3. Adaptive capability: learning how to change and maintain adaptive systems (e.g., warning systems) and build community competencies to help minimize the impacts of flooding.
4. Post-flood learnings: learning how to improve preparedness levels, mitigation behaviors and adaptive capability after a flood.

In developing a program, community leaders should consider a commitment to community participation in the design, implementation, and evaluation of flood education programs. A more participatory approach to community flood and other hazards can enhance community resilience to adversity by stimulating participation and collaboration of stakeholders and decision makers in building its capability for preparedness, response, and recovery. In addition, community flood education programs should be ongoing as it is unsure when a flood event will occur (Dufty 2008).

8.10 ALTERNATIVE #4-10: DEVELOPMENT/UPDATING OF A COMPREHENSIVE PLAN

Local governments are responsible for planning in a number of areas, including housing, transportation, water, open space, waste management, energy, and disaster preparedness. In New York State, these planning efforts can be combined into a comprehensive plan that steers investments by local governments and guides future development through zoning regulations. A comprehensive plan will guide the development of government structure as well as natural and built environment.

Significant features of comprehensive planning in most communities include its foundations for land use controls for the purpose of protecting the health, safety, and general welfare of the community's citizens. The plan will focus on immediate and long-range protection, enhancement, growth, and development of a community's assets. Materials included in the comprehensive plan will include text and graphics, including but not limited to maps, charts, studies, resolutions, reports, and other descriptive materials. Once the comprehensive plan is completed, the governing board, i.e., town or village board, motions to adopt it (EFC 2015).

Development of a comprehensive plan in general is optional, as is the development of a plan in accordance with state comprehensive plan statutes. However, statutes can guide plan developers through the process. Comprehensive plans provide the following benefits to municipal leaders and community members (EFC 2015):

- Provides a legal defense for regulations
- Provides a basis for other actions affecting the development of the community (i.e., land use planning and zoning)
- Helps establish policies regarding creation and enhancement of community assets

All communities within the watershed should develop or update their respective comprehensive plans in an effort to coordinate and manage any and all land use changes and development within the Honeoye Creek floodplain.

In addition, any comprehensive plan developed for communities within the watershed should include future climate change and NYS Smart Growth practices. Local governments should incorporate sustainability elements throughout the comprehensive plan. “Future-proofing” management and mitigation strategies by taking climate change into consideration would ensure that any strategy pursued would have the greatest possible chance for success. NYS Smart Growth practices would maximize the social, economic, and environmental benefits from public infrastructure development, while minimizing unnecessary environmental degradation, and disinvestment in urban and suburban communities caused by the development of new or expanded infrastructure.

9. NEXT STEPS

Before selecting a flood mitigation strategy, securing funding or commencing an engineering design phase, Ramboll recommends that additional modeling simulations and wetland investigations be performed.

9.1 ADDITIONAL DATA MODELING

Additional data collection and modeling would be necessary to more precisely model WSELs and the extent of potential flooding in overbank areas and the floodplain. 2-D unsteady flow modeling using the HEC-RAS program, would incorporate additional spatial information in model simulations producing more robust results with a higher degree of confidence than the currently modeled 1-D steady flow simulations. 2-D ice simulations are highly recommended to access the wintery condition with the suggested alternatives to evaluate the water level rises due to presence of ice, ice-jam or break-up ice jam conditions.

9.2 STATE AND LOCAL REGULATIONS

Prior to implementation of any mitigation alternative, pertinent local municipality Flood Damage Prevention laws, NYSDEC Part 502 regulations (for state-related facilities), and any other applicable state and local laws or regulations should be determined and appropriate steps taken to ensure compliance. These laws and regulations should also reflect the FEMA requirements for work within the regulated floodplain.

9.3 STATE/FEDERAL WETLANDS INVESTIGATION

Any flood mitigation strategy that proposes using wetlands in any capacity needs to be evaluated based on federal and state wetland criteria before that mitigation strategy can be recommended for final consideration.

For any proposed mitigation alternatives within any jurisdictional NYSDEC wetlands or on lands that historically were designated wetlands, the NYSDEC would require wetland delineations. In addition to any flood bench mitigation project, the areas with identified wetlands that would require wetland delineations include the areas both downstream and upstream of the Main Street/US-20A bridge in the Hamlet of Honeoye, and upstream of the railroad embankments in the Village of Honeoye Falls. Wetland delineations will verify whether the NYSDEC would require an Article 24 Wetland Permit for any mitigation project.

9.4 NYSDEC PROTECTION OF WATERS PROGRAM

Honeoye Creek is protected under Article 15 of Title 6 of the New York Codes, Rules, and Regulations (6NYCRR Part 608). Honeoye Creek has a waterbody classification of C, which indicates a best usage for fishing under Regulation 821-109, for most of its reach, except for a small portion in the Village of Honeoye Falls where waterbody classification changes to B, which indicates a best usage for swimming and other recreation, and fishing (NYSDEC 2021c).

In addition, Honeoye Creek is designated as a Mussel Screening Stream with the designation of "S1 or S2 Freshwater Mussels." The "S" designation is known as the Subnational Rank and indicates the status of the species within New York according to the NY Natural Heritage Program. An "S1" designation is known as "critically imperiled" and indicates extreme rarity (often 5 or fewer occurrences) or because of some factor(s) such as very steep declines making it especially vulnerable to extinction or extirpation from the area. An "S2" designation is known as "imperiled" and indicates rarity due to very restricted range, very few populations (often 20 or fewer), steep declines, or other factors making it very vulnerable to global extinction or extirpation from the area (NYNHP 2017).

Any changes to the bed or bank of Honeoye Creek in the vicinity of imperiled and/or critically imperiled mussels would need to be reviewed and approved by the NYSDEC (NYSDEC 2020a; NYSDEC 2021a).

9.5 ENDANGERED AND THREATENED SPECIES OF FISH AND WILDLIFE

Honeoye Creek is protected under Article 15 of Title 6 of the New York Codes, Rules, and Regulations (6NYCRR) Part 182, which refers to the "Endangered and Threatened Species of Fish and Wildlife." For any flood mitigation alternative that has a proposed project area that includes an endangered and threatened species, the NYSDEC will require an analysis for any endangered and/or threatened species within the proposed project area.

9.6 ICE EVALUATION

Due to the complex interaction of ice formation and water flow through a river, it is difficult to draw conclusions regarding proposed flood mitigation strategies and ice-jam formations based on observational data alone. The river bathymetry and channel meanders can complicate the ice dynamics and freeze-up jams. Spring runoff is affected by multiple environmental factors, including:

- Air temperature
- Water temperature
- Snow and ice melt intensity
- Upstream flow
- Upstream ice concentration
- Land cover
- Precipitation

Therefore, river reaches with potential ice jams should be analyzed using more comprehensive ice studies, possibly a 2-D ice dynamic study, to better understand the nature of the flooding and the potential mitigation strategies. Ice-jam flooding is very different compared to regular flooding due to the presence of solid and frazil ice. The transportation of frazil ice and solid ice in a river constantly changes the hydrodynamics of the flow, and even at low flows can still raise water levels high enough to cause flooding. The growth of single-layer ice jams can create conditions that change low flood hazards, to high flood hazards, even at low flow conditions.

The impact of these factors will be amplified by climate change. Projected increases in precipitation across New York State indicates the potential for increases in spring runoff, which in turn would increase water levels and velocities in nearby streams and rivers (Rosenzweig et al. 2011). In theory, the increased velocities would move solid ice and frazil ice down the river channel more quickly, possibly preventing ice-jam formations. However, due to the limited available research in this area, additional data collection and modeling needs to be performed before a recommendation can be made regarding a flood mitigation strategy and its specific influence on ice jam formations.

9.7 EXAMPLE FUNDING SOURCES

There are numerous potential funding programs and grants for flood mitigation projects that may be used to offset municipal financing, including:

- New York State Office of Emergency Management (NYSOEM) Homeland Security Grant Program
- New York State Department of Transportation Bridge NY Program
- Regional Economic Development Councils/Consolidated Funding Applications (CFA)
- Natural Resources Conservation Services (NRCS) Watershed Funding Programs
- FEMA Unified Hazard Mitigation Assistance (HMA) Program
- FEMA Safeguarding Tomorrow through Ongoing Risk Mitigation (STORM) Act
- USACE Continuing Authorities Program (CAP)

9.7.1 NYS Office of Emergency Management (NYSOEM)

The NYSOEM, through the U.S. Department of Homeland Security (DHS), offers several funding opportunities under the Homeland Security Grant Program (HSGP). The priority for these programs is to provide resources to strengthen national preparedness for catastrophic events. These include improvements to cybersecurity, economic recovery, housing, infrastructure systems, natural and cultural resources, and supply chain integrity and security. In 2018, there was no cost share or match requirement.

9.7.2 NYSDOT Bridge NY Program

The NYSDOT, in accordance with Governor Andrew Cuomo's infrastructure initiatives, announced the creation of the Bridge NY program. The Bridge NY program provides enhanced assistance for local governments to rehabilitate and replace bridges and culverts. Particular emphasis will be provided for projects that address poor structural conditions; mitigate weight restrictions or detours; facilitate economic development or increase competitiveness; improve resiliency and/or reduce the risk of flooding.

The program is currently open and accepting applications from local municipalities through the State Fiscal Years 2020-21 and 2021-22. A minimum of $200 million was made available for awards in enhanced funding under the Bridge NY program for local system projects during the two-year period. More funding may be added to either the bridge or culvert program if it becomes available after the announcement of the solicitation.

9.7.3 Regional Economic Development Councils/Consolidated Funding Applications (CFA)

The Consolidated Funding Application is a single application for state economic development resources from numerous state agencies. The ninth round of the CFA was offered in 2019.

9.7.3.1 Water Quality Improvement Project (WQIP) Program

The Water Quality Improvement Project Program, administered through the Department of Environmental Conservation, is a statewide reimbursement grant program to address documented water quality impairments. Eligible parties include local governments and not-for-profit corporations. Funding is available for construction/implementation projects; projects exclusively for planning are not eligible. Match for WQIP is a percentage of the award amount, not the total project cost. Deadlines are in accordance with the CFA application cycle.

9.7.3.2 Climate Smart Communities (CSC) Grant Program

The Climate Smart Communities Grant Program is a 50/50 matching grant program for municipalities under the New York State Environmental Protection Fund, offered through the CFA by the NYS Office of Climate Change. The purpose of the program is to fund climate change adaptation and mitigation projects and includes support for projects that are part of a strategy to become a Certified Climate Smart Community. The eligible project types that may be relevant include the following:

- The construction of natural resiliency measures, conservation or restoration of riparian areas and tidal marsh migration areas
- Nature-based solutions such as wetland protections to address physical climate risk due to water level rise, and/or storm surges and/or flooding
- Relocation or retrofit of facilities to address physical climate risk due to water level rise, and/or storm surges and/or flooding
- Flood risk reduction
- Climate change adaptation planning and supporting studies

Eligible projects include implementation and certification projects. Deadlines are in accordance with the CFA cycle.

9.7.4 Natural Resources Conservation Services (NRCS) Watershed Funding Programs

The United States Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS) administers three separate funding programs to promote landscape planning, flood prevention, and rehabilitation projects in communities throughout the country.

9.7.4.1 Emergency Watershed Protection (EWP) Program

The NRCS administers the Emergency Watershed Protection (EWP) Program, which responds to emergencies created by natural disasters. It is not necessary for a national emergency to be declared for an area to be eligible for assistance. The EWP Program is a recovery effort aimed at relieving imminent hazards to life and property caused by floods, fires, windstorms, and other natural disasters.

All projects must have a project sponsor. Sponsors include legal subdivisions of the state, such as a city, county, general improvement district, conservation district, or any Native American tribe or tribal organization.

The NRCS may bear up to 75% of the eligible construction cost of emergency measures (90% within limited-resource areas as identified by the U.S. Census data). The remaining costs must come from local sources and can be in the form of cash or in-kind services.

Public and private landowners are eligible for assistance but must be represented by a project sponsor.

Eligible projects include, but are not limited to, debris-clogged stream channels, undermined and unstable streambanks, and jeopardized water control structures and public infrastructures.

9.7.4.2 Watershed and Flood Prevention Operations (WFPO) Program

The Watershed Protection and Flood Prevention Operations (WFPO) Program includes the Flood Prevention Operations Program (Watershed Operations) authorized by the Flood Control Act of 1944 (P.L. 78-534) and the provisions of the Watershed Protection and Flood Prevention Act of 1954 (P.L. 83- 566). It provides for cooperation between the federal government and the states and their political subdivisions to address resource concerns due to erosion, floodwater, and sediment, and provide for improved utilization of the land and water resources.

The WFPO Program provides technical and financial assistance to states, local governments and Tribes to plan and implement authorized watershed project plans for the purpose of:

- Flood Prevention
- Watershed Protection
- Public Recreation
- Public Fish and Wildlife

- Agricultural Water Management
- Municipal and Industrial Water Supply
- Water Quality Management
- Watershed Structure Rehabilitation (there is a separate program that manages rehabilitation projects)

9.7.4.3 Watershed Rehabilitation (REHAB) Program

The Watershed Rehabilitation (REHAB) Program helps project sponsors rehabilitate aging dams that are reaching the end of their design life and/or no longer meet federal or state standards. Watershed Rehabilitation addresses critical public health and safety concerns. Since 1948, NRCS has assisted local sponsors in constructing 11,850 project dams. Rehabilitation of watershed project dams is authorized for dams originally constructed as part of a watershed project carried out under any of the following four authorities—Public Law 83-566, Public Law 78-534, the Pilot Watershed Program authorized under the Department of Agriculture Appropriation Act of 1954, or the Resource Conservation and Development Program authorized by the Agriculture and Food Act of 1981.

Watershed project sponsors represent interests of the local community in federally-assisted watershed projects. Sponsors request assistance from NRCS. When funding is allocated, the sponsor and NRCS enter into an agreement that defines the roles and responsibilities of each party to complete the rehabilitation.

Many aging dams no longer meet current state and NRCS design and safety criteria and performance standards, and may pose a potential hazard to lives and property if dam failure would occur. NRCS provides technical and financial assistance to local project sponsors to rehabilitate aging dams that protect lives and property, and infrastructure. Local sponsors who are interested in rehabilitating their aging dam may request technical and financial assistance from NRCS. NRCS prioritizes dams for rehabilitation based on the risks to life and property if a dam failure would occur.

9.7.5 FEMA Hazard Mitigation Grant Program (HMGP)

The Federal Emergency Management Agency Hazard Mitigation Grant Program (HMGP), offered by the New York State Division of Homeland Security and Emergency Services (NYSDHSES), provides funding for creating/updating hazard mitigation plans and implementing hazard mitigation projects. The HMA program consolidates the application process for FEMA's annual mitigation grant programs not tied to a state's Presidential disaster declaration. Funds are available under the Building Resilient Infrastructure and Communities (BRIC) and Flood Mitigation Assistance (FMA) Programs.

For flood mitigation measures that are being considered for funding through FEMA grant programs, a benefit-to-cost analysis will be required. In order to qualify for FEMA grants and/or funding, the benefit to cost ratio must be greater than one.

9.7.5.1 Building Resilient Infrastructure and Communities (BRIC)

Beginning in 2020, the Building Resilient Infrastructure and Communities grant program, which was created as part of the Disaster Recovery Reform Act of 2018 (DRRA), replaced the existing Pre-Disaster Mitigation (PDM) program and is funded by a 6% set-aside from federal post-disaster grant expenditures. BRIC will support states, local communities, tribes and territories as they undertake hazard mitigation projects, reducing the risks they face from disasters and natural hazards. BRIC aims to categorically shift the federal focus away from reactive disaster spending and toward research-supported, proactive investment in community resilience. Through BRIC, FEMA will invest in a wide variety of mitigation activities, including community-wide public infrastructure projects. Moreover, FEMA anticipates BRIC will fund projects that demonstrate innovative approaches to partnerships, such as shared funding mechanisms and/or project design.

9.7.5.2 Flood Mitigation Assistance (FMA) Program

The Flood Mitigation Assistance Program provides resources to reduce or eliminate long-term risk of flood damage to structures insured under the National Flood Insurance Program. The FMA project funding categories include Community Flood Mitigation – Advance Assistance (up to $200,000 total federal share funding) and Community Flood Mitigation Projects (up to $10 million total). Federal funding is available for up to 75% of the eligible activity costs. FEMA may contribute up to 100% federal cost share for severe repetitive loss properties, and up to 90% cost share for repetitive loss properties. Eligible project activities include the following:

- Infrastructure protective measures
- Floodwater storage and diversion
- Utility protective measures
- Stormwater management
- Wetland restoration/creation
- Aquifer storage and recovery
- Localized flood control to protect critical facilities
- Floodplain and stream restoration
- Water and sanitary sewer system protective measures

9.7.6 FEMA's Safeguarding Tomorrow through Ongoing Risk Mitigation (STORM) Act

The STORM Act provides capitalization grants to participating states and tribes in order to loan money to local governments for hazard mitigation projects to reduce risks from disasters and natural hazards. The act states that $100 million would be authorized for fiscal years 2022 and 2023. As loans are repaid, the funds are available for other mitigation project loans.

This "resilience revolving loan fund" will be eligible for projects intended to protect against wildfires, earthquakes, flooding, storm surges, chemical spills, seepage resulting from chemical spills and floods, and any other event deemed catastrophic by FEMA. These low-interest funds will allow for cities and states to repay the loan with savings from mitigation projects. It also gives states and localities the flexibility to respond to oncoming disasters without paying high interest rates so they can invest in their communities.

9.7.7 USACE Continuing Authorities Program (CAP)

The USACE Continuing Authorities Program (CAP) is a group of nine legislative authorities under which the Corps of Engineers can plan, design, and implement certain types of water resources projects without additional project specific congressional authorization. The purpose of the CAP is to plan and implement projects of limited size, cost, scope and complexity. Table 45 lists the CAP authorities and their project purposes (USACE 2019).

Table 45. USACE Continuing Authorities Program (CAP) Authorities and Project Purposes

(Source: USACE 2019)

Authority	Project Purpose
Section 14, Flood Control Act of 1946, as amended	Streambank and shoreline erosion protection of public works and non-profit public services
Section 103, River and Harbor Act of 1962, as amended (amends Public Law 79-727)	Beach erosion and hurricane and storm damage reduction
Section 107, River and Harbor Act of 1960, as amended	Navigation improvements
Section 111, River and Harbor Act of 1968, as amended	Shore damage prevention or mitigation caused by federal navigation projects
Section 204, Water Resources Development Act of 1992, as amended	Beneficial uses of dredged material
Section 205, Flood Control Act of 1948, as amended	Flood control
Section 206, Water Resources Development Act of 1996, as amended	Aquatic ecosystem restoration
Section 208, Flood Control Act of 1954, as amended (amends Section 2, Flood Control Act of August 28, 1937)	Removal of obstructions, clearing channels for flood control
Section 1135, Water Resources Development Act of 1986, as amended	Project modifications for improvement of the environment

All projects in this program include a feasibility phase and an implementation phase. Planning activities, such as development of alternative plans to achieve the project goals, initial design and cost estimating, environmental analyses, and real estate evaluations are performed during the feasibility phase to develop enough information to decide whether to implement the project. The feasibility phase is initially federally funded up to $100,000. Any remaining feasibility phase costs are shared 50/50 with the non-federal sponsor after executing a feasibility cost sharing agreement (FCSA). The final design, preparation of contract plans and specifications, permitting, real estate acquisition, project contracting and construction, and any other activities required to construct or implement the approved project are completed during the implementation phase. The USACE and the non-federal sponsor sign a project partnership agreement (PPA) near the beginning of the implementation phase. Costs beyond the feasibility phase are shared as specified in the authorizing legislation for that section (USACE 2019).

10. SUMMARY

The Towns of Richmond and Mendon, including the Village of Honeoye Falls, have had a history of flooding events along Honeoye Creek. Flooding along Honeoye Creek can occur during any season as a result of numerous natural processes, including: the collusion of a large mass of warm moisture-laden air form the north; from sharp rises in temperature in the spring that melt the snow cover of the basin and are followed by rains; and from localized thunderstorms. Most often, floods occur in the late winter-early spring months when melting snow may combine with intense rainfall to produce increased runoff (FEMA 2008b).

In response to persistent flooding, the State of New York in conjunction with the Towns of Richmond and West Bloomfield in Ontario County, and the Towns of Rush and Mendon, including the Village of Honeoye Falls, in Monroe County, are studying and evaluating potential flood mitigation projects for Honeoye Creek as part of the Resilient NY Initiative.

This report analyzed the historical and present day causes of flooding in the Honeoye Creek watershed. H&H data was used to model potential flood mitigation measures. The model simulation results indicated that there are flood mitigation measures that have the potential to reduce WSELs along high-risk areas of Honeoye Creek, which could potentially reduce flood-related damages in areas adjacent to the creek.

Based on the flood mitigation analyses performed in this report, the mitigation measures that provided the greatest reductions in WSELs were: the removal of the railroad embankments, increasing the bridge openings of both the N Main Street/NY-65 and Ontario Street/NY-65 bridge structures in the Village of Honeoye Falls, and increasing the size of the Main Street/US-20A bridge opening in the Hamlet of Honeoye.

Based on the analysis of the bridge widening simulations, multiple bridge crossings along Honeoye Creek benefited from increased bridge openings. However, the bridge widening measures are the costliest of the discussed flood mitigation measures. The benefits of the measures in their respective reaches should be balanced with the associated costs of each bridge widening measure to determine if it would be feasible to move a bridge widening measure forward. In addition, other complications, such as traffic re-routing, should be taken into account when considering any of the bridge widening measures.

Flood benches are effective, nature-based flood mitigation solutions that can provide many benefits both in regard to flood mitigation and as natural or recreational assets to the community. With the proper design, engineering, and maintenance, flood benches can be effective long-term solutions for flood mitigation.

The debris maintenance around waterway crossing infrastructure, riparian restoration, and detention basin and wetland management measures would help to maintain the flow channel area in Honeoye Creek, help to reduce and/or manage runoff into the waterway during precipitation events, trap and/or reduce sediment entering the waterway, and improve overall water quality. Sediment and debris that enters the waterway reduces the channel flow area, which over time can reduce the flow capacity of the channel and potentially lead to greater occurrences of, and more damaging flooding.

The sediment removal alternative in the vicinity of Main Street/US-20A provided some flood mitigation benefits. It is important to note that sediment removal can cause irreparable damages to aquatic ecosystems, release contaminants in sediments and creek beds, and increase flood risk to downstream areas. In addition, any modifications or construction in the vicinity of the canal would need to consult and adhere to NYS historic site guidelines and requirements.

Streambank stabilization measures can potentially reduce flood risk in small- and medium-size watersheds by re-establishing or reinforcing streamside vegetation, which in turn can increase streambank resistance to erosion and reduce the force of flowing water in the channel. Reducing streambank erosion has multiple benefits, including reducing the amount of available sediment in the channel, reducing loss of land, and maintaining flow or storage capacity. It is important to note that streams and rivers are dynamic systems, and erosion is a natural process. As such, not all eroding banks should be stabilized. Prior to pursuing a streambank stabilization measure, the cause of erosion should be determined and addressed on a site-specific basis. For example, if the banks are eroding due to a natural meander, then it may be best to leave the bank alone as long as there is little to no threat to surrounding infrastructure or buildings.

Ice management to control ice buildup at critical points along Honeoye Creek should be considered for areas upstream of known flood-prone zones. An ice prediction method using the FDD would be a good starting point to monitor and mitigate any ice-related flooding before it actually occurs. For example, planning, preparation, equipment and labor management for ice break-up using amphibious excavators is highly effective at preventing ice jams and potential flooding at key infrastructure points. Therefore, good prediction of possible ice jams enables municipalities to have appropriate equipment available at the right time and place. This will reduce indirect costs and inconvenience. To alleviate costs of equipment purchase, operation, and maintenance, the county and local townships could share ownership. Recurring maintenance and staffing required in order to operate the equipment should be factored into any cost analysis.

For flood mitigation measures that are being considered for funding through FEMA grant programs, a benefit-to-cost analysis will be required. In order to qualify for FEMA grants and/or funding, the benefit-to-cost ratio must be greater than one. Flood buyouts/property acquisitions can qualify for FEMA grant programs with a 75% match of funds. The remaining 25% of funds is the responsibility of state, county, and local governments. The case-by-case nature of buyouts and acquisitions requires widespread property owner participation to maximize flood risk reductions. An unintended consequence of buyout programs is the permanent removal of properties from the floodplain, including tax revenue, which would have long-term implications for local governments and should be considered prior to implementing a buyout program.

Floodproofing is an effective mitigation measure but requires a large financial investment in individual residential and non-residential buildings. Floodproofing can reduce the future risk and flood damage, but leaves buildings in flood risk areas so that future flood damages remain. A benefit to floodproofing versus buyouts is that property and structures remain intact, thereby maintaining the tax base for the local municipality.

In general, there would be an overall greater effect in WSELs if multiple alternatives were built in different phases, rather than a single mitigation project. For example, building multiple flood benches along a single reach would compound the flood mitigation benefits of each bench. Table 46 is a summary of the proposed flood mitigation measures, including modeled water surface elevation reductions and estimated ROM costs.

Table 46. Summary of Flood Mitigation Measures

Alternative No.	Description	Benefits Related to Alternative	ROM cost ($U.S. dollars)
1-1	Remove Railroad Abutments	Model simulated WSEL reductions of up to 3.7-ft	$6.3 million
1-2	Streambank Stabilization in the Vicinity of the Honeoye Falls DPW/WWTP Facility	Reduce force of flowing water and/or increase resistance of the bank to erosion	Variable [iii] (case-by-case)
1-3	Flood Benches Upstream and Downstream of N Main Street/NY-65	Model simulated WSEL reductions of: Flood Bench A: up to 1.7-ft Flood Bench B: up to 1.0-ft	Flood Bench A: $3.2 million Flood Bench B: $1.1 million
1-4	Increase Size of N Main Street/NY-65 Bridge Opening	Model simulated WSEL reductions of up to 2.3-ft	$4.6 million
1-5	Streambank Stabilization in the Vicinity of Honeoye Falls and East Street/NY-65	Reduce force of flowing water and/or increase resistance of the bank to erosion	Variable [iii] (case-by-case)
1-6	Flood Benches Upstream of Honeoye Falls	Model simulated WSEL reductions of: Flood Bench A: up to 1.4-ft Flood Bench B: up to 1.3-ft	Flood Bench A: $1.7 million Flood Bench B: $3.4 million
1-7	Increase Size of Ontario Street/NY-65 Bridge Opening	Model simulated WSEL reductions of up to 2.5-ft	$6.5 million
1-8	Flood Benches Upstream and Downstream of Ontario Street/NY-65	Model simulated WSEL reductions of: Flood Bench A: up to 0.7-ft Flood Bench B: no change	Flood Bench A: $3.0 million Flood Bench B: $2.2 million
1-9	Dam Removal Analysis within the Village of Honeoye Falls	Model simulated WSEL reductions of: TK&T Dam Removal: up to 6.1-ft Hamilton Dam Removal: up to 1.7-ft Combined Dam Removal: up to 6.1-ft	Variable [iiii]

Alternative No.	Description	Benefits Related to Alternative	ROM cost ($U.S. dollars)
2-1	Flood Benches at Confluence of Honeoye and Mill Creeks	Model simulated WSEL reductions of: Flood Bench A: up to 0.8-ft Flood Bench B: up to 0.5-ft Flood Bench C: up to 0.5-ft	Flood Bench A: $8.6 million Flood Bench B: $2.9 million Flood Bench C: $4.1 million
2-2	Increase Size of Main Street/US-20A Bridge Opening	Model simulated WSEL reductions of up to 2.3-ft	$5.1 million
2-3	Streambank Stabilization Downstream of Main Street/US-20A	Reduce force of flowing water and/or increase resistance of the bank to erosion	Variable [iii] (case-by-case)
2-4	Sediment Removal Analysis in the Vicinity of Main Street/US-20A	Model simulated WSEL reductions of up to 0.3-ft	$2.9 million
2-5	Debris and Sediment Management Downstream of Main Street/US-20A	Reduce watercourse and gully erosion, trap sediment, reduce and manage runoff, and improve downstream water quality	$470,000
3-1	New Channel Geomorphology and Confluence with Mill Creek	Model simulated WSEL reductions of up to 0.3-ft	$530,000
3-2	Streambank Stabilization Adjacent to 8565-8615 Main Street	Reduce force of flowing water and/or increase resistance of the bank to erosion	Variable [iii] (case-by-case)
3-3	Streambank Stabilization Downstream of East Lake Road	Reduce force of flowing water and/or increase resistance of the bank to erosion	Variable [iii] (case-by-case)
3-4	Sediment and Debris Management Study for Mill and Upper Honeoye Creeks	Identify areas where sediment and debris build-up contributes to flooding risk and develop a management plan with specific strategies to reduce those risks	$80,000

Alternative No.	Description	Benefits Related to Alternative	ROM cost ($U.S. dollars)
4-1	Early-Warning Flood Detection System	Early flood warning for open-water and ice-jam events	$120,000 [v] (not including annual operational costs)
4-2	Riparian Restoration	Restores natural habitats, reduces/manages runoff, and improves water quality	Variable [iiii] (case-by-case)
4-3	Debris Maintenance Around Culverts/Bridges	Maintains channel flow area and reduces flood risk	$20,000 [v] (not including annual operational costs)
4-4	Retention Basin and Wetland Management	Reduces erosion, traps sediments, reduces/manages runoff, and improves water quality	Variable [iiii] (case-by-case)
4-5	Ice Management	Control/prevent ice-jam formation by maintaining ice coverage	Variable [iiii] (case-by-case)
4-6	Flood Buyouts/Property Acquisitions	Reduces and/or eliminates future losses	Variable (case-by-case)
4-7	Floodproofing	Reduces and/or eliminates future damages	Variable (case-by-case)
4-8	Area Preservation/Floodplain Ordinances	Reduces and/or eliminates future losses	Variable (case-by-case)
4-9	Community Flood Awareness and Preparedness Programs/Education	Engages the community to actively participate in flood mitigation and better understand flood risks	Variable (case-by-case)

Alternative No.	Description	Benefits Related to Alternative	ROM cost ($U.S. dollars)
4-10	Development of a Comprehensive Plan	Guides future development, provides legal defense for regulations, and helps establish policies related to community assets	Variable (case-by-case)

[i] Note: ROM cost does not include land acquisition costs for survey, appraisal, and engineering coordination.

[ii] Note: Due to the variable nature of identifying, designing, and constructing a sediment retention basin, no ROM costs were determined for this alternative.

[iii] Note: Due to the variable, conceptual, and site-specific nature of streambank stabilization strategies, no ROM costs were determined for this measure.

[iiii] Note: Due to the conceptual nature of this measure, and significant amount of data required to produce a reasonable ROM cost, it is not feasible to quantify the costs of this measure without further engineering analysis and modeling.

[v] Note: ROM cost does not include annual maintenance or land acquisition costs for survey, appraisal, and engineering coordination.

11. CONCLUSION

Municipalities affected by flooding along Honeoye Creek can use this report to support flood mitigation initiatives within their communities. This report is intended to be a high-level overview of potential flood mitigation strategies, their impacts on WSELs, and the associated ROM cost for each mitigation strategy. The research and analysis that went into each mitigation strategy should be considered preliminary, and additional research, field observations, and modeling are recommended before final mitigation strategies are chosen.

In order to implement the flood mitigation strategies discussed in this report, communities should engage in a process that follows the following steps:

1. Obtain stakeholder and public input to assess the feasibility and public support of each mitigation strategy presented in this report.
2. Complete additional data collection and modeling efforts to assess the effectiveness of the proposed flood mitigation strategies.
3. Develop a list of final flood mitigation strategies based on the additional data collection and modeling results.
4. Select a final flood mitigation strategy or series of strategies to be completed for Honeoye Creek based on feasibility, permitting, effectiveness, and available funding.
5. Develop a preliminary engineering design report and cost estimate for each selected mitigation strategy.
6. Assess funding sources for the selected flood mitigation strategy.

Once funding has been secured and the engineering design has been completed for the final mitigation strategy, construction and/or implementation of the measure should begin.

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APPENDICES

APPENDIX A
SUMMARY OF DATA AND REPORTS COLLECTED

Appendix A. Summary of Data and Reports Collected			NYSOGS Project # SC498
Resilient New York Flood Mitigation Initiative			OBG Project # SD867
Honeoye Creek, Monroe, Livingston, and Ontario Counties, New York			1-July-2022
Year	**Type**	**Title**	**Author**
1996	Data	Q3 Flood Data, Madison County, New York	Federal Emergency Management Agency (FEMA)
2007	Data	2006 LiDAR – LiDAR Procession Document – Ontario County Project Area	Institute for the Application of Geospatial Technology (IAGT)
2017	Data	2017 Monroe County LiDAR Data	Monroe County Department of Environmental Services (MCDES)
2018	Data	2018 6-inch Resolution 4-Band Orthoimagery State Plane Central Zone	New York State Office of Information Technology Services (NYSOITS)
2018	Data	National Register Sites	New York State Office of Parks, Recreation & Historic Preservation (NYSOPRHP)
2018	Data	New York State Historic Sites and Park Boundary	New York State Office of Parks, Recreation & Historic Preservation (NYSOPRHP)
2019	Data	Repetitive Loss and Severe Repetitive Loss dataset	Federal Emergency Management Agency (FEMA)
2019	Data	Bridge Point Locations & Select Attributes	New York State Department of Transportation (NYSDOT)
2019	Data	Culvert Point Locations & Select Attributes	New York State Department of Transportation (NYSDOT)
2019	Data	RailroadsNew	New York State Department of Transportation (NYSDOT)
2019	Data	LIDAR collection (QL2) for Erie, Genesee, and Livingston Counties New York Lidar; Hydro Flattened Bare Earth DEM	New York State Office of Information Technology Services (NYSOITS)
2020	Data	2020 12-inch Resolution 4-Band Orthoimagery West Zone	New York State Office of Information Technology Services (NYSOITS)
2021	Data	Dams	New York State Department of Environmental Conservation (NYSDEC)
2021	Data	Tax Parcels	New York State Office of Information Technology Services GIS Program Office, New York State Department of Taxation and Finance's Office of Real Property Tax Services (ORPTS), Erie County Real Property Tax Services (ECRPTS)
2021	Data	National Hydrography Dataset Best Resolution (NHD) for Hydrologic Unit (HU) 8 - 04140202 (published 20210903)	United States Geologic Service (USGS)

Year	Type	Title	Author
2021	Data	National Land Cover Database (NLCD)	United States Geologic Service (USGS)
2022	Data	Ice Jam Database	Cold Regions Research and Engineering Laboratory (CRREL)
2022	Data	Storm Events Database	National Centers for Environmental Information (NCEI)
2022	Data	Resilient NY – Flooding in Honeoye Creek - Field Work	Ramboll Americas Engineering Solutions, Inc.
1910	Report	Soil Survey of Ontario County, New York	United States Department of Agriculture (USDA)
1956	Report	Soil Survey – Livingston County, New York	Soil Conservation Service (SCS)
1973	Report	Soil Survey – Monroe County, New York	Soil Conservation Service (SCS)
1973	Report	Tropical Storm Agnes - June 1972 - Genesee River Basin	United States Army Corps of Engineers (USACE)
1977	Report	Flood Insurance Study, Town of West Bloomfield, Ontario County, New York	Federal Insurance Administration (FIA)
1977	Report	Flood Insurance Study, Village of Honeoye Falls, Monroe County, New York	Federal Insurance Administration (FIA)
1978	Report	Flood Insurance Rate Map, Town of West Bloomfield, Ontario County, New York	Federal Insurance Administration (FIA)
1978	Report	National Handbook of Recommended Methods for Water-Data Acquisition, Chapter 7: Physical Basin Characteristics from Hydrologic Analysis	United States Geologic Service (USGS)
1979	Report	Techniques for Estimating Magnitude and Frequency of Floods on Rural Unregulated Streams in New York State Excluding Long Island	United States Geological Survey (USGS)
1981	Report	Flood Insurance Study, Town of Mendon, Monroe County, New York	Federal Emergency Management Agency (FEMA)
1981	Report	Flood Insurance Study, Town of Rush, Monroe County, New York	Federal Emergency Management Agency (FEMA)
1983	Report	Flood Insurance Rate Map, Town of Lima, Livingston County, New York	Federal Emergency Management Agency (FEMA)
1984	Report	Flood Insurance Rate Map, Town of Richmond, Ontario County, New York	Federal Emergency Management Agency (FEMA)
1984	Report	Flood Insurance Study, Town of Richmond, Ontario County, New York	Federal Emergency Management Agency (FEMA)
1991	Report	Regionalization of flood discharges for rural unregulated streams in New York excluding Long Island	United States Geologic Service (USGS)

Year	Type	Title	Author
1995	Report	Numerical Simulation of River Ice Processes	Shen HT, Wang DS, Wasantha Lal AM
2000	Report	Title 44. Emergency Management and Assistance Chapter I. Federal Emergency Management Agency, Department of Homeland Security Subchapter B. Insurance and Hazard Mitigation	Federal Emergency Management Agency (FEMA)
2000	Report	Guidelines for Streambank Restoration	Georgia Soil and Water Conservation Commission (GSWCC)
2002	Report	Water and Sediment Control Basin (No.) CODE 638	Natural Resources Conservation Service (NRCS)
2004	Report	Technical & Operational Guidance Series (TOGS) 5.1.9 In-Water and Riparian Management of Sediment and Dredged Material	New York State Department of Environmental Conservation (NYSDEC)
2006	Report	Floodplain Management Requirements: A Study Guide and Desk Reference for Local Officials	Federal Emergency Management Agency (FEMA)
2006	Report	Engineering and Design - ICE ENGINEERING	United States Army Corps of Engineers (USACE)
2006	Report	Magnitude and Frequency of Floods in New York	United States Geologic Service (USGS)
2007	Report	Elevation Data for Floodplain Mapping	National Research Council (NRC)
2007	Report	Part 654 National Engineering Handbook – Stream Restoration Design	Natural Resources Conservation Service (NRCS)
2008	Report	Flood Insurance Study, Monroe County, New York (All Jurisdictions)	Federal Emergency Management Agency (FEMA)
2008	Report	Flood Insurance Rate Map, Monroe County, New York (All Jurisdictions)	Federal Emergency Management Agency (FEMA)
2009	Report	Environmental Impact and Benefits Assessment for Final Effluent Guidelines and Standards for the Construction and Development Category	United States Environmental Protection Agency (USEPA)
2009	Report	Stormwater Wet Pond and Wetland Management Guidebook	United States Environmental Protection Agency (USEPA)
2009	Report	Bankfull discharge and channel characteristics of streams in New York State	United States Geologic Service (USGS)
2010	Report	Sediment Management – Engineering in the Water Environment: Good Practice Guide	Scottish Environment Protection Agency (SEPA)
2011	Report	Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation	New York State Energy Research and Development Authority (NYSERDA)
2011	Report	A Unified Degree-Day Method for River Ice Cover Thickness Simulation	Shen HT, Yapa P
2012	Report	Hydraulic Design of Safe Bridges	Federal Highway Administration (FHA)
2013	Report	Floodproofing Non-Residential Buildings	Federal Emergency Management Agency (FEMA)
2013	Report	Levees and the National Flood Insurance Program: Improving Policies and Practices	National Research Council (NRC)

Year	Type	Title	Author
2013	Report	The 16th Annual Conference Litigating Takings Challenges to Land Use and Environmental Regulations: Anatomy of a Buyout – New York Post-Superstorm Sandy	Siders, AR
2015	Report	New York State Comprehensive Plan Development: A Guidebook for Local Officials	Environmental Finance Center (EFC)
2015	Report	Guidance for Flood Risk Analysis and Mapping – Redelineation Guidance	Federal Emergency Management Agency (FEMA)
2015	Report	Reducing Flood Risk to Residential Buildings That Cannot Be Elevated	Federal Emergency Management Agency (FEMA)
2015	Report	Development of flood regressions and climate change scenarios to explore estimates of future peak flows	United States Geologic Service (USGS)
2016	Report	HEC-RAS River Analysis System 2D Modeling User's Manual Version 5.0	United States Army Corps of Engineers (USACE)
2016	Report	HEC-RAS River Analysis System User's Manual Version 5.0	United States Army Corps of Engineers (USACE)
2016	Report	Lexington Green – Section 205 of the 1948 Flood Control Act – Flood Risk Management	United States Army Corps of Engineers (USACE)
2017	Report	DMA 2000 Monroe County Hazard Mitigation Plan Update	Tetra Tech, Inc.
2018	Report	Ontario County Multi-Jurisdictional All-Hazard Mitigation Plan Update	Genesee/Finger Lakes Regional Planning Council (G/FLRPC)
2018	Report	Highway Design Manual: Chapter 8 - Highway Drainage	New York State Department of Transportation (NYSDOT)
2019	Report	Continuing Authorities Program	United States Army Corps of Engineers (USACE)
2020	Report	New York State Flood Risk Management Guidance for Implementation of the Community Risk and Resiliency Act	New York State Department of Environmental Conservation (NYSDEC)
2020	Report	Standard Specifications (US Customary Units), Volume 1	New York State Department of Transportation (NYSDOT)
2021	Report	New York State Codes, Rules, and Regulations – Title 6	New York State Department of Environmental Conservation (NYSDEC)
2016	Software	Application of Flood Regressions and Climate Change Scenarios to Explore Estimates of Future Peak Flows - Future Flow Explorer v1.5	United States Geologic Service (USGS)
2019	Software	RSMeans Cost Works 2019 v16.03	Gordian, Inc.
2019	Software	The VERTCON 3.0 Project	National Oceanic and Atmospheric Administration (NOAA)
2021	Software	HEC-RAS 6.1.0	United States Army Corps of Engineers (USACE), Hydrologic Engineering Center (HEC)
2021	Software	StreamStats v4.6.2	United States Geologic Service (USGS)
2022	Software	Environmental Resource Mapper	New York State Department of Environmental Conservation (NYSDEC)
2022	Software	Information for Planning and Consultation (IPaC)	United States Fish and Wildlife Service (USFWS)

APPENDIX B

AGENCY AND STAKEHOLDER MEETING SIGN-IN SHEET

Resilient New York – Honeoye Creek, Monroe, Livingston, & Ontario Counties, New York

Engagement Meeting #1

Date: Thursday, December 9, 2021
Time: 11:30 AM – 12:30 PM
Format: WebEx Virtual Meeting

Highland as Host:
Jen Topa, Highland Planning
Tyra Jones, Highland Planning
Susan Charland, Highland Planning

Ramboll, NYSOGS and NYDEC as Co-Hosts:
Shaun Gannon, Ramboll
Kadir Goz, Ramboll
Tom Snow, NYSDEC
Eric Baurle, NYSOGS
Robert Call, NYSDEC (Region 8)
Geoffrey Golick, NYSDEC Region 8
Mark Gooding, NYSDEC Region 8
Luke Scannell, NYSDEC Region 8
Brienna Wirley, NYSDEC Region 8
Timothy Walsh, NYSDEC Region 8

Attendees:
Laura Ortiz, USACE
Joe Rowley, USACE
Bill Butts, NYSDOT (Region 4)
Noel Kurth, NYSDOT (Region 4)
Maryellen Papin, NYSDOT (Region 4)
Daryl Marshall, Town of Richmond (Supervisor)
Jake Calabrese, MRB Group (Town Engineer)
Tom Fromberger, MRB Group (Town Engineer)
Jon Hinman, MRB Group (Town Engineer)
Brian Anderson, Village of Honeoye Falls
Terry Gronwall, Honeoye Watershed Council
Megan Webster, Ontario County Soil & Water Conservation District
Katie Lafler, Ontario County Soil & Water Conservation District
Steven May, Ontario County Department of Public Works

APPENDIX C
FIELD DATA AND COLLECTION FORMS

Stream Channel Classification

Data Collection Form

Project: ______________________ Date: ______________________

County: ______________________ Stream: ______________________

Reach No.: ______________________ Logged By: ______________________

Horizontal Datum: NAD ________ Projection: ☐ Transverse Mercator ☐ Lambert Conformal Conical

Coordinate System: ☐ ___________ County Coordinates ☐ WTM ☐ State Plane Coordinates ☐ UTM

Units: ☐ Meters ☐ Feet Horizontal Control: N or Lat. ____________ E or Long. ____________

Elevation: _____________ ☐ Assumed ☐ DOT ☐ NAVD (29 / 88) Units: ☐ Meters ☐ Feet

Fluvial Geomorphology Features (3 Cross Sections) for Stream Classification

				Average
Bankfull Width (W_{bkf}):	_________ ft.	_________ ft.	_________ ft.	0.00 ft.

Width of the stream channel, at bankfull stage elevation, in a riffle section.

Mean Depth (d_{bkf}):	_________ ft.	_________ ft.	_________ ft.	0.00 ft.

Mean depth of the stream channel cross section, at bankfull stage elevation, in a riffle section. ($d_{bkf}=A_{bkf}/W_{bkf}$)

Bankfull X-Section Area (A_{bkf}):	_________ sq. ft.	_________ sq. ft.	_________ sq. ft.	0.00 sq. ft.

Area of the stream channel cross section, at bankfull stage elevation, in a riffle section.

Width / Depth Ratio (W_{bkf}/d_{bkf}):	_________ ft.	_________ ft.	_________ ft.	0.00 ft.

Bankfull width divided by bankfull mean depth, in a riffle section.

Maximum Depth (d_{mbkf}):	_________ ft.	_________ ft.	_________ ft.	0.00 ft.

Maximum depth of the Bankfull channel cross section, or distance between the bankfull stage and thalweg elevations, in a riffle section.

Width of Flood-Prone Area (W_{fpa}):	_________ ft.	_________ ft.	_________ ft.	0.00 ft.

Twice maximum depth, or (2 x d_{mbkf}) = the stage/elevation at which flood-prone area width is determined (riffle section).

Entrenchment Ratio (ER):	_________ ft.	_________ ft.	_________ ft.	0.00 ft.

The ratio of flood-prone area width divided by bankfull channel width. (W_{fpa}/W_{bdf}) (riffle section)

Reach Characteristics

Channel Materials (Particle Size Index) D50: _________ mm

The D50 particle size index represents the median diameter of channel materials, as sampled from the channel surface, between the bankfull stage and thalweg elevations.

Water Surface Slope (S): ________________ ft./ft.

Channel slope = "rise" over "run" for a reach approximately 20-30 bankfull channel widths in length, with the "riffle to riffle" water surface slope representing the gradient at bankfull stage.

Channel Sinuosity (K): ________________.

Sinuosity is an index of channel pattern, determined from a ratio of stream length divided by valley length (SL/VL); or estimated from a ratio of valley slope divided by channel slope (VS/S).

Distance to Up-Stream Structures: _____________________________.

Stream Type: _____________________ (For reference, note Stream Type Chart and Classification Key)

Dominant Channel Soils at an Eroding Bank Location

Bed Material: __________________________ Left Bank: ___________ Right Bank: ___________

Description of Soil Profiles (from base of bank to top):

Left: ____

____

Right: ____

____

Riparian Vegetation at an Eroding Bank Location

Left Bank: _____________________________ Right Bank: ____________________________

Percent Total Area (Mass): Left: __________________ Right: ___________________________

Percent Total Height with Roots: Left: __________________ Right: ______________________

Other Bank Features at an Eroding Bank Location

Actual Bank Height: _______________________ Bankfull Height: _________________________

Bank Slope (Horizontal to Vertical):

Left:
- ☐ 0-20º (flat)
- ☐ 21-60º (moderate)
- ☐ 61-80º (steep)
- ☐ 81-90º (vertical)
- ☐ 90º+ (undercut)

Right:
- ☐ 0-20º (flat)
- ☐ 21-60º (moderate)
- ☐ 61-80º (steep)
- ☐ 81-90º (vertical)
- ☐ 90º+ (undercut)

Visible Seepage in Bank? ☐ Yes ☐ No Where? _________________________________

Thalweg Location: ☐ Near 1/3 ☐ Mid 1/3 ☐ Far 1/3

Wolman Pebble Count

Data Collection Form

Project: ____________________________ Date: ____________________________

Reach No.: ________ Location: ____

Reach No.: ________ Location: ____

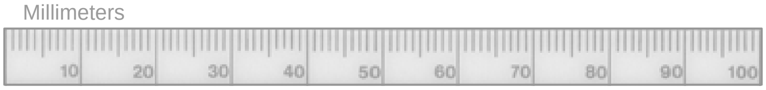
Reach No.: ________ Location: ____

Reach No.: ________ Location: ____

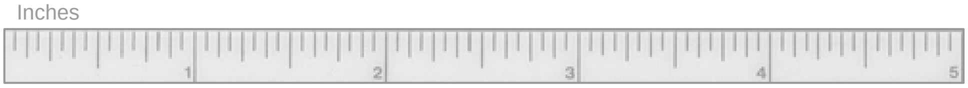
Reach No.: ________ Location: ____

Inches	Millimeters	Particle	Particle Count					
			1	2	3	4	5	Total
<.002	<.062	Silt/Clay						
.002 - .005	.062 - .125	Very Fine Sand						
.005 - .01	.125 - .25	Fine Sand						
.01 - .02	.25 - .50	Medium Sand						
.02 - .04	.50 - 1.0	Coarse Sand						
.04 - .08	1.0 - 2	Very Coarse Sand						
.08 - .16	2 - 4	Very Fine Gravel						
.16 - .22	4 - 5.7	Fine Gravel						
.22 - .31	5.7 - 8	Fine Gravel						
.31 - .44	8 - 11.3	Medium Gravel						
.44 - .63	11.3 - 16	Medium Gravel						
.63 - .89	16 - 22.6	Coarse Gravel						
.89 - 1.26	22.6 - 32	Coarse Gravel						
1.26 - 1.77	32 - 45	Very Coarse Gravel						
1.77 - 2.5	45 - 64	Very Coarse Gravel						
2.5 - 3.5	64 - 90	Small Cobbles						
3.5 - 5.0	90 - 128	Small Cobbles						
5.0 - 7.1	128 - 180	Large Cobbles						
7.1 - 10.1	180 - 256	Large Cobbles						
10.1 - 14.3	256 - 362	Small Boulders						
14.3 - 20	362 - 512	Small Boulders						
20 - 40	512 - 1024	Medium Boulders						
40 - 80	1024 - 2048	Large-Very Large Boulders						
		Bedrock						
Total								

Millimeters



Inches



Stream Assessment Protocol Form

Step 1 – Wollman Pebble Count – use additional form

Step 2 – Bank Vegetation Assessment: Record Percentage of Bank Covered by Ground Cover, record presence of absence of roots in, on or exposed.

Zone	Percent Coverage	Description
Bank		
Stream Edge		
Overbank		

Step 3 – Bank Soil Assessment: Count the total number of stratifications, record the total and then complete the table to record the type from Table 1 of the instructions and description of relevant features.

Number of total Stratifications ___________________

Stratification No.	Type	Description

Step 4 – Bank Angle: Select one of the following and record the type in the space provided

Bank Angle Type	Check the appropriate One Below
Mild (0°-30°)	
Moderate (30°-60°)	
Steep (60°-90°)	
Overhang (> 90°)	

Record the Type per the figure provided in the instructions ______________________________________

Step 5 – Evidence of Bank Failure / Bed Stability: Selected one of the following and record the type and provide and relevant description.

Bank Angle Type	Check the appropriate One Below	Type	Description
Low (0 – 25%)			
Moderate (25 – 50%)			
High (50 – 75%)			
Severe (70 – 100%)			

Field Observation Form

By:______________________ Date: ____________________ Project Name: _________________________________

Project Number: _______________________________

Location/Description

Sketches (Include flow depth, channel bed material, Manning values, flow direction, etc.)

Plan View:

Section View:

Structure Data

☐ Bridge ☐ Culvert

Height: ______________ Width: _____________ ☐ Box # Sides: _____ ☐ Pipe ☐ Arch ☐ Other

Length in direction of flow: ________________ Manning Value Top: _____________ Bottom: ______________

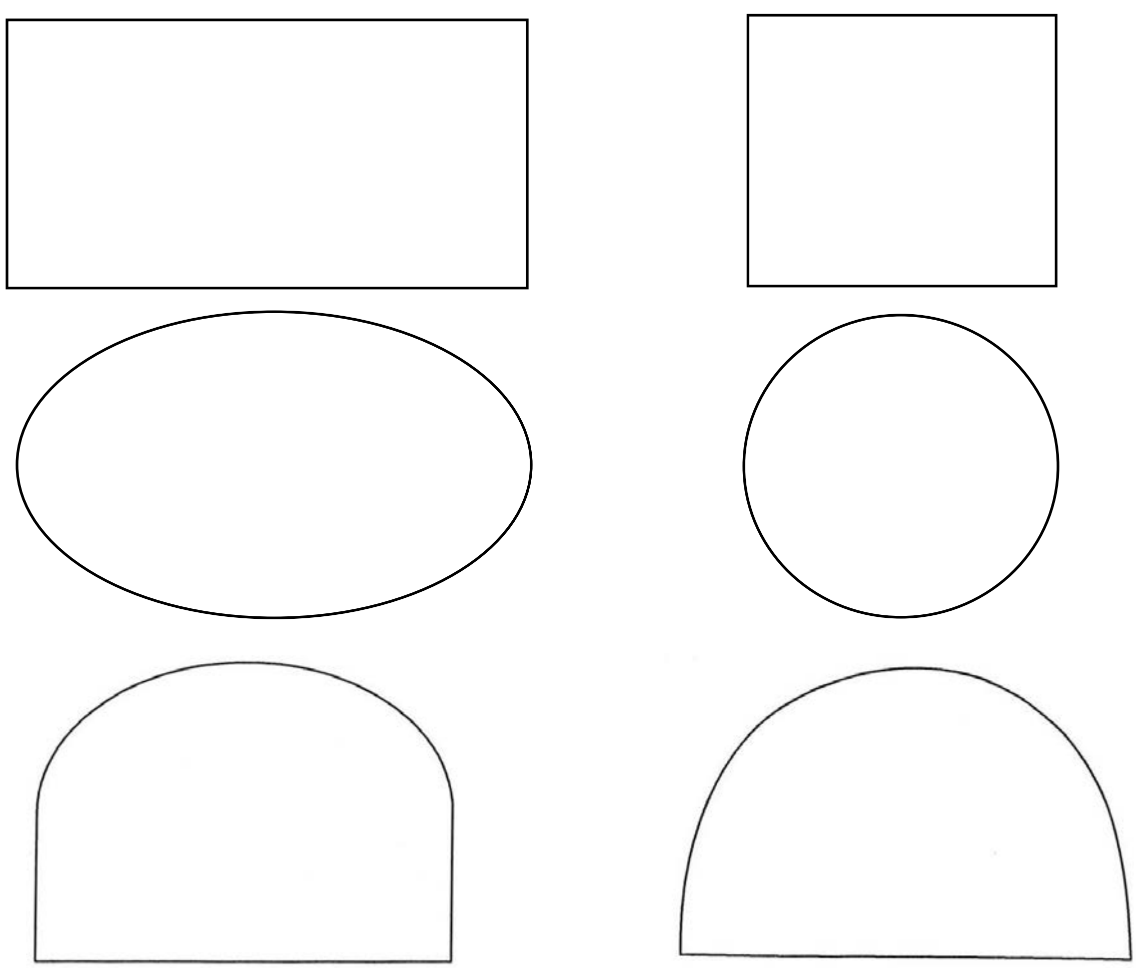
Description:

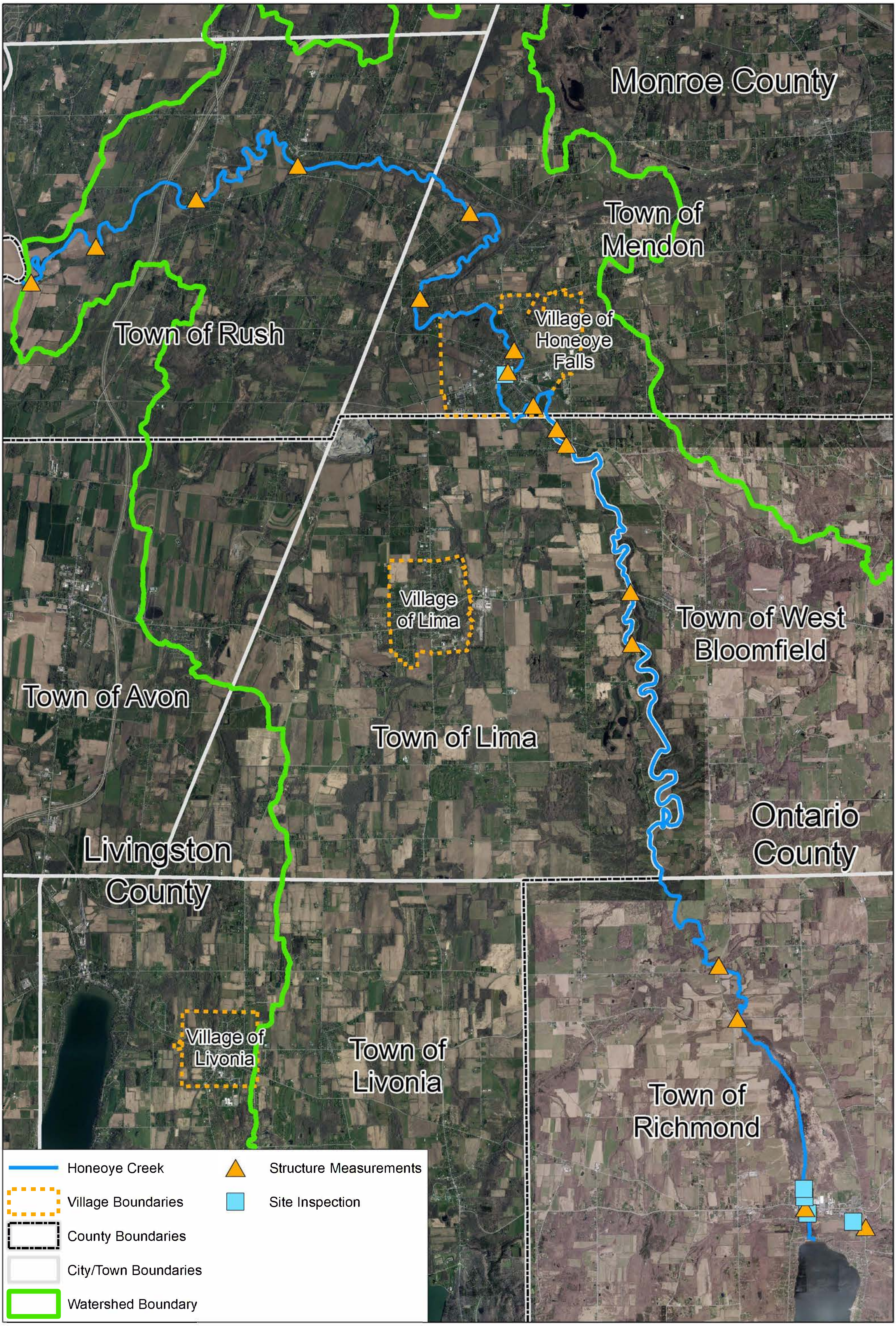
____

____

____

Typical Culvert Shapes (fill in dimensions)





This figure was prepared as part of the Hazard Mitigation Study of Honeoye Creek conducted for the New York State Department of Environmental Conservation as part of the Governors Resilient NY Initiative (NYSOGS Contract SC498).

PLOTDATE: 05/16/22 GOZK

RAMBOLL

APPENDIX C

FIELD WORK LOCATIONS
HONEOYE CREEK
MONROE, LIVINGSTON, & ONTARIO COUNTIES, NY

APPENDIX D
PHOTO LOGS

APPENDIX D. PHOTO LOG

Photo log of select locations within the Honeoye Creek corridor.

Photo No. 1 **Description:** Livonia, Avon & Lakeville Railroad	
Photo No. 2 **Description:** East River Rd	

Photo No. 3 **Description:** NY-15/W Henrietta Rd	
Photo No. 4 **Description:** E Henrietta Rd	

Photo No. 5 **Description:** Town of Rush Dam		
Photo No. 6 **Description:** Plains Road		

Photo No. 7
Description:
Sibley Road

Photo No. 8
Description:
N Main Street/NY-65

Photo No. 9 **Description:** USGS gage downstream N Main Street/NY-65	
Photo No. 10 **Description:** Honeoye Falls from the East Street bridge	

Photo No. 11 **Description:** In-channel abandoned structure upstream Honeoye Falls	
Photo No. 12 **Description:** Ontario Street/NY-65	

Photo No. 13 **Description:** NY-65	
Photo No. 14 **Description:** Martin Road	

Photo No. 15 **Description:** Upstream Martin Road		
Photo No. 16 **Description:** NY 5 & 20/US-20		

Photo No. 17 **Description:** Factory Hollow Road	
Photo No. 18 **Description:** County Road 37	

Photo No. 19 **Description:** County Road 15	
Photo No. 20 **Description:** Upstream Main Street/US-20A at Honeoye Lake Wastewater Treatment Plant Discharge Outlet	

Photo No. 21 **Description:** Facing Upstream Towards Main Street/US-20A	
Photo No. 22 **Description:** Downstream Main Street/US-20A	

Photo No. 23 **Description:** Main Street/US-20A		
Photo No. 24 **Description:** Upstream Main Street/US-20A – Confluence of Honeoye and Mill Creeks		

Photo No. 25 **Description:** Mill Creek – Facing Upstream Towards Brookview Drive	
Photo No. 26 **Description:** Mill Creek – Facing Downstream From East Lake Road	

Photo No. 27 **Description:** East Lake Road (Mill Creek)	
Photo No. 28 **Description:** East Lake Road (Mill Creek)	

APPENDIX E
ICE-JAM MITIGATION STRATEGIES

1. ICE JAM FLOODING MITIGATION ALTERNATIVES

There are several widely accepted and practiced standards for ice jam controls to mitigate the ice jam related flooding. These are referred to as ice jam mitigation strategies and each strategy is very much site dependent. A strategy that works for a certain reach of a river wouldn't work for another reach in the same river due to river morphology and hydrodynamics. Therefore, each of these strategies need to be analyzed with numerical modeling and simulations to check if they work for a considered area/reach of a river before implementing or recommending with the previous observational experience alone. The standard strategies that are widely accepted and practiced in cold region engineering are:

- Ice Booms
- Ice Breaking using Explosives
- Ice breaking using ice-breaker ferries and Cutters
- Installing inflatable dams (Obermeyer Spillways)
- Mixing heated effluent to the cold water
- Removal of Bridge Piers or Heated bridge piers or heated riverbank dikes
- Ice retention Structures
- Ice Forecasting Systems and Ice Management

1.1 Ice booms

Ice booms are the most widely used ice jam control strategy to control ice movement and minimizes surface ice transport. They can be both permanent and temporary structures depending on the emergency measure in high-risk situations. They mainly consist of a series of timber beams or pontoons connected and strung across a river. Once the ice disappears, the booms can be removed if needed and transported elsewhere for storage during the summer months. Ice booms are flexible and can be designed to release ice gradually when overloaded. They can be a relatively cost-effective intervention and can be placed seasonally to reduce potential negative environmental impacts. Ice booms can also be deployed relatively rapidly, rendering them effective as an emergency response measure.

However, the removal of ice booms can be costly since the components of each boom must be disconnected, cleaned, transported and stored until their next deployment. Ice booms can also be ineffective given that ice jams have the potential to circumvent the booms by moving underneath them. Ice booms do not suit all river environments and require low river flow velocity and adequate upstream ice storage capacity.

1.2 Ice breaking using explosives

Thermally grown ice is relatively easy to break up by blasting, while frazil ice is more difficult because it absorbs much of the blast energy. Ice blasting using dynamite is being widely used in rivers where very thick ice jams are formed. It is a very efficient method that can be performed within minutes. It is easily transported to remote locations and does not require any maintenance. Holes are drilled in the ice and dynamite is inserted to blow the ice apart. The most effective results can be achieved by placing the charges underneath the ice surface.

Using dynamite to clear ice can, however, be harmful to the environment. It is also a dangerous method to employ with potentially fatal consequences. Dynamite is not a sustainable solution and can require multiple treatments during extreme cold. It also requires the containment of large areas, which might have to be repeated several times.

1.3 Ice breaking using ice-breaker ferries and Cutters

Ice breakers are specialized vessels designed to break ice jams in wide rivers. They represent a non-structural ice jam mitigation method that is used internationally, in lakes, wide rivers, and oceans. Ice breakers are generally operated when temperatures start to rise, before it reaches the peak cold. They are most suitable for ice sheet breaking (juxtaposed type ice jams), as there are limitations for the ice thickness that they are capable of breaking.

Cutting thick ice covers can also mechanically weaken the ice jams and help relive the internal pressure of an ice-covered channel due to the thick ice cover. A thick ice cover increases the resistance to flow and slowdown the discharge under the ice covers and increase the backwater effects upstream. By cutting the ice cover this pressure can be relieved and the backwater effects can be minimized to reduce upstream flooding potentials. This can also help to control the ice jam breakup and control large ice pieces release from the break-up.

Ice breakers can typically break thick ice covers of up to three to ten feet. Ice breakers have proven to be effective tools for breaking up ice cover on rivers. There are multiple types of ice breakers and, being a mobile solution, they can be flexibly targeted at areas with the most need. Operating ice breakers requires a highly skilled command and crew and are not suitable in all environments. Transporting ice breakers is also relatively difficult, making it a time-consuming and potentially cost-intensive solution.

1.4 Installing inflatable dams (Obermeyer Spillways)

Removing permanent run-of-river low head dams that are prone to ice jams and replacing them with floatable dams can be a good solution for flow control for all seasons. Since the crest elevation can altered, they allow for a control release of incoming ice, allowing it to spillover without jamming. Also, in case of a sudden freeze-up jam that lead to an overnight thick jam can also be broken by frequent or oscillatory movement of lowering and raising the crest to break or weaken the ice jam. Obermeyer Spillway gates are recommended in areas where it is more prone to ice accumulation and flow control is still essential during all seasons.

Obermeyer Spillway Gates consist of a row of steel gate panels installed either at the top of dams or as free-standing structures. The system utilizes a combination of metal flap-gate panels supported by multiple small inflatable "bladders" that adjust the panels' angle and elevation. By controlling the pressure in the bladders, the water flow can be infinitely adjusted within the system control range. Panels can also be designed to include heated abutment plates to prevent ice formation.

1.5 Mixing heated effluent to the cold water

The release of warm water waves into a river from a nearby treatment plants or additions of heated water mixing can help mitigate ice jam formations where the above mentioned alternatives won't work. Provided that the effluent is added to the river prior to ice jam formation, the additional water volume can increase the river flow velocities and prevent ice jam creation in the first place. The wastewater can also be used for the thermal control of ice, as the released warm water can melt or thin ice jams.

1.6 Removal of Bridge Piers or Heated bridge piers or heated riverbank dikes

Bridge piers are a hotspot for capturing surface and suspended frazil ice. When surface ice floes are adhered to the bridge piers and abutments the lateral growth of ice rapidly increase thus snagging more ice on the surface creating an ice bridge across the river. When there are more piers across the river the potential of ice bridging between piers increase due to a series of small ice bridging between two piers can be rapidly form than between longer between the longer pier spans.

Removing bridge piers can lead to high cost construction projects with inconvenience to the daily traffic through the bridge and the structural integrity. Therefore, heated bridge piers can be a good alternative to the existing piers that are prone to more ice cohesion and that can lead to high cost of removing the piers. This will limit the ice adhesion to the bridge and pass through the surface and suspended ice without encouraging snagging, capturing and flocculation of surface ice at bridge piers avoiding the possible ice jams.

Also, the heating of piers can heat the surrounding water and mix with the ambient cold water that will lead to the melt existing surface and suspended ice in the water. This reduces any extra ice generation in the water column.

However, heating bridge piers involves carful installation of the wiring and maintenance of the heating elements and energy costs. More frequent inspections of the bridge piers are also needed since the temperature can affect the concrete composition or special treatment for the concrete is needed.

1.7 Ice retention Structures

Ice retention structures are used to control ice jams by actively initiating jams in more suitable locations where they are less damaging. Ice is captured and retained upstream of residential areas.

Ice retention structures are cost-effective, installation methods are simple, however the design is highly customizable according to the site. A retention structure can be associated with a flood bench so that increased water levels due to ice accumulation can be compromised be allowing more storage in the flood bench. The retention structures don't increase the water level during normal flows.

However, the structures do require ongoing maintenance to remove debris. Channel bed scour is a concern for these structures, therefore, a scour analysis needed to perform in the vicinity of the structure to make sure the ice mitigation strategy will not adversely affect the normal river flow.

1.8 Ice Forecasting Systems and Ice Management

Visual monitoring of the ice formation, and ice cover progressions and water levels are good elements of monitoring the ice conditions of a river during the wintertime, but not sufficient to accurately predict the upstream back water effects or ice jam formations or ice jam break-ups. Ice condition and ice jam monitoring system is a useful tool for emergency ice management but limited in ice forecasting ability.

Ice long-term forecasting and short-term freeze-up and ice jam breakup predictions is a complicated process and challenging due to several reasons. Ice forecasting needs geomorphological, meteorological, coupled thermodynamics and hydrodynamics to identify the factors effecting an ice jam condition.

Therefore, an ice forecasting simulation will not be able to be carried out in a timely manner to help making emergency decisions. Therefore, a good forecasting system that will recommend an ice management plan would and customized ice monitoring strategy would be the most appropriate alternative to follow. An annual ice jam simulation with that accounts for forecasted meteorological and hydrological conditions and simulated ice control strategy that is suitable for the upcoming winter can identify the flood prone areas and enable to calculate the associate risk beforehand. These annual studies can also suggest the type of monitoring that is needed in different reaches or areas. For example, if an area needed to visually monitor the ice formation and ice transport through webcams or need to perform a calculation procedure such as "Freezing-Degree-Day" (FDD) method to predict the thickness of an ice jam to break to make decision when to start breaking. This will help officials to manager the resources and order the equipment and staff available before an emergency occur.

Ramboll suggests that to perform a freeze-up or a break-up ice simulation study before implement or recommend any of the above discussed strategies. The basic data needs and steps involved in an ice simulation analysis is also outlined below.

2. ICE FORECASTING MODEL SIMULATIONS

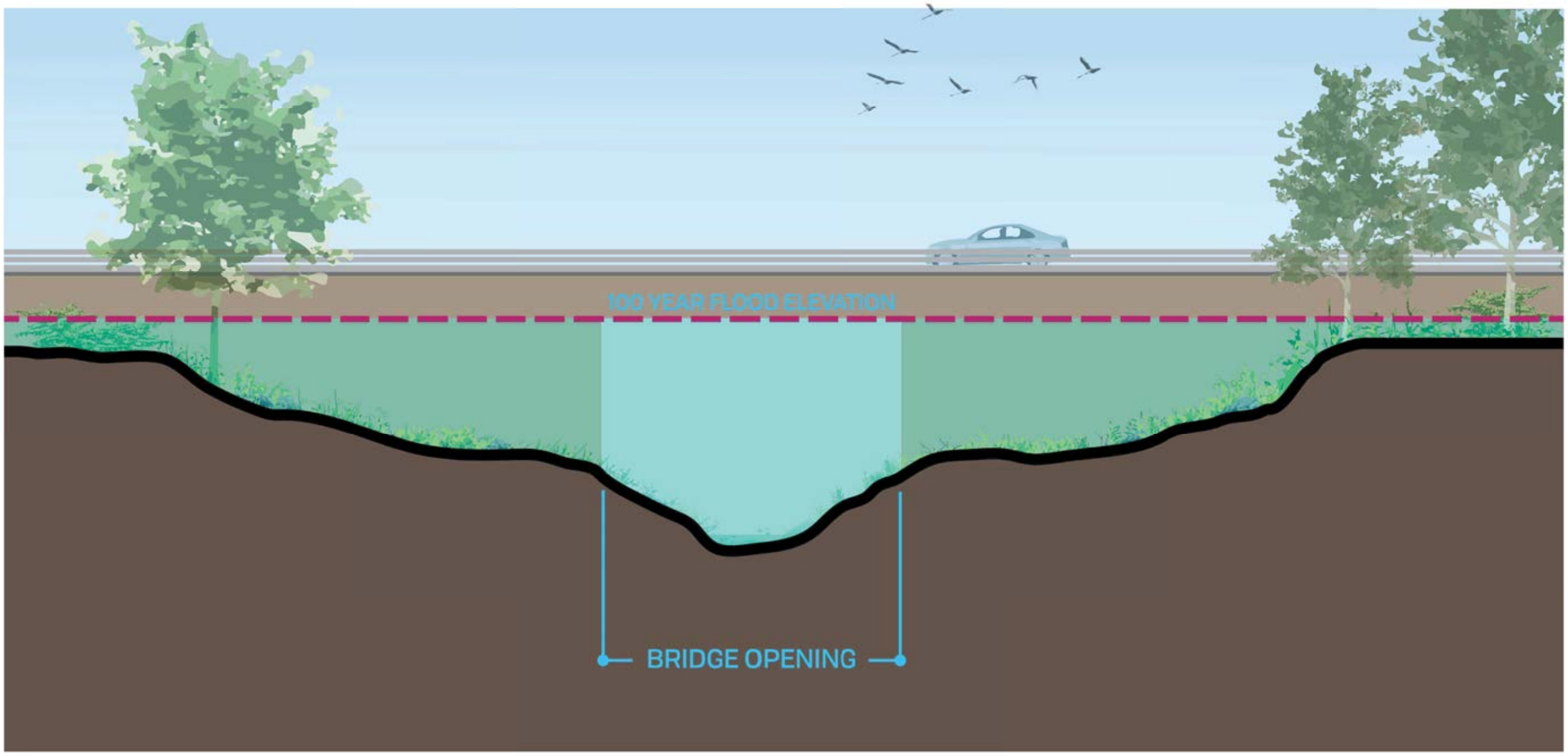
Freeze-up ice simulation is a complex simulation carried out to predict ice generation, movement and coagulation with the change of air temperature, water temperature and water flow over a period of time. Usually these simulations and carried out for a two to three-month time period. A calibration and validation is also needed to ensure accuracy. A freeze-up or ice jam simulation needs the following input data:

- Accurate river bathymetry created from LiDAR survey or hydro-corrected bathymetric data from the state agencies.
- Weather data such as air temperature, wind condition, cloud cover, snowfall and precipitation data.
- Flow conditions, from gauge data or measured data. (e.g. upstream discharge and downstream water level data).
- Ice conditions data, such as water temperature data, incoming ice concentration, and initial ice cover thickness or initial ice floe concertation's and ice floe thickness.
- Visual observation data that are useful to calibrate the model, such as ice cover leading edge propagation locations, water temperature and ice thickness measurements.

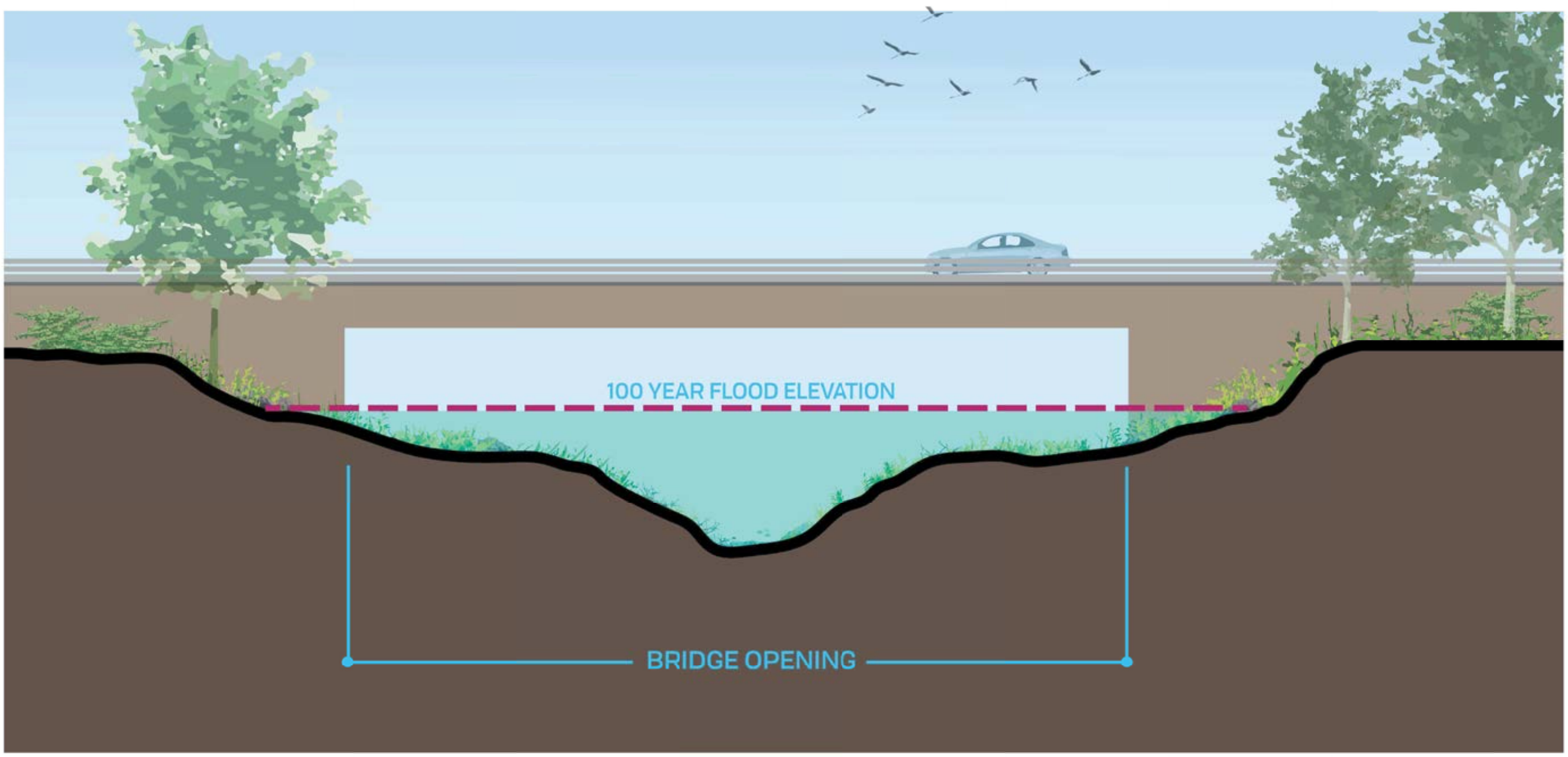
The results of such a simulation, when the results are in agreement with observational data, can lead to a better understanding of ice behavior and associated ice jam flooding in the simulated areas that will aid officials and emergency responders in developing better ice management plans.

APPENDIX F

MITIGATION RENDERINGS

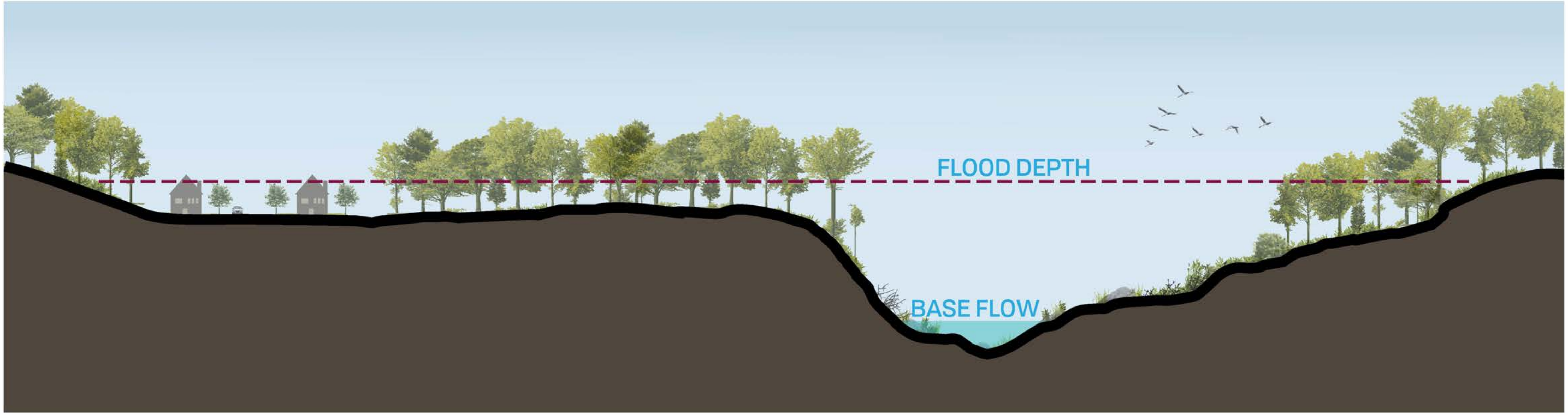


Existing Condition

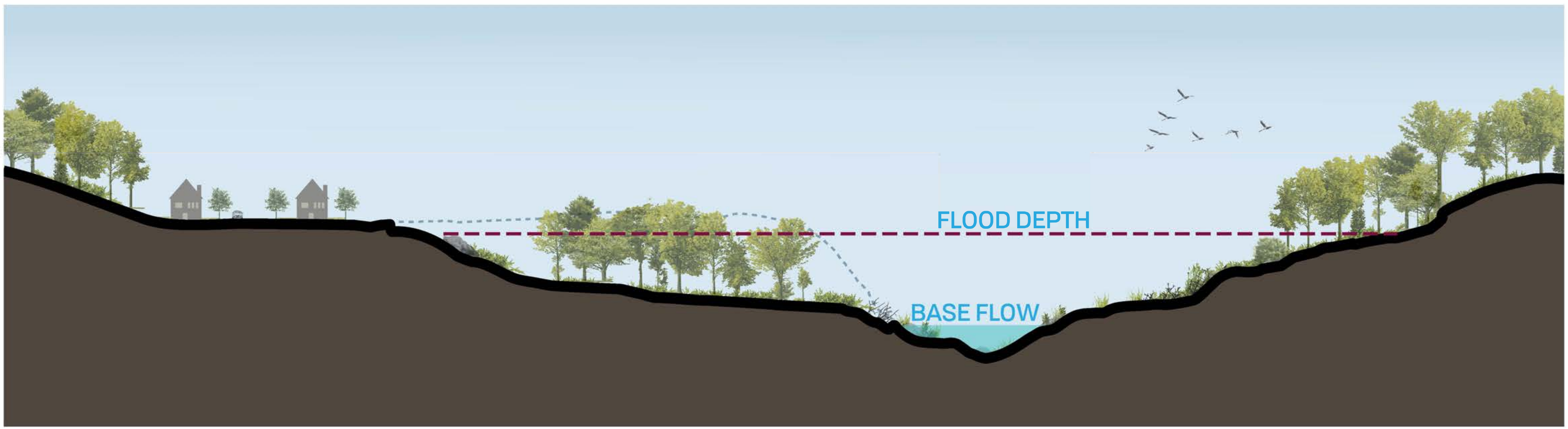


Future Condition

EXPANDED BRIDGE OPENING



Existing Condition



Future Condition

FLOODPLAIN BENCH

APPENDIX G
STREAMBANK STABILIZATION STRATEGY SHEETS

MANAGEMENT AND MITIGATION STRATEGIES

There are two types of engineering strategies to sediment and debris management and flood mitigation: structural and non-structural. Structural adjustments involve two different approaches: hard and soft structures. Hard engineering strategies act as a barrier between the river and the surrounding land where artificial structures are used to change or disrupt natural processes. Soft engineering does not involve building artificial structures, but takes a more sustainable and natural approach to managing the potential for erosion, deposition, and flooding by enhancing or protecting a river's natural features (NRC 2013).

Examples of hard engineering strategies include (NRC 2013):

- Dams (new construction or restoration)
- Pump Stations
- Engineered Drainage Systems
- Increase Bridge & Culvert Openings
- Levees
- Floodways, Spillways, and Channels

Examples of soft engineering strategies include (USACE 2001; NRCS 2002; NRC 2013):

- Flood Benches
- Streambank Stabilization and Protection
  - Live willow staking with some biodegradable soil stabilization
  - Vegetated Coir Roles
  - Burlap tiers
  - Rootwads with boulders
  - Riprap with live stakes
  - Live Fascines
  - Slope softening and vegetation
  - Hardwood tree planting
  - Brush layers
- Sediment Detention Basin/Retention Ponds
- Removal of Debris/Loose Vegetation from Floodplain
- In-channel Obstruction/Barrier Removal (i.e. dams, large debris, etc.)
- Sediment Removal

The purpose of non-structural flood mitigation is to change the way that people interact with the floodplain, flood risk, and also aim to move people away from flood-prone areas. Non-structural flood damage reduction measures have historically not been generally desired by the public and therefore, have not been utilized to their potential extent. This attitude of the general public has been gradually changing with continued implementation of the NFIP and the increasing national interest in a more pristine environment in which to live. This change became more abrupt with the large-scale, catastrophic flooding events since the 1990s (e.g. the Great Flood of 1993 in the Mississippi River Basin, Hurricane Katrina in 2005, Superstorm Sandy in 2012, etc.). More and more communities have looked for alternatives to structural flood damage reduction techniques and instead have begun to pursue non-structural techniques used to reduce flood damages that do not disturb the environment or that can lead to environmental restoration. Non-structural flood damage reduction techniques have proven to be extremely viable in alternatives consisting of total non-structural or a combination non-structural and structural measures. Examples of non-structural flood damage reduction measures include (USACE 2001; NRC 2013):

- Riparian Vegetation Restoration
- Retention Basin and Wetland Management
- Soil and Watershed Promotion Legislation
- Land Use Planning/Ordinances
- Floodproofing Residential/Commercial Properties
- Flood Buyouts
- Flood Monitoring & Warning System
- Community Flood Awareness and Preparedness Programs/Education

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United States Army Corps of Engineers (USACE). 2001. Non-Structural Flood Damage Reduction Within the Corps of Engineers: What Districts Are Doing. Davis (CA): United States Army Corps of Engineers (USACE), National Flood Proofing Committee (NFPC). Available from: USACE.

Vegetated Coir Logs

Vegetative plugs placed in densely-packed coconut fiber rolls (Figure 1)

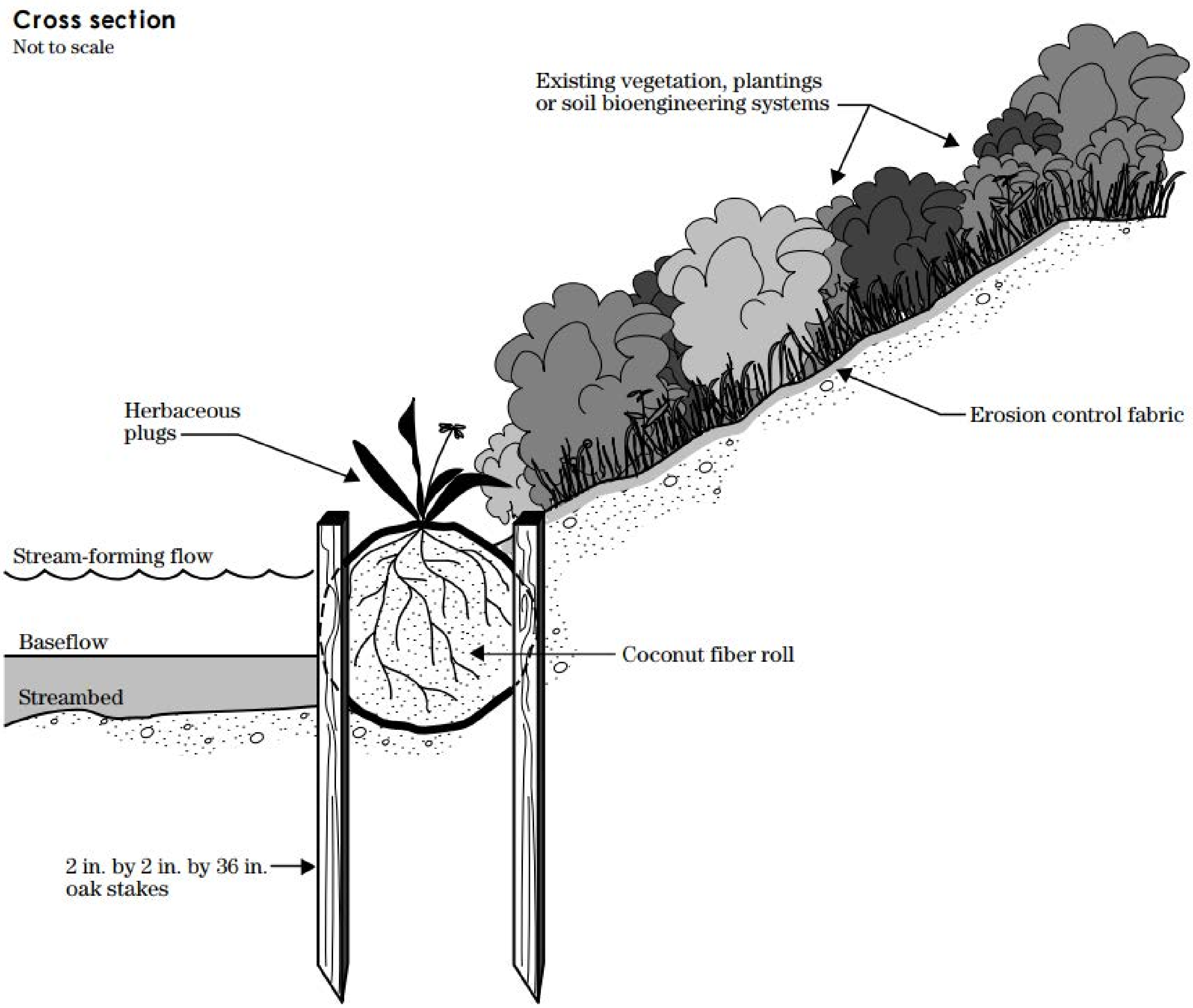

Figure 1. **Vegetated coir logs (NRCS 1996).**

Issue Solution Addresses

Vegetated coir logs prevent erosion by reinforcing the streambank and acting as a natural retaining wall against water velocity. The vegetated rolls are flexible and can mold to the existing curvature of the streambank. They are also highly effective in developing stream channel banks by trapping sediment behind the fiber rolls and improving conditions for vegetation establishment on the water's edge.

Ideal Location

Coir logs are suitable in low energy environments and work best in areas with minimal ice build-up. High energy environmental can dislodge the logs or cause the logs to break down before rooting the vegetative plugs. Gradual slopes less than 1V:2H (vertical:horizontal) are preferred.

Design and Construction Considerations

- **Site-Specific Conditions:** Vegetated coir logs are suitable in water velocities of 8 ft/s or less.
- **Materials:** Pre-constructed coir logs, coir netting (optional), vegetated plugs (pre-rooted is preferred), rot-resistant wooden stakes, and erosion control blanket (optional). Erosion control blankets and coir netting are recommended and can reduce the need for maintenance long-term.
- **Construction:** The density of vegetated plugs depends on the fiber roll diameter (Table 1). The root system shall be placed below the water level. The stakes shall be placed on both sides of the roll every 2-4 ft, depending on anticipated water velocity.

Table 1. **Vegetated Plug Density**

Log Diameter (inch)	Vegetated Plug Density (plug/linear foot)
8	1
12	2
16	3
20	5

- **Spacing:** If the shoreline is greater than 10 ft, the coir logs shall be laced together in a continuous line with no gapping between rolls.
- **Placement:** Install the first row of the coir logs parallel to the streambank such that the top two inches of the log are visible at mean water elevation. Additional vertical tiers can be added on the bank slope for further stabilization (Table 2).

Table 2. **Interval Spacing**

Slope (V:H)	Interval Spacing (ft)
1:1	5-10
1:2 > Slope > 1:1	10-20
1:4 > Slope > 1:2	20-40

- **Maintenance:** Replacement of the rolls may be required if the log begins to break apart due to elevated water velocity or ice damage. For the first year, it is encouraged to inspect the structure after the first few floods (~ 3 visits). Monitoring can reduce to once a year after that. Over time, sediment will cover the coir logs, and vegetation will establish.

Other design considerations include installation schedule (i.e., time of year), bank preparation, trench excavation methods, backfilling, compaction and drainage.

Permitting and Regulatory Considerations

The extent of permit requirements will depend on the location and final design of the project. Consult with your local municipality, NYSDEC, and USACE before beginning any stabilization activities.

Rough Order of Magnitude Cost

The total cost is approximately $1,000/20 linear ft. This price includes materials, transportation, and installation. Costs vary with design, site access, installation timeframe, supplier, and labor rates.

Applications and Effectiveness

- Protect slopes and encourage deposition of sediment

- Coir logs expedite vegetative cover by providing stabilized medium
- Molds to existing curvature of streambank
- Minimal disturbance of streambank

Brush Mattresses

Living ground cover of layered branch cuttings (Figure 2)

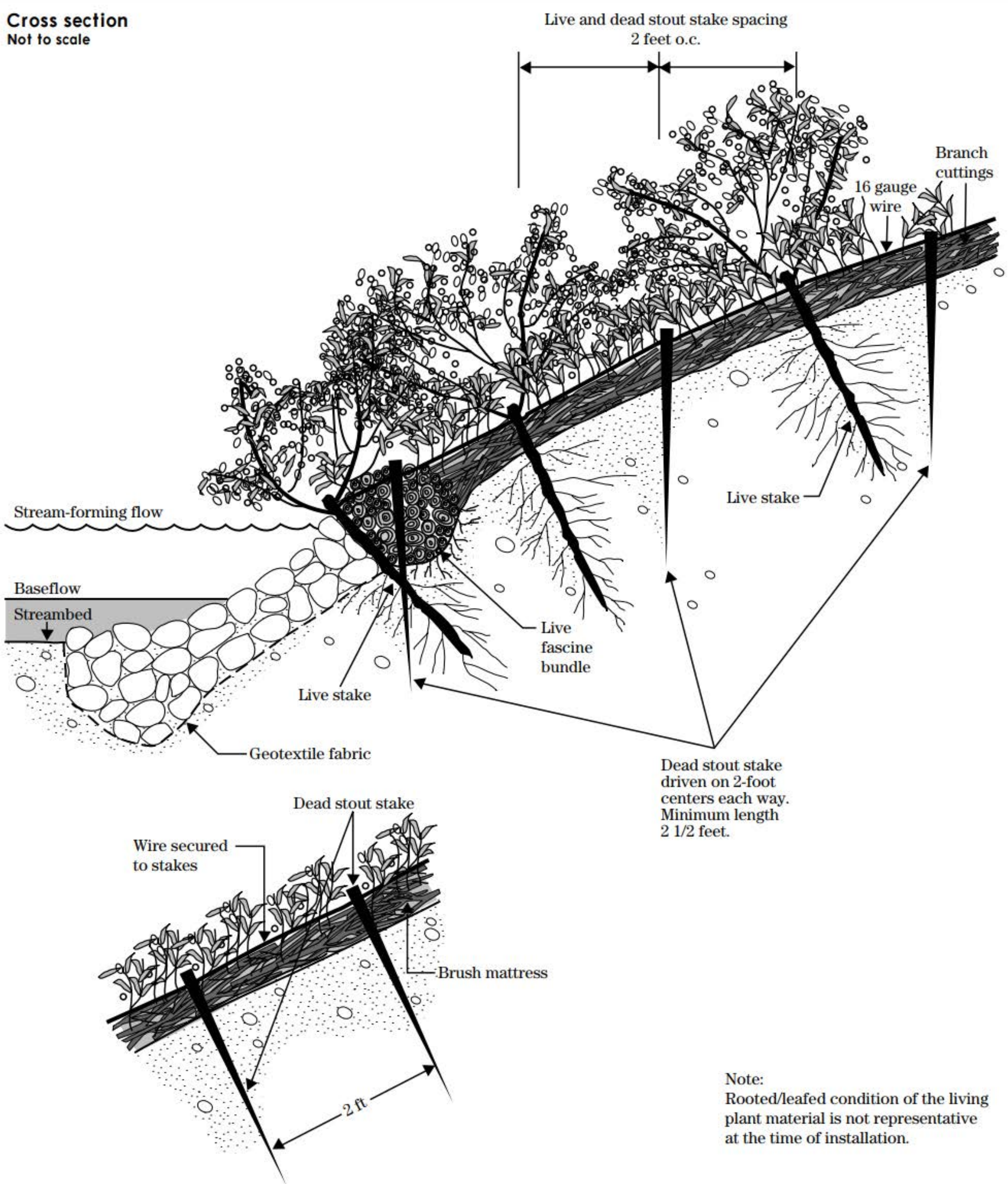

Figure 2. Brush mattresses (NRCS 1996).

Issue Solution Addresses

Brush mattresses slow water velocities along the streambank and reduce erosion. The open space between the woody material allows for sediment deposition and water drainage. The build-up of sediment enhances the colonization of native plants.

Ideal Location

Brush mattresses are best suited for perennial streams with low to medium water velocities. Constant water flow and sunny conditions will encourage the growth of the wood cuttings. Brush mattresses can be installed on slopes 1V:2H or flatter.

Design and Construction Considerations

- **Site-Specific Conditions:** Brush mattresses are suitable in water velocities of 5 ft/s. Brush mattresses are commonly implemented with other shoreline stabilization methods to ensure proper protection. Rock bolsters provide toe stabilization against high water velocities and shear stress, Table 3. Note, shoreline protection is dependent on vegetation establishment.

Table 2. **Brush Mattresses Configuration**

Brush Mattress Type	Water Velocity (ft/sec)	Shear (lb/ft^2)
Staked only without rock bolster at toe	Initial Planting: < 4.0	0.4 – 3
	Established Vegetation: < 5.0	4.0 – 7.0
Staked with rock bolster at toe	Initial Planting: < 5	0.8 – 4.1
	Established Vegetation: < 12	4.0 – 8.0

- **Materials:** Live branch cuttings of a native growing species (e.g., willow) approximately 6 to 9 ft in length, biodegradable untreated twine, dead stout stakes (minimum length of 2.5 ft), 12 gauge galvanized wire, and live fascines. Additional materials may include rock bolster and geotextile fabric for toe stabilization.
- **Placement:** First, install the live fascines in a trench (8 to 10 inches deep and wide) at the streambank base. Place the live branches into the fascines so that the basal end (where the roots grow) faces the riverbed. Drive dead stout stakes into the brush mattress approximately 12 to 18 inches apart. Lastly, wrap metal wire around each stake and pull tightly across the live branches.
- **Maintenance:** Repair of the nature-based structure may be required dependent on stream velocity, flood frequency, sediment load, and timing. For the first year, inspect the structure for loose branches or live fascines after the first few floods (~ 3 visits). Add additional stakes as needed. For the first two dry seasons, water the branches every two weeks if a soaking rain does not occur during a three-week timeframe.

Other design considerations include installation schedule (i.e., time of year), bank preparation, stock type, trench excavation methods, backfilling, compaction and drainage.

Permitting and Regulatory Considerations

The extent of permit requirements will depend on the location and final design of the project. Consult with your local municipality, NYSDEC, and USACE before beginning any stabilization activities.

Rough Order of Magnitude Cost

Total cost ranges from \$38 to \$84/10 ft^2. This price includes materials, transportation, and installation. Costs vary with design, site access, installation timeframe, supplier and labor rates.

Applications and Effectiveness

- Applicable for steep fast-flowing streams
- Captures sediment and encourages vegetation establishment
- Requires good soil to stem contact and moist conditions for branches to grow
- Encourages conditions for colonization of native vegetation
- Immediate protection of streambank after installation

Willow Stakes (Live)

Live willow cuttings with the branches trimmed off (Figure 3)

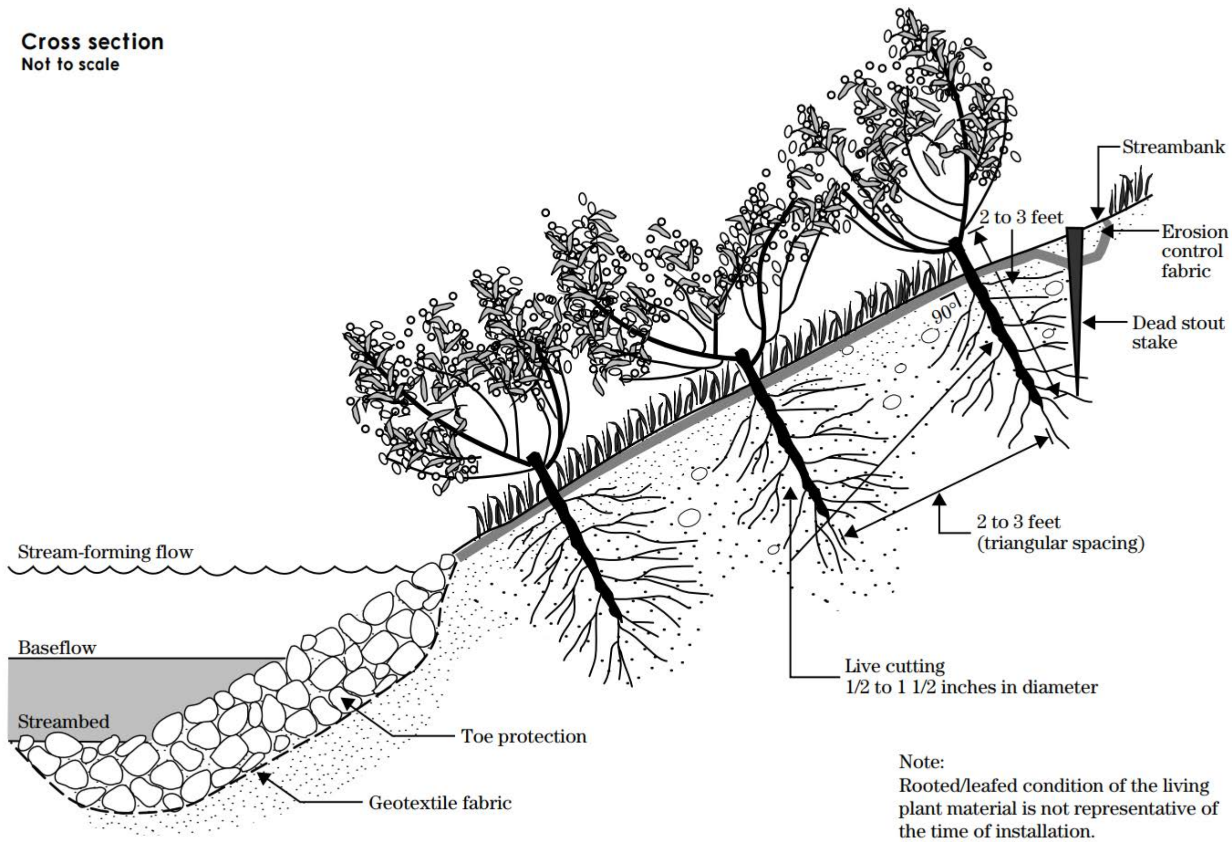

Figure 3. **Willow stakes (live) (NRCS 1996).**

Issue Solution Addresses

Live willow stakes are a cost-effective streambank stabilization method for slopes with soil exposure or minor erosion. The willow roots and branches will stabilize the soil, uptake soil moisture, and reduce over-bank runoff. Live stakes can be used alone or with other nature-based stabilization methods.

Ideal Location

Willow stakes are most successful on low to medium slopes with sunlight exposure and minimal invasive species presence. Best planted on soils with high water tables or soils with moderate draining conditions (high organic matter and clay content).

Design and Construction Considerations

- **Site-Specific Conditions**: Willow stakes are best suitable for water velocities below 9.8 ft/s and shear stress below 2 lb/ft^2. The willow stakes will not protect the slope until the willow has developed roots.

- **Materials:** Willow Cuttings (approximately 0.5 to 1.5 inches in diameter and 2 to 3 feet long). Optional materials include erosion control fabric, grass seeds, and dead stout stakes. Fertilizer or other soil amendments may be required based on soil conditions.
- **Branch Preparation:** Soak the branches before installation. Do not install dried stakes. The branch's basal end should be cut on an angle for easier planting, while the top should have a squared cut. Remove all side branches with minimal damage to the bark.
- **Spacing:** Place the live cuttings approximately 2 to 3 feet apart using a triangular spacing, at a density of 2 to 4 stakes per yd^2. Install the first row of cuttings about 4 ft from the edge of the water at low tide.
- **Installation:** The stakes shall be tapped four-fifths of length into the ground at a 90-degree angle. Remove the stake if it splits during installation and try again. After installation, firmly press the soil surrounding the cutting and cover all exposed ground will grass seed.
- **Maintenance:** The live stakes should be watered once per week during the 1^{st} growing season if placed in dry soil conditions. Pruning may be required if the willow grows too large.

Other design considerations include installation schedule (i.e., time of year), bank preparation, stock type and size, exposed soils and invasive species presence.

Permitting and Regulatory Considerations

The extent of permit requirements will depend on the location and final design of the project. Consult with your local municipality, NYSDEC, and USACE before beginning any stabilization activities.

Rough Order of Magnitude Cost

The cost of live willow stakes ranges from $ 0.7 to $ 5 per stake. This price does not include installation. Costs vary with design, site access, supplier and labor rates.

Applications and Effectiveness

- A cost-effective method for slopes that require minimal effort
- Repair small earth slips and slumps
- Some species of willow can grow in unfavorable soil conditions
- Can be combined with other hard and/or soft stabilization methods

Vegetated Geogrid (Soil Lifts)

Biodegradable matting wrapped around the soil to form tiers

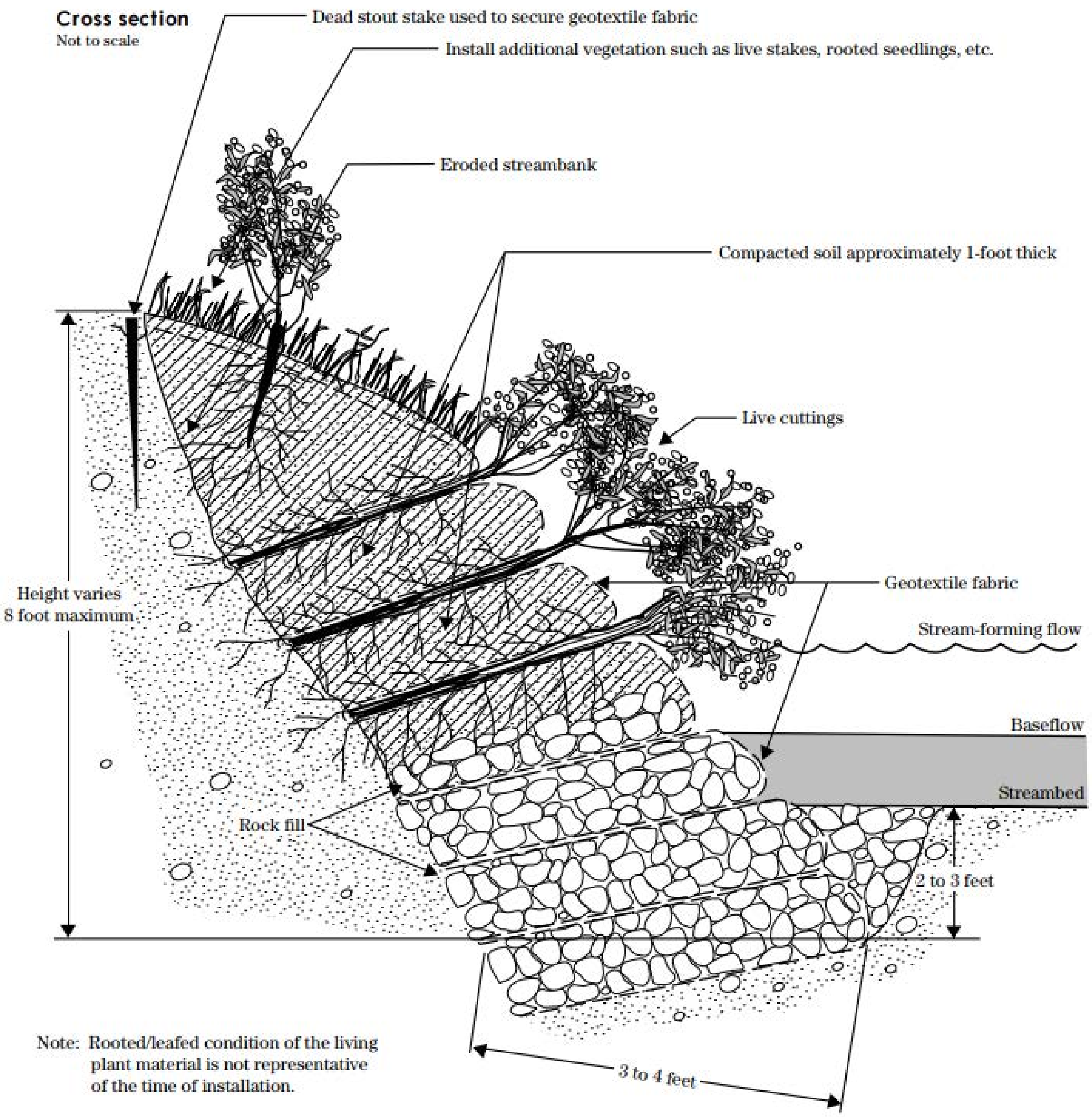

Figure 1. **Soil lift (NRCS 1996).**

Issue Solution Addresses

Soil lifts are used on moderate to high energy riverbanks to help protect against erosion and sliding soil. They are also used to rebuild a bank that is already compromised by moderate erosion. The tiers enhance the slope's condition for colonization of native vegetation.

Ideal Location

Soil lifts are best implemented on outside bends that are experiencing moderate erosion. The tie-in slow should not be steeper than 2V:1H.

Design and Construction Considerations

- **Site-Specific Conditions**: Soil lifts are best suitable for water velocities below 12 ft/sec and shear stress below 6.25 lb/ft^2 for fully grown vegetation.
- **Materials:** Biodegradable erosion control fabric, soil suitable for plant growth, dead stout stakes (2.5-4 ft long), branch cuttings (0.5-2 in diameter and 4-6 ft long), rock fill, and batter board (optional). The batter board helps define the front edge of the lift during construction.
- **Rock Toe:** Rockfill is required for toe establishment. The toe should start 2-3 ft below the streambed elevation and 3-4 ft wide. Wrap the fabric over the rock in 12 in. increments.
- **Spacing:** Each tier should be approximately 1-ft thick.
- **Installation:** The first layer of live cuttings (6-8 in. thick) shall be placed at the stream-forming flow, with the basal end touching the back of the excavated slope. Cover the branches with a layer of soil until the stems are mostly covered. Place the geotextile layer over the cuttings and leave an overhang of geotextile material. Cover the geotextile with 12 in. of soil and compact the soil to ensure good soil contact with the branches. Pull overhang of geotextile material over the soil and adjust the cloth until the desired contour. Continue this process, alternating layers of branch clippings and wrapped soil until the bank is restored—the maximum total height of 8 ft.
- **Maintenance:** Minimal maintenance is required due to the geotextile fabric. However, the system is susceptible to erosion prior to vegetation establishment. The vegetation is essential to ensure the tiers do not fail after the fabric begins to deteriorate.

Other design considerations include installation schedule (i.e., time of year), bank preparation, stock type, and geotextile selection. Engineering analysis is recommended for soil lift designs with a total height greater than 7 ft and 20 ft in length.

Permitting and Regulatory Considerations

The extent of permit requirements will depend on the location and final design of the project. Consult with your local municipality, NYSDEC, and USACE before beginning any stabilization activities.

Rough Order of Magnitude Cost

Total cost is approximately $104/linear ft. This price includes materials, transportation, and installation. Costs vary with design, site access, installation timeframe, supplier and labor rates.

Applications and Effectiveness

- Provides a newly constructed streambank that functions immediately
- Encompasses the soil to prevent soil slides
- The system can be complicated and expensive
- Produces rapid vegetative growth and ideal conditions for colonization of native vegetation

Rootwad with Boulders

The placement of a trunk of a dead tree (Rootwad) and large stone (Figure 5)

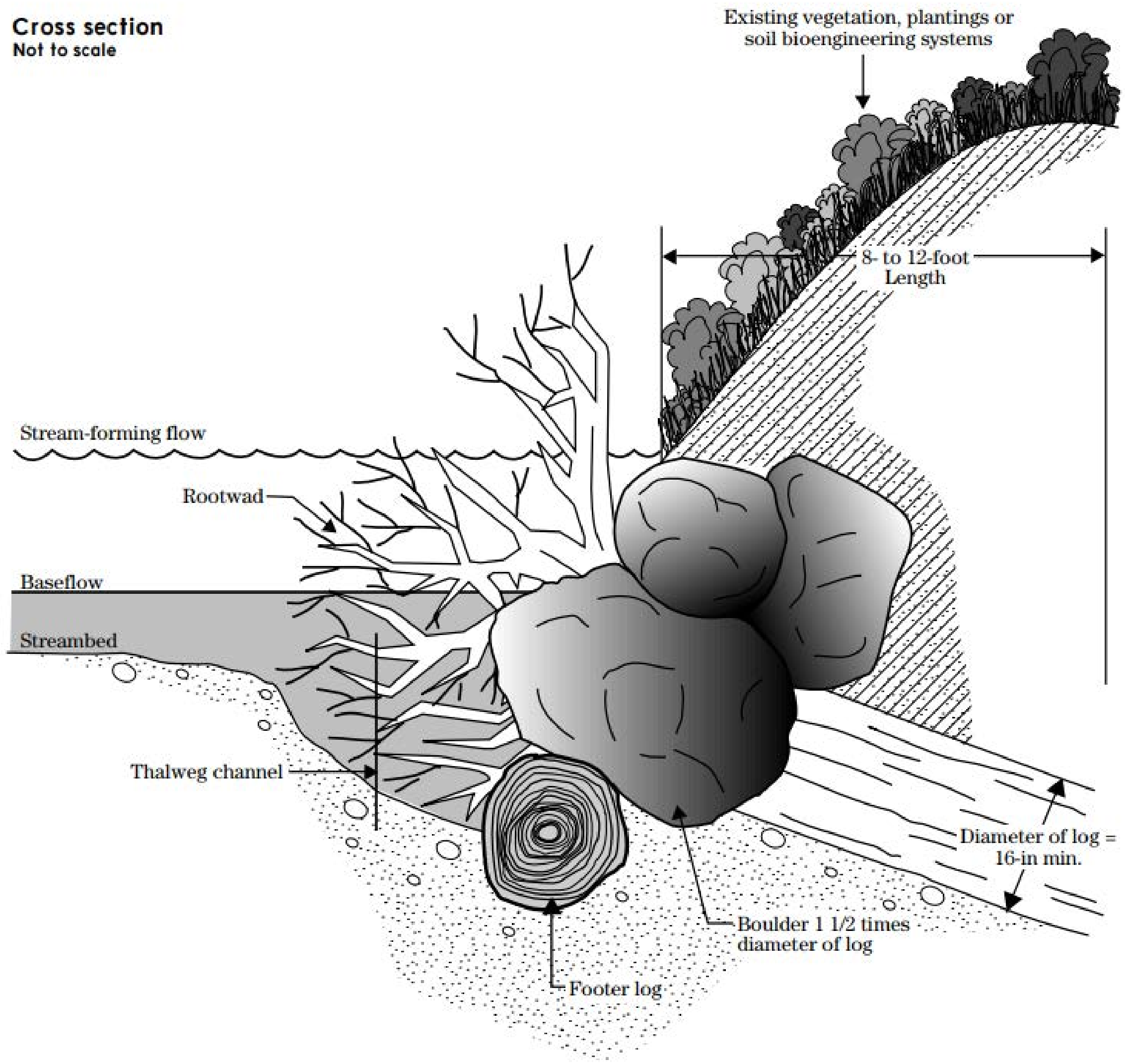

Figure 1. **Rootwad with boulders (NRCS 1996).**

Issue Solution Addresses

The combination of rootwad and boulders are best utilized for streambed stabilization and enhanced in-stream habitat. This combined technique is also effective on meandering streams with out-of-bank flow conditions.

Ideal Location

Rootwads and boulders are ideal in newly constructed channels to mimic natural conditions or where woody habitat is limited. They can be placed in riffles (shallow depths with fast/turbulent water) or pools (deep depths and slow current), depending on the stream type. Banks need to have at least 15% silt or clay; otherwise, bank erosion will occur around rootwads.

Design and Construction Considerations

- **Site-Specific Conditions**: Rootwads and boulders are best used on sites with water velocities below 8 ft/sec. The rootwads can tolerate high boundary shear stress if the rootwads are correctly anchored.
- **Materials:** Trees (hemlock or hardwood) with root ball intact (~12 ft long boles), footer log, and boulders (minimum of 1.5 times the log diameter).
- **Spacing:** Space the rootwads 3-4 times the root bulb diameter continuously along the channel bank.
- **Installation:** Install the footer log, at the expected scour depth, on a slight angle against streamflow along the eroding bank. Install the rootwad so the brace roots are flush with the streambank and are slightly angled towards the direction of the streamflow. Lastly, place boulders around the rootwad and footer log to prevent the trees from dislodging.
- **Maintenance:** For the first year, inspect the rootwads after significant flow events for channel bank erosion. Inspect the site for signs of undercutting, vegetation survival, and animal damage.

Other design considerations include installation schedule (i.e., time of year), soil composition, bank preparation, and exposed soils (upper bank). Professional installation and design is required.

Permitting and Regulatory Considerations

The extent of permit requirements will depend on the location and final design of the project. Consult with your local municipality, NYSDEC, and USACE before beginning any stabilization activities.

Rough Order of Magnitude Cost

Total cost ranges from $18 to $91/linear ft, with an average cost of $37/ linear ft. This price includes materials, transportation, and installation. Costs vary with design, site access, installation timeframe, supplier and labor rates.

Applications and Effectiveness

- Immediate stabilization of the streambed
- Creates in-stream habitat for fish rearing and spawning
- Requires vegetation planting or other shoreline stabilization methods for the upper portion of the bank
- May be used in high-velocity streams
- Requires professional installation and engineering design

Riprap with live stakes

The combination of large, loose, angular stone with live, vegetative cuttings (Figure 6)

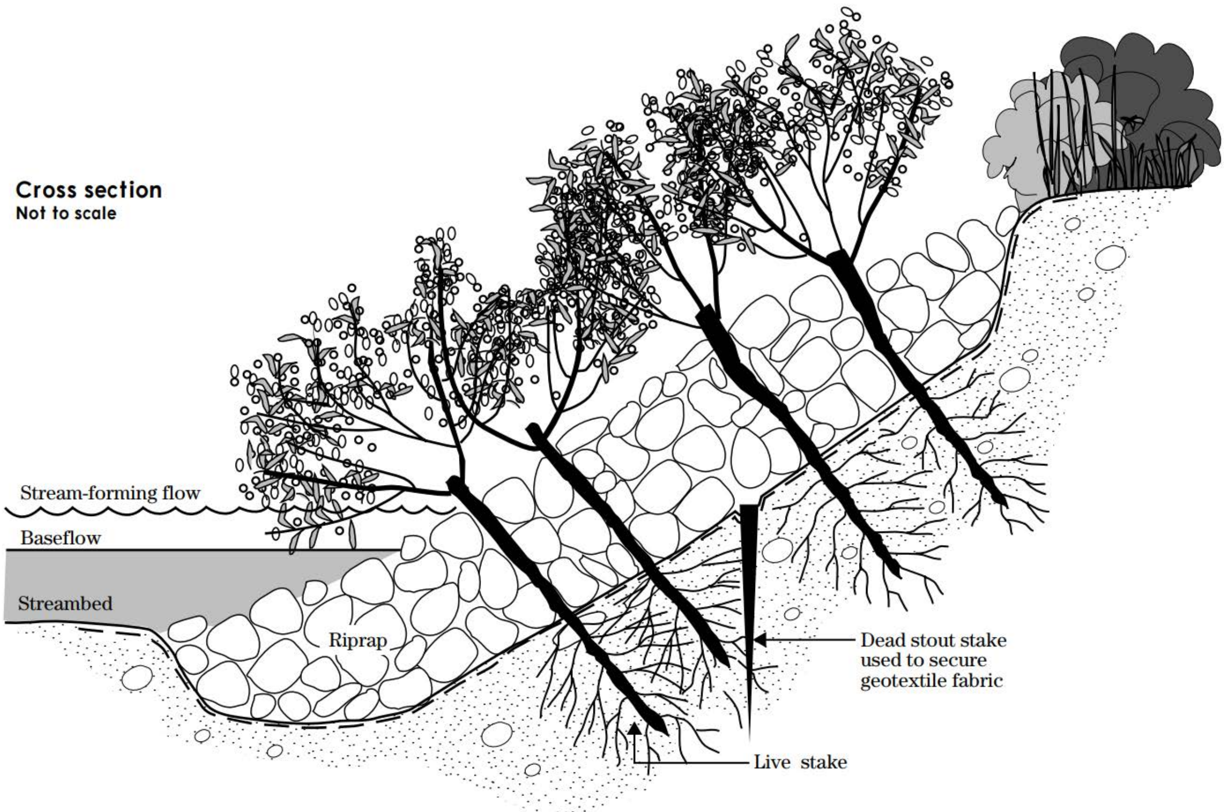

Figure 1. Riprap with live stakes (NRCS 1996).

Issue Solution Addresses

Riprap and live stakes are an effective method for shoreline stabilization and toe establishment. This technique can also repair small earth slips and slumps and prevent scouring. The live stakes are planted in the rock joints to establish riparian vegetative cover and provide further erosion control after root establishment.

Ideal Location

Riprap and live stakes are best in locations where erosion forces are severe and softer methods are not effective. The individual stone allows for shoreline protection along meandering riverbeds that require a flexible structure. The maximum recommended slope of the riverbank is 1V:2H; however, 1V:3H is preferred.

Design and Construction Considerations

- **Site Specific Conditions**: Live stakes and riprap are best used for water velocities between 5 and 15 ft/sec.
- **Materials:** Stem Cuttings (long woody branches) of a native naturally growing species (minimum diameter of 0.25 inches and a minimum length of 4 ft), geotextile fabric, wooden stakes (minimum length of 2.5 ft), and dense, hard angular riprap that meets NYSDOT Specifications.

➢ **Riprap Sizing:** The size of the riprap will increase with water velocity. See Table 3 for maximum sizing requirements.

Table 4. **Riprap Sizing**

Velocity (fps)	D_{max} (in)
5	6
8.5	12
10	18
12	24
15	36

➢ **Placement and Spacing:** Stake the geotextile fabric in place along the streambed and bank. The placement of the vegetative stakes is dependent on soil cohesion and slope (Table 4). The cuttings should be placed at random intervals above the stream-forming flow. Carefully place the riprap around the vegetative stakes and use smaller stones in any void space that does not have cuttings. If rip-rap is already present, insert the live stakes perpendicular to the slope using a dead blow hammer.

Table 4. **Spacing for Vegetative Stakes**

	Spacing (ft on Center)	
Slope Steepness (V:H)	Cohesive Soils (high clay content)	Non-Cohesive Soils (high sand content)
1:5:1	N/A	N/A
1:2	1.5 – 3	1.5 – 2
1:3 or flatter	3 – 5	2 – 4

➢ **Maintenance:** Vegetative cuttings may require watering for 6 weeks after installation, dependent on installation timeframe. For the first year, it is encouraged to inspect the system after each of the first few floods (~ 3 visits). Monitoring can reduce to once a year thereafter. Repair of the nature-based structure may be required until the vegetation is fully established.

Other design considerations include installation schedule (i.e., time of year), stone quality (graded vs uniform), bank preparation, trench excavation, backfilling, and stone placement.

Permitting and Regulatory Considerations

The extent of permit requirements will depend on the location and final design of the project. Consult with your local municipality, NYSDEC, and USACE before beginning any stabilization activities.

Rough Order of Magnitude Cost

Total cost ranges from $6 to $23/linear foot. This price includes materials, transportation, and installation. Costs vary with design, site access, installation timeframe, supplier and labor rates.

Applications and Effectiveness

- Useful for slopes subject to seepage or weathering
- Vegetative roots can improve drainage by removing soil moisture and prevent washout between the rip-rap.
- Provides immediate protection and is effective in reducing erosion on actively eroding banks.
- Dissipates some of the energy along the streambank and induces sedimentation.
- Rip-rap sizing and vegetative density will depend on the water velocities.

Live Fascines

Live fascines (Figure 7) are long bundles of live woody cuttings tied together and buried in a streambank parallel to the stream's flow.

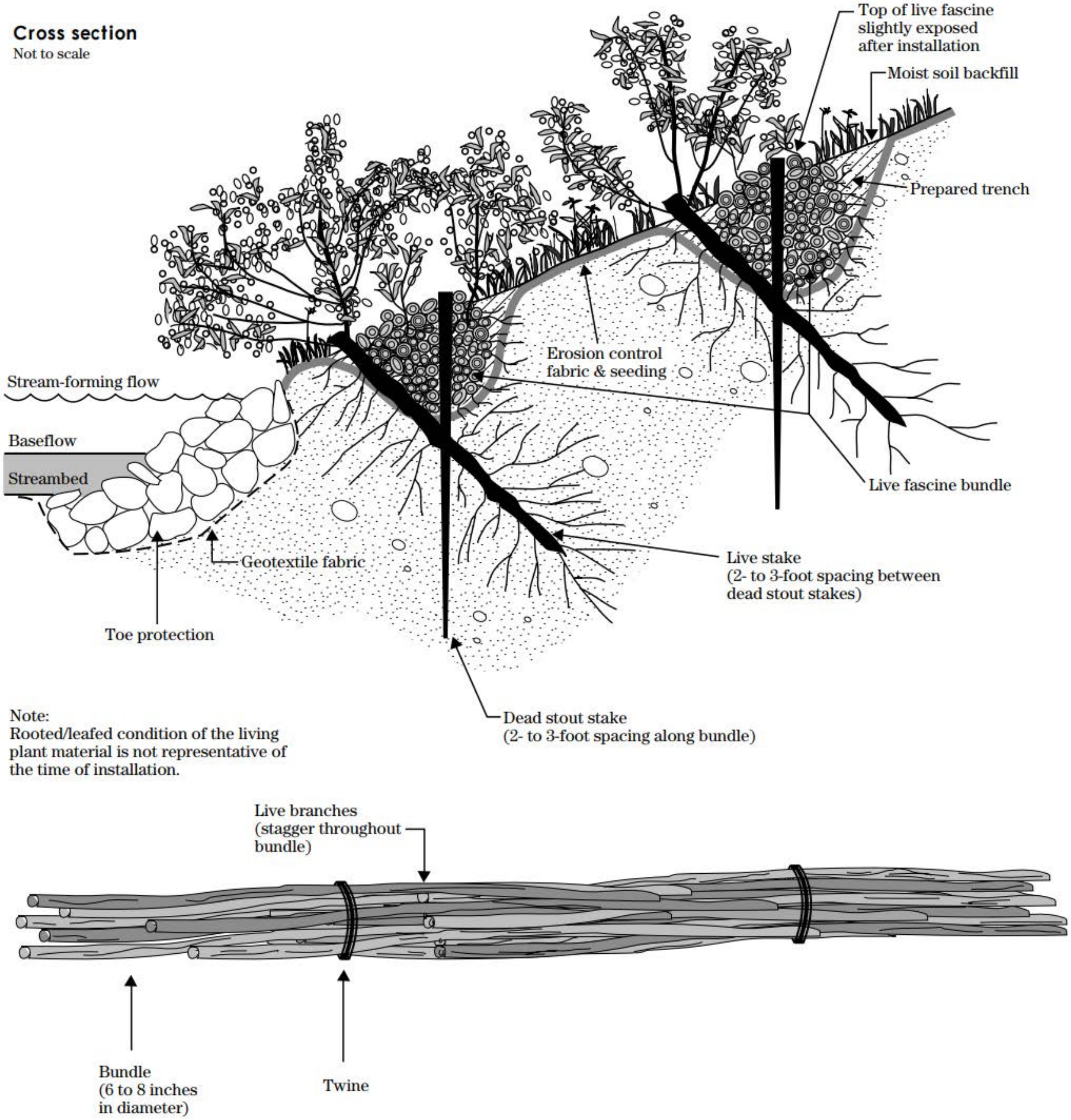

Figure 1. **Live Fascines (NRCS 1996).**

Issue Solution Addresses

Live fascines are useful in controlling erosion related to wave action and over-bank runoff on long slopes. A series of plant-filled trenches will reduce slope segments and dissipate water energy available for erosion. Angled or horizontally plant-filled trenches act as a water retention system, allowing for improved infiltration rates and reducing over-bank runoff. In time, the live fascines will produce roots and top growth, providing soil reinforcement, surface protection, and groundwater uptake. Other benefits include improved fishery habitat, water quality, and natural-looking aesthetics.

Ideal Location

Best applied on gentle slopes experiencing light to moderate erosion. The bank face must be a maximum of 15 feet long and should not have slopes steeper than 1V:2H; a slope of 1V:3H is preferred. Live fascines require soil conditions with high organic matter and clay content to ensure that the fascines stay anchored to the shoreline and have enough moisture for vegetation growth.

Design and Construction Considerations

- **Configuration:** Live fascines are commonly implemented with other shoreline stabilization methods to ensure full protection. The rip-rap provides toe stabilization and prevents wave reflection (Table 5).

***Table 5*. Stress Type and Levels**

Bundle Configuration	Velocity	Shear
Angle only without rock bolster protection	< 8 ft/sec	1.2 to 2.1 lb/ft^2
Angle with rock bolster protection	< 12 ft/sec	>3.1 lb/ft^2
On-contour only without rock bolster protection	< 6 ft/sec	0.1 to 0.6 lb/ft^2
On-contour w/rock bolster protection	< 8 ft/sec	>2.0 lb/ft^2

- **Materials:** Stem Cuttings (long woody branches) of a native naturally growing species (minimum diameter of 0.25 inches and a minimum length of 4 ft), biodegradable untreated twine, wooden stakes (minimum length of 2.5 ft). The bundles should consist of branches of different ages, sizes and species.
- **Bundle Construction:** The live end of each branch must be pointed in the same direction, and the cut ends shall be staggered throughout the bundle, with a total bundle length of approximately 4 ft.
- **Spacing:** The vegetated bundles must be anchored to non-eroding portions of the bank. The spacing between the live fascines bundles is dependent on soil type and slope. For a slope of 2:1, the live fascines shall be placed 3-5 ft apart for loose erosive soil and 5-7 ft for cohesive soil.
- **Placement:** Install the live fascine bundles above the stream-forming flow, except on small drainage area sites (generally less than 2,000 acres).
- **Maintenance:** Repair of the nature-based structure may be required until the vegetation is fully established. For the first year, it is encouraged to inspect the system after each of the first few floods (~ 3 visits). Monitoring can reduce to once a year thereafter.

Other design considerations include installation schedule (i.e., time of year), bank preparation, trench excavation, backfilling, compaction and drainage.

Permitting and Regulatory Considerations

The extent of permit requirements will depend on the location and final design of the project. Consult with your local municipality, NYSDEC, and USACE before beginning any stabilization activities.

Rough Order of Magnitude Cost

Total cost ranges from $10 to $30/ft for 6 to 8 in. bundles. This price includes materials, transportation, and installation. Costs vary with design, site access, installation timeframe, supplier and labor rates.

Applications and Effectiveness

- Effective for streambank stabilization with minimum disturbance
- Provides immediate protection again surface erosion and shallow slides (1 to 2 ft depth)
- An angular installation will facilitate drainage while the roots uptake water seepage
- Bundles are capable of trapping soil and reduce slope length by creating a series of shorter slopes
- Encourages growth of native vegetation by providing surface stabilization

Hardwood Tree Planting

A native hardwood tree planted upland of other shoreline stabilization techniques

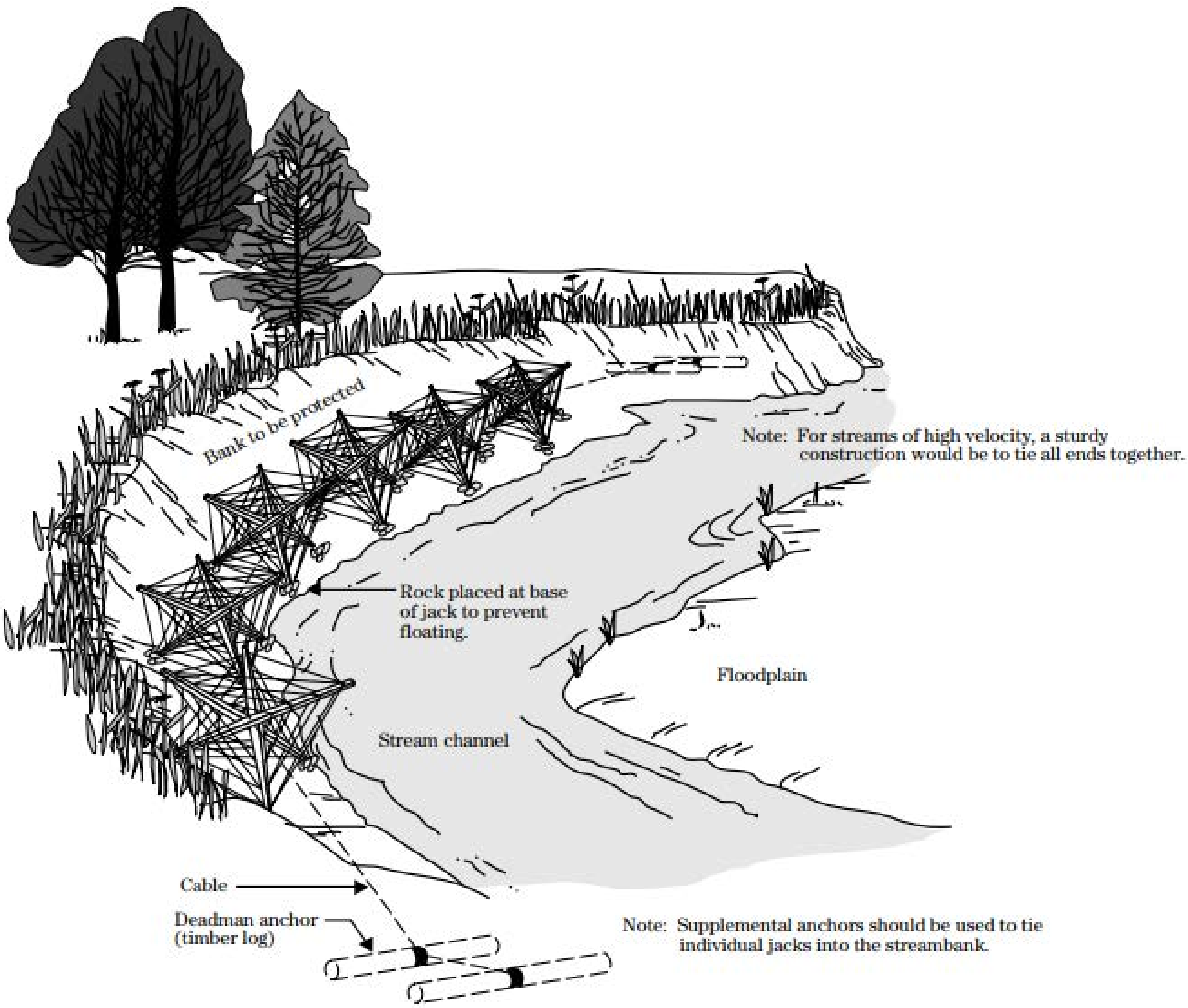

Figure 8. **Tree planting upland of shoreline stabilization method (NRCS 1996).**

Issue Solution Addresses

Upland tree planting is a useful technique to protect against erosion caused by over-bank runoff. Trees intercept the falling rain in their canopies and absorb the water through their roots. Woody species have a deep root structure which prevents against earth slips by holding the soil in place, trapping upland sediment carried by stormwater and absorbing excess soil moisture. Also, trees provide other ecological benefits, including natural habitat, reduction in stream water temperatures, and improved water quality.

Ideal Location

Tree plantings are most successful against over-bank runoff when placed upland of other streambank stabilization methods. The tree plantings will require sunlight, ideal soil conditions (dependent on species) and room to grow to maturity.

Design and Construction Considerations

- **Materials:** Native trees, fertilizer, and mulch. Conduct a site evaluation to determine the appropriate tree species, e.g., light exposure, wind, aboveground and belowground utilities, soil characteristics, surrounding vegetation, and distance to the water table.
- **Placement and Spacing:** Tree spacing (Table 6) will allow room for the tree to expand as it grows to maturity. The placement of the tree is dependent on soil moisture conditions, sunlight availability, and site size.

***Table 6.* Tree Spacing**

Tree Description	Spacing (ft)
Columnar Species	6-8
Small Trees	20-30
Large Trees	50-60

- **Installation Schedule:** For deciduous species, planting shall occur during April to June 1 and October 15 to December 15. For Evergreen trees, planting should be completed during April 1 to Jun 1 and September 1 to November 15.
- **Planting:** Dig a hole twice the size of the root ball. Mix the soil with slow-releasing fertilizer. Remove the tree from the container, gently loosen roots and place the tree within the hole. Once the tree looks level, put additional soil within the hole and compress down. Apply 2-3" layer of wood chips around the base. Pull the mulch 1" away from the base of the tree to avoid fungus or insect damage.
- **Maintenance:** The tree plants will require watering two weeks after planting. For the first two dry seasons, water trees every two weeks if a soaking rain does not occur during a three week timeframe. Monitor the tree(s) for dead, diseased, or dying limbs and prune and thin as necessary.

Other design considerations include site preparation (weed control, scalping of sod), soil health, sunlight availability, insect treatment, and stock.

Permitting and Regulatory Considerations

The extent of permit requirements will depend on the location and final design of the project. Consult with your local municipality, NYSDEC, and USACE before beginning any stabilization activities.

Rough Order of Magnitude Cost

Total cost ranges from $106 for smaller trees to 2,423 for larger trees. This price includes materials, transportation, and installation. Costs vary with design, site access, installation timeframe, supplier and labor rates.

Applications and Effectiveness

- Reduces over-bank runoff and captures stormwater sediment
- The root structure prevent against earth slips through soil moisture uptake and soil stabilization
- Increases diversity and available habitat
- Increase water quality through pollutant uptake from groundwater and stormwater runoff

Vegetated Riparian Buffer

Vegetated corridors that parallel streams, rivers, lakes, and wetlands.

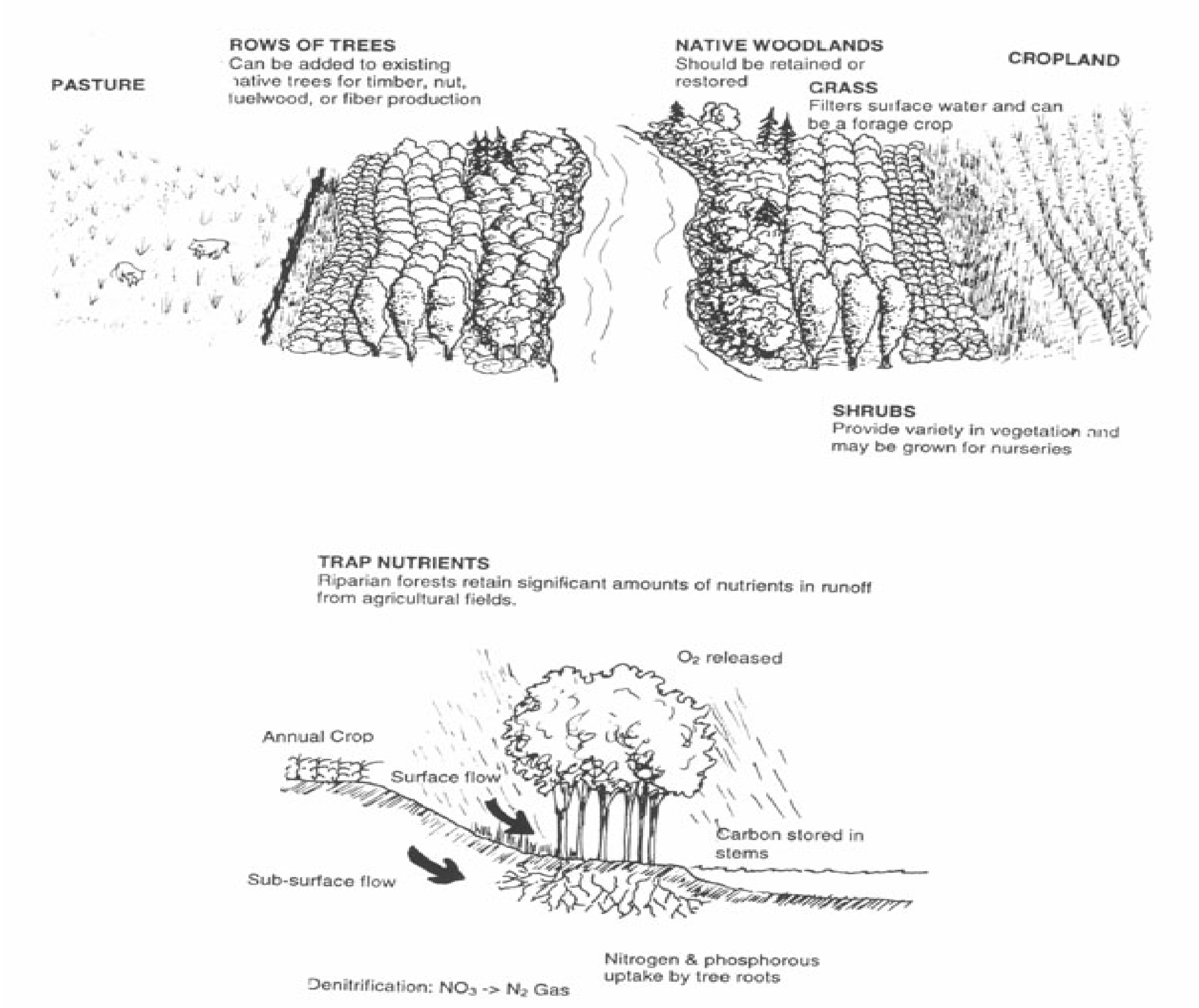

Figure 9. **Vegetated riparian buffers adjacent to pasture and cropland (NRCS [date unknown]).**

Issue Solution Addresses

Vegetated riparian buffers are designed to intercept stormwater runoff before it enters adjacent water bodies. In the process, they trap sediment, nutrients, and contaminants that are carried within stormwater before it reaches the waterbodies. The mechanisms through which they accomplish this include:

- Stoppage of transport of sediment by buffer vegetation.
- Slowing runoff to allow for stormwater infiltration, settling of sediment, and uptake of water, nutrients, and contaminants by vegetation.

It is estimated that vegetated riparian buffers can reduce sediment concentrations of up to 90 percent. Their ability to reduce concentrations of nitrogen, phosphorus, and other constituents also significantly improve the quality of the adjacent water bodies.

Ideal Location

Vegetated riparian buffers generally parallel the shoreline of the adjacent water bodies and should be placed so that they are located within the flow path of contributing sources of stormwater runoff that contains significant concentrations of sediment and other constituents (e.g., pasture and cropland). Designers need to work with the landowners to maximize the efficacy of the buffer while minimizing the amount of land that is taken out of revenue generation (e.g., agricultural production, commercial real estate).

Design and Construction Considerations

Essentially, any vegetated buffer that can be established between the contributing drainage area and the adjacent water body will improve water quality within the aquatic resource. That said, the following should be considered during design:

- The ideal total width of the buffer is at least 150-feet, but should be no less than 30 feet.
- As illustrated in Figure 9, the buffer will ideally contain various elements. Inclusion of woody species improves soil stabilization and evapotranspiration and should be implemented where practicable. Specific elements should include:
  - A band of grasses and forbs closest to the adjacent land use. In an agricultural setting, these bands can be planted with harvestable crops such as hay or straw provided that the stubble is left to stabilize the soil.
  - A band of shrubs and small trees. This band can be made up of fruit and nut trees from which crops can be harvested or can be harvested for biofuels (e.g., willow).
  - A band of woodlands that are allowed to mature with minimal harvest or ongoing maintenance.
- All native species should be included in design.
- It is recommended that several different species be used on one site to maximize diversity.
- Livestock should be excluded from all buffers to the extent practicable.

Materials: Native trees, shrubs, and seed; fertilizer; and mulch. Conduct a site evaluation to determine the appropriate species, e.g., light exposure, wind, aboveground and belowground utilities, soil characteristics, surrounding vegetation, and distance to the water table. Fast growing hardwoods such as cottonwood and poplars, silver maple, and willows can be used so they can be harvested for biofuels within 4-6 years or can be left longer to produce small dimension lumber and biofuels.

Placement and Spacing: spacing between rows and trees within a row varies with species and objectives. Common plantings will be 8 to 10 feet between rows and 4 to 6 feet between trees within the row; shrubs will be planted at closer spacings.

Installation Schedule: For deciduous species, planting shall occur during April to June 1 and October 15 to December 15. For Evergreen trees, planting should be completed during April 1 to June 1 and September 1 to November 15. Seeding shall be performed during two seasonal windows: April 1 to June 15, October 15 through December 1.

Maintenance:

- The grass and forb zone should be mowed a minimum of once annually to control woody vegetation.
- The tree and shrub species can be selectively cut to produce biofuels and/or lumber or can be left to mature. Monitor the woody species for dead, diseased, or dying limbs and prune and thin as necessary.

Other design considerations include site preparation (weed control, scalping of sod), soil health, sunlight availability, insect treatment, and stock.

Permitting and Regulatory Considerations

The extent of permit requirements will depend on the location and final design of the project. Consult with your local municipality, NYSDEC, and USACE before beginning any stabilization activities.

Rough Order of Magnitude Cost

Costs are site-specific and will depend on the length/width of the buffer and the vegetation species used. If the riparian zone is vegetated and hydrologically connected between the upland and stream, there may be no cost at all, other than the cost and effort of negotiating an easement with the landowner to promote long-term buffer health.

If riparian buffers do not exist and must be newly established (e.g., by way of stream bank reengineering), costs for a forest buffer costs between $250–$700 per acre to plant and maintain. Costs include site preparation, plants, planting, maintenance, and replanting by the landowner.

Riparian forest buffers qualify for the conservation programs (e.g., Trees for Tribs), which can help with the cost of establishment and provides an annual payment. Forest buffers might also result in a bonus for trees planted and a per-acre incentive.

Applications and Effectiveness

- Reduces poullutant and nutrient loading to adjacent water bodies
- Shade provided by trees can reduce thermal impacts
- The vegetative root structure helps stabilize site soils
- Increases diversity and available wildlife habitat

References

Natural Resources Conservation Service (NRCS). [date unknown]. Guidance on Agroforestry System Design – Riparian Forest Buffer. In: Sustaining Agroforestry Systems for Farms and Ranches. Washington DC (US): United States Department of Agriculture (USDA). Available from: https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/landuse/forestry/sustain/guidance/?cid=nrcsdev11_009302.

Natural Resources Conservation Service (NRCS). 1996. Engineering Field Handbook - Chapter 16: Streambank and Shoreline Protection. Washington DC (US): United States Department of Agriculture (USDA). Available from: https://efotg.sc.egov.usda.gov/references/public/IA/Chapter-16_Streambank_and_Shoreline_Protection.pdf.

WISCONSIN SUPPLEMENT
CHAPTER 16 - ENGINEERING FIELD HANDBOOK
STREAMBANK AND SHORELINE PROTECTION
STANDARD 580
COMPANION DOCUMENT 580-10
Allowable Velocity and Maximum Shear Stress

Type of Treatment	Allowable Shear lb/sq ft	Velocity ft/sec
Brush Mattresses[1]		
Staked only w/ rock riprap toe (initial)	0.8 - 4.1	5
Staked only w/ rock riprap toe (grown)	4.0 - 8.0	12
Coir Geotextile Roll[2]		
Roll with coir rope mesh staked only without rock riprap toe	0.2 - 0.8	< 5
Roll with Polypropylene rope mesh staked only without rock riprap toe	0.8 - 3.0	< 8
Roll with Polypropylene rope mesh staked and with rock riprap toe	3.0 - 4.0	< 12
Live Fascine[3]		
LF Bundle w/ rock riprap toe	2.0 - 3.1	8
Soils[4]		
Fine colloidal sand	0.02-0.03	1.5
Sandy loam (noncolloidal)	0.03-0.04	1.75
Alluvial silt (noncolloidal)	0.045-0.05	2
Silty loam (noncolloidal)	0.045-0.05	1.75-2.25
Firm loam	0.075	2.5
Fine gravels	0.075	2.5
Stiff clay	0.26	3-4.5
Alluvial silt (colloidal)	0.26	3.75
Graded loam to cobbles	0.38	3.75
Graded silts to cobbles	0.43	4
Shales and hardpan	0.67	6
Gravel/Cobble[4]		
1-inch	0.33	2.5-5
2-inch	0.67	3-6
6-inch	2	4-7.5
12-inch	4	5.5-12
Vegetation[4]		
Class A turf (ret class)	3.7	6-8
Class B turf (ret class)	2.1	4-7
Class C turf (ret class)	1	3.5
Retardance Class D	0.6	Design of roadside channels HEC-15
Retardance Class E	0.35	
Long native grasses	1.2-1.7	4-6
Short native and bunch grass	0.7-0.95	3-4

EFH Notice 210-WI-119
February 2009

Type of Treatment	Allowable Shear lb/sq ft	Velocity ft/sec
Soil Bioengineering[4]		
Wattles	0.2-1.0	3
Reed fascine	0.6-1.25	5
Coir roll	3-5	8
Vegetated coir mat	4-8	9.5
Live brush mattress (initial)	0.4-4.1	4
Live brush mattress (grown)	3.90-8.2	12
Brush layering (initial/grown)	0.4-6.25	12
Live fascine	1.25-3.10	6-8
Live willow stakes	2.10-3.10	3-10
Hard Surfacing[4]		
Gabions	10	14-19
Concrete	12.5	>18
Boulder Clusters[5]		
Boulder		
Very large (>80-inch diameter)	37.4	25
Large (>40-in diameter)	18.7	19
Medium (>20-inch diameter)	9.3	14
Small (>10-inch diameter)	4.7	10
Cobble		
Large (>5-inch diameter)	2.3	7
Small (>2.5-inch diameter)	1.1	5
Gravel		
Very Course (>1.25-inch diameter)	0.54	3
Course (>.63-inch diameter)	0.25	2.5

[1] Brush mattresses (ERDC TN EMRRP-SR-23): http://el.erdc.usace.army.mil/emrrp/pdf/sr23.pdf.
[2] Coir Geotextile roll (ERDC TN EMRRP-SR-04): http://el.erdc.usace.army.mil/emrrp/pdf/sr04.pdf.
[3] Live Fascine (ERDC TN EMRRP-SR-31): http://el.erdc.usace.army.mil/emrrp/pdf/sr31.pdf.
[4] Stream Restoration Materials (ERDC TN EMRRP-SR-29): http://el.erdc.usace.army.mil/emrrp/pdf/sr29.pdf.
[5] Boulder Clusters (ERDC TN EMRRP-SR-11): http://el.erdc.usace.army.mil/emrrp/pdf/sr11.pdf.

Additional Sources:

Wisconsin Department of Transportation, Erosion Control - Product Acceptability List (PAL):
http://www.dot.wisconsin.gov/library/research/docs/finalreports/tau-finalreports/erosion.pdf

Texas Department of Transportation, Approved Products List:
http://www.dot.state.tx.us/mnt/erosion/contents.htm

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Natural Resources Conservation Service (NRCS). 2009. Engineering Field Handbook - Chapter 16: Streambank and Shoreline Protection - Wisconsin Supplement. Washington DC (US): United States Department of Agriculture (USDA). Report No.: EFH Notice 210-WI-119. Available from: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_024948.pdf.