant barrier/HIGH	Moderate to High	Moderate	SRA 19’x8’2”x30’	$119,800
						Project Total	$395,800

5.0 QA/QC Summary and Data Limitation

Data analysis was completed by TU. To ensure data quality control on the analysis and prioritization methods, Jeremiah Stone, acting as the QA/QC manager, reviewed 20% of the data for accuracy and ranking effectiveness. Any discrepancies in the review were reexamined. Managing TU engineer, Jeff Tenley, reviewed all designs and specification for the priority crossings for accuracy.

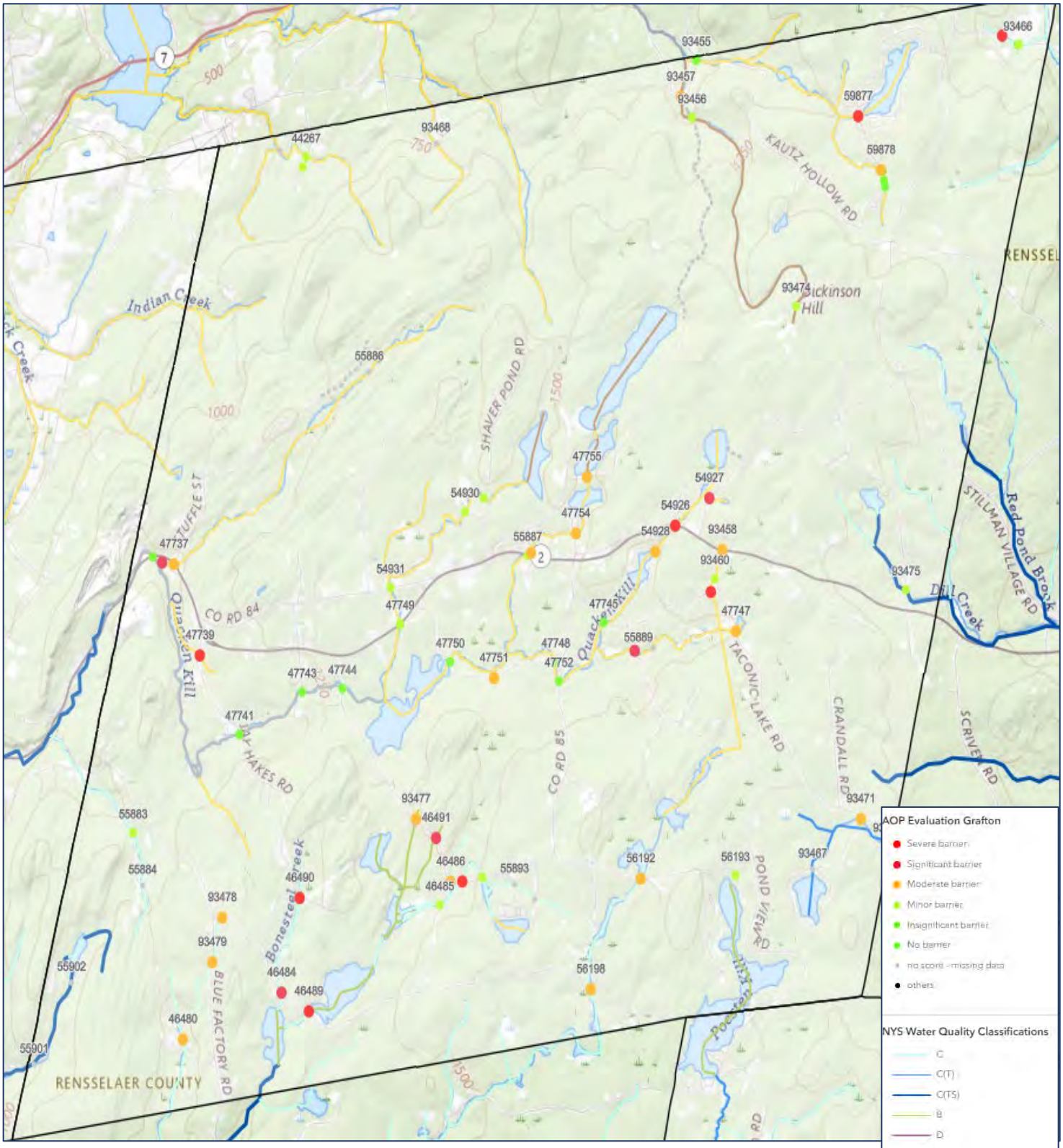
The results of prioritization activity are based on the several datasets that were generated by different entities. The metadata for each dataset is available and described in Appendix A: Table A1. The results are therefore dependent on the accuracy and the ability for these datasets to characterize the landscape in its current conditions. The use of these datasets was useful as a starting point but on the ground site visits and fish surveys were conducted in order to verify habitat conditions.

Also, the hydraulic model results consider each structure in isolation and do not consider flow impacts caused by upstream structures. As a result, it is recommended that further flood analysis should be completed in replacement scenarios where the replacement of an upstream structures may cause increased flows to downstream structures.

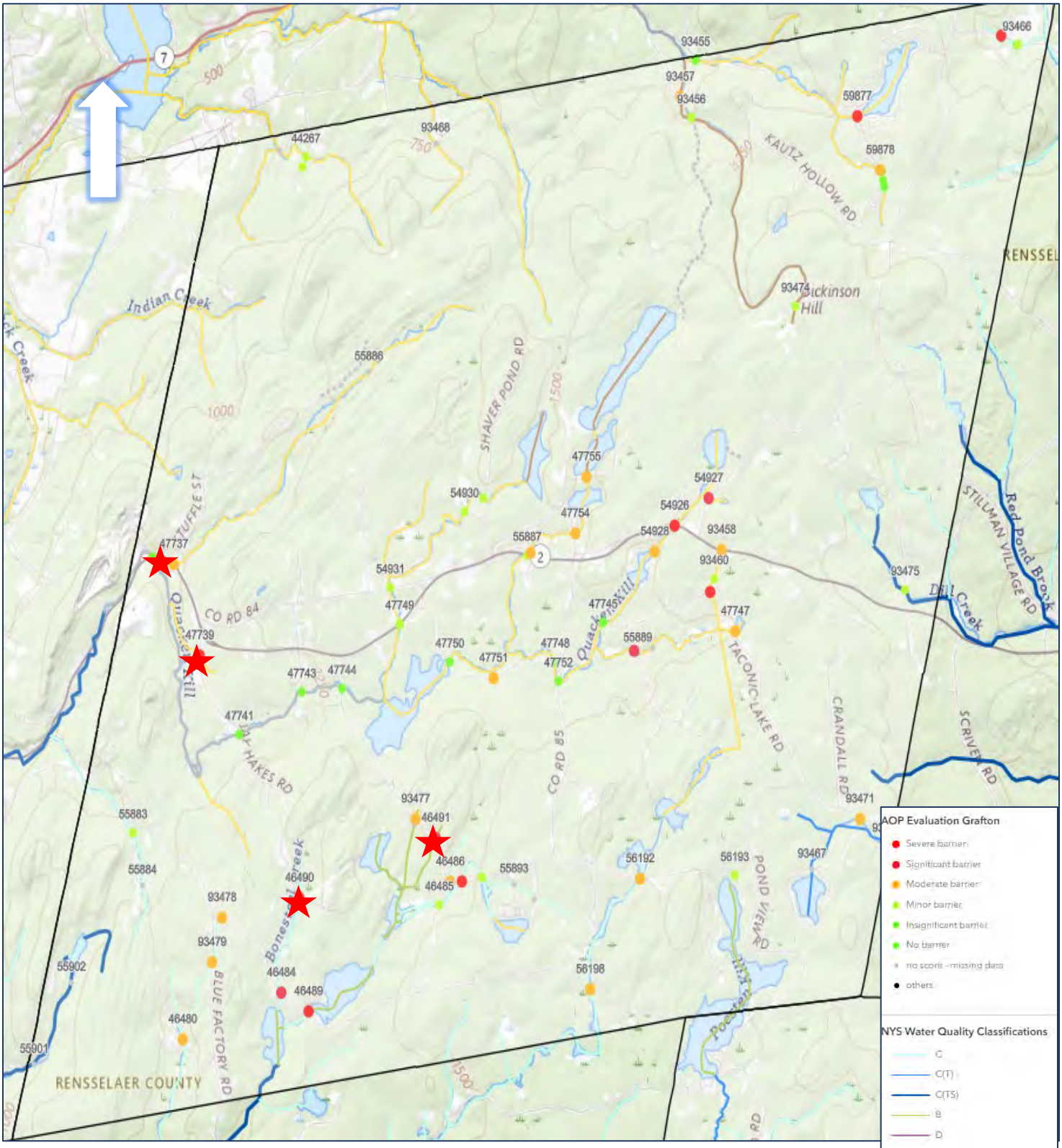
Special thanks to the Town of Grafton Board of Directors, Supervisor and Highway Supervisor for supporting this project. The town spent countless hours working with the TU team to complete our work. Additional thanks to our project partners who participated and supported TU throughout the process. Our partners include, Emily Bialowas, NEIWPCC, Jim Kat and Scott Cuppett from and HREP, Steve Swenson and his crew from NYS DEC Region 4 Fisheries, Audrey Kropp from Cornell Cooperative Extension of Columbia and Greene County, and Megan Myers and Nate Woodworth from Rensselaer County Soil and Water Conservation District.

Appendix A - Project Maps and Data

Map 1: Road Stream Crossing Aquatic Organism Barrier Evaluation Result



Map 2: Prioritized Road Stream Crossings



★ Priority Site

Map 3: Locations of Grafton Dams

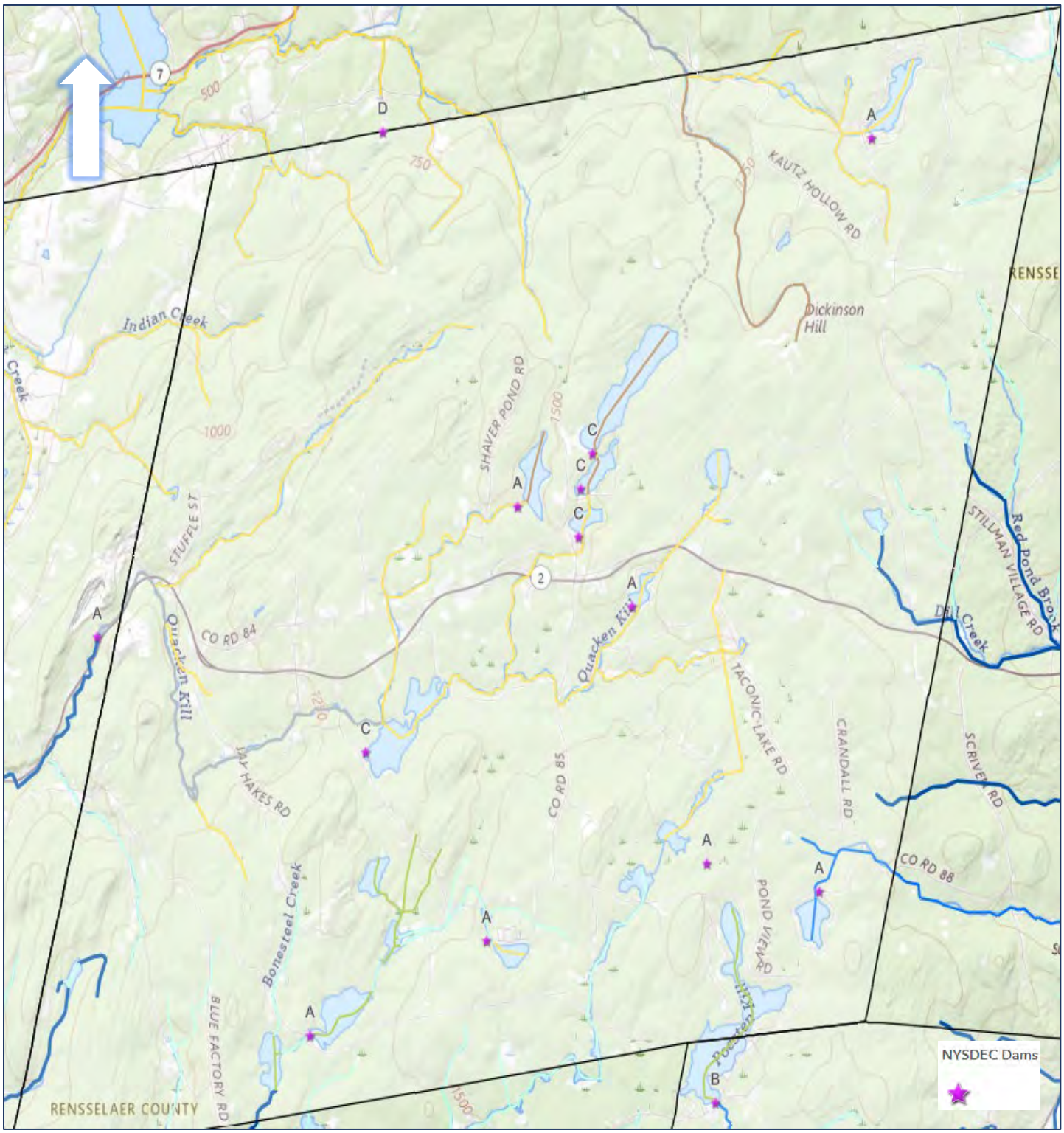


Table A1: Prioritization Metrics

Priority	Metric	Dataset/Methodology	Ranking
Ecological Risk	**Freshwater Type** **Table**	Datasets - Topo Maps; National Hydrography Dataset (NHD) Dataset; National Wetland Inventory Dataset Method - Perennial - Mapped; topographical info and obviou based on dataset and survey info; Intermittent based on topo - obvious drainage connected to perennial stream; Stormwat topographical info with no obvious drainage and no wetland	Perennial = HIGH Intermittent/Wetland = MEDIUM Stormwater = NOT RANKED
	AOP Barrier Significance class	Datasets – NAACC Method - The barrier severity scores for field-surveyed road-stream crossings are calculated in the NAACC database using the scoring algorithm described in the NAACC Numeric Scoring System.	Severe/Significant barrier = HIGH, Moderate barrier = MEDIUM, Minor/Insignificant/No barrier = LOW No Data = Not Ranked
	Downstream Habitat Connectivity - Used for ranking high priority crossings	Dataset – NAACC Method - Manually count number of barriers from barrier of concern to confluence with next downstream mainstem using ARCGIS; include all barriers except minor or insignificant; No data was considered if the freshwater type was categorized as intermittent or stormwater.	Barrier Ranking (1 Downstream Barrier = 1, Otherwise = 0)
	Habitat Quality	Dataset – Hudson River Stream Condition Index; TU Conservation Portfolio for Eastern Brook Trout Method – Locate crossing and determine Stream Condition ranking at the location; if stream condition ranking is not available for the crossing consider TUs Conservation Portfolio results	Habitat Condition Ranking for Perennial Streams (High, Average, Low) Eastern Brook Trout Ranking for Streams without a Habitat Conditions Ranking (Allopatric Brook Trout Patch – Very High, Resilient of Redundant

			Patch = High; Other Populations = Medium; No Patch = Low)
	Fisheries Priority Used for ranking high priority crossings	Dataset – Region 4 Fisheries Dataset Method – Occurrence data within the watershed upstream or downstream of barriers was considered for this analysis. Brook and Eel; Brook; Eel; Brown and Rainbow; Brown; Rainbow; No Trout or Eel	Brook Trout, American eel presence
Flood Risk	**Hydraulic Capacity**	Dataset – NAACC Method - Cornell Water Resources modeling results from NAACC survey data (See description on page 8).	< 25 year = HIGH 25-50 year = MEDIUM >50 year = LOW
Infrastructure Risk	**Town Priority** Used for ranking high priority crossings	Input from Town	Town Priority (High =3, Med=2, Low=1
	Geomorphic Compatibility Used for ranking high priority crossings	Dataset – NAACC Method – Survey data results in either flow aligned, or flow skewed	Alignment Ranking (Flow Aligned = 0, Skewed = 1)
Infrastructure Risk	**Crossing Condition** Used for ranking high priority crossings	Dataset – NAACC survey results with input from the town.	Crossing Condition Ranking (Poor = 3, Ok = 2, New = 0)

Table A2: Summary of Dams Found in the Town of Grafton

DAM NAME	HAZARD CODE	OWNERSHIP	TYPE	USE	IMPOUNDMENT (ACRES)	LATITUDE	LONGITUDE
BABCOCK LAKE DAM	LOW	BABCOCK LAKE ESTATES, INC.	RE - EARTH	Recreation	52	42.813333	-73.403333
CRANBERRY POND DAM	LOW	FIRST GRAFTON CORPORATION	RE - Earth, ER - Rockfill	Recreation	19	42.741111	-73.429722
FOREST LAKE DAM	LOW	IRA HARROD	RE - Earth, MS - Masonry	Recreation	19	42.733333	-73.465000
LAKE ELIZABETH DAM	LOW	WALLACE BRYCE	RE - Earth, ER - Rockfill	Recreation	15	42.766667	-73.441667
LONG POND DAM	HIGH	NYS PARKS, RECREATION & HISTORIC PRESERVATION	RE - Earth	Recreation	120	42.781944	-73.448056
MARTIN DUNHAM RESERVOIR DAM	HIGH	NYS PARKS, RECREATION & HISTORIC PRESERVATION	RE - Earth	Recreation	88	42.752222	-73.484444
MILL POND DAM	HIGH	NYS PARKS, RECREATION & HISTORIC PRESERVATION	RE - Earth	Recreation	18	42.773611	-73.450278
SECOND POND DAM	HIGH	NYS PARKS, RECREATION & HISTORIC PRESERVATION	RE - Earth	Recreation	32	42.778333	-73.450000
SHAVER POND DAM	LOW	NYS PARKS & RECREATION CAPITOL DISTRICT	CN - Concrete Gravity	Recreation	44	42.776667	-73.460000
TACONIC POND DAM	LOW	TOWN OF GRAFTON	CN - Concrete Gravity	Recreation	34	42.738333	-73.411667
WAGER DAM	LOW	Nick Petitti & Angela Petitti	CN - Concrete Gravity	Recreation	62	42.723944	-73.493389

Table A3: Summary of Prioritization Results for Aquatic Passage Perennial Streams

SURVEY ID	ROAD	ECOLOGICAL VALUE	AQUATIC BARRIER EVALUATION	AQUATIC BARRIER RISK	LATITUDE	LONGITUDE
44246	Kautz Hollow Road	HIGH	No barrier	LOW	42.819426	-73.431092

44267	Cold Springs Road	HIGH	Minor barrier	LOW	42.809678	-73.494406
46480	Clickner Road	MEDIUM	Moderate barrier	MEDIUM	42.72098	-73.514395
46490	Claus Road	HIGH	Severe barrier	HIGH	42.7352	-73.495442
46491	Dunham Road	HIGH	Significant barrier	HIGH	42.741237	-73.473315
47738	Roark Road	HIGH	Significant barrier	HIGH	42.768928	-73.517758
47739	Jay Hakes Road	HIGH	Severe barrier	HIGH	42.759581	-73.51164
47741	Jay Hakes Road	HIGH	No barrier	LOW	42.751629	-73.505202
47743	Bailey Road	HIGH	No barrier	LOW	42.755919	-73.495063
47744	Dunham Reservoir Road	HIGH	Insignificant barrier	LOW	42.756248	-73.488493
47745	Steve Odell Road	HIGH	Insignificant barrier	LOW	42.762903	-73.446126
47746	Cranberry Pond Road	MEDIUM	Significant barrier	HIGH	42.760054	-73.441089
47748	Johnson Road	HIGH	Insignificant barrier	LOW	42.758939	-73.453902
47749	Dumbleton Road	MEDIUM	Minor barrier	LOW	42.762755	-73.47916
47750	Johnson Road	HIGH	No barrier	LOW	42.758928	-73.471029
47754	North Long Pond Road	HIGH	Moderate barrier	MEDIUM	42.77185	-73.450634
47755	North Long Pond Road	HIGH	Moderate barrier	MEDIUM	42.777549	-73.448827
47756	Dumbleton Road	HIGH	Moderate barrier	MEDIUM	42.769887	-73.457893
54928	Lake Camp Way	HIGH	Moderate barrier	MEDIUM	42.770019	-73.437743
54929	Shaver Pond Road	MEDIUM	Minor barrier	LOW	42.775443	-73.4656
54930	Martin Road	MEDIUM	Minor barrier	LOW	42.774044	-73.468617
55883	Behuniak Road	HIGH	Minor barrier	LOW	42.741755	-73.522477
55884	Behuniak Road	HIGH	no score - missing data	NO DATA	42.736435	-73.520946
55888	State Highway 2	MEDIUM	No barrier	LOW	42.762681	-73.479163
55891	Steve Odell Road	MEDIUM	Severe barrier	HIGH	42.765958	-73.428727
55892	Willets Way	HIGH	no score - missing data	NO DATA	42.735041	-73.457323
55893	Forest Lake Way	HIGH	no score - missing data	NO DATA	42.736566	-73.460589
55901	Burney Pond Road	HIGH	no score - missing data	NO DATA	42.718438	-73.538533
55902	Burney Pond Road	HIGH	no score - missing data	NO DATA	42.726683	-73.532483
56192	South Long Pond Road	MEDIUM	Moderate barrier	MEDIUM	42.737153	-73.44011
56198	Dyken Pond Road	HIGH	Moderate barrier	MEDIUM	42.726017	-73.448207
59877	Kelyer Ave	MEDIUM	Severe barrier	HIGH	42.813753	-73.40482
59878	Kelyer Road	HIGH	Moderate barrier	MEDIUM	42.808353	-73.401106

59879	Kelyer Road	HIGH	No barrier	LOW	42.808251	-73.400843
93453	Fox Hollow Road	HIGH	Severe barrier	HIGH	42.821851	-73.381471
93454	Fox Hollow Road	HIGH	Minor barrier	LOW	42.821	-73.378746
93455	Sweet Road	HIGH	Insignificant barrier	LOW	42.819404	-73.431094
93466	Fox Hollow Road	HIGH	No barrier	LOW	42.820924	-73.378932
93467	Taconic Lake Way	HIGH	no score - missing data	NO DATA	42.73807	-73.41222
93469	Cunningham Road	HIGH	no score - missing data	NO DATA	42.810288	-73.498638
93474	Fire Tower Road	HIGH	Minor barrier	LOW	42.794673	-73.414871
93475	Josh Hall Pond Road	HIGH	Minor barrier	LOW	42.766186	-73.397096
93477	Dunham Road	HIGH	Moderate barrier	MEDIUM	42.743149	-73.476563

Table A4: Summary of Flooding Prioritization Results for Town Structures

SURVEY ID	ROAD	CURRENT FLOOD RISK	CROSSING ALIGNMENT	CROSSING CONDITION	ROAD TYPE	LATITUDE	LONGITUDE
44232	Cold Springs Road	HIGH	Flow-Aligned	OK	Unpaved	42.808658	-73.494965
44246	Kautz Hollow Road	HIGH	Flow-Aligned	OK	Unpaved	42.819426	-73.431092
44267	Cold Springs Road	HIGH	Flow-Aligned	OK	Unpaved	42.809678	-73.494406
46480	Clickner Road	HIGH	Flow-Aligned	OK	Unpaved	42.72098	-73.514395
46490	Claus Road	HIGH	Flow-Aligned	OK	Unpaved	42.7352	-73.495442
46491	Dunham Road	HIGH	Skewed (>45°)	OK	Unpaved	42.741237	-73.473315
47738	Roark Road	HIGH	Flow-Aligned	OK	Unpaved	42.768928	-73.517758
47739	Jay Hakes Road	HIGH	Flow-Aligned	OK	Unpaved	42.759581	-73.51164
47741	Jay Hakes Road	HIGH	Flow-Aligned	OK	Unpaved	42.751629	-73.505202
47743	Bailey Road	HIGH	Flow-Aligned	OK	Unpaved	42.755919	-73.495063
47744	Dunham Reservoir Road	HIGH	Flow-Aligned	OK	Unpaved	42.756248	-73.488493
47745	Steve Odell Road	HIGH	Flow-Aligned	OK	Paved	42.762903	-73.446126
47746	Cranberry Pond Road	HIGH	Flow-Aligned	OK	Unpaved	42.760054	-73.441089
47748	Johnson Road	HIGH	Flow-Aligned	OK	Unpaved	42.758939	-73.453902
47749	Dumbleton Road	HIGH	Skewed (>45°)	OK	Paved	42.762755	-73.47916
47750	Johnson Road	HIGH	Flow-Aligned	OK	Unpaved	42.758928	-73.471029
47751	Johnson Road	HIGH	Flow-Aligned	Poor	Unpaved	42.757308	-73.4639
47754	North Long Pond Road	HIGH	Flow-Aligned	OK	Paved	42.77185	-73.450634
47755	North Long Pond Road	HIGH	Flow-Aligned	OK	Unpaved	42.777549	-73.448827
47756	Dumbleton Road	HIGH	Flow-Aligned	OK	Paved	42.769887	-73.457893
54928	Lake Camp Way	HIGH	Flow-Aligned	OK	Unpaved	42.770019	-73.437743
54929	Shaver Pond Road	HIGH	Flow-Aligned	Poor	Unpaved	42.775443	-73.4656
54930	Martin Road	HIGH	Flow-Aligned	OK	Unpaved	42.774044	-73.468617
55883	Behuniak Road	HIGH	Flow-Aligned	OK	Unpaved	42.741755	-73.522477
55884	Behuniak Road	HIGH	Skewed (>45°)	Poor	Trail	42.736435	-73.520946
55888	State Highway 2	HIGH	No data	No data	Paved	42.762681	-73.479163
55891	Steve Odell Road	HIGH	Flow-Aligned	OK	Paved	42.765958	-73.428727
55892	Willets Way	HIGH	No data	No data	Driveway	42.735041	-73.457323
55893	Forest Lake Way	HIGH	No data	No data	Driveway	42.736566	-73.460589

55901	Burney Pond Road	HIGH	No data	No data	Unpaved	42.718438	-73.538533
55902	Burney Pond Road	HIGH	No data	No data	Unpaved	42.726683	-73.532483
56192	South Long Pond Road	HIGH	Flow-Aligned	OK	Unpaved	42.737153	-73.44011
56193	Benker School Way	HIGH	Flow-Aligned	OK	Unpaved	42.737466	-73.424748
56198	Dyken Pond Road	HIGH	Flow-Aligned	OK	Unpaved	42.726017	-73.448207
59877	Kelyer Ave	HIGH	Flow-Aligned	Poor	Unpaved	42.813753	-73.40482
59878	Kelyer Road	HIGH	Flow-Aligned	OK	Paved	42.808353	-73.401106
59879	off Kelyer Road	HIGH	Flow-Aligned	OK	Trail	42.808251	-73.400843
93453	Fox Hollow Road	HIGH	Flow-Aligned	OK	Unpaved	42.821851	-73.381471
93454	Fox Hollow Road	HIGH	Flow-Aligned	OK	Unpaved	42.821	-73.378746
93455	Sweet Road	HIGH	Flow-Aligned	OK	Unpaved	42.819404	-73.431094
93466	Fox Hollow Road	HIGH	No data	No data	Driveway	42.820924	-73.378932
93467	Taconic Lake Way	HIGH	No data	No data	Unpaved	42.73807	-73.41222
93469	Cunningham Road	HIGH	No data	No data	Driveway	42.810288	-73.498638
93474	Fire Tower Road	HIGH	Flow-Aligned	OK	Unpaved	42.794673	-73.414871
93475	Josh Hall Pond Road	HIGH	Flow-Aligned	OK	Paved	42.766186	-73.397096
93477	Dunham Road	HIGH	Flow-Aligned	OK	Paved	42.743149	-73.476563

Table A5: Summary of Aquatic Habitat Prioritization Results for Perennial Streams

SURVEY ID	ROAD	ECOLOGICAL VALUE	AQUATIC BARRIER RISK	MILES CONNECTED	CONNECTIVITY VALUE	CONDITION	LATITUDE	LONGITUDE
46490	Claus Road	HIGH	HIGH	0.23	LOW	OK	42.7352	-73.495442
46491	Dunham Road	HIGH	HIGH	0.10	LOW	OK	42.741237	-73.473315
47738	Roark Road	HIGH	HIGH	0.12	LOW	OK	42.768928	-73.517758
47739	Jay Hakes Road	HIGH	HIGH	0.20	LOW	OK	42.759581	-73.51164
93453	Fox Hollow Road	HIGH	HIGH	0.18	LOW	OK	42.821851	-73.381471

Table A6: Summary of Priority Crossings by Multiple Objectives

SURVEY ID	ROAD	ECOLOGICAL VALUE	AQUATIC BARRIER EVALUATION	AQUATIC BARRIER RISK	CONNECTIVITY VALUE	CURRENT FLOOD RISK	CROSSING CONDITION	LATITUDE	LONGITUDE
46490	Claus Road	HIGH	Severe barrier	HIGH	LOW	HIGH	OK	42.7352	-73.495442
46491	Dunham Road	HIGH	Significant barrier	HIGH	LOW	HIGH	OK	42.741237	-73.473315
47738	Roark Road	HIGH	Significant barrier	HIGH	LOW	HIGH	OK	42.768928	-73.517758
47739	Jay Hakes Road	HIGH	Severe barrier	HIGH	LOW	HIGH	OK	42.759581	-73.51164
93453	Fox Hollow Road	HIGH	Severe barrier	HIGH	LOW	HIGH	OK	42.821851	-73.381471

Table A7: Summary of Crossings by Freshwater Type

SURVEY ID	ROAD	FRESHWATER TYPE	CROSSING ALIGNMENT	CROSSING CONDITION	ROAD TYPE	LATITUDE	LONGITUDE
44232	Cold Springs Road	Intermittent	Flow-Aligned	OK	Unpaved	42.808658	-73.494965

47751	Johnson Road	Intermittent	Flow-Aligned	Poor	Unpaved	42.757308	-73.4639
56193	Benker School Way	Intermittent	Flow-Aligned	OK	Unpaved	42.737466	-73.424748
44246	Kautz Hollow Road	Perennial	Flow-Aligned	OK	Unpaved	42.819426	-73.431092
44267	Cold Springs Road	Perennial	Flow-Aligned	OK	Unpaved	42.809678	-73.494406
46490	Claus Road	Perennial	Flow-Aligned	OK	Unpaved	42.7352	-73.495442
46491	Dunham Road	Perennial	Skewed (>45°)	OK	Unpaved	42.741237	-73.473315
47738	Roark Road	Perennial	Flow-Aligned	OK	Unpaved	42.768928	-73.517758
47739	Jay Hakes Road	Perennial	Flow-Aligned	OK	Unpaved	42.759581	-73.51164
47741	Jay Hakes Road	Perennial	Flow-Aligned	OK	Unpaved	42.751629	-73.505202
47743	Bailey Road	Perennial	Flow-Aligned	OK	Unpaved	42.755919	-73.495063
47744	Dunham Reservoir Road	Perennial	Flow-Aligned	OK	Unpaved	42.756248	-73.488493
47745	Steve Odell Road	Perennial	Flow-Aligned	OK	Paved	42.762903	-73.446126
47748	Johnson Road	Perennial	Flow-Aligned	OK	Unpaved	42.758939	-73.453902
47750	Johnson Road	Perennial	Flow-Aligned	OK	Unpaved	42.758928	-73.471029
47754	North Long Pond Road	Perennial	Flow-Aligned	OK	Paved	42.77185	-73.450634
47755	North Long Pond Road	Perennial	Flow-Aligned	OK	Unpaved	42.777549	-73.448827
47756	Dumbleton Road	Perennial	Flow-Aligned	OK	Paved	42.769887	-73.457893
54928	Lake Camp Way	Perennial	Flow-Aligned	OK	Unpaved	42.770019	-73.437743
55883	Behuniak Road	Perennial	Flow-Aligned	OK	Unpaved	42.741755	-73.522477
55884	Behuniak Road	Perennial	Skewed (>45°)	Poor	Trail	42.736435	-73.520946
55892	Willets Way	Perennial	No data	No data	Driveway	42.735041	-73.457323
55893	Forest Lake Way	Perennial	No data	No data	Driveway	42.736566	-73.460589
55901	Burney Pond Road	Perennial	No data	No data	Unpaved	42.718438	-73.538533
55902	Burney Pond Road	Perennial	No data	No data	Unpaved	42.726683	-73.532483
56198	Dyken Pond Road	Perennial	Flow-Aligned	OK	Unpaved	42.726017	-73.448207
59878	Kelyer Road	Perennial	Flow-Aligned	OK	Paved	42.808353	-73.401106
59879	Kelyer Road	Perennial	Flow-Aligned	OK	Trail	42.808251	-73.400843
93453	Fox Hollow Road	Perennial	Flow-Aligned	OK	Unpaved	42.821851	-73.381471
93454	Fox Hollow Road	Perennial	Flow-Aligned	OK	Unpaved	42.821	-73.378746
93455	Sweet Road	Perennial	Flow-Aligned	OK	Unpaved	42.819404	-73.431094
93466	Fox Hollow Road	Perennial	No data	No data	Driveway	42.820924	-73.378932
93467	Taconic Lake Way	Perennial	No data	No data	Unpaved	42.73807	-73.41222

93469	Cunningham Road	Perennial	No data	No data	Driveway	42.810288	-73.498638
93474	Fire Tower Road	Perennial	Flow-Aligned	OK	Unpaved	42.794673	-73.414871
93475	Josh Hall Pond Road	Perennial	Flow-Aligned	OK	Paved	42.766186	-73.397096
93477	Dunham Road	Perennial	Flow-Aligned	OK	Paved	42.743149	-73.476563
46480	Clickner Road	Perennial	Flow-Aligned	OK	Unpaved	42.72098	-73.514395
47746	Cranberry Pond Road	Perennial	Flow-Aligned	OK	Unpaved	42.760054	-73.441089
47749	Dumbleton Road	Perennial	Skewed (>45°)	OK	Paved	42.762755	-73.47916
54929	Shaver Pond Road	Perennial	Flow-Aligned	Poor	Unpaved	42.775443	-73.4656
54930	Martin Road	Perennial	Flow-Aligned	OK	Unpaved	42.774044	-73.468617
55888	State Highway 2	Perennial	No data	No data	Paved	42.762681	-73.479163
55891	Steve Odell Road	Perennial	Flow-Aligned	OK	Paved	42.765958	-73.428727
56192	South Long Pond Road	Perennial	Flow-Aligned	OK	Unpaved	42.737153	-73.44011
59877	Kelyer Ave	Perennial	Flow-Aligned	Poor	Unpaved	42.813753	-73.40482

Figure A1: Summary of Cornell University Resiliency Model Strategy

