THE VERMONT FUNCTIONING FLOODPLAIN INITIATIVE (FFI) TO RECONNECT RIVERS

User Guide (Version 2.1)

Prepared for:

Vermont Department of Environmental Conservation

June 2023

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SUMMARY

The Functioning Floodplain Initiative (FFI) establishes planning tools that promote stream and floodplain connectivity for water quality, flood resiliency, and habitat benefits. This edition of the User Guide summarizes FFI activities that include data collection; development of connectivity departure scoring; creation of project opportunity screening; incorporation of Vermont-based research on river, floodplain, and wetland process; assignment of phosphorus TMDL base load allocation and phosphorus project crediting; flood resiliency methods; watershed data reporting capabilities; and the FFI Web Application.

Even as this document was written, FFI continues to grow. A habitat component will be added to the FFI through two Lake Champlain Basin Program projects.

Floodplain and stream reconnection projects are becoming more common as project applications and research are illustrating the high cost-effectiveness of this type of natural resource restoration over the long term for water quality protection and improved flood resiliency. Greater interest in the natural, social, and economic value of floodplain functions and natural stream processes have created the need for a system to prioritize projects, track reconnection, and direct funds to the most beneficial projects. FFI creates a decision-support system and tracking framework in Vermont to respond to this need.

Initial FFI methods have been developed with a wide range of data sources. FFI departure scoring and project selection/prioritization are assessed down to sub-units of the river corridor for floodplain connectivity and at the geomorphic reach scale for stream connectivity. Scores can be aggregated to the (sub)watershed or basin scale.

In this guide, we define floodplain connectivity as having both lateral and vertical components. The lateral component of floodplain connectivity is characterized by the available space in the river corridor that is free of physical constraints to river movement; land protections such as river corridor easements; and natural vegetation. The vertical connection between a channel and its river corridor or floodplain is represented by the incision ratio, which is either measured during geomorphic assessment, or estimated from lidar-derived digital elevation models. Departure scores range from 0 (lowest-no connectivity) to 100 (maximum-full connectivity) for ease of interpretation.

Stream connectivity is defined to have both longitudinal and temporal components. Longitudinal connectivity is important for the downstream movement of water, sediment, large wood, coarse particulate organic matter, nutrients, and ice; and for the upstream and downstream movement of fish, aquatic organisms, and wildlife. The existing longitudinal connectivity score is reduced from a maximum of 100 due to the presence of instream structures and channel incision. Temporal connectivity affects the timing, frequency, magnitude, and duration of flows that activate floodplains and drive stream processes to support a variety of ecosystem functions and services such as sediment transport and instream habitat maintenance. The existing temporal connectivity score is made up of deductions from a maximum score of 100 for four components – instream structures, channel incision, developed/impervious lands, and agricultural lands.

To better integrate river process and function into assessments of floodplain and stream connectivity, the FFI incorporates new research from the University of Vermont funded by partner agencies. River reaches

in the Lake Champlain Basin have been classified by their degree of lateral or vertical disconnection to floodplains; these classifications indicate variable capacity to attenuate floodwaters and to erode, transport, and store coarse and fine sediment (and associated nutrients). A comprehensive mapping of floodplains for the Basin has been developed to define inundation extents, inform estimates of fine sediment and nutrient storage, and quantify infrastructure at risk of flooding. Floodplain and wetland sites distributed around the Basin have been monitored to build a region-specific empirical data set of sediment and nutrient deposition, and to better understand the site- and watershed-scale factors that influence deposition. Research on wetland processes has better characterized the relative source/sink role of riparian wetlands and factors that influence net retention of nutrients over varying time scales.

A tiered set of filters has been created to develop an initial list of project opportunities to begin an alternatives analysis to reconnect floodplains and stream channels. The method selects a general approach (e.g., restore lateral-vertical connectivity, remove constraints, improve protections, and revegetate the buffer), project type, and prioritization based on the departure score and the geomorphic setting of the stream reach.

Note that the potential reconnection projects identified in FFI have been found to be beneficial to restoring and protecting river-floodplain connectivity. The screening and listing of potential projects does not imply that the project is ready for design and implementation. Potential projects listed here have not been reviewed in the context of exact land boundaries, vetted with landowners, or evaluated in the field in detail. To develop a project, the information provided by the FFI web application should be used with companion data sources and verified in the field.

ACKNOWLEDGEMENTS

We thank the many people who have contributed to the FFI. The Project Advisory Committee (PAC) participated in regular meetings and provided important guidance on method development. The project was led by Staci Pomeroy and Gretchen Alexander of the Vermont Department of Environmental Conservation (DEC) Rivers Program.

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The project stakeholders participated in quarterly meetings and provided important guidance on the desired uses and capabilities of the FFI.

Many members of the consulting firms and the University of Vermont contributed to this project other than those listed as authors. We would like to acknowledge the members of the extended project team that made contributions to developing the FFI.

FFI has led to countless collaborations and leveraged additional funding for floodplain research. We would like to thank the Lake Champlain Basin Program, Lake Champlain Sea Grant, Vermont Water Resources and Lake Studies Center, GUND Institute of the Environment, and The Nature Conservancy of Vermont for their continuing support of river and floodplain projects in Vermont.

Finally, we would like to thank the State of Vermont, and in particular the Department of Environmental Conservation for investing in a water quality, resiliency, and habitat strategy that will naturalize Vermont's rivers and floodplains over the long term. FFI will guide us towards healthier water resources, safer river corridors, and improved habitat while also meeting our water quality obligations.

The recommended citation for the FFI User Guide follows.

Schiff, R., E. Fitzgerald, M. Kline, K. Underwood, E. Boardman, J. Stryker, B. Patterson, R. Diehl, E. Roy, J. C. Louisos, B. Wemple, D. Rizzo, G. Alexander, and S. Pomeroy, 2023. The Vermont Functioning Floodplain Initiative (FFI) User Guide (Version 2.1). Prepared by SLR Consulting, Fitzgerald Environmental, Fluvial Matters, Stone Environmental, South Mountain Research & Consulting, and the University of Vermont in collaboration with the Vermont Department of Environmental Conservation and Others, Montpelier, VT.

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David Mears	Audobon
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Holden Sparacino	VAACD
Corrie Miller	Friends of the Mad River
Kate Kelley	Lewis Creek Association
Mary Russ	White River Partnership
Ryan Patch	VT Agency of Agriculture
Lindsay Wight	Missisquoi River Basin Association
Jim Eikenberry	NRCS

1. INTRODUCTION

1.1 BACKGROUND

Connected rivers and floodplains perform many important functions such as storing flood waters to reduce downstream flood levels, improving water quality through sediment and nutrient uptake, and reducing stream power to maintain geomorphically stable, least-erosive channels, including natural in-stream and riparian habitats (Loos and Shader, 2016). Statewide stream geomorphic assessments (Kline et al., 2009) and the first major Vermont floodplain restorations that took place in the early 2000s (Schiff et al., 2008b), led to the development of river corridor plans (Kline, 2010) for restoring and protecting rivers within the broader context of floodplain and stream connectivity. Flood recovery work in particular increased Vermont's interest in floodplain functions and the resulting economic benefits (Watson et al., 2016); and thus floodplain restoration, stream restoration, and conservation projects have increased across the state.

Stream geomorphic instability and loss of floodplain storage are caused by human alterations of watershed hydrology and stream processes that may be assessed as departures in vertical, lateral, longitudinal, and temporal hydrologic connectivity (Ward, 1989) (Figure 1-1). Breaks in connectivity create an imbalance between the otherwise beneficial processes of erosion and deposition in stream networks (i.e., stream disequilibrium) and a loss of inundation-related processes in natural wetland and floodplain features (Harvey and Gooseff, 2015). The FFI builds on Vermont river corridor planning with new Vermont-based research and a set of web-based planning tools that promote stream and floodplain connectivity for the restoration and protection of natural stream processes.

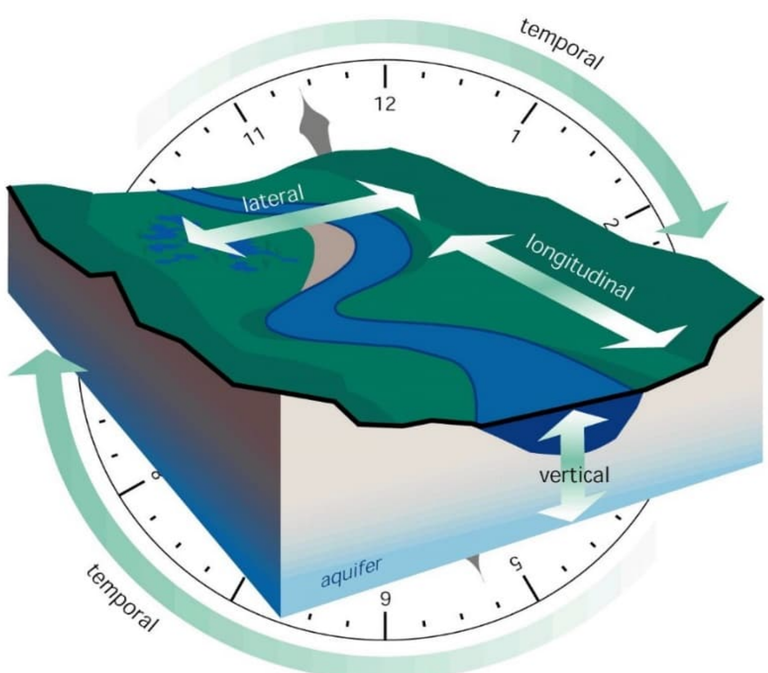


Figure 1-1 Stream and Floodplain Connectivity (FISRWG, 1998)

Greater interest in securing the natural, social, and economic value of stream and floodplain functions has created the need for a system to prioritize projects, track reconnection, and direct funds to the most beneficial projects. The implementation of the Total Maximum Daily Load (TMDL) for Phosphorus for Lake Champlain (USEPA, 2016b), further illustrated the need for tracking the water quality functions and benefits of natural stream processes and floodplains. The novel Lake Champlain TMDL is predicated on allowing channel evolution to take place that leads to the most stable, connected, equilibrium forms in river corridors consistent with Vermont river management (Kline et al., 2006; Kline, 2010, 2011) and the Vermont Stream Alteration Rules (2013).

> *The erosion control "practice" in this TMDL context is not actually a BMP in the conventional sense. Given that channel erosion control projects (such as bank stabilization) in one part of a stream system can have destabilizing effects on other parts of the system, the goal in this case was to estimate the phosphorus reduction associated with bringing an entire stream reach (and watershed subbasin) to a more stable geomorphic condition. (Tetra Tech, 2015a, b).*

1.2 OBJECTIVES

The objectives of the Vermont Functioning Floodplain Initiative are to:

- Create a framework to identify the rivers/streams and the percentage of their river corridors/floodplains that are disconnected in a watershed due to existing constraints or stressors;
- Determine the opportunity to restore stream and floodplain connectivity and establish a crediting and tracking method at a reach and watershed scale to support strategic restoration and protection planning; and
- Develop a decision-support system to identify reconnection projects.

1.3 OVERVIEW OF FFI

The Functioning Floodplain Initiative (FFI) creates a web application for planning and tracking the restoration and protection of streams and floodplains (Figure 1-2). FFI users can evaluate projects based on the degree that they restore and preserve the hydrologic connectivity that maintains water quality, flood resiliency, and natural habitats. FFI tools utilize social and economic feasibility factors to further prioritize projects, and a debit-credit system to assess the connectivity gains achieved with project implementation in and along larger streams and their headwaters.

FFI terminology is defined in the glossary (Appendix A).

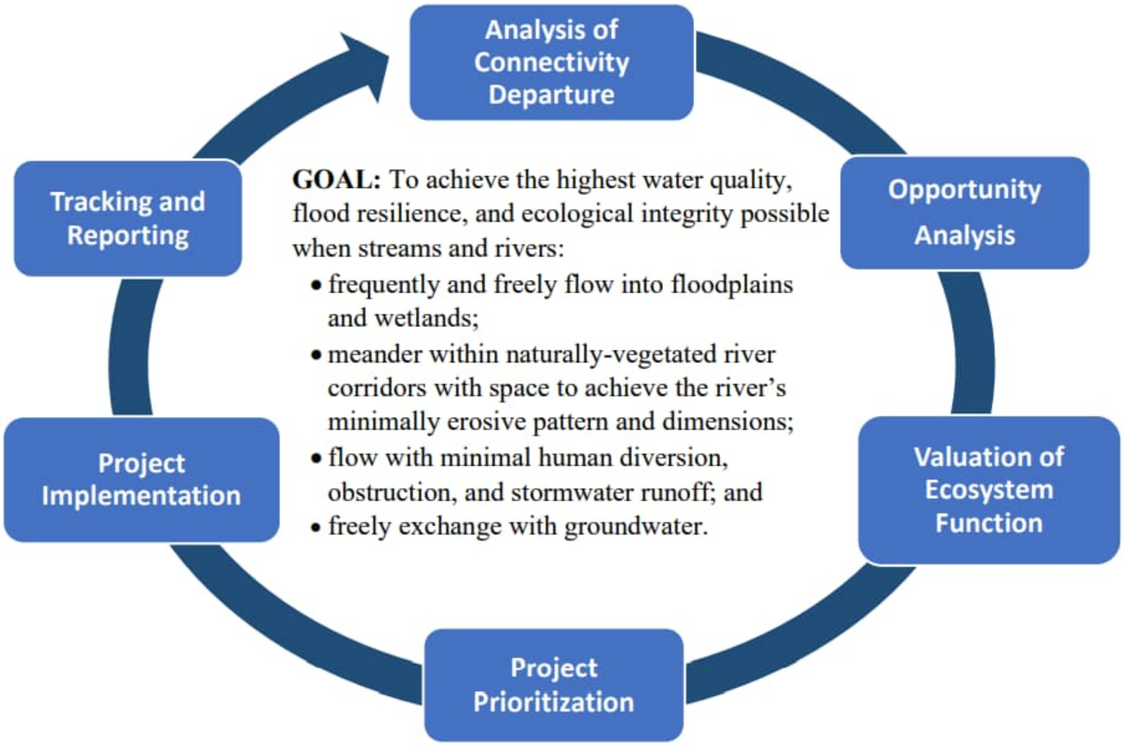


Figure 1-2 FFI Overview

Restoration and conservation projects will be screened by DEC scientists and planners for eligibility for state funding and eventual inclusion in the DEC Watershed Project Database (WPD). DEC, Clean Water Service Providers, and other stakeholders will be able to develop, track, and credit water quality improvements projects at the corridor subunit, (sub)watershed, and basin scales.

FFI evaluates floodplain (lateral-vertical) and stream (longitudinal-temporal) connectivity. Fluvial form (i.e., channel and floodplain shape and dimensions) and processes (i.e., erosion, deposition, and storage) are characterized to identify losses in floodplain functions and identify restoration and protection projects that generate functional lift to create and maintain human and intrinsic natural values (Figure 1-3).

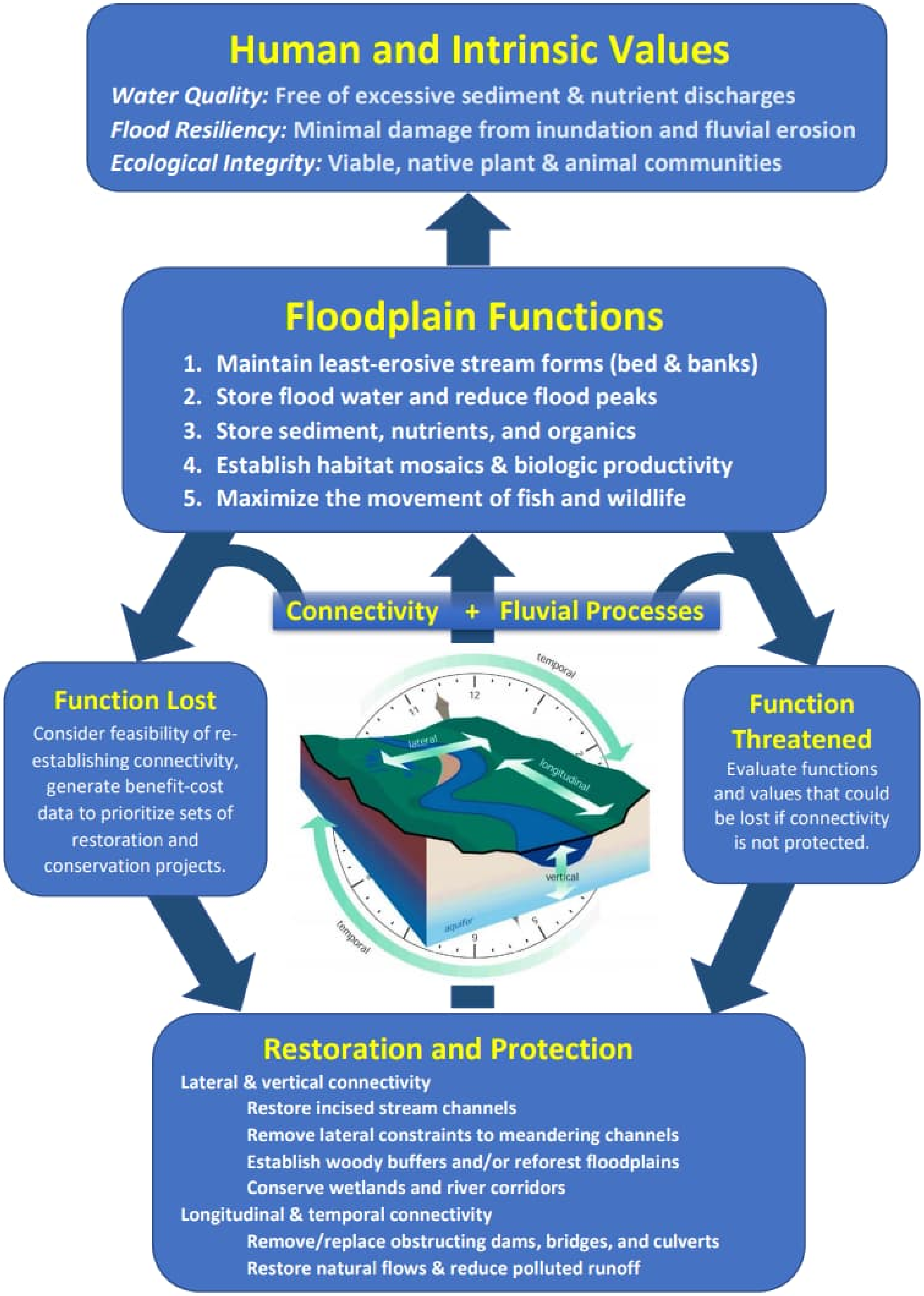


Figure 1-3 Achieving Functional Lift

1.4 FFI USES AND AUDIENCE

FFI planning tools give users the opportunity to select a (sub)watershed or specific river corridor subunit they might be interested in for project implementation. Users may also screen for projects by (sub)watershed, function, project type, and priority to create lists of feasible and cost-effective protection and restoration projects. For example, a Clean Water Service Provider may use the FFI planning tools to create a table of the most feasible projects in a subwatershed that may cumulatively provide an annual phosphorus load reduction that local watershed stakeholders have the capacity to implement.

Streams, river corridors, and floodplains are attributed with information about the functions and values that may be accrued with the set of identified projects for restoring connectivity and stream processes. Periodic maintenance and updating of these data by DEC as projects are completed will provide practitioners, program managers, and policymakers the opportunity to track projects and generate reports on the progress of restoration and protection efforts in their watersheds.

FFI planning tables are prepared to: a) Predict the floodplain area or stream miles that may be feasible to reconnect in a watershed; b) Estimate quantities of phosphorus that reconnected streams and floodplains may deposit and store; c) Approximate savings by reconnecting floodplains and streams to achieve natural storage of phosphorus compared to treating runoff at smaller scales via stormwater best management practices. Estimates of flood resiliency and ecosystem co-benefits may also be assessed.

The location and status of restoration and conservation projects, as tracked in the DEC WPD, is viewable within the FFI data and mapping tools. This functionality helps FFI users focus on the appropriate next phase of projects as they develop workplans.

DEC scientists and basin planners will review priority projects identified by the FFI for eligibility and inclusion in the WPD. DEC will periodically (e.g., on 5-year intervals) update connectivity and watershed process data in the FFI and report out the revised stream stability, floodplain function, and benefits across scales ranging from corridor subunits to the Lake Champlain Basin. The integration of FFI data into the State's Tactical Basin Planning process will bring the benefits of reconnecting Vermont rivers and floodplains to a wide audience – reassured that the FFI will be maintained as a reliable tool for watershed planning and public outreach.

The FFI web tool will likely be used several times to predict and update potential water quality improvement and co-benefit calculations as a project advances via the following steps.

- Initial project identification through planning table or site review
- Alternatives analysis and project type selection
- Concept and preliminary design
- Final design
- Post-construction documentation
- Monitoring

FFI information may be used in conjunction with Vermont river corridor planning data (Appendix B), a design-level feasibility analysis, and landowner agreements to develop and implement projects.

2. PROJECT PLANNING AND TRACKING IN THE FFI WEB APP

The FFI information and data are housed in a publicly accessible web application by VTDEC (https://ffi.stone-env.net/home) that allows users to view floodplain connectivity data, prioritize floodplain, stream, and wetland restoration projects, and track progress towards reconnecting Vermont's rivers and floodplains. This section provides information on how to navigate, extract information, and perform calculations in the application. Refer to the FFI training videos for detailed information on the FFI website navigation (https://youtu.be/m-xaJUCER6s?t=5691) and example calculations of water quality credits (https://youtu.be/m-xaJUCER6s?t=10989).

The FFI web application will ultimately serve as the interface for the State of Vermont and extended watershed community to support: (i) Water quality improvements achieved through connection projects that promote sediment storage and nutrient attenuation; (ii) Flood resilience projects to reduce risks due to flooding and erosion; and (iii) Habitat enhancement projects accomplished by restored connectivity and physical complexity.

The FFI web application was developed for a range of users such as DEC river scientists, watershed group program managers, DEC wetland ecologists, state hazard mitigation planners, Clean Water Initiative program managers, clean water service providers, regional planning commission staff, conservation organizations, and federal agency partners. A user story exercise was conducted to collect information from future FFI users about how they would want to use the web application (Appendix C). The outcomes of that exercise contributed to the development of functionality in the application.

2.1 MAP AND DATA BROWSING

The 'Explore Data' page of the FFI Web Application is designed for map browsing and data exploration. This is the location to navigate a map and browse connectivity scores (Figure 2-1). Darker colors (on both river corridor subunit polygons and stream segment lines) indicate lower connectivity – find darker areas and you will have located disconnected streams and floodplains. Data pop-ups have been developed to provide connectivity data details (Figure 2-2) and project prioritization information (Figure 2-3).

FFI brings together a broad data set and this information can be turned on and off in the layers panel (Figure 2-4). The two options for base maps – topography or imagery – can be toggled at the top right of the map.

Figure 2-1 Explore Data Page of the FFI Web Application with the Connectivity Scores

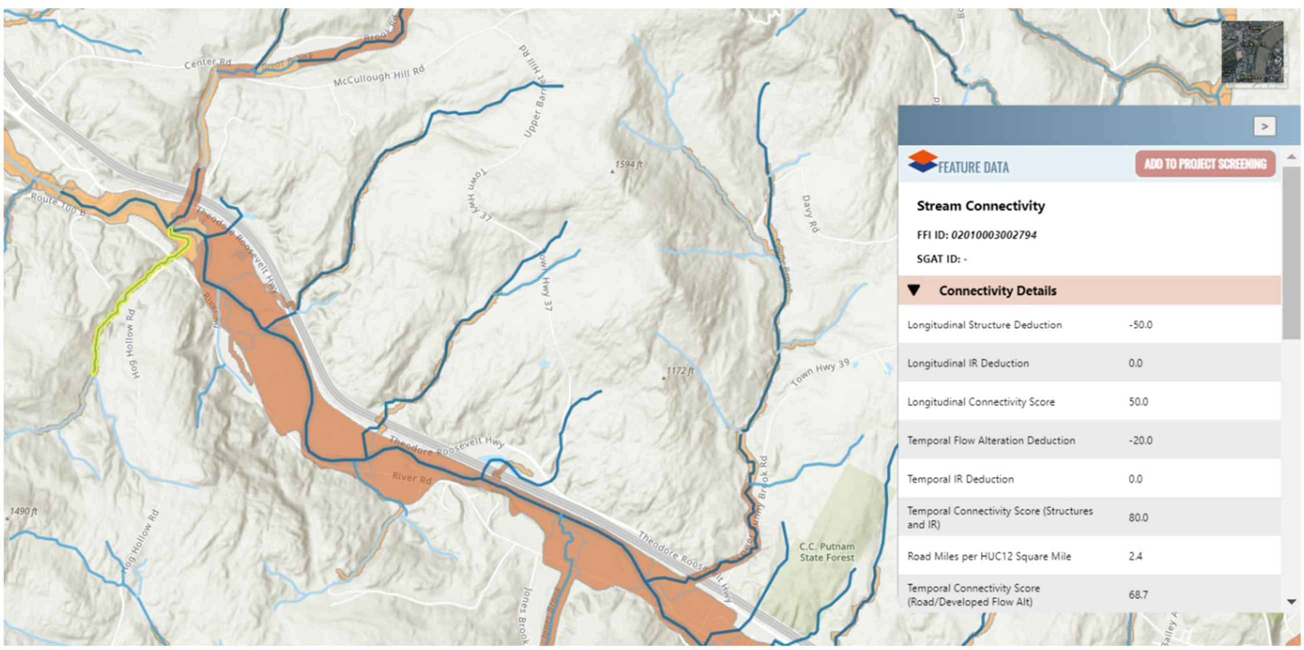


Figure 2-2 Data Pop-Up on Stream Connectivity Layer Showing Connectivity Data Details

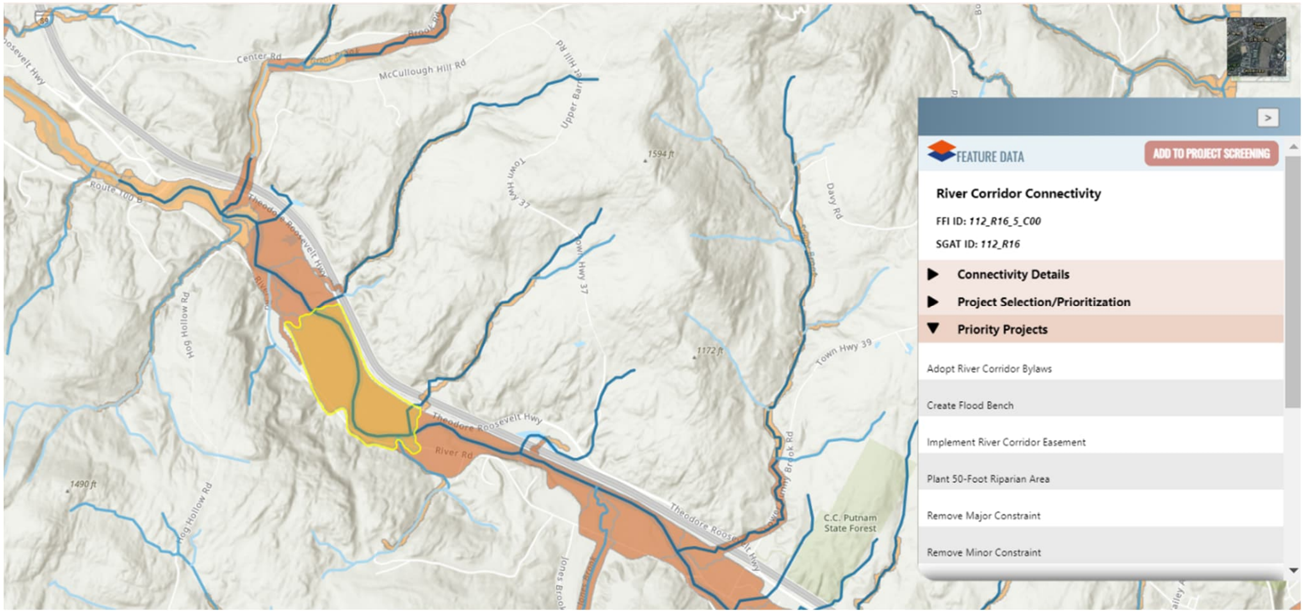


Figure 2-3 Data Pop-Up on River Corridor Connectivity Layer Showing Priority Projects

Figure 2-4 Explore Data Page with Imagery Base Map and Select Background Data

2.2 PROJECT PLANNING

The FFI web application supports planning of restoration and conservation projects by allowing users to identify projects (either by criteria such as practice type or by a known location); providing screening level information on connectivity scores and potential projects; and allowing users to estimate water quality, flood resilience, and habitat benefits based on user inputs and reach/project-specific information.

2.2.1 PROJECT IDENTIFICATION

Two primary workflows exist in FFI to identify a project: (i) Identifying and exploring practices for a specific location; and (ii) Identifying practices based on specified criteria (Figure 2-5). The search criteria include location and geographic scale, river and floodplain functions, project type, and priority level (Figure 2-6). Either workflow leads to the user populating a Project Screening Table with feature and project data.

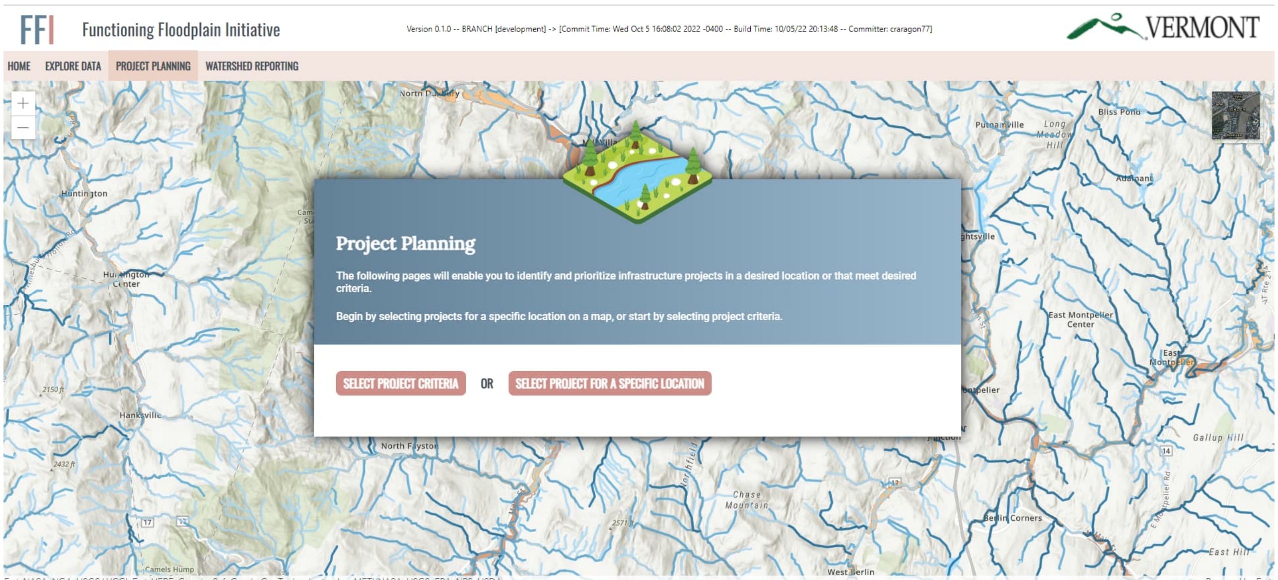


Figure 2-5 Project Planning Landing Page in the FFI Web Application

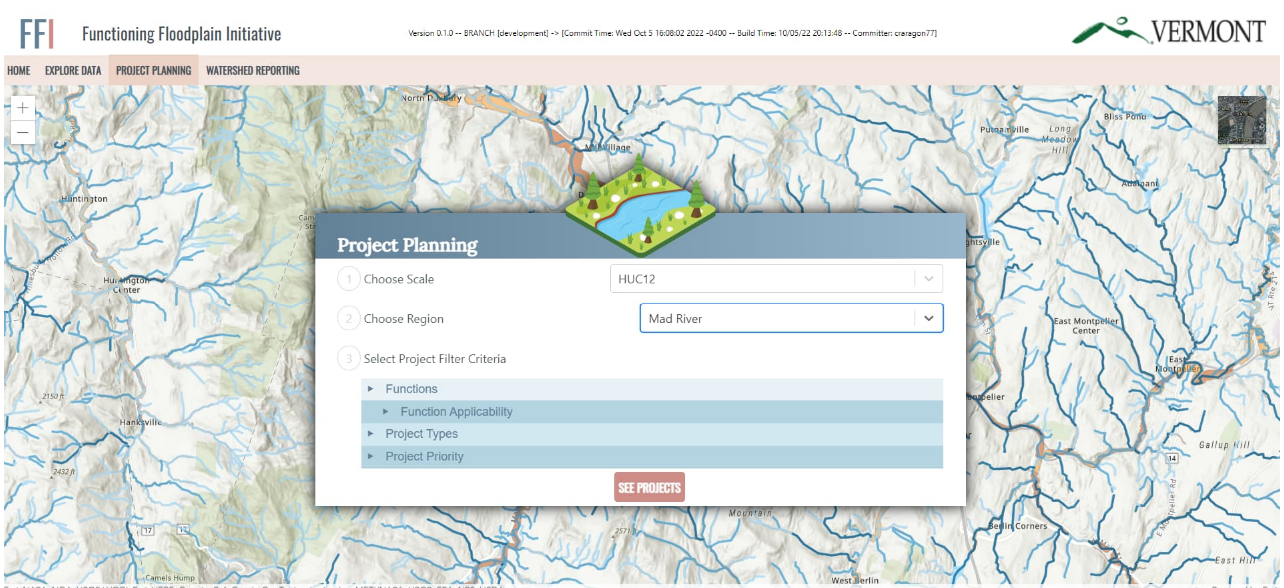


Figure 2-6 Project Planning Filtering Criteria Menu

2.2.1.1 Identifying Potential Projects by Search Criteria

The first step to obtain a list of projects is to select the spatial scale, location, and filtering criteria. Possible functions that can be achieved through floodplain and stream reconnection are:

- Nutrient Load Reduction from Unstable Streams (Water Quality)
- Nutrient Load Reduction with Increased Floodplain Storage (Water Quality)
- Reduction of Erosion-Related Damages (Flood Resiliency)
- Reduction of Inundation – Related Damages (Flood Resiliency)
- Floodplain Habitat Mosaics and Lateral Riverscape Migration (Habitat)
- Instream Cover Mosaics and Organism Passage (Habitat)

Potential reconnection projects have been identified in FFI by evaluating the existing connection level and geomorphic site conditions. The methodology then assigns a high, medium, or low ranking for each of the functions. For example, an incised reach with a berm where no property or infrastructure exists in the floodplain would rank high for the opportunity to secure water quality, flood resiliency, and habitat benefits. Berm removal and floodplain lowering projects to improve connectivity would also rank high.

Users can select a function and an applicability rank to further refine a search. For example, if a user selects 'Reduction of Erosion-Related Damages' and 'High' applicability, only projects in their search area that have a high applicability to reducing erosion-related damages would be identified. If the user does not select a function or function applicability rank, the default is that all functions and all rankings are returned in the initial project planning table.

Users can also select from a list of project types that are grouped by Floodplain (Lateral-Vertical) Connectivity that occurs at the river corridor subunit scale and Stream (Longitudinal-Temporal) Connectivity that occurs at the stream segment scale. Users can also select the project priority such as locations where floodplain lowering would have a high likelihood of achieving significant gains in connectivity and functional lift based on FFI data.

User selections of function, project type, and project priority filter dynamically such that if a user selects an area, the function "Nutrient Load Reduction from Unstable Stream," and a Function Applicability of "High", only those project types that exist in the area and meet all the criteria will be selected on the initial project screening table.

After making filtering selections, a user presses the 'See Projects' button and a list of the river corridor subunits and stream reaches with projects that match the criteria is generated and shown in the Project Screening table (See Section 2.2.2). After data are loaded into the Project Screening table, a side panel is available so the user can see and edit the selected criteria to update the Project Screening table (Figure 2-7).

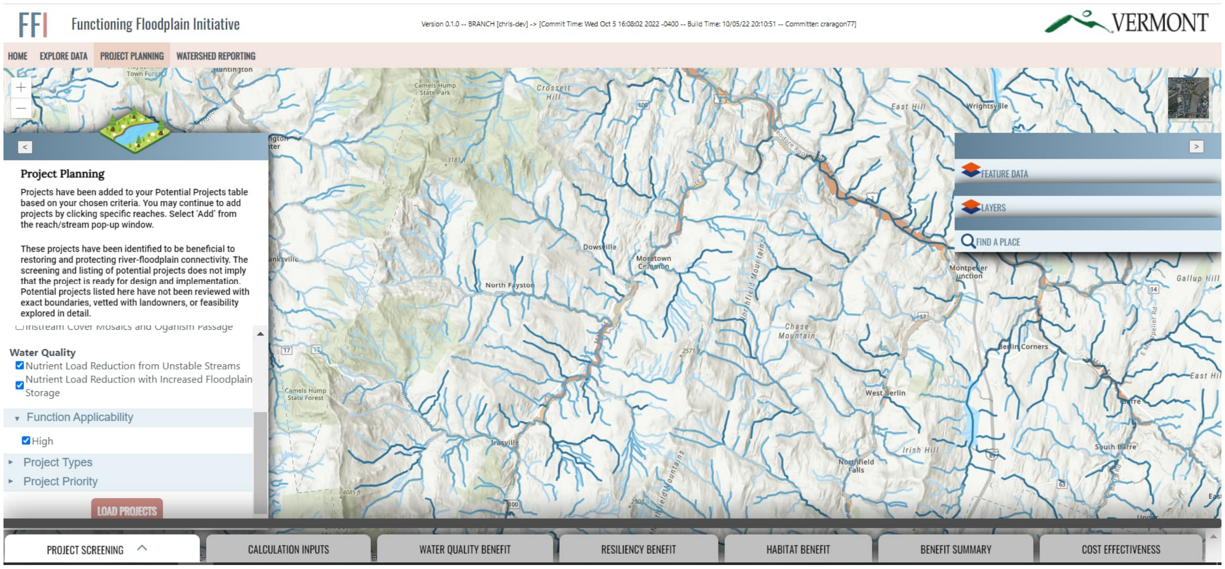


Figure 2-7 Side Panel for Project Planning for Modifying Criteria Searches once the Project Screening Table has been Initially Populated

2.2.1.2 Identifying Potential Projects by Location

'Select Project For A Specific Location' is available on the project planning landing page (See Figure 2-5). Selecting this option moves the user into the Explore Data module of the application where you can navigate to a known location to find subunits or stream reaches of interest. The 'Find a Place' search can be used to navigate to an address or town. Alternatively, the user can enter a full or partial FFI ID that is built on the Vermont Stream Geomorphic data network IDs for a river corridor or stream segment and be directed on the map to its location (Figure 2-8). A user can also manually navigate to a desired area and explore connectivity levels and supporting data.

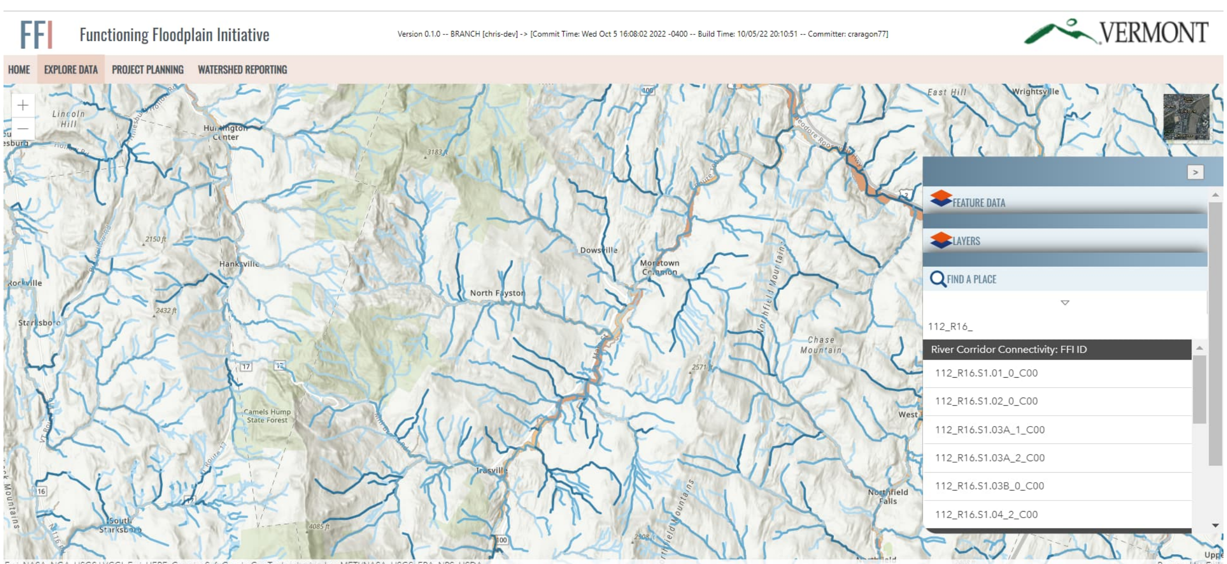


Figure 2-8 Search by FFI ID Option to Locate a River Corridor Sub-Unit

When a user clicks on a river corridor subunit or stream segment on the map, the feature is selected and the associated data are available in the 'Feature Data' section of the right side panel. Adjacent to the 'Feature Data' heading, an option is available to add that feature to the Project Screening (Figure 2-9). Thus, users can manually populate the Project Screening table from the map by adding one or more sub-units or stream segments.

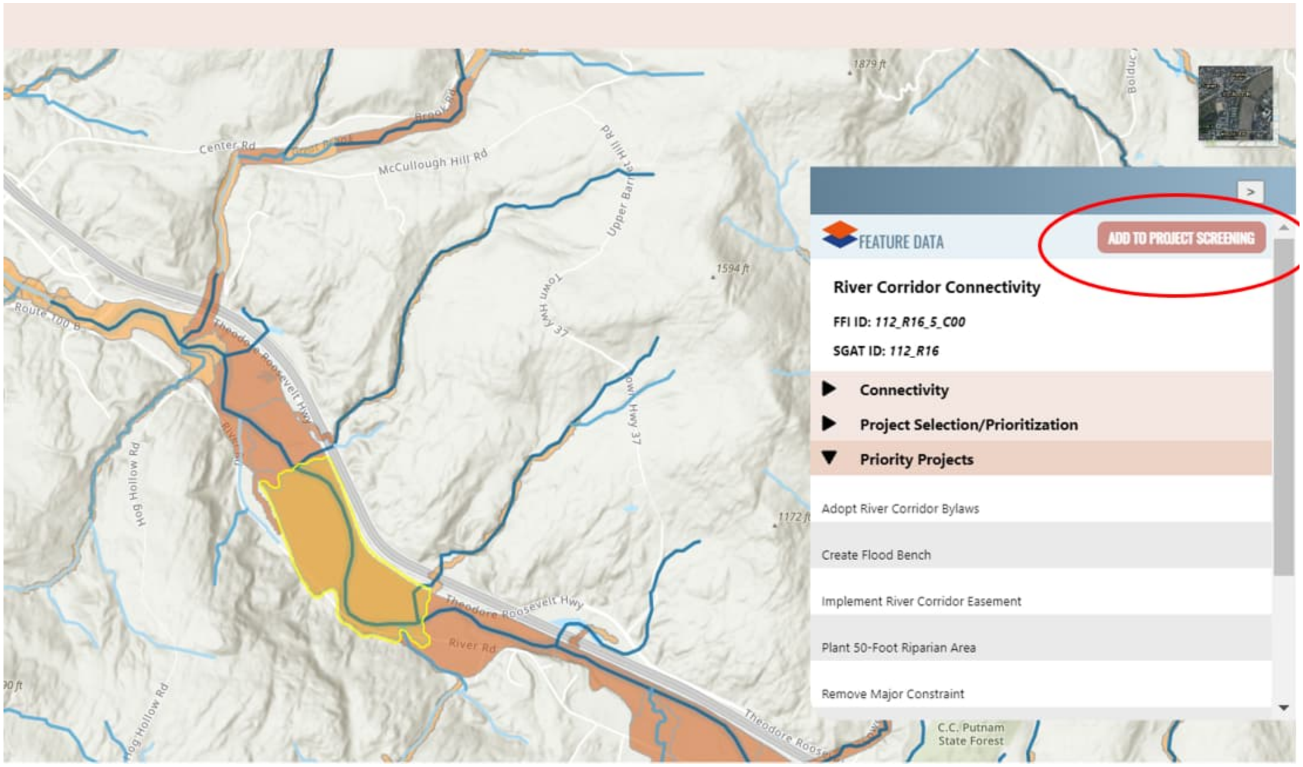


Figure 2-9 Manual Population of Project Screening Table from Feature Data Pop-Ups

2.2.2 THE PROJECT SCREENING TABLE

The Project Screening table is the location to view screening level information about identified river corridor subunits and stream segments. The table is structured so the river corridor subunits are the base feature that appear first (Figure 2-10). Several levels of drop-down menus are nested within the river corridor heading. The first drop-down menu provides a list of either all prioritized projects associated with that river corridor or a reduced list associated with the selected list of search criteria (Figure 2-11).

The drop-down menu also shows the stream segment associated with the river corridor. The stream segment can then also be further opened to show stream projects – again either all prioritized projects associated with that stream segment or a reduced list associated with the search criteria (See Figure 2-11).

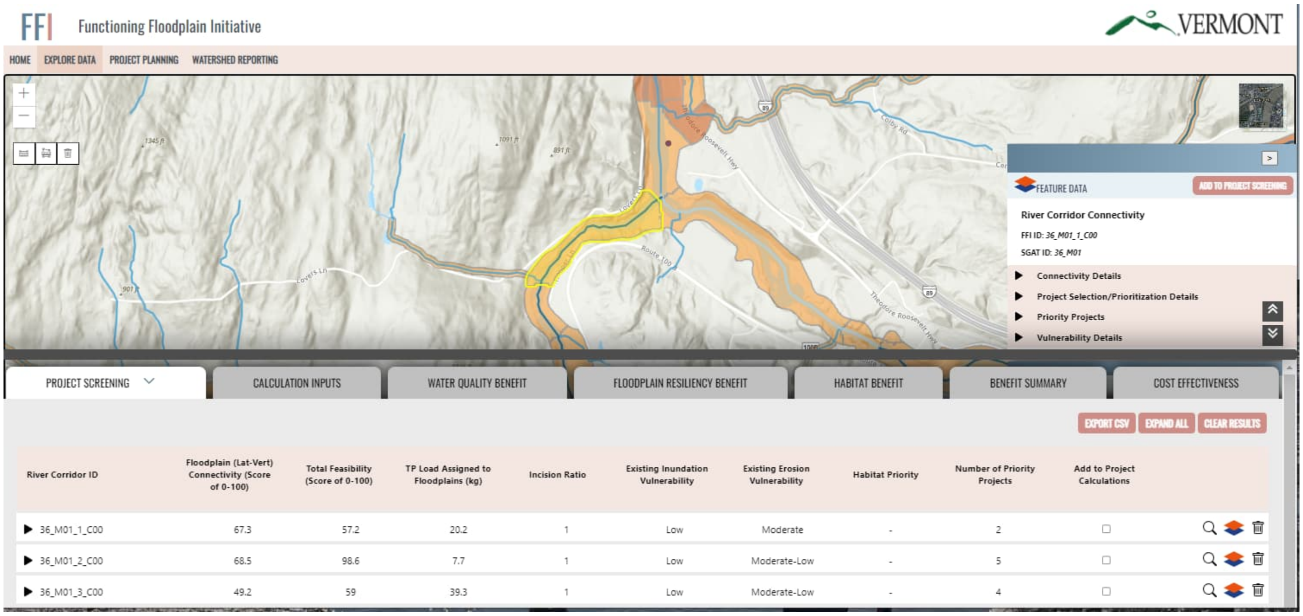


Figure 2-10 Project Screening Table with Three River Corridor Sub-Units and Associated Screening Information

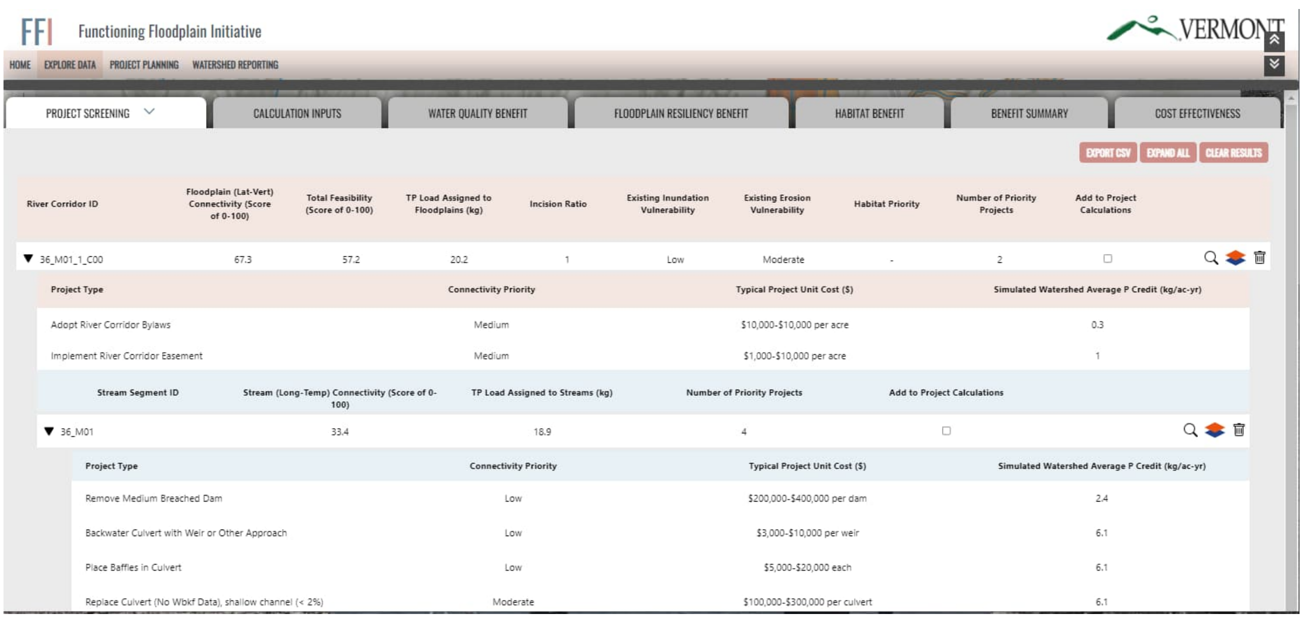


Figure 2-11 Project Screening Table Drop-down Menus Showing Potential River Corridor and Stream Segments Projects

The icons on the right of the Project Screening table provide a way to interact with the table and map. The trash icon allows users to delete a feature from the table. The magnifying glass will highlight and zoom to the selected feature on the map. The layers icon will open the Feature Data pop-up. After initially populating the Project Screening table, additional corridors and stream segments can be manually added from the map.

2.3 PROJECT CALCULATIONS

A user can evaluate the anticipated benefits of a reconnection project for water quality, flood resiliency, and habitat for one or more projects on a river corridor and a stream segment by checking the 'Add to Project Calculations' box on the right end of screening data (Figure 2-12). The user can add many river corridor subunits and one stream segment to the table. When a user selects one or more subunits, the 'Calculation Inputs' tab becomes highlighted in yellow to indicate data entry is required.

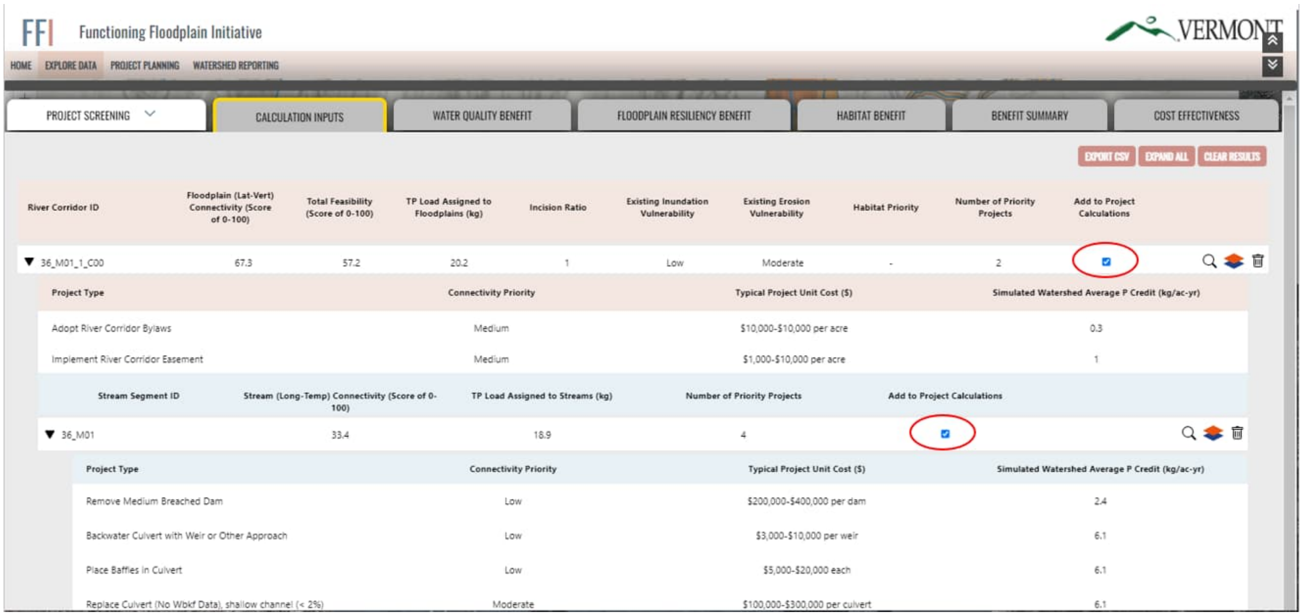


Figure 2-12 Selection of Potential Projects to be Brought into the Calculation Inputs Module

2.3.1 CALCULATION INPUTS

The 'Calculation Inputs' tab accepts data inputs about potential projects to predict the benefits of Flood-plain Connectivity (Lateral / Vertical) and Stream Connectivity (Longitudinal / Temporal). The Floodplain Connectivity data are further broken down into 'Stream Stability' (Figure 2-13) and 'Storage' components (Figure 2-14). The Stream Connectivity section provides existing data on the added stream segment and unique data input cells (Figure 2-15).

Note that two incision ratio inputs exist on the table. The 'Existing Incision Ratio' column shows the inci-sion ratio determined to represent the entire corridor subunit based on field data or a computer-gener-ated estimate. The user has the option to modify the existing incision ratio should the local value differ from the reach-based value, such as along a short berm. The proposed incision ratio is the anticipated incision ratio that will be achieved by a reconnection project.

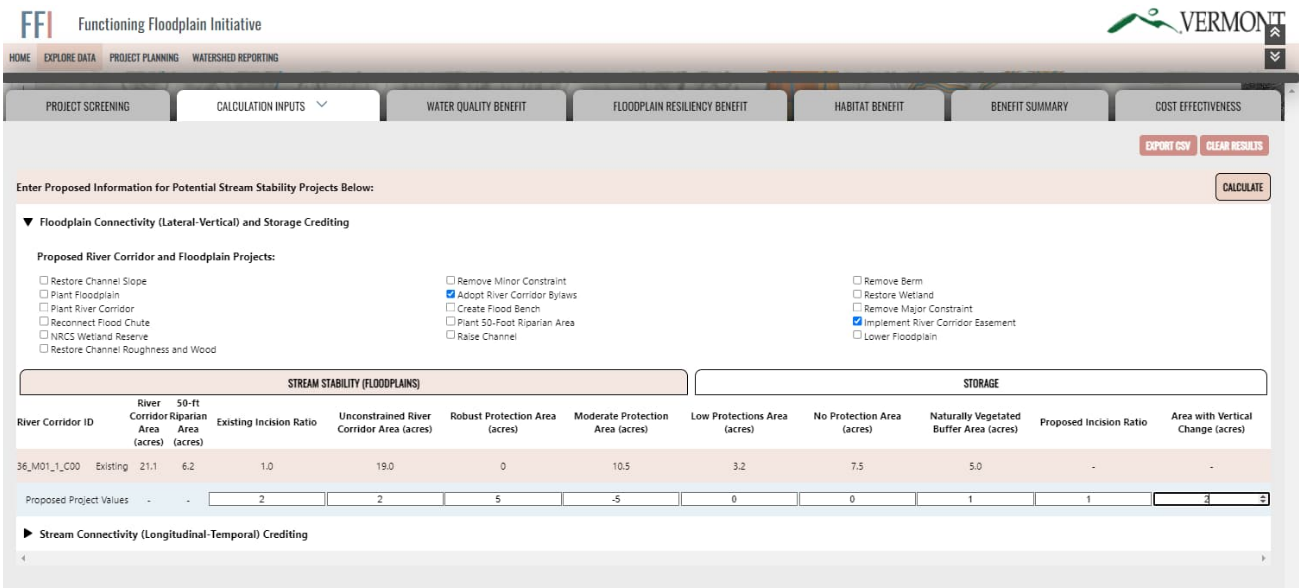


Figure 2-13 Stream Stability (Floodplain) Input Data on the 'Calculation Inputs' Page

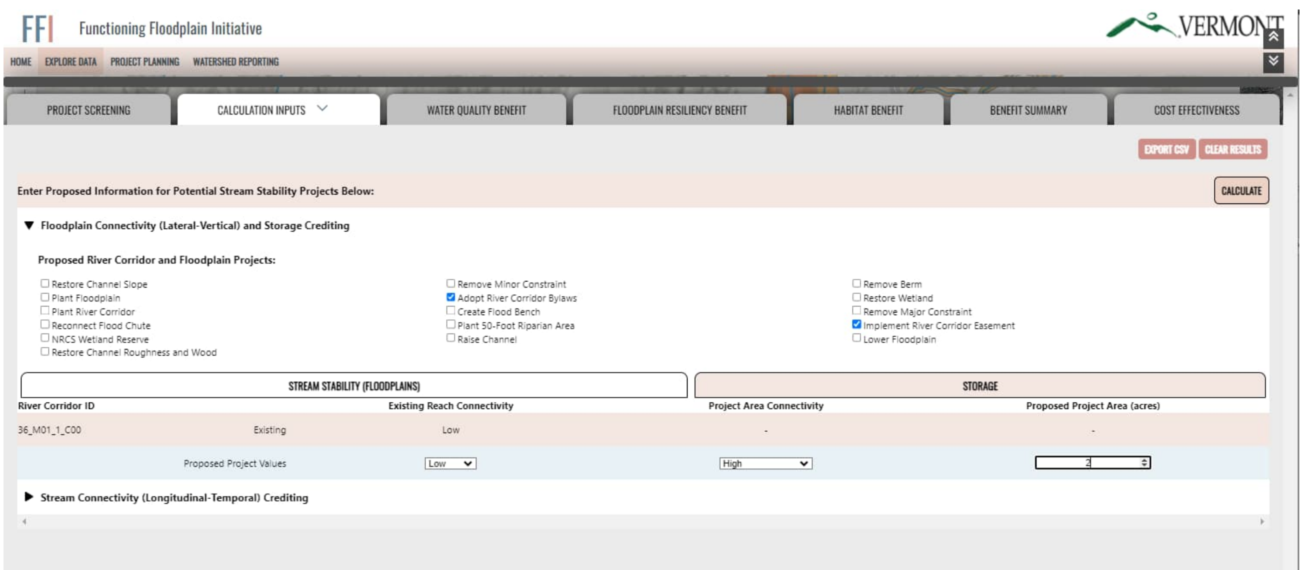


Figure 2-14 Storage Input Data on the 'Calculation Inputs' Page

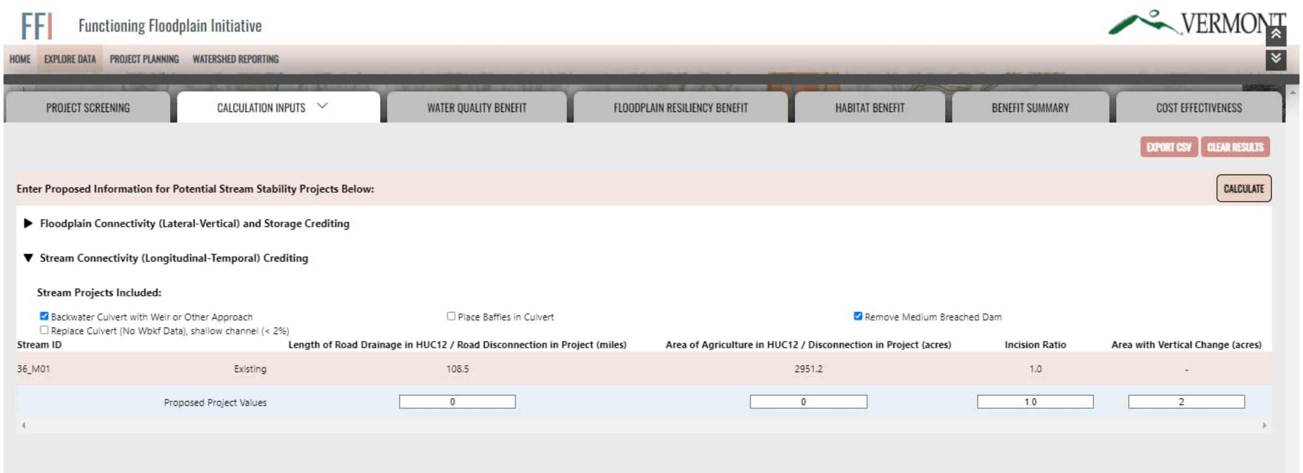


Figure 2-15 Stream Connectivity Data on the 'Calculation Inputs' Page

Potential reconnection projects are located at the top of the data input sections for both corridor and stream reconnection projects. Either all possible projects are checked, or a subset of projects are checked based on search criteria. Projects can be unchecked from the list if the user is not interested in implementing that type of project. Additional projects can be added to the river corridor list since floodplain water quality crediting is solely based on project area (i.e., the acres of reconnected river corridor or floodplain) and not project type. Only stream projects that have been identified for the single stream segment are available for selection since crediting for stream connection projects is directly a function of project type (i.e., dam removal or culvert replacement).

The required input data for crediting calculations (Table 2-1) have been simplified to include information typically used in exploring project feasibility and in the early stages of design. The input data mostly consist of the areas where project elements will change (i.e., lateral connectivity, protections, woody buffer, and vertical connectivity) and incision ratio.

Table 2-1 Data Inputs for Phosphorus Crediting Calculations

FLOODPLAIN CONNECTIVITY (LATERAL-VERTICAL) AND STORAGE CREDITING - STREAM STABILITY (FLOODPLAINS)				
Variable	**Units**	**Description**	**Data Entry Controls**	**Proposed Input Data**
Existing Incision Ratio	None	The existing incision ratio at the specific project location (the provided value represents the reach-scale incision ratio).	Should be greater than or equal to 1, less than or equal to 3.	Existing local incision ratio at project site.

Unconstrained River Corridor	Acres	The proposed area of the corridor that is free to river movement and flooding without damage to property or infrastructure.	Should not exceed total 'River Corridor Area'	Unconstrained Corridor Areas (Measure additional area of corridor where constraints will be removed)
Robust Protection Area	Acres	The additional area of robust protections such as river corridor easements due to project implementation. This value is typically positive to indicate an increase in robust protection land.	Sum of robust, moderate, low, and no protection areas (existing and proposed) should not exceed total 'River Corridor Area'	Protection Level (Measure area of each category with a change in level of protection)
Moderate Protection Area	Acres	The change in area of land with moderate protections such as an Act 250 parcel due to project implementation. This value is typically positive to indicate an increase in moderate protection land.		
Low Protection Area	Acres	The change in area of land with low protections such as a FEMA special flood hazard area due to project implementation. This value is typically negative to indicate a reduction in low protection land.		
No Protection Area	Acres	The change in area of no protections due to project implementation. This value is typically negative to indicate a reduction in non- protected land.		
Naturally Vegetated Buffer Area	Acres	The proposed area of additional woody vegetation being added due to the project(s).	Should not exceed ['50-ft Riparian Area' - existing 'Naturally Vegetated Buffer Area']	50 ft Stream Buffers (Measure area within the 50-foot buffer to be vegetated)
Incision Ratio	None	The proposed incision ratio after project implementation.	Should not be less than 1, greater than 3, or more than existing 'Incision Ratio'	

Area with Vertical Change	Acres	The proposed area where incision ratio change will improve vertical connectivity.	Should not exceed 'River Corridor Area'	River Corridor Connectivity (Measure Area within Corridor with a vertical change)
Floodplain Connectivity (Lateral-Vertical) and Storage Crediting - Storage				
Variable	**Units**	**Description**	**Data Entry Controls**	
Existing Reach Connectivity	Rank	Existing lateral meander connectivity score, where the user can select a rank specific to the project area.	Low, Medium, or High	
Project Area Connectivity	Rank	The anticipated post-project connectivity. For example, if incision ratio is equal to or less than 1.2, than this value would be set to High.	Low, Medium, or High	
Proposed Project Area	Acres	Area where added storage will take place due to project implementation.	Unbounded	
Stream Connectivity (Longitudinal-Temporal) Crediting				
Variable	**Units**	**Description**	**Data Entry Controls**	
Road Disconnection in Project	Miles	The length of road in the HUC12 watershed that is proposed to be removed from the hydrologic flow path due to project implementation.	Should be less than existing length of road in the HUC12.	
Ag Disconnection in Project	Acres	The area of farm field in the HUC12 watershed that is proposed to be removed from the hydrologic flow path due to project implementation.	Should be less than area of agriculture in the HUC12.	

Incision Ratio		The anticipated incision ratio after project implementation.	Should not be less than 1, greater than 3, or more than existing 'Incision Ratio'	
Area with Vertical Change	Acres	The proposed area where incision ratio change will improve vertical connectivity.	Should not exceed 'River Corridor Area'	

In the Calculations Input page, the user is provided with a row of existing data that show existing information for the river corridor subunit and empty data input cells. The existing incision ratio can be changed should the vertical connection status at the proposed reconnection project differ from the reach-based measurement or computer-generated value. A common setting where the local incision ratio differs from the larger reach is when a small berm is present that is being removed. **The proposed input data for areas (i.e., acres) are the increases associated with the project, not the resulting total values.**

For floodplain storage the user is provided with an existing connectivity rank (i.e., High, Medium, Low) that is pre-determined from the lateral and vertical connectivity of the corridor subunit. The user can change the existing connectivity rank if knowledge of the site suggests that local connectivity is better or worse than the subunit average. A user then enters the proposed connectivity rank that will be achieved by the project, and the area where improved storage will occur.

After the project information is entered, the 'Calculate' button at the top right of the screen is pressed to execute FFI calculations to estimate project benefits. The results are returned in the Water Quality, Resiliency, and Habitat Benefits tabs and the tabs will become outlined in yellow when data are available for viewing (or requested for input). Primary results are also located in the Summary tab to view key project co-benefits in a single location.

2.3.2 CALCULATION OUTPUTS

2.3.2.1 Water Quality Benefit

The Water Quality Benefits tab contains TMDL phosphorus load reduction crediting for channel stability and improved floodplain storage (Figure 2-16). Location information, feature IDs, and a list of project types are provided at the top of the page. A summary table provides credit estimates aggregated across one or more corridor subunits and a single stream segment. A drop-down table provides a more detailed breakdown of connectivity improvements and phosphorus load reduction crediting (Figure 2-17).

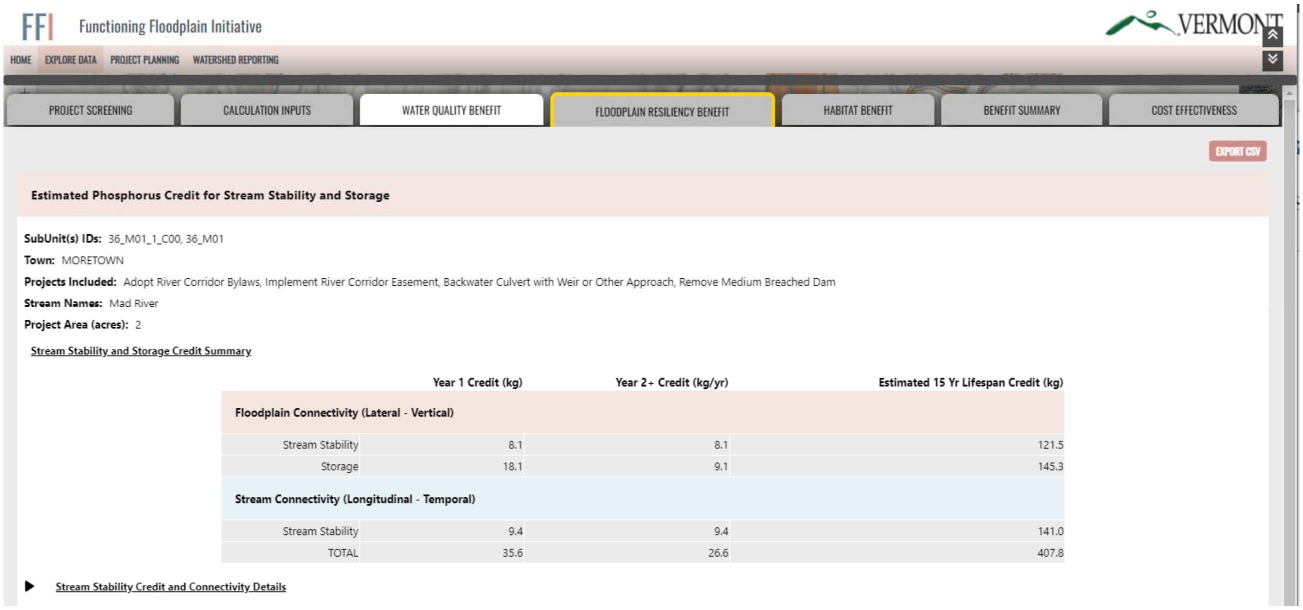


Figure 2-16 Phosphorus Credit Calculation Results for Floodplain Connection Projects

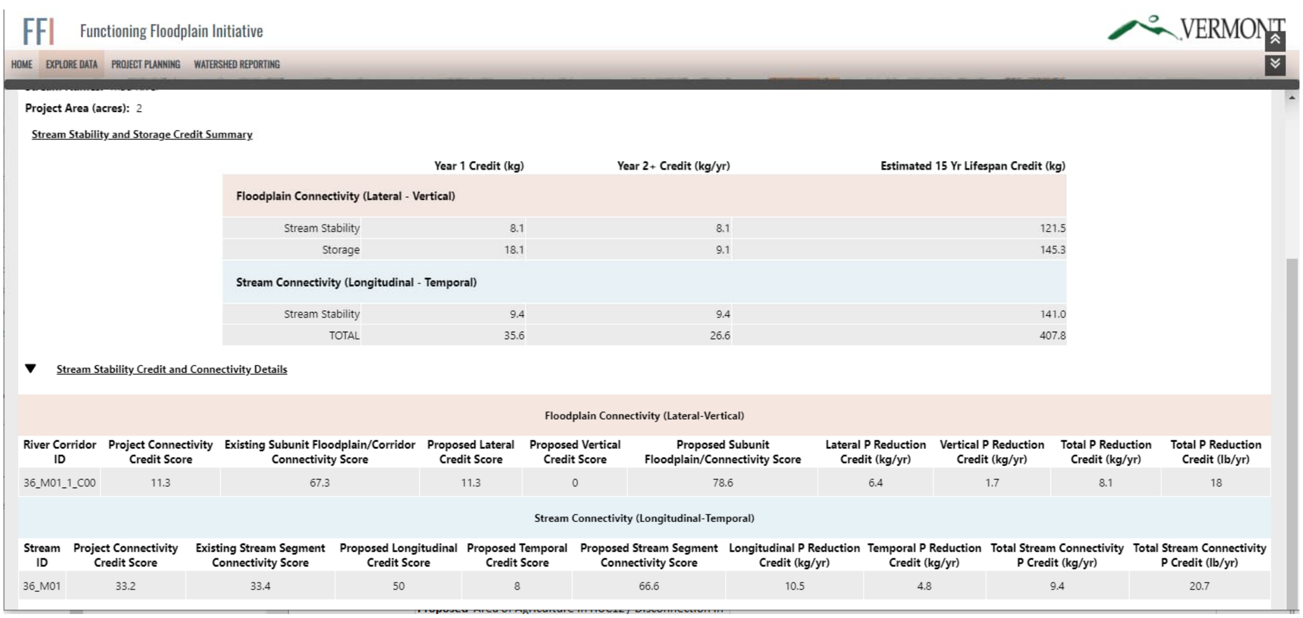
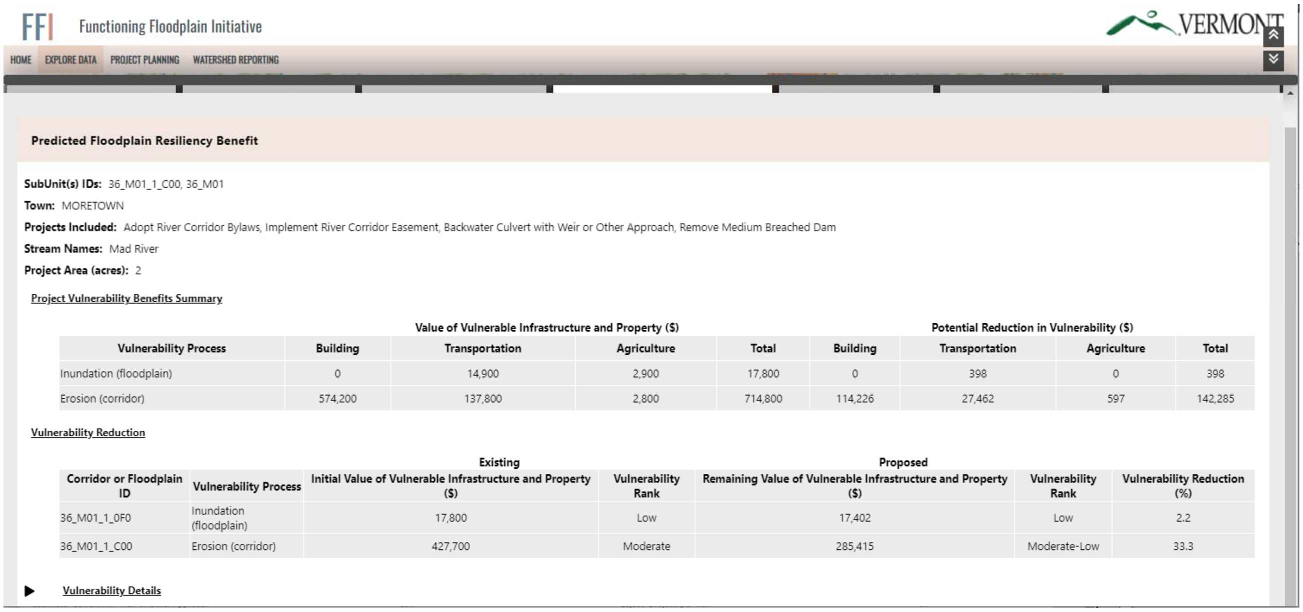


Figure 2-17 Phosphorus Credit Calculation Results for Stream Connection Projects

2.3.2.2 Resiliency Benefit

The Resiliency Benefit tab shows the estimated value of vulnerable infrastructure and property in river corridor subunits and floodplains ($USD), and the estimated reductions in vulnerability values due to a reconnection project. The 'Project Vulnerability Benefits Summary' aggregates all subunits included in the Calculation Inputs and indicates vulnerability value reductions due to inundation in floodplains and erosion reductions in river corridors (Figure 2-18). The 'Vulnerability Reduction' table provides existing and proposed values of vulnerable infrastructure and property, as well as the vulnerability rank and percent reduction.



FFI Functioning Floodplain Initiative

HOME EXPLORE DATA PROJECT PLANNING WATERSHED REPORTING

Predicted Floodplain Resiliency Benefit

SubUnit(s) IDs: 36_M01_1_C00, 36_M01
Town: MORETOWN
Projects Included: Adopt River Corridor Bylaws, Implement River Corridor Easement, Backwater Culvert with Weir or Other Approach, Remove Medium Breached Dam
Stream Names: Mad River
Project Area (acres): 2

Project Vulnerability Benefits Summary

	Value of Vulnerable Infrastructure and Property ($)				Potential Reduction in Vulnerability ($)			
Vulnerability Process	**Building**	**Transportation**	**Agriculture**	**Total**	**Building**	**Transportation**	**Agriculture**	**Total**
Inundation (floodplain)	0	14,900	2,900	17,800	0	398	0	398
Erosion (corridor)	574,200	137,800	2,800	714,800	114,226	27,462	597	142,285

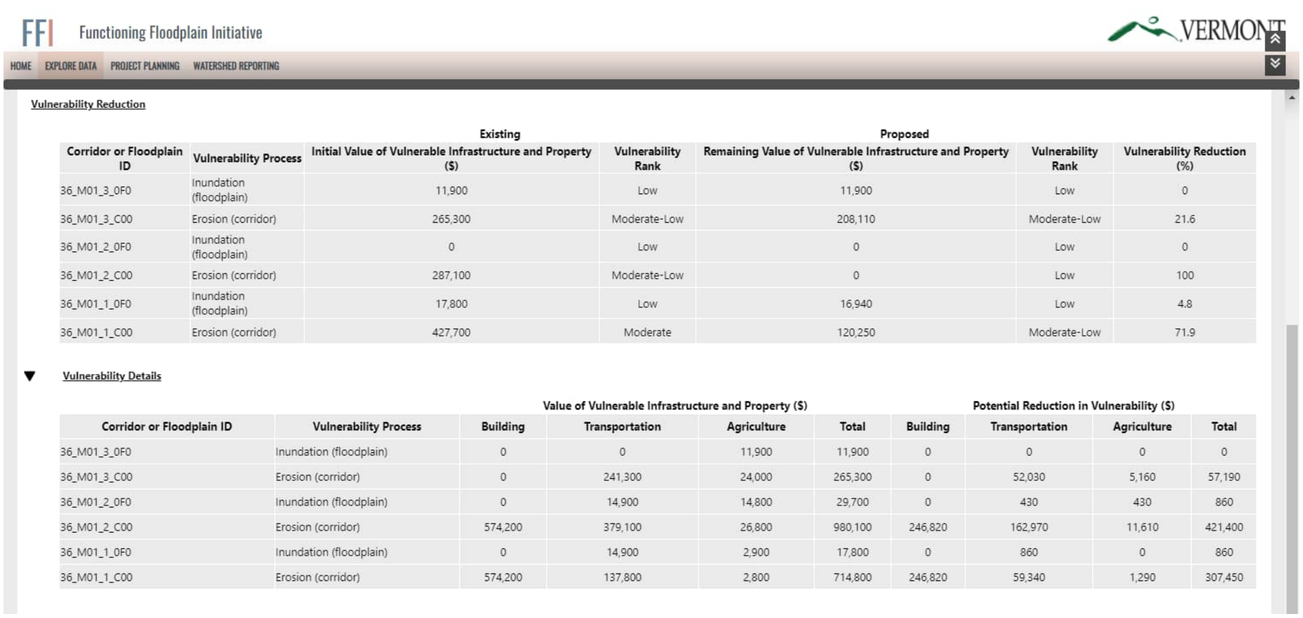
Vulnerability Reduction

		Existing		Proposed		
Corridor or Floodplain ID	**Vulnerability Process**	**Initial Value of Vulnerable Infrastructure and Property ($)**	**Vulnerability Rank**	**Remaining Value of Vulnerable Infrastructure and Property ($)**	**Vulnerability Rank**	**Vulnerability Reduction (%)**
36_M01_1_0F0	Inundation (floodplain)	17,800	Low	17,402	Low	2.2
36_M01_1_C00	Erosion (corridor)	427,700	Moderate	285,415	Moderate-Low	33.3

▶ Vulnerability Details

Figure 2-18 Value of Vulnerable Infrastructure and Property and Potential Resiliency Benefits

Clicking on the arrow near 'Vulnerability Details' provides a breakdown of the values of vulnerable infrastructure and property associated with floodplain and corridor processes for each of the corridor subunits included in the calculations (Figure 2-19).



FFI Functioning Floodplain Initiative

HOME EXPLORE DATA PROJECT PLANNING WATERSHED REPORTING

Vulnerability Reduction

		Existing		Proposed		
Corridor or Floodplain ID	**Vulnerability Process**	**Initial Value of Vulnerable Infrastructure and Property ($)**	**Vulnerability Rank**	**Remaining Value of Vulnerable Infrastructure and Property ($)**	**Vulnerability Rank**	**Vulnerability Reduction (%)**
36_M01_3_0F0	Inundation (floodplain)	11,900	Low	11,900	Low	0
36_M01_3_C00	Erosion (corridor)	265,300	Moderate-Low	208,110	Moderate-Low	21.6
36_M01_2_0F0	Inundation (floodplain)	0	Low	0	Low	0
36_M01_2_C00	Erosion (corridor)	287,100	Moderate-Low	0	Low	100
36_M01_1_0F0	Inundation (floodplain)	17,800	Low	16,940	Low	4.8
36_M01_1_C00	Erosion (corridor)	427,700	Moderate	120,250	Moderate-Low	71.9

▼ Vulnerability Details

		Value of Vulnerable Infrastructure and Property ($)				Potential Reduction in Vulnerability ($)			
Corridor or Floodplain ID	**Vulnerability Process**	**Building**	**Transportation**	**Agriculture**	**Total**	**Building**	**Transportation**	**Agriculture**	**Total**
36_M01_3_0F0	Inundation (floodplain)	0	0	11,900	11,900	0	0	0	0
36_M01_3_C00	Erosion (corridor)	0	241,300	24,000	265,300	0	52,030	5,160	57,190
36_M01_2_0F0	Inundation (floodplain)	0	14,900	14,800	29,700	0	430	430	860
36_M01_2_C00	Erosion (corridor)	574,200	379,100	26,800	980,100	246,820	162,970	11,610	421,400
36_M01_1_0F0	Inundation (floodplain)	0	14,900	2,900	17,800	0	860	0	860
36_M01_1_C00	Erosion (corridor)	574,200	137,800	2,800	714,800	246,820	59,340	1,290	307,450

Figure 2-19 Resiliency Benefit Details

2.3.2.3 Habitat Benefit

To be inserted as part of on-going FFI project.

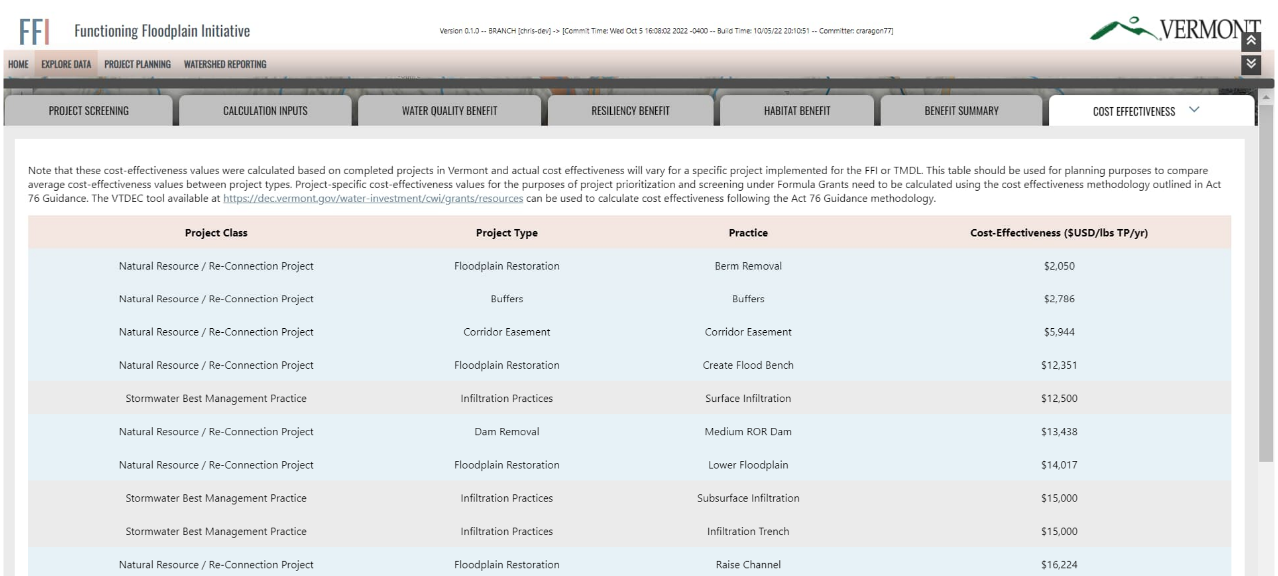
2.3.2.4 Project Benefit Summary

To be inserted as part of on-going FFI project.

2.3.3 COST EFFECTIVENESS

The development of the FFI phosphorus load reduction crediting methodology has created a novel opportunity to estimate cost effectiveness of natural resource projects. The benefits of pursuing natural resource projects are evaluated by comparing their costs to the better-known cost of completing closed-system water quality projects such as stormwater best management practices. A summary of cost effectiveness data for both natural resource reconnection projects and stormwater projects was compiled for comparison (See Section 5.1.4). The typical price of stormwater projects was taken from a previous state project evaluating cost-effectiveness of stormwater best management practices.

The cost-effectiveness data (Figure 2-20) are provided to allow for comparisons between natural resource and stormwater projects. The data suggest that berm removal and buffer plantings are the most cost-effective ways to treat phosphorus. The cost effectiveness information is static and available for use as a reference in project planning. Note that project-specific cost-effectiveness values for the purposes of project prioritization and screening under Formula Grants need to be calculated using the cost effectiveness methodology outlined in Vermont Act 76 Guidance. The VTDEC tool available at https://dec.vermont.gov/water-investment/cwi/grants/resources can be used to calculate cost effectiveness following the Act 76 Guidance methodology.



Note that these cost-effectiveness values were calculated based on completed projects in Vermont and actual cost effectiveness will vary for a specific project implemented for the FFI or TMDL. This table should be used for planning purposes to compare average cost-effectiveness values between project types. Project-specific cost-effectiveness values for the purposes of project prioritization and screening under Formula Grants need to be calculated using the cost effectiveness methodology outlined in Act 76 Guidance. The VTDEC tool available at https://dec.vermont.gov/water-investment/cwi/grants/resources can be used to calculate cost effectiveness following the Act 76 Guidance methodology.

Project Class	Project Type	Practice	Cost-Effectiveness ($USD/lbs TP/yr)
Natural Resource / Re-Connection Project	Floodplain Restoration	Berm Removal	$2,050
Natural Resource / Re-Connection Project	Buffers	Buffers	$2,786
Natural Resource / Re-Connection Project	Corridor Easement	Corridor Easement	$5,944
Natural Resource / Re-Connection Project	Floodplain Restoration	Create Flood Bench	$12,351
Stormwater Best Management Practice	Infiltration Practices	Surface Infiltration	$12,500
Natural Resource / Re-Connection Project	Dam Removal	Medium ROR Dam	$13,438
Natural Resource / Re-Connection Project	Floodplain Restoration	Lower Floodplain	$14,017
Stormwater Best Management Practice	Infiltration Practices	Subsurface Infiltration	$15,000
Stormwater Best Management Practice	Infiltration Practices	Infiltration Trench	$15,000
Natural Resource / Re-Connection Project	Floodplain Restoration	Raise Channel	$16,224

Figure 2-20 Cost Effectiveness Information Developed as a Reference for Project Planning

2.3.4 CASE STUDY 1 – FLOODPLAIN RESTORATION, PLANTING, EASEMENT

Please see the video for project information and phosphorus credit calculations for the Dog River Floodplain Restoration Project in Northfield (insert YouTube URL at proper location).

2.3.5 PROJECT EXAMPLE 2 – DAM REMOVAL

Please see the video for project information and phosphorus credit calculations for the Mill Pond Dam Removal on Indian Brook in Colchester (insert YouTube URL at proper location).

2.3.6 PROJECT EXAMPLE 3 – BUFFER PLANTING, CORRIDOR EASEMENT, BANK STABILIZATION

Please see the video for project information and phosphorus credit calculations for the Buffer Planting, Corridor Easement, and Bank Stabilization on the New Haven River in Bristol (insert YouTube URL at proper location).

2.3.7 PRACTICE EXERCISES

Please see the video for practice phosphorus credit calculations in follow-the-leader format (insert YouTube URL at proper location).

2.4 WATERSHED REPORTING

The Watershed Reporting module in the FFI application is designed to summarize information at user specified scales. This app feature can be used as a tool to track larger scale improvements in connectivity and progress towards water quality goals as projects are completed and FFI is updated. The Watershed Reporting module is accessed at the top of the FFI home page. Four reports have been designed – Connectivity Summary Report, Connectivity Details Report, Project Report, and Resiliency Report (Figure 2-21).

The Connectivity Summary Report provides connectivity information on river corridors and streams such as overall floodplain connectivity scores and percent attainment. The Connectivity Details Report provides additional metrics such as the sum of the area in each protection class. The Project Report shows the number of projects of each type in the area selected. The Resiliency Report aggregates values of vulnerable infrastructure.

The user must select an aggregation scale that is the scale data will be summarized and the units at which the output will be provided (i.e., the Lake Champlain Basin, HUC-10 watershed, HUC-12 subwatershed, county, town, and FFI subunit). The user can further select a specific geographic area to include (e.g., specific watershed(s) or specific town(s), as well as filter by other attributes such as connectivity ranking (floodplain or stream), protection rank, and watershed position (Figure 2-22). The default is to provide a summary of all data at the aggregation scale if additional filters are not selected. Once a user has selected the desired scale and filter options, clicking on 'Generate Report' will produce a comma-separated values (CSV) file that can be read in a spreadsheet program. The CSV exports come with two header lines – the first line shows the aggregation scale and filter options, and the second line shows column headers (Figure 2-23).

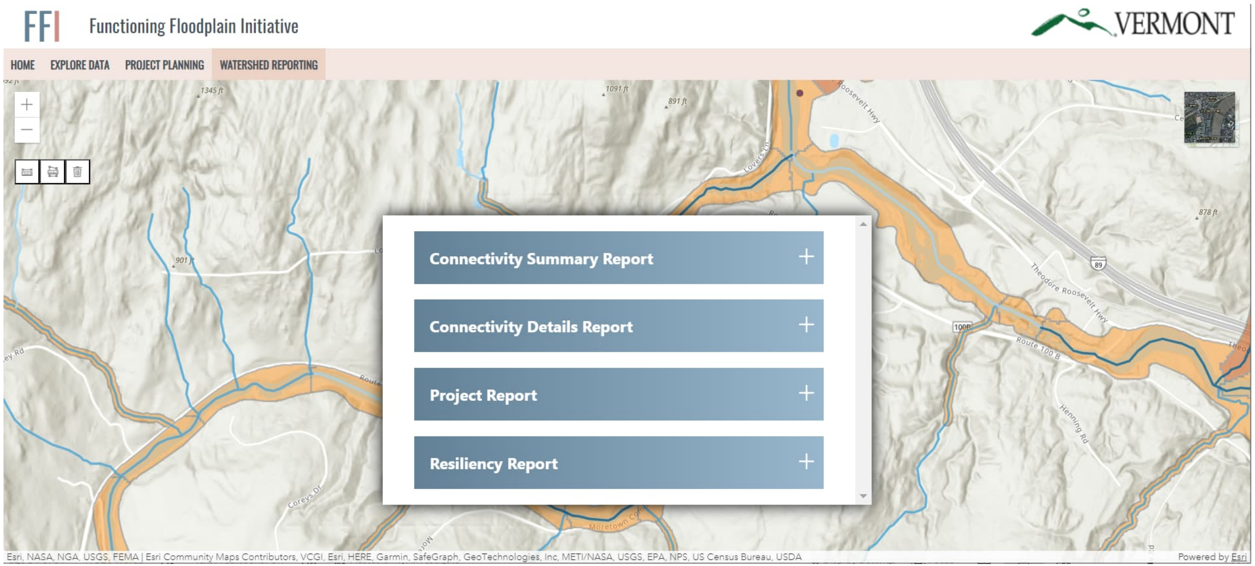


Figure 2-21 Watershed Report Menu

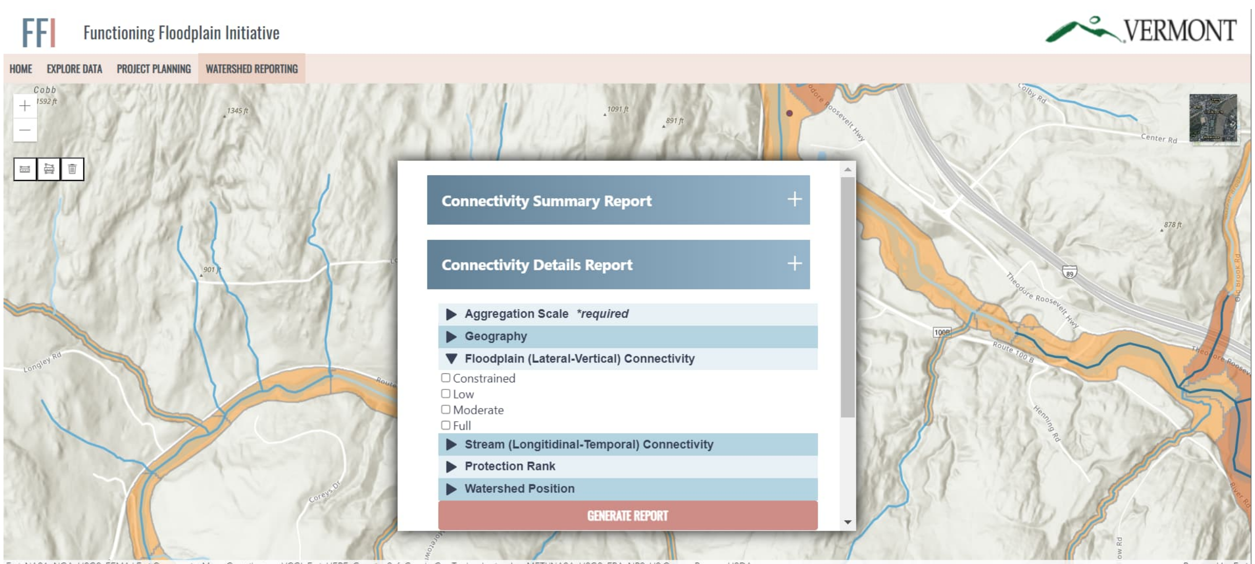


Figure 2-22 Watershed Report Selections

Aggregation Scale = Huc12;	Scale = BASINS;	Geography = Winooski (8);	Floodplain (Lateral-Vertical) Connectivity = Low,Constrained;	Stream (Longitidinal-Temporal) Connectivity = Fragmented,Partially Disconnected;	Protection Rank = Low,Mostly Absent;	Watershed Position = Lower Valley;			
Area	Total Floodplain Connectivity (Score)	Potential Floodplain Connectivity (Score)	Floodplain Connectivity Attainment (%)	Floodplain Connectivity Departure (%)	Total Floodplain Connectivity Departure (Score)	Total Floodplain Project Feasibility (Score)	Floodplain Project Feasibility (%)	Floodplain Stability P Load (kg/yr)	Total Stream Connectivity (Score)
043001030101: Headwaters Steven	530	2000	27	73	1470	960	48	354	1492
043001030102: Jail Branch	553	1900	29	71	1347	954	50	291	1703
043001030103: Stevens Branch	274	1600	17	83	1326	551	34	416	768
043001030201: Headwaters Winoo	249	900	28	72	651	402	45	151	955
043001030202: Nasmith Brook-Win	420	1200	35	65	780	642	53	268	2280
043001030203: Kingsbury Branch	715	1900	38	62	1185	957	50	268	1803
043001030204: Sodom Pond Brook	506	1600	32	68	1094	750	47	532	876
043001030301: Headwaters North I	139	300	46	54	161	206	69	30	523
043001030302: North Branch Wino	386	1100	35	65	714	524	48	461	1007
043001030401: Headwaters Dog Riv	842	1900	44	56	1058	976	51	118	1469
043001030402: Dog River	1220	2600	47	53	1380	1318	51	883	1134
043001030403: Great Brook-Winoo	568	2000	28	72	1432	877	44	800	878
043001030501: Headwaters Mad Ri	87	200	44	56	113	80	40	11	947
043001030502: Mill Brook-Mad Riv	130	400	33	67	270	203	51	72	680
043001030504: Mad River	887	2500	35	65	1613	1289	52	956	1135
043001030601: Graves Brook-Wino	571	1800	32	68	1229	862	48	626	1528

Figure 2-23 Connectivity Details Report CSV Example

2.5 PROJECT TRACKING

The FFI application was designed to support connectivity tracking via a future approach for updating connectivity scores, phosphorus base load allocations, and connection project priority. Project input and output data can be exported as a CSV file. At this time, these FFI data exports will be the basis of tracking a project as the data will be entered into the Vermont Watershed Project Database (WPD) (https://anrweb.vt.gov/DEC/cleanWaterDashboard/WPDSearch.aspx).

The data entered into the Calculation Inputs tab that includes area-based inputs such as change in unconstrained river corridor and incision ratio, are the basis for updating the connectivity scores in FFI and reallocating remaining HUC12 phosphorus base loads.

The 'WQBenefitSummary' export from the Water Quality Benefit tab in the FFI application provides phosphorus crediting information for stream stability and floodplain storage. This information will be submitted to DEC to enter phosphorus credits in the WPD and track progress towards meeting the reduction targets for the stream stability sector of the Lake Champlain TMDL.

Current WPD projects are visible in the FFI web application (Figure 2-24). The color of project points reflects project status (i.e., completed, funded, proposed, etc.). When a user clicks on a WPD point, a pop up will display showing summary information about that project and a link to an ANR webpage where more information can be found on that project.

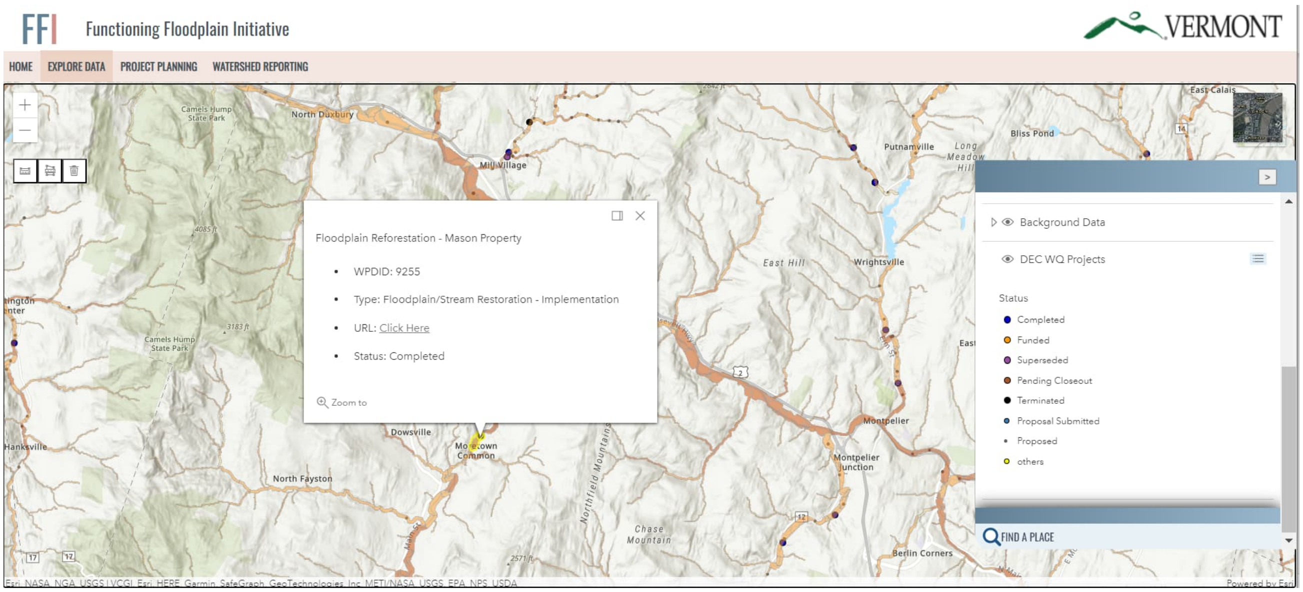


Figure 2-24 WPD Project Visualization in the FFI

Development of the process for tracking and updating the FFI is ongoing. We envision that within the next year, users will be provided with login options and will be able to save project information directly to the FFI application. Also under development is a process by which the FFI data, including subunit connectivity scores and identification of prioritized projects, will be updated based on project completion. This will be critical for keeping TMDP base load allocations, phosphorus reduction targets, and project prioritization current.

3. CONNECTIVITY ASSESSMENT METHODS (FORM-BASED)

FFI connectivity departure methods have been developed using a range of data sources that include Vermont stream geomorphic assessment data (Kline et al., 2009), Vermont river corridor planning information (Kline, 2010), and available GIS layers.

3.1 PRIMARY DATA

A variety of geospatial datasets were used for connectivity and departure scoring, feasibility analysis, and project selection and prioritization (Table 3-1 and Appendix D). The datasets include key environmental datasets covering hydrography, land cover, soils, and terrain data, as well as land ownership, conservation, and regulatory jurisdictions. **Bold datasets** in the tables below indicate "backbone" datasets in the analysis – HUC 12 watersheds, river corridors, and stream centerlines that establish the spatial structure of FFI.

Table 3-1 Datasets Used in FFI Methods

Data	Source and Format
River, River Corridor, Floodplain and Watershed Data	**2019 River Corridor, HUC 12 Watersheds, Stream Centerlines**, UVM LiDAR-Informed Flood Inundation Layer (HAND Floodplains) and derivatives
Land Cover and Environmental Data	LiDAR Digital Elevation Model, National Land Cover Database, NRCS Soils, Quebec Province Crop Data, AgTile-US Layer, UVM SAL LULC 2016 and Derivatives
Land Ownership, Conservation, and Regulation Data	ACT 250 Permits, Designated Downtown, Designated New Town Center, Designated Village Centers, FEMA Floodways & SFHA, Parcel Boundaries, River Corridor Bylaws, River Corridor Easement, RPC Digitized SFHA, Vermont Significant Wetlands Inventory (VSWI), VSWI Advisory Layer, VT Protected Lands Database
Other Data	Dam Inventories, Railroads, Road Centerlines, SGA - Phase II Data, Structure Inventory, FIT, TRPT Crossings Data, E911 Points

3.1.1 SCALE OF ANALYSIS

The FFI analysis includes two different analysis scales for floodplain (lateral-vertical) and stream (longitudinal-temporal) connectivity. Departure scoring and project selection/prioritization are assessed down to subunits of the river corridor for Floodplain Connectivity. The stream geomorphic segments and reaches (if available from Stream Geomorphic Assessments) are the selected spatial scale for Stream Connectivity given this type of connectivity is more closely linked to the stream network at a larger scale. The origin and intended use of each scale is explained further below.

The departure and attainment scores can then be aggregated up to the HUC 12 watershed scale or the basin scale. Project opportunities are only displayed at the subunit and reach scales.

3.1.1.1 Basin / Watersheds

The USGS Hydrologic Unit Code (HUC) 12 watersheds are the scale at which watershed and river corridor planning often occurs in Vermont. Reach, segment, and subunit departure and attainment data have been aggregated to this scale to facilitate connectivity project planning and lay the groundwork for phosphorus crediting under the Lake Champlain TMDL.

Departure and attainment data are aggregated to the HUC 12 scale based on a maximum score of 100 for each unit, the number of units within each HUC 12, and a sum of the attainment scores within the HUC 12.

The scores in a HUC 12 can ultimately be summed to the Vermont Tactical Basins (i.e., Vermont Planning Basins) and the Lake Champlain Basin (Figure 3-1). The basin scale will facilitate project planning at larger scales and linking TMDL P load reduction targets between Lake segments and subunits, stream segments, and stream reaches.

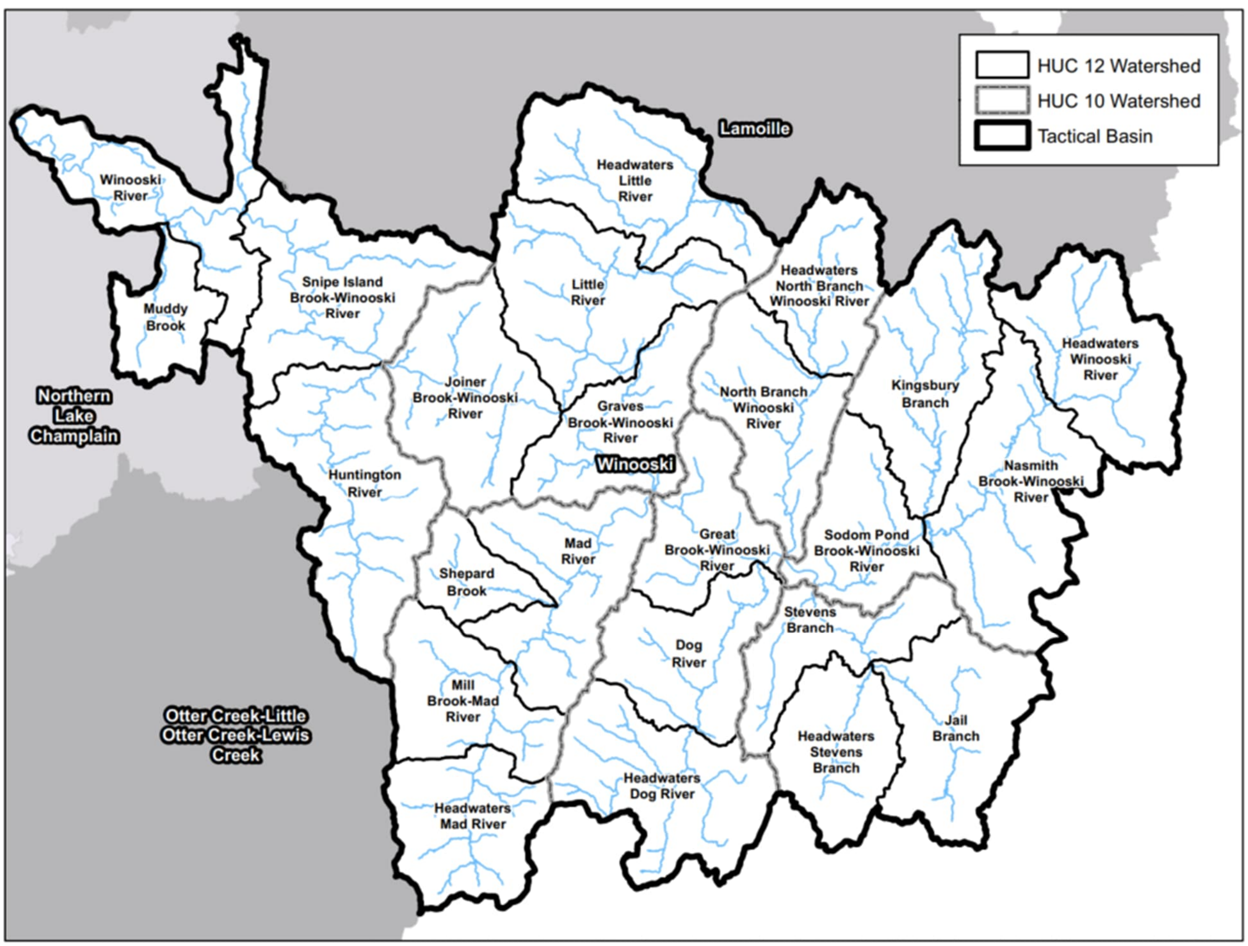


Figure 3-1 FFI Watersheds and Basins – Winooski River Basin Example

3.1.1.2 Floodplains

Across Vermont, practitioners and researchers use various data layers to estimate the area of floodplain inundation. FEMA's Special Flood Hazard Areas (SFHA) are most often used to map inundation, but in many areas this mapping has either not been completed or may underestimate historical and current floodplain extents. For the maximum floodplain extent, FFI uses the approximate 500-year flood inundation mapping prepared by UVM researchers generated from low-complexity hydraulic modeling based on LiDAR data (i.e., the "probHAND" method) (Diehl et al., 2021a) (See also Section 4.1).

A geoprocessing approach has been developed to divide river corridors (Figure 3-2, middle frame) and floodplains (Figure 3-2, right frame) along subunits, segments, and reaches. In the future, FFI will include a broader scale to include wildlife corridors and large habitat blocks in the uplands to evaluate habitat connectivity to floodplains and corridors.

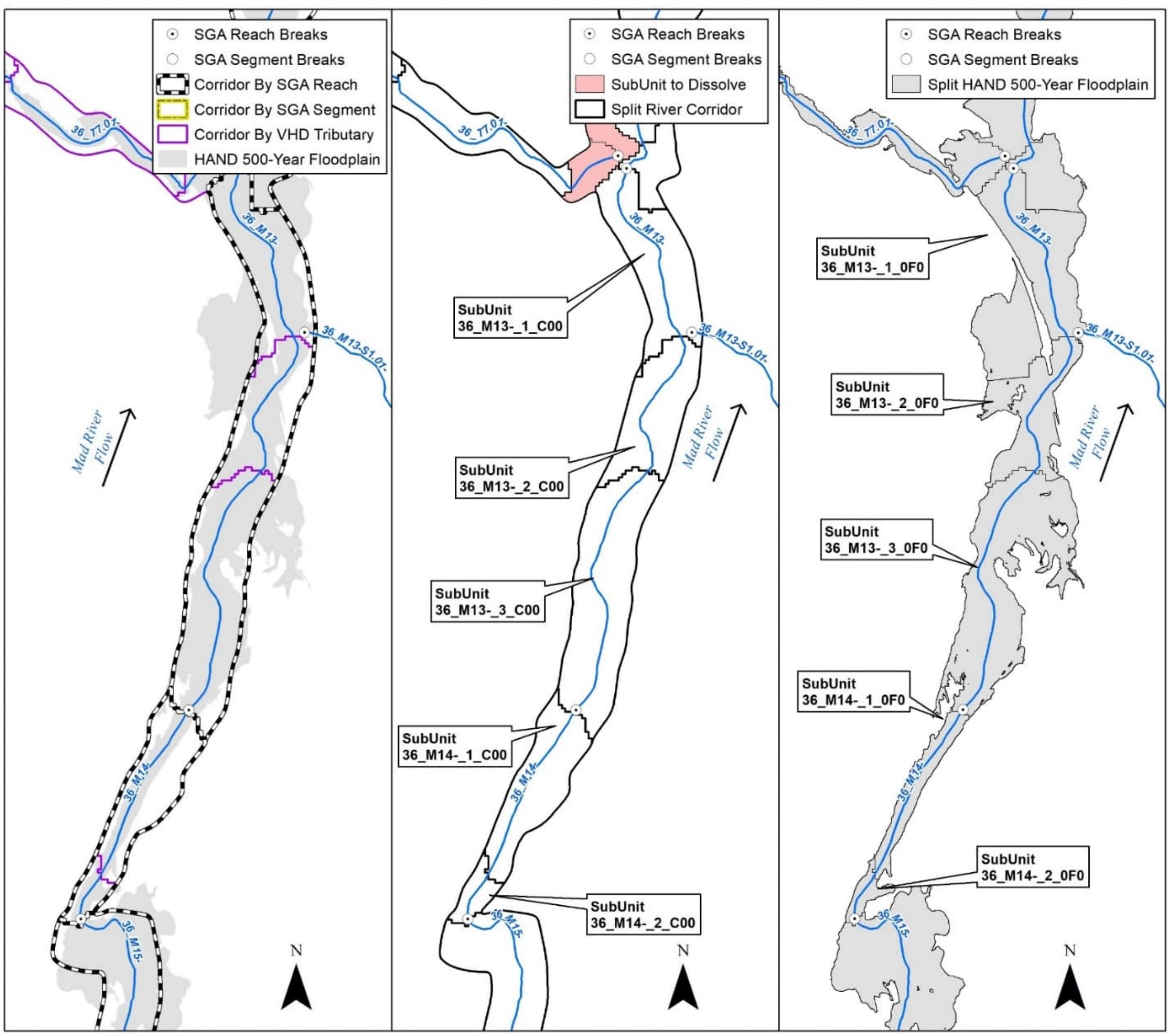


Figure 3-2 FFI Sub-Units, Segments, Reaches, and Naming Convention

3.1.1.3 River Corridors & Sub-Units

The VTDEC "bumped" and "clipped" river corridor (Figure 3-2, left frame) is the basis for Floodplain Connectivity scoring in FFI. The River Corridor layer includes breaks along the network for Stream Geomorphic Assessment (SGA) reaches and segments. Additional breaks called subunits are catchment divides of the channels in the Vermont Hydrography Dataset (VHD) burned into the Vermont state river corridor (VTANR, 2019) (Figure 3-2). The subunits were retained in the FFI for viewing lateral and vertical connectivity and identifying project opportunities that can change at a more local scale than stream geomorphic segments and reaches (Figure 3-2, middle frame).

As part of the FFI, a unique identifier was assigned based on the length up and down the river (i.e., subunit, segment, or reach) and the lateral extent being considered (i.e., river corridor, floodplain, or upland habitat areas) (Appendix E). In addition, geoprocessing rules were developed to eliminate the relatively few numbers of small subunits that are not meaningful for floodplain planning.

3.1.1.4 Reaches and Segments

Vermont Hydrography Dataset (VHD) segments are the unit of analysis for Stream Connectivity scoring. A hybrid SGA-VHD stream geometry originally developed for the VT River Sensitivity Coarse Screen (Schiff et al., 2015b) was modified to incorporate new SGA data and tag streams with their VHD REACHCODE. This layer includes SGA reach and segment breaks where assessments have been completed and VHD reaches, mostly on smaller streams, where SGA's have not been performed. Stream segments and reaches were dissolved by SGA ID, if available. Where no SGA ID was available, stream reaches were dissolved by the VHD REACHCODE.

3.1.1.5 Headwater

Headwater streams in the Lake Champlain Basin of Vermont are comprised of stream segments draining less than 2 square miles (approximately 75% of the stream network). Past research in Vermont has indicated an approximate threshold of 0.1 square mile drainage area for initiation of the channel network, and 0.25 square mile for a transition from intermittent to perennial stream flow in headwater channels (Olson and Brouillette, 2006). For FFI, headwater channels were split into three categories.

Intermittent: drainage area ≤ 0.25 mi^2
Perennial High Gradient: 0.25 mi^2 ≤ drainage area ≤ 2 mi^2 AND slope > 3%
Perennial Low Gradient: 0.25 mi^2 ≤ drainage area ≤ 2 mi^2 AND slope ≤ 3%

For the perennial headwater streams, a 3% slope was selected to separate steeper and flatter streams where the potential for floodplains varies. Perennial low-gradient headwaters can have important pockets of floodplain that begin forming as a stream shifts from a step-pool, sediment transport stream (narrow valley Rosgen stream type "B") to a riffle-pool, sediment deposition stream (broader valley Rosgen stream type "C") (Montgomery and Buffington, 1997).

The VTDEC Small Streams Vector Product was used to split the headwater streams into two classes of river corridor widths:

0.25 mi^2 - 0.5 mi^2: 110 feet (10 foot channel + 50 feet on each side)
0.5 mi^2 - 2 mi^2: 118 feet (18 foot channel + 50 feet on each side)

Estimated channel widths were determined using the VT Hydraulic Geometry Regression equations for 0.5 mi^2 and 2 mi^2 drainage areas. The headwater stream network was buffered on each side off the VHD stream centerline to delineate an approximate river corridor for application of the P crediting framework under the TMDL. Buffered corridors of different size classes were dissolved by stream reach or segment id as described in section 3.1.1.4.

3.2 CONNECTIVITY ASSESSMENT (FORM-BASED)

Methods have been developed for floodplain and stream connectivity (Appendix F) largely based on stream geomorphic data of river form and available GIS data characterizing river channels and floodplains. The methods are used to: (i) Identify how encroachments or land uses within a reach, segment, subunit, or watershed have reduced connectivity; (ii) Assign TMDL phosphorus base load allocations for unstable streams; and (iii) Credit connectivity projects to track benefits.

The connectivity methods determine a departure value indicating how far a reach, segment, or subunit is from a target condition where natural river form and processes are taking place. A score of 0 indicates that a location is fully disconnected, while 100 indicates that the location is in the target condition. The departure may be summed to watershed scale (e.g., HUC12).

3.2.1 FLOODPLAIN CONNECTIVITY (LATERAL / VERTICAL)

3.2.1.1 Introduction

Floodplain connectivity has two components – lateral and vertical. The vertical connection between a channel and its river corridor or floodplain is represented by the incision ratio, which in the lower valley reaches is either measured during Phase II stream geomorphic assessments, or estimated from lidar-derived digital elevation models (Appendix G). In headwaters, where field measurements are scarce and the lidar-based method is limited by the small channel size, incision ratio was estimated based in the degree of lateral floodplain connectivity and channel slope unless an SGA measurement was available (Table 3-2). Headwater streams in lower gradient valley settings, that are moderately to severely constrained, are often forced into straightened, steeper planforms with higher flow velocities and sediment transport processes, resulting in greater incision and floodplain disconnection. The lateral component of floodplain connectivity is characterized by the available space in the river corridor that is free of physical constraints to river movement; has land protections such as river corridor easements; and is covered with natural vegetation (See Appendix F).

Table 3-2 Estimated Incision Ratios for Headwater Streams without SGA Data

Channel Slope	Lateral Connectivity Score	Default Incision Ratio
> 3%	0 – 100	1.25
< 3%	51 – 100	1.25
	0 – 50	1.5

3.2.1.2 Floodplain Connectivity Target Condition

The target condition for floodplain connectivity is a river corridor and floodplain that are fully connected both laterally and vertically to the river or stream channel, have robust protections (e.g., conservation easements) so the land remains open and stream alterations are curtailed to allow for river processes to take place in the future, and are covered in natural vegetation. In this target condition, water quality, flood resiliency, and habitat functions are maximized (See Section 4).

3.2.1.3 Floodplain Connectivity Departure Method

The existing floodplain connectivity score (i.e., the river corridor existing connectivity score $RC_{existing\text{-}connect}$ Score) is calculated by:

$RC_{existing\text{-}connect}$ Score = [(0.5 * lateral connectivity) + (0.35 * protection) + (0.15 * natural buffer vegetation)] / incision ratio.

A qualitative rank is assigned to floodplain connectivity scores to describe the expected level of connectivity (Table 3-3).

Table 3-3 Floodplain Connectivity Score and Rank

$RC_{existing\text{-}connect}$ Score	Lateral-Vertical River Corridor Connectivity Rank
90 – 100	Full
75 – 89	Moderate
36 – 74	Low
0 – 35	Constrained

3.2.2 STREAM CONNECTIVITY (LONGITUDINAL / TEMPORAL)

3.2.2.1 Introduction

Stream connectivity has two components – longitudinal and temporal. Longitudinal connectivity is important for the downstream movement of water, sediment, large wood, coarse particulate organic matter, nutrients, and ice; and for the upstream and downstream movement of fish, aquatic organisms, and wildlife. Temporal (i.e., hydrological) connectivity affects the timing, frequency, magnitude, and duration of flows that activate floodplains and drive stream processes to support a variety of ecosystem functions and services.

River channels, corridors, and floodplains may become longitudinally disconnected by infrastructure in and across the channel and floodplain (i.e., dams, weirs, culverts, bridges, roads, and railroads). These longitudinally fragmented channels can become unstable due to excessive sedimentation upstream and lack of sediment downstream of barriers.

Temporal disconnection may result from excessive storage behind large dams and regulated release of impounded water. Disturbance of the natural flow and sediment regimes may also occur due to undersized bridges and culverts; water diversions; excessive runoff from impervious cover; artificial extension of the river network by the road or farm ditch network; and accelerating agricultural runoff in tile drains.

An incised or entrenched channel with limited active floodplain also contributes to longitudinal and temporal disconnection as floodplains are less frequently accessed and channels become more dominated by sediment transport rather than having an even distribution of sediment transport and storage reaches.

3.2.2.2 Stream Connectivity Target Condition

The target condition for stream connectivity is full longitudinal and temporal connectivity. This includes the absence of obsolete and non-functioning dams that alter the timing of flow and transport of materials. Bridges and culverts that constrict the channel do not exist and are at least equal to the bankfull channel width. Floodplains are not artificially constricted by fills so that they can store and convey flood flows. The natural frequency and duration of floodplain inundation exists in a well-connected system. The target for stream connectivity includes low levels of impervious cover, ditching, and tile drains that that would otherwise alter overland flow generation, infiltration, and hydrograph timing.

3.2.2.3 Stream Connectivity Departure Method

The existing longitudinal connectivity score (i.e., $LONG_{existing\text{-}connect}$ Score) is reduced from a maximum of 100 due to the presence of instream structures (Table 3-4) and channel incision (Table 3-5). The deductions are added over a geomorphic stream reach or segment to determine the score.

Table 3-4 Deductions to Longitudinal and Temporal Connectivity Score from Instream Structures

Barrier	Longitudinal	Temporal	AOP
Large Flood Control Dam	-90	-100	-100
Large Peaking Hydro Dam	-90	-100	-100
Large Run of River (ROR) Dam	-80	-40	-100
Medium Peaking Hydro Dam	-70	-90	-100
Medium ROR Dam	-50	-20	-100
Medium Breached Dam	-40	-20	-100
Small Intact ROR Dam	-30	-20	-100
Small Breached Dam	-20	-10	-80
Bridge (Wbkf>100%)	-10	-10	0
Bridge (50%>Wbkf>100%)	-30	-20	-10
Bridge (Wbkf<50%), shallow channel (< 2%)	-40	-30	-20
Bridge (Wbkf<50%), steep channel (> 2%)	-20	-10	-30
Culvert (Wbkf>100%)	-10	-20	-20
Culvert (50%>Wbkf>100%), shallow	-50	-30	-30
Culvert (50%>Wbkf>100%), steep	-30	-10	-40
Culvert (Wbkf<50%), shallow	-80	-40	-60
Culvert (Wbkf<50%), steep	-50	-20	-80
Gully	-30	-30	-30
Headcut	0	0	-30
Permitted Surface Withdrawal, no structure*	-10	-10	-10
Permitted Surface Withdrawal, with a structure*	-50	-10	-70
Groundwater Withdrawal*	-10	-10	-10

* Excluded from current departure scoring due to lack of data

Table 3-5 Deductions to Longitudinal and Temporal Connectivity Score due to Incision

Incision	Incision Ratio[1]	Longitudinal Score Deduction	Temporal Score Deduction
Minor	IR < 1.3	0	0
Moderate	1.3 ≤ IR < 1.5	-10	-5
High	1.5 ≤ IR < 2.0	-20	-8
Severe	IR ≥ 2.0	-30	-10

A qualitative rank is assigned to longitudinal connectivity scores (Table 3-6).

Table 3-6 The Longitudinal Connectivity Score and Rank

$LONG_{existing\text{-}connect}$ Score	Longitudinal Connectivity Rank
80 – 100	Connected
41 – 79	Partially Disconnected
0 – 40	Fragmented

The existing temporal connectivity score (i.e., $TEMP_{existing\text{-}connect}$ Score) is made up of deductions from four components – instream structures (See Table 3-4), channel incision (See Table 3-5), developed/impervious lands as represented by the length of roads per HUC12 watershed, and agricultural lands as represented by crops, pasture, and hay. Ditched or tile drained areas are weighted double due to increased impacts on temporal connectivity. The deductions are weighted over a geomorphic stream reach to determine the score.

$TEMP_{existing\text{-}connect}$ Score = (0.4 * $TEMP_{existing\text{-}chstructures}$) + (0.3 * $TEMP_{existing\text{-}dev\text{-}rds}$) + (0.3 * $TEMP_{existing\text{-}ag}$)

A qualitative rank is assigned to temporal connectivity scores (Table 3-7).

Table 3-7 The Temporal Connectivity Score and Rank

$TEMP_{existing\text{-}connect}$ Score	Temporal Connectivity Rank
80 – 100	Connected
41 – 79	Partially Disconnected
0 – 40	Fragmented

The existing stream connectivity score (i.e., $STREAM_{existing\text{-}connect}$ Score) is calculated by:

$STREAM_{existing\text{-}connect}$ Score = (0.6 * $LONG_{existing\text{-}connect}$ Score) + (0.4 * $TEMP_{existing\text{-}connect}$ Score)

A qualitative rank is assigned to stream connectivity scores (Table 3-8).

Table 3-8 Stream Connectivity Score and Rank

$STREAM_{existing\text{-}connect}$ Score	Stream Connectivity Rank
80 – 100	Connected
41 – 79	Partially Disconnected
0 – 40	Fragmented

3.3 PROJECT SELECTION

A tiered set of filters has been created to develop an initial list of projects to begin an alternatives analysis to reconnect floodplains and streams. First, a general approach is identified based on connectivity departure scores or the presence of instream structures. Next, project types are selected based on the departure score and the geomorphic setting on the stream reach. Project feasibility is considered in the lateral-vertical project selection that is a function of constraints and the number of parcels. Finally, the projects are prioritized based on the geomorphic setting and the feasibility of implementing a successful project. The screening to identify and prioritize reconnection opportunities allows one to prepare maps with a list of high-priority reconnection projects to begin project development.

These screens must be field-verified and discussed with river scientists, river engineers, and local stakeholders to refine the project opportunity list based on local knowledge.

3.3.1 FLOODPLAIN RECONNECTION PROJECT OPPORTUNITIES

The first set of filters selects no action, restore lateral-vertical connectivity, remove constraint, protection, and revegetation (Table 3-9).

Table 3-9 Project Approach Selection

ID	APPROACH	IR (Vertical Connectivity)	Lateral Meander Connectivity Rank	Level of Protection Rank	Woody Buffer Rank	Signficant Wetlands or Hydric Soils Present and Land Use Not Natural	Berm Present
1	No Action	Mi (and)	Full (and)	High (and)	Full (and)	None (and)	None
2	Restore lateral-vertical connectivity	Mo, H, S (or)	M, L, C (or)			Present (or)	Present
3	Constraint removal		M, L, C				
4	Protection			M, L, MA (or)		Present	
5	Revegetation				M, L, MA		
						(override)	(override)

NOTES

Level of Incision Rank: Mi = Minor, Mo = Moderate, H = High, S = Severe
Lateral Meander Connectivity Rank: F = Full; M = Moderate; L = Low; C = Constrained
Level of Protection and Woody Buffer Rank: H = High, M = Moderate, L - Limited, MA = Mostly Absent
Wetlands mapped on Vermont Significant Wetlands Inventory or with NRCS Hydric Soils, and Land Cover Not Forest or Shrub/Scrub
Berms and Disconnected Flood Chutes mapped during Stream Geomorphic Assessments and accessible through Feature Indexing Tool GIS coverage.

Floodplain connectivity project types (Table 3-10) are selected based on how incised the channel is, how much of the river corridor is filled with constraints, how large the channel is, if wetlands are present, if berms are present, and if river corridor bylaws are present (Appendix H).

Table 3-10 Floodplain Connectivity Project Types

ID	APPROACH	PROJECT
1	No Action	No Action
2	Restore lateral-vertical connectivity	Lower floodplain[a]
3	Restore lateral-vertical connectivity	Reconnect flood chute[b]
4	Restore lateral-vertical connectivity	Create flood bench[c]
5	Restore lateral-vertical connectivity	Restore channel slope and pattern[d]
6	Restore lateral-vertical connectivity	Restore channel roughness [e]
7	Restore lateral-vertical connectivity	Raise channel [f]
8	Restore lateral-vertical connectivity	Remove berm[g]
9	Restore lateral-vertical connectivity	Restore wetland[h]
10	Constraint removal	Remove major constraint[i]
11	Constraint removal	Remove minor constraint[j]
12	Protection	Implement river corridor easement
13	Protection	Conserve wetlands (e.g., NRCS Wetland Reserve)
14	Protection	Adopt river corridor bylaws
15	Revegetation	Plant woody 50-foot buffer
16	Revegetation	Plant woody river corridor / floodplain
17	Revegetation	Plant woody floodplain (beyond corridor)

Potential project opportunities are prioritized based on the degree of incision, level of protection, geomorphic setting (i.e., bank erosion, straightening, aggradation, planform adjustment, channel sensitivity to change), number of parcels, area of land involved, wetland presence, berm presence, flood chute presence, and channel size (See Appendix H).

3.3.2 STREAM RECONNECTION PROJECTS

The approach to stream reconnection is selected based on the degree of existing longitudinal and temporal connectivity and aquatic organism passage (AOP) in the reach (Table 3-11).

Table 3-11 Project Approach Selection for Stream Reconnection

ID	APPROACH	Longitudinal Connectivity Rank	Temporal Connectivity Rank due to Structures	AOP
1	No Action	Connected	Connected	Connected
2	Restore longitudinal, temporal or AOP	Partial or Fragmented	Partial or Fragmented	Partial or Fragmented

Stream connectivity project types (Table 3-12) are selected based on the presence of instream structures, withdrawals, gullies, and converted land cover (i.e., developed and agriculture) (Appendix I).

Table 3-12 Stream Connectivity Project Types

Barrier
Remove Large Flood Control Dam
Remove/Convert Large Peaking Hydro Dam
Remove Large Run of River (ROR) Dam
Remove/Convert Medium Peaking Hydro Dam
Remove Medium ROR Dam
Remove Medium Breached Dam
Remove Small Intact ROR Dam
Remove Small Breached Dam
Replace Bridge (Wbkf>100%)
Replace Bridge (50%>Wbkf>100%)
Replace Bridge (Wbkf<50%), shallow channel (< 2%)
Replace Bridge (Wbkf<50%), steep channel (> 2%)
Replace Culvert (Wbkf>100%)
Replace Culvert (50%>Wbkf>100%), shallow
Replace Culvert (50%>Wbkf>100%), steep
Replace Culvert (Wbkf<50%), shallow
Replace Culvert (Wbkf<50%), steep
Remove Re-Permit Diversion / Withdrawal
Remove Groundwater Extraction (commercial, wells)
Stabilize Headcut in Perennial Streami
Stabilize Gully
Stabilize Gully w-Treatment of Stormwater
Disconnect Municipal or Private Road Ditch
Treat Legacy Forest Trail/Road Drainage

Potential project opportunities for stream reconnection are prioritized based on how many structures exist in the channel, the channel geomorphic sensitivity to change, and the structure geomorphic compatibility (See Appendix I).

4. FLUVIAL PROCESS ASSESSMENT METHODS (EROSION, DEPOSITION, AND STORAGE)

The FFI began with a form-based analysis of river corridors to identify the degree of (dis)connection of Vermont's rivers and inferred a corresponding functional departure associated with the current form. To better integrate stream process and function into these connectivity maps, the FFI incorporates new Vermont research to: 1) better define the geographic extents of stream equilibrium, channel evolution, and sediment regime conditions; 2) map probabilistic floodplain extents to inform inundation extents and estimate the variable capacity for fine-sediment and nutrient storage; and 3) characterize the relative source/sink role of riparian wetlands and factors that influence net nutrient retention over varying time scales. The enhanced composite mapping of connectivity, stream process, and functional departure, when viewed in the context of existing technical, social, and financial constraints, helps to better prioritize restoration or conservation opportunities to maximize river and floodplain connectivity.

In the absence of human modifications rivers function to erode, transport, and deposit sediments and organic matter in a manner that is in balance with the material and water loads provided under the current hydrologic regime (Lane, 1955). This state of dynamic equilibrium relies on connected floodplains and wetlands as a particular focus of floodwater and material exchange (Opperman et al., 2010). To varying degrees, our land use choices along river corridors and across watersheds have led to greater disequilibrium, largely by disconnecting rivers from their floodplains (laterally and vertically), creating discontinuities in material and floodwater movement up- and downstream (longitudinal), and modifying the frequency, duration and periodicity of water and material loads supplied to rivers (temporal) (Kline and Cahoon, 2010). A focus on reconnecting rivers and floodplains will restore these natural functions, leading to enhanced ecosystem services of value to society, including: 1) improved water quality; 2) greater flood resiliency; and 3) enhanced habitat (Table 4-1).

Table 4-1 Function of Connected Rivers and Floodplains

FUNCTIONAL TARGET	Stream and Floodplain Processes	Values and Ecosystem Service	Anticipated Outcome
NATURALLY STABLE STREAM BED AND BANKS	Stream Equilibrium and Natural Erosion and Depositional Process	Water Quality	Reduced Sourcing of Sediment & Nutrients through decreased stream power
		Flood Resiliency	Reduced of erosion-related Damages
		Habitat	Improved Instream Cover Mosaics and Organism Passage

FLOODPLAIN & WETLAND STORAGE OF FLOOD FLOW AND MATERIALS	Regular Inundation and Variable Duration of Groundwater, Wetland, and Floodplain Inundation	Water Quality	Reduced Downstream Loading of Sediment & Nutrients with Increased Floodplain Storage
		Flood Resiliency	Reduced Inundation-related Damages
		Habitat	Improved Floodplain Habitat Mosaics and Lateral Riverscape Migration

To assess fluvial process at the scale of the Lake Champlain Basin, ongoing research in Vermont has developed various low-complexity, data-driven modeling approaches relying on remote sensing data, field data, and historical observations. Methods are summarized in the sections below, and further details may be found in cited journal articles and technical reports.

4.1 FLOODPLAIN DELINEATION

A riverine floodplain is a relatively level, landscape feature that periodically receives inputs of water, sediment, ice, and debris from the adjacent river channel as well as more distant hillslopes (Opperman et al., 2010). Floodplains surrounding Vermont's river channels have typically been visualized as the flood inundation extent associated with the 1% annual exceedance probability (AEP) flood (i.e., the 100-year flood) mapped as part of the FEMA National Flood Insurance Program, yet these maps are available for limited locations around Vermont, usually along larger rivers in developed areas, and may not reflect updated hydrologic and topographic conditions.

The FFI methods rely on a more holistic definition of floodplains, delineated to the active river extent within the current hydrologic regime. As such, we needed a comprehensive mapping of floodplains for the region to support analyses of floodplain and wetland processes and restoration and conservation planning for improved water quality, enhanced flood and climate resilience, and expanded habitat and ecosystem functions. We relied on a recent dataset of flood inundation maps for the Vermont portion of the Lake Champlain Basin for rivers draining greater than 2 square miles developed using a low-complexity methodology (i.e., simplifying hydraulic conditions) that is driven by high-resolution, remotely-sensed elevation and land cover data (Diehl et al., 2021a; Diehl et al., 2022a). This modeling approach requires less rigorous site-scale data development than other floodplain products relying on hydrodynamic models (e.g., HEC-RAS). This new publicly-available dataset includes a representation of variable inundation extents for a range of peak discharges ranging from events that are common (e.g., 2-year flood with a 50% probability of occurring in any given year) to those that are rare (e.g., 500-year flood with 0.2% probability) (Figure 4-1).

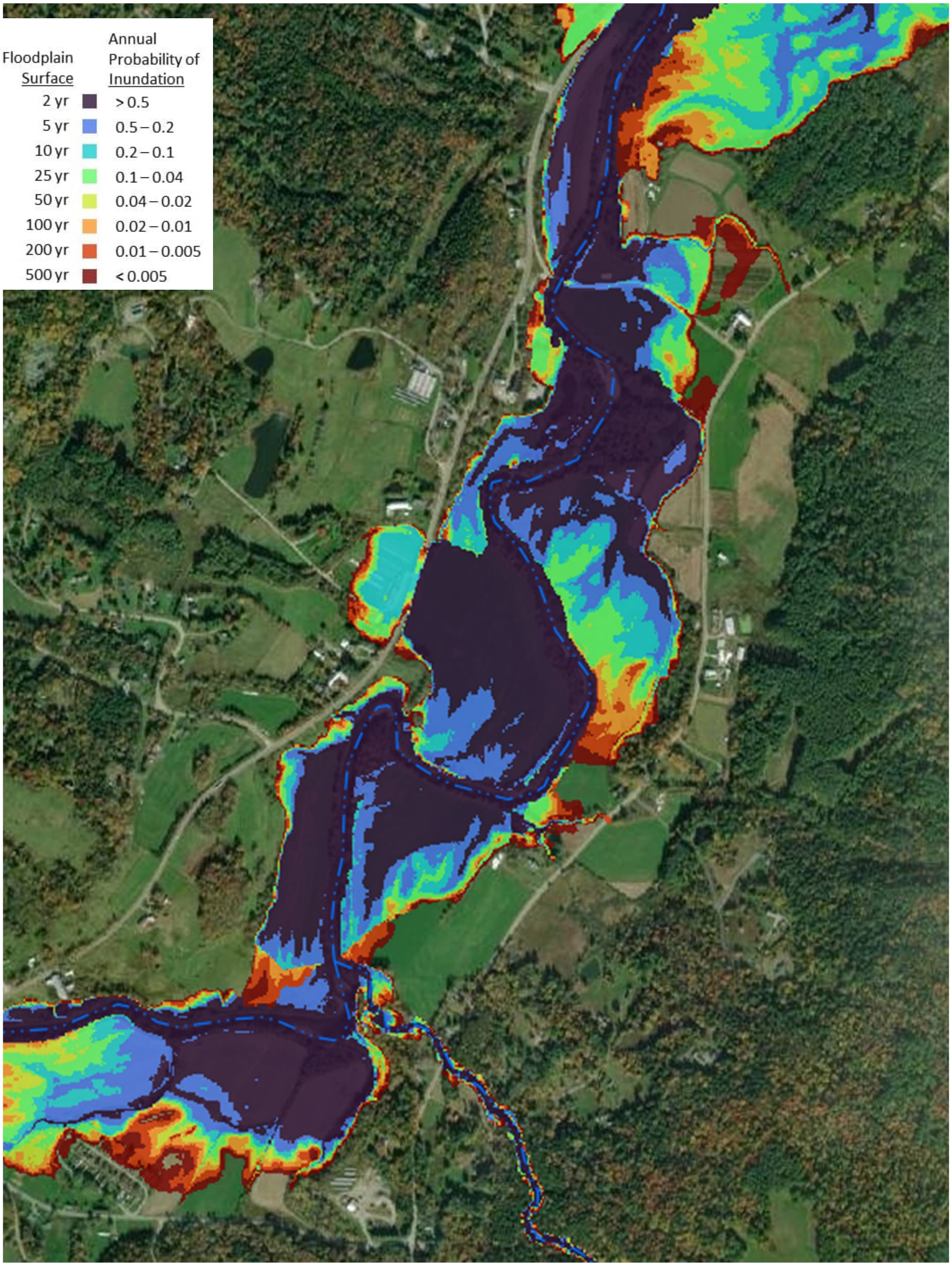


Figure 4-1 A Composite Map of the "probHAND" Inundation Extents for a Range of Peak Discharges (2-Year to 500-Year) Along the Mad River in Waitsfield (Diehl et al., 2022a)

The 500-year floodplain extent provides a conservative estimate of the active river area and is used as the floodplain unit of analysis (Section 3.1.1.2). Annual inundation probabilities (i.e., 0.50, 0.20, 0.1, 0.04, 0.02, 0.01, 0.005) are used to estimate inundation hazard reduction potential that varies based on flood size (Section 5.2.1).

4.2 REACH-BASED SEDIMENT REGIME CLASSES

Vermont's River Corridor Planning guidance defines sediment regime classes (Kline, 2010). The sediment regime classes reflect varying degrees of lateral and vertical disconnection resulting from natural and human causes. The classes also indicate differing capacities to store/attenuate floodwaters and erode, transport, and store coarse and fine sediment (and associated nutrients). As such, sediment regime classes might be more aptly described as hydrologic and sediment connectivity classes.

Six sediment regime classes are applicable to the wide range of stream types encountered in Vermont from steeper-gradient, confined settings with limited floodplains to lower-gradient, unconfined settings with larger floodplain development (Jain et al., 2008). Montgomery & Buffington (1997) have described the sediment transport ability of mountainous rivers on a continuum from supply-limited to transport-limited. Vermont's sediment regime classes are consistent with this classification but expand upon it to consider the vertical disconnection of channels from their floodplains resulting from channel incision.

Underwood et al. (2021) analyzed sediment process in Vermont. Two classes (gray shading in Figure 4-2) are found in channel settings that are closely confined by the valley walls; the remaining four classes are found in unconfined, wider-valley settings. When the channel is vertically well connected to the floodplain (top row in Figure 4-2), the bankfull discharge is equivalent to incipient overtopping into the floodplain. In the case of confined reaches, floodplains (when present) are typically discontinuous, narrow, flood benches along the channel margins. When the channel is vertically disconnected from the floodplain (bottom row in Figure 4-2), the bankfull discharge is contained within the channel, and flows are not able to access the floodplain except during the more rarely-occurring, higher-magnitude floods.

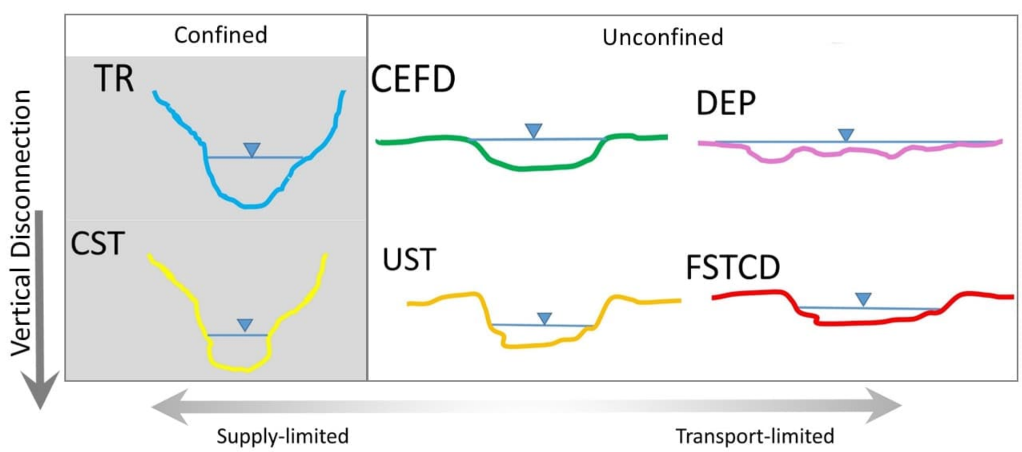


Figure 4-2 Idealized channel cross sections depicting six sediment regime classes, ranging from supply-limited on the left to transport-limited on the right. (TR = Transport; CEFD = Coarse

Equilibrium Fine Deposition; DEP = Depositional; CST = Confined Source & Transport; UST = Unconfined Source & Transport; FSTCD = Fine Source & Transport, Coarse Deposition)

Reaches and segments in the Lake Champlain Basin defined through stream geomorphic assessments (Kline et al., 2009) were approximately classified into the above sediment regime classes using a rule set (Appendix J). This rule set provisionally classifies reaches that have not yet been assessed by field-based methods in SGA Phase 2. The rule set relies on remote-sensing parameters and either field-measured or computer-estimated incision ratio. Sediment regime classes were then tagged to FFI corridor sub-units to screen for erosion hazards (Section 5.2.2).

4.3 REACH-BASED SPECIFIC STREAM POWER

Specific stream power (SSP) is a metric that has been used to assess erosion potential and channel stability (Magilligan, 1992; Nanson and Croke, 1992; Bizzi and Lerner, 2013) (Appendix K). SSP is broadly a function of slope and drainage area, and is calculated as:

$$SSP=\frac{\gamma Q s}{W},$$

where γ is the unit weight of water, Q is the discharge, S is channel slope, and W is channel bankfull width.

UVM researchers have developed a method to calculate reach-averaged SSP relying upon data sets developed from the floodplain mapping workflow (i.e., the probHAND model) (Matt et al., 2022). Reach-averaged SSP varies depending on the discharge through a given reach, and an SSP curve (Figure 4-3) expresses this variability (Matt et al., 2022). SSP variation with increasing flow rate creates unique patterns of in-channel and overbank SSP for each reach, depending on factors such as valley confinement, channel slope, and degree of floodplain connectivity. During FFI, a curve was generated for each reach in the Vermont portion of the Lake Champlain Basin and plotted alongside a band defining an erosion hazard zone between 60 and 300 Watts per square meter (Figure 4-3). The curves are used to predict erosion hazard potential in non-bedrock, alluvial channels (Section 5.2.2).

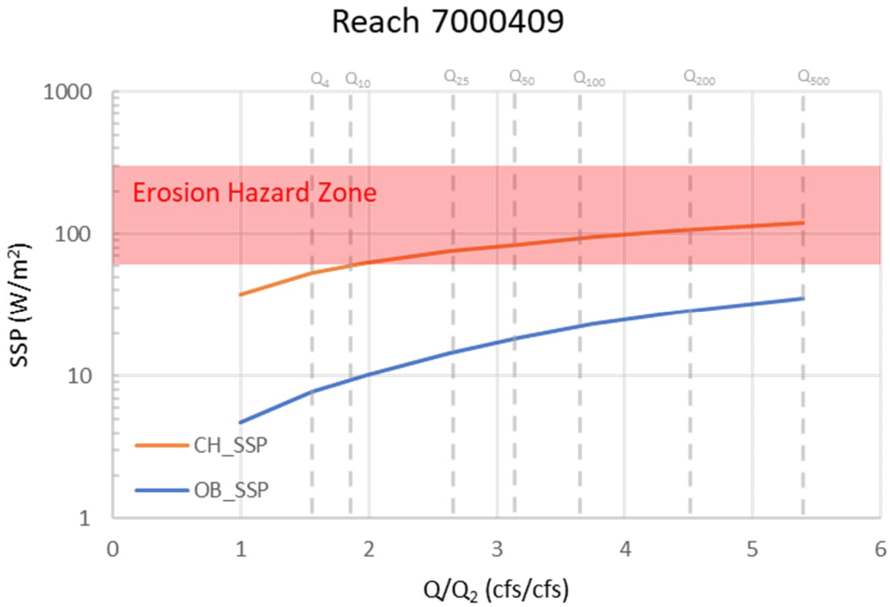


Figure 4-3 Example of an Curves for In-Channel SSP and Overbank SSP for an alluvial reach (Matt et al., 2022). Red Band Indicates the Estimated Critical SSP Erosion Threshold.

4.4 FLOODPLAIN SEDIMENT AND P DEPOSITION

Well-connected floodplains can serve as a transient sink for sediments and nutrients including phosphorus (Noe and Hupp, 2005, 2009). Yet, the magnitude of deposition varies across a region or watershed and over time (at a given site). Ongoing research in the Lake Champlain Basin (Diehl et al., 2021c) is refining estimates of floodplain sediment and phosphorus deposition. Based on observations collected over three years (2019 to 2021) from 128 plots located at 20 sites across the Lake Champlain Basin following eight flood events, representative P deposition rates across floodplains vary from 1.4 to 11.8 kilograms (3 to 26 pounds) of P per acre per year. The P deposition rates were driven by sediment deposition patterns and appeared to be a function of valley width, energy (i.e., SSP), and vertical connectivity (incision ratio) (Diehl et al., 2021b; Diehl et al., 2023).

Diehl et al. (2023) found that sediment deposition varies across a floodplain – being the largest near the channel and decreasing moving away from the channel. Site-specific deposition rates as low as 0.9 pounds (0.4 kilograms) of P per acre per year were observed in settings located far from the channel that have low inundation frequencies and are characterized by fine-grained sediment particles. In contrast, some settings may see much higher P deposition rates on the order of 4.5 to 9.1 kilograms (10 to 20 pounds) of P per acre per year along moderately-steep (i.e., moderate-energy) channels at floodplain sites that are close to the channel and experience regular inundation (Diehl et al., 2019; Diehl et al., 2023).

The research findings (Diehl et al., 2021c) were used in the FFI to set P credit values due to enhanced floodplain storage (Section 5.1.2.3). UVM researchers have developed statistical models to estimate floodplain P deposition at the FFI corridor subunit scale to guide prioritization of floodplain reconnection sites and to optimize P attenuation in connected (or reconnected) floodplains (Diehl et al., 2022b; Diehl et al., 2023). These models are available to predict more refined estimates of P deposition in floodplains to support floodplain restoration design and conservation. In future years, these initial models will be updated with new data from continuing floodplain research.

At present, sediment and phosphorus deposition models are not addressing losses from the floodplain (e.g., due to erosion from the streambank, floodplain stripping, flood chutes). Therefore, these estimates do not constitute net deposition and nutrient uptake estimates. Future research is needed to advance the understanding of the ultimate fate of sediment and nutrients deposited on floodplains.

4.5 RIPARIAN WETLAND NUTRIENT RETENTION

Riparian wetlands are negative-relief floodplain features that may preferentially capture sediments and particulate forms of P. On the other hand, riparian wetlands that remain saturated, allowing anoxic conditions to persist, may become a source of soluble forms of phosphorus. Vermont-based research in riparian wetlands indicates that in settings with high levels of legacy P such as recently farmed fields and during times of persistently saturated conditions, the potential for soluble reactive phosphorus release exists (Wiegman et al., 2022).

UVM researchers have developed a quantitative model to estimate expected P dynamics (i.e., the flow, storage, uptake, and release) in a theoretical range of Vermont riparian wetlands as a function of soils, hydrology, and influent river water quality (Diehl et al., 2022b). This model is available to predict more refined estimates of P retention in riparian wetlands at the FFI corridor subunit scale to support floodplain and wetland restoration project design. Future research will focus on development of soil texture data combined with measures of farming history to map potential risk of soluble phosphorus release from riparian wetlands in the Vermont portion of the Lake Champlain Basin. Currently the FFI awards wetland restoration acreage in river corridors with the same P load reduction credits from storage processes as those awarded to restored floodplains (i.e., acres).

4.6 INSTREAM HABITAT

Instream processes that create and maintain aquatic habitat quality will be evaluated and added to the FFI framework using the connectivity departure data developed for corridor subunits, with different emphasis placed on one or more of the connectivity components depending on the criticality and sensitivity of the headwater or lower valley subunits for providing thermal, resting/feeding cover, and spawning habitats. For instance, lateral-riparian vegetation, longitudinal, and temporal connectivity may be factored higher in steeper headwaters to reflect their importance for groundwater, stream shading, channel spanning wood recruitment (providing for cover and sediment storage), and AOP. Moving downstream into larger, lower gradient (unconfined) streams where depositional processes are key to the retention of cover (sediment sorting and distribution and wood retention), the connectivity components of lateral-meander and vertical connectivity may be factored higher. Lateral-meander connectivity combined with lateral-riparian vegetation connectivity also become more important factors in lower gradient headwaters because they provide conditions suitable for beaver colonization.

SGA Reach Habitat Assessment data (Schiff et al., 2008a), where available, will also be used in the FFI to evaluate instream habitat processes and validate the use of connectivity data in assessing departures in habitat quality.

4.7 FLOODPLAIN HABITAT

Floodplains are home to unique communities of plants and animals that are adapted to high disturbance riparian regimes. The Vermont Fish and Wildlife Department's Natural Heritage program has identified all river corridors as high priority restoration areas. The FFI floodplain habitat research effort seeks to provide a higher level of resolution, at the river corridor sub-unit and stream reach scales, to inform conservation and restoration planning and project prioritization. Research to characterize the reference distribution of floodplain natural communities and animal occupancy is ongoing and will provide the basis for assigning floodplain habitat departure and upland connectivity assessments that can be added to the FFI framework.

5. METHODS TO QUANTIFY PROJECT BENEFITS

Restoration and conservation projects that restore and preserve stream and floodplain connectivity will provide functional lift. In the sections below, we summarize the methods and assumptions used to quantify project benefits in the FFI App (Section 2.3) for water quality, flood resiliency, and habitat.

5.1 WATER QUALITY

Restoration and conservation projects that restore stream and floodplain connectivity will lead to improved water quality, by reducing sediment and nutrient loading to rivers and receiving water bodies. The FFI aims to achieve nutrient load reductions through two primary means: 1) reducing flow depths and velocities, leading to reduced specific stream power that acts on channel bed and banks to mobilize phosphorus-laden sediments; and 2) leveraging (re)connected floodplains and riparian wetlands for enhanced deposition of fine sediments and nutrients.

A river's vertical disconnection from the floodplain induced by watershed-scale disturbances (e.g., increased imperviousness) or reach-scale manipulations (e.g., straightening, dredging) can lead to increased streambank erosion (Simon and Rinaldi, 2006), as the channel is subjected to greater stream power. Similar erosion effects can result when the channel experiences increased entrenchment due to floodplain encroachments (e.g., berms, roads, rails, buildings) that laterally disconnect the channel from its floodplain (Blanton and Marcus., 2009) Enhanced streambank and bed erosion may also occur downstream of longitudinal discontinuities such as dams due to sediment-starved conditions below the impoundment (Williams and Wolman, 1984). These channel and floodplain modifications can cause a stable, near-equilibrium or deposition-dominated reach to shift toward more unstable, transport-dominated and erosive conditions as the disturbance(s) sets in motion a channel evolution process (Schumm et al., 1984; Simon and Rinaldi, 2006) (Figure 5-1).

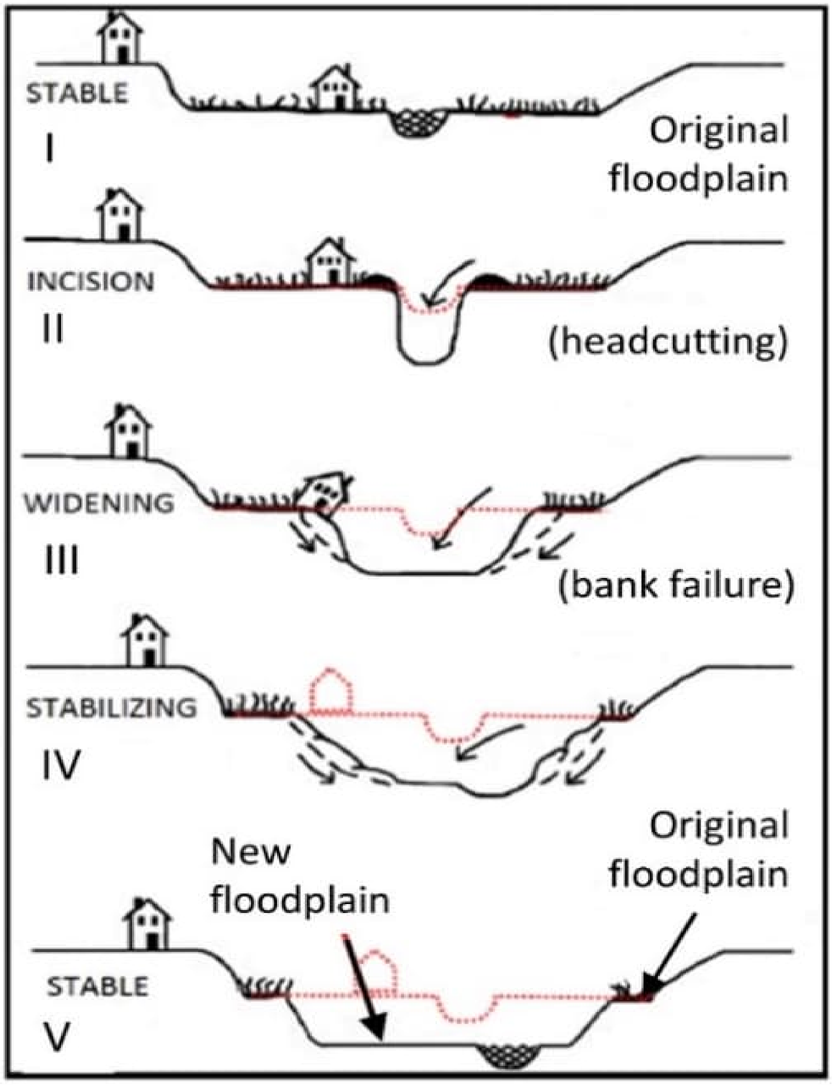


Figure 5-1 Channel Evolution Model Describing Response to a Stressor (Schumm et al., 1984)

In the process of recovering floodplain and stream connectivity, the channel cross section becomes wider and shallower, a more natural meander pattern and reduced channel slope are supported, water depths and channel velocities decrease, and thus stream power exerted on the bed and banks is reduced. In turn, streambank and bed erosion are decreased, leading to a reduction in sediment and nutrient sourcing in the restored reach and a reduction in loading to downstream reaches and waterbodies. In this way, a channel can be returned toward a more stable state that supports equilibrium transport of coarse sediments and allows for overbank deposition of fine sediments and nutrients.

Restoring streams and floodplains can be accomplished through either passive or active techniques. Active approaches essentially accelerate the channel evolution process by re-establishing some degree of floodplain connection through projects including floodplain lowering (Figure 5-2), flood benching, or raising of the channel using stone or wood structures (Appendix L). Passive approaches involve removing constraints such as berms or buildings to give the river the room it needs to express full lateral movement and naturally evolve to a more stable state, well connected to its floodplain. Passive approaches also include establishing protection mechanisms (e.g., river corridor easements, adopting river corridor by-laws) that prevent future floodplain encroachments. When communities refrain from dredging or berming channels after a major flood event, in accordance with recently enacted state policies for flood recovery, these approaches also constitute a passive restoration approach.

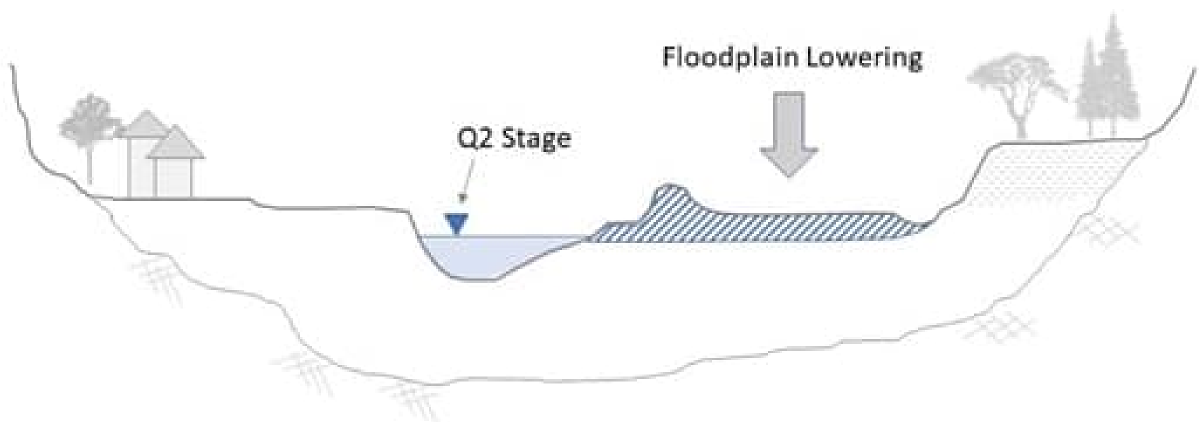


Figure 5-2 Schematic of Floodplain Lowering to Restore the Channel-Floodplain Connection

5.1.1 TMDL BASE LOAD ALLOCATIONS

Under the Lake Champlain TMDL, the baseline phosphorus (P) load attributed to stream instability has been allocated to TMDL sub-basins – one or more that make up each HUC 12 watershed in the Lake Champlain Basin (Figure 5-3). P base load allocations at the sub-basin level are needed for TMDL tracking and accounting of P load reductions resulting from resource management and projects implemented at the reach or subunit scale. Allocating P base loads to river channels at a sub-basin scale recognizes that stream processes, channel evolution trajectories, and stream stability largely operate over geomorphic stream reaches at the watershed scale rather than at individual sites.

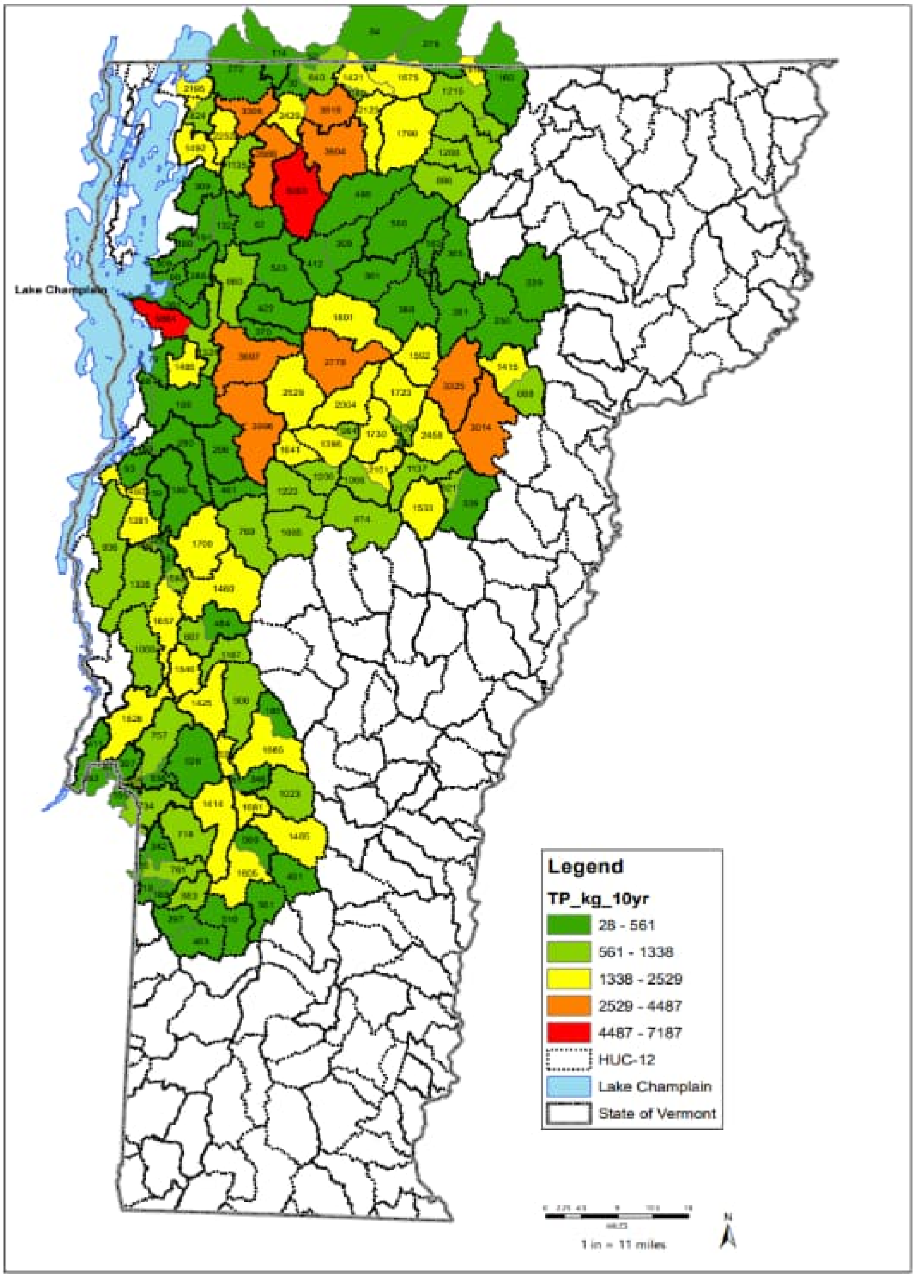


Figure 5-3 Lake Champlain Sub-Basin Phosphorus Load Allocations (Source: VTANR)

Stream stability base loads are allocated in three steps (Kline et al., 2021) (Appendix M). The first step involves splitting the base load between headwaters and lower valley reaches within each HUC 12. The second stage allocates the base load between the stream connectivity (longitudinal/temporal) and flood-plain connectivity (lateral/vertical) considering their relative contribution to the departure or imbalance of the stream-floodplain processes that drive sediment and nutrient loading at the watershed scale (Figure 5-4). The third step in the allocation process gives weight to the size (i.e., acres) of a river corridor and the degree of connectivity departure (Section 3) within the corridor.

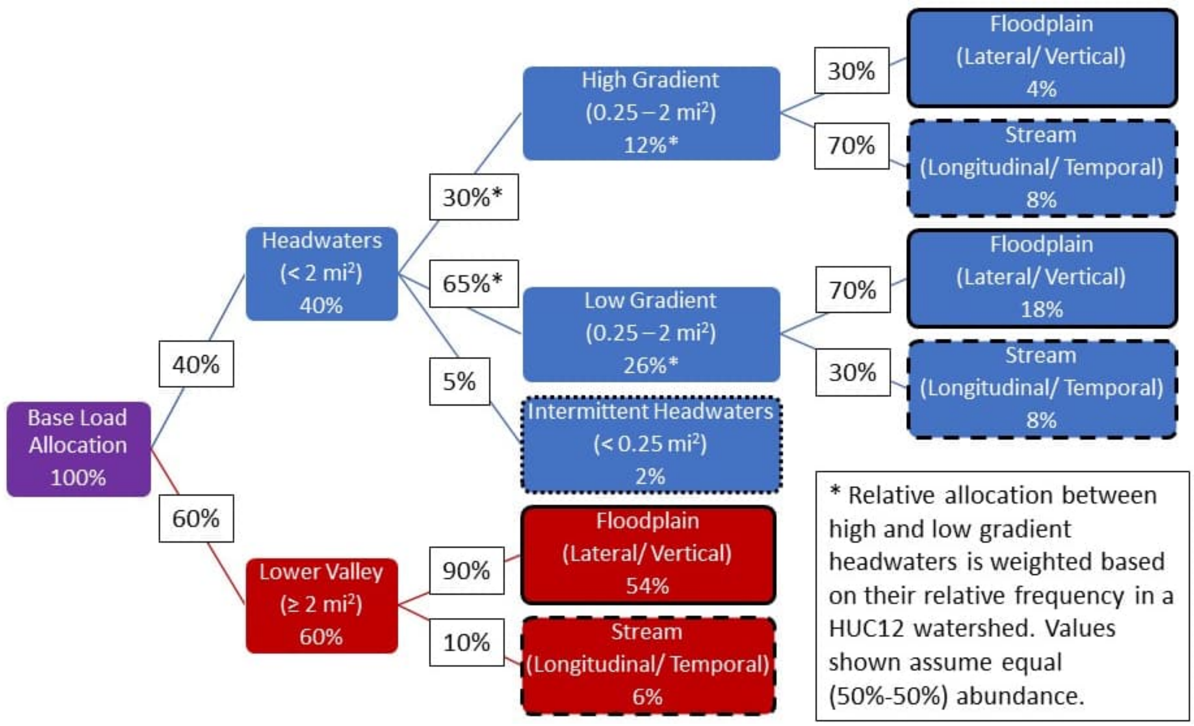


Figure 5-4 Stream stability baseload allocations

5.1.2 PROJECT PHOSPHORUS CREDITING

5.1.2.1 Nutrient Load Reduction Through Floodplain and Stream Reconnection

Floodplain and stream connectivity projects affect ongoing stream processes at both the reach and watershed scales. Therefore, once awarded, P load reduction credits against the TMDL subbasin loads for stream stability (kg/yr or lb/yr) remain constant over time and are directly proportional to the increase in floodplain and/or stream connectivity score achieved by the project when it was completed. It is important to note that projects such as buffer plantings and those that disperse concentrated runoff (i.e., restore temporal connectivity) are awarded P load reduction credits because of their effects on stream stability. However, these project types may also be awarded credits in the development, agriculture, and forest sectors because they treat overland runoff and erosion. P load reductions and crediting related to overland runoff and erosion are not defined in this user guide.

FFI methods for P load crediting for both channel stability and storage (Kline et al., 2021) (See Appendix M) have been incorporated into the TMDL Standard Operating Procedures for Tracking & Accounting of Natural Resources Restoration Projects (VTANR, 2022).

5.1.2.2 Simulations

Median values for P load reduction credits for the stream stability sector were estimated using the FFI dataset for floodplain and stream connectivity for headwater and lower valley streams. For each simulated project, the data were filtered to select subunits meeting the required minimum conditions for the practice implementation (Appendix N).

The simulated typical credits for projects in the Lake Champlain basin have been estimated at various scales for the Lake Champlain Basin - HUC-12 watershed (See Appendix N) and Vermont Planning Basins (Table 5-1, Figure 5-5, and Appendix N). The simulated credits vary based on the stream or floodplain's degree of connectivity departure from target conditions and the stream stability P base load allocation to the HUC12 watershed where the project is located.

Table 5-1 Simulated Median Phosphorus Load Reduction Credits for Common Stream and Floodplain Connectivity Projects

	Basin					
Simulated Project	**Lamoille**	**Missisquoi**	**N. Lake Champlain**	**Otter Creek-Little Otter Creek-Lewis Creek**	**S. Lake Champlain**	**Winooski**
Floodplain Restoration with Buffer Revegetation and Easement (kg/ac/yr)	0.2	1.6	0.4	0.8	0.8	1.4
Floodplain Restoration with Buffer Revegetation (kg/ac/yr)	0.2	1.2	0.3	0.6	0.6	1.1
Remove Hard Constraint (kg/ac/yr)	0.1	0.9	0.2	0.4	0.4	0.9
Passive Restoration - Easement and Buffer Revegetation (kg/ac/yr)	0.1	0.6	0.2	0.3	0.4	0.7
Restore Wetland (kg/ac/yr) - median of HUC12 Sums	0.01	0.03	0.00	0.02	0.01	0.06
Adopt Corridor Bylaws (kg/ac/yr)	0.04	0.2	0.1	0.1	0.1	0.3
Plant 50-Foot Riparian Area (kg/ac/ ac)	0.1	0.4	0.1	0.2	0.3	0.3
Replace Undersized Bridge (kg/bridge/ yr)	0.4	2.4	0.5	1.5	1.1	1.3
Replace Undersized Culvert (kg/culvert/yr)	0.8	6.8	0.7	3.1	2.6	6.1
Large/medium dam removal with floodplain restoration (kg/ac/yr)	0.3	1.8	0.4	1.0	1.0	1.6
Small/ medium intact ROR or breached dam removal with floodplain restoration (kg/ac/yr)	0.3	1.8	0.4	0.9	0.9	2.4
Stabilize Gully on Perennial Stream (kg/project/yr)	0.2	2.7	0.1	0.1	1.7	0.9

In direct drainage watersheds where the stream stability loads are incorporated into the loads of other sectors (i.e., no direct load allocation has been made to the stream stability sector), the North and South

Lake Champlain simulation median credits provide appropriate values for crediting stream and floodplain connectivity projects, given their similarities in land use and natural settings to direct drainages (i.e., topography, soils, precipitation patterns).

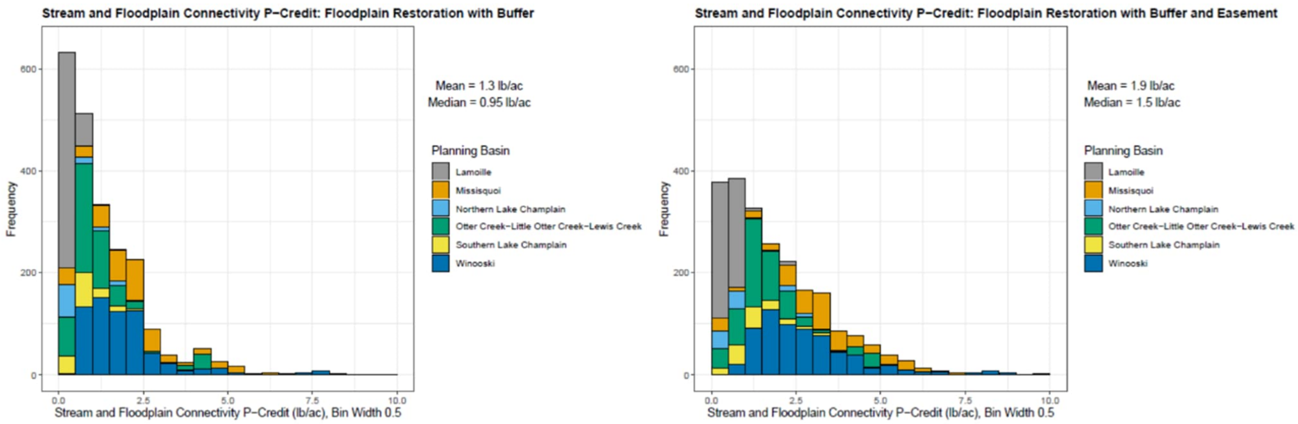


Figure 5-5 Simulated Median P Credit for Stream Stability Sector Projects by VT Planning Basin

5.1.2.3 Nutrient Load Reduction with Increased Storage

In addition to increasing channel stability, most projects that restore connectivity between channel and floodplains improve the natural storage function of floodplains and riparian wetlands allowing for greater attenuation of sediment and nutrient loads (Opperman et al., 2010; Van Appledorn et al., 2019). Phosphorus credits for increased storage are estimated in the FFI Application based on the relative change in floodplain connectivity (Table 5-2). Default P storage credits are provided in full for the initial period of one (1) year, with a 50% reduction in subsequent years, reflecting P attenuation loss over time.

Table 5-2 Estimated P Load Reduction due to Improved Floodplain and Riparian Wetland Storage Indicated by a Change in Floodplain Connectivity

	Default TP Storage Credits (kg/ac/yr)*		
	Low to High	Low to Moderate	Moderate to High
Initial	9.1	6.8	4.5
Future (50%)	4.5	3.2	2.3

	Default TP Storage Credits (lb/ac/yr)*		
	Low to High	Low to Moderate	Moderate to High
Initial	20	15	10
Future (50%)	10	7	5

*To be updated by project specific measurements or future research.

DEC is currently planning on assigning the phosphorus reduction credit associated with floodplain storage to the stream stability sector. Floodplains deposit, store, and release sediment and nutrients that were sourced from the upstream watershed. For this reason, storage credit will also be tracked separately from the channel stability credit in case the methods and capacity are created for assigning the load to upstream watershed sectors where the deposited sediment likely originated from.

Sediment stored for decades or centuries, that is built up behind aging, non-maintained dams or on floodplains in heavily incised channels (i.e., legacy sediment), hold volumes of phosphorus that were not specifically quantified and added to the loads modeled and assigned to the stream stability sector in the TMDL. Although this sediment removal does have an immediate benefit, these volumes are instead considered part of the nutrient load reductions that are credited annually over the longer period of channel evolution that would have otherwise occurred with improving connectivity and equilibrium process accumulated at the watershed scale.

5.1.3 PHOSPHORUS LOAD REDUCTIONS ACHIEVED THROUGH WATERSHED MANAGEMENT AND NATURAL CHANNEL EVOLUTION

Natural events such as floods remove overburden constraints and accelerate the channel evolution process, similarly to the restoration projects described previously. During flood recovery efforts, new public policies ensure that eroded constraints are not always replaced (e.g., FEMA buyouts), or are replaced with more geomorphically-compatible structures (e.g., upsized culverts). Limits on post-flood channel dredging, windrowing, berming and armoring are also in place, so that flood-accelerated channel evolution gains are preserved.

Post-flood steam geomorphic assessments (SGA) have become a priority of VTDEC, especially as the frequency of larger floods seems to be increasing. At the conclusion of an SGA, changes in the acres of (lateral) meander, protection, and buffer connectivity, subunit-scale changes in incision ratio, and changes in structures affecting longitudinal and temporal connectivity within a HUC 12 watershed would be entered in the FFI for a connectivity credit. The resulting changes in connectivity component departures (Section 3) would be translated into a P load reduction from the natural channel evolution observed in the field following a flood, as long as the stream channel was not re-constrained.

5.1.4 COMPARING COST EFFECTIVENESS OF NATURAL RESOURCE PROJECTS AND STORMWATER BEST MANAGEMENT PRACTICES

Phosphorus removal cost-effectiveness values were estimated based on recently completed projects in Vermont (Table 5-3). Cost was compared to the FFI predicted level of annual phosphorus removal built on research and literature (See Sections 4.4 and 5.1.2). Project costs include Project Management, Administration, Assessment, Design, Permitting, Bidding, and Construction. Operation and maintenance, which is expected to be very low for natural resource projects, was excluded to be consistent with state project cost estimating methods. Natural resource project characteristics such as project type, restored floodplain area (acres), and existing connectivity were used to estimate total cost per area ($US/acre), estimated change in P retention (kg/ac/yr), and ultimately cost per kilogram of total P ($US/kg TP/yr) (Appendix O).

Table 5-3 Typical Cost-Effectiveness of Natural Resource Projects

Project Type	Practice	Cost-Effectiveness - Cost per Kilogram TP ($US/kg TP/yr)	
		Practice	Average
Floodplain Restoration	Berm Removal	$4,519	**$22,000**
	Lower Floodplain	$30,902	
	Raise Channel	$35,768	
	Create Flood Bench	$27,229	
Dam removal	Small ROR Dam	$45,236	**$42,000**
	Medium ROR Dam	$29,626	
	Medium Breached Dam	$43,682	
Buffers			**$6,142**
Corridor easement			**$13,103**

Cost-effectiveness values for stormwater best management practices were obtained from a previous Vermont project (USEPA, 2016a) (Table 5-4) to allow for comparison between the cost effectiveness of natural resource and stormwater projects. A list is provided in the FFI application that orders project types from most cost effective to least cost effective (Table 5-5). This table should be used for planning purposes to compare average cost-effectiveness values between project types. Project-specific cost-effectiveness values for the purposes of project prioritization and screening under Formula Grants need to be calculated using the cost effectiveness methodology outlined in Act 76 Guidance. The VTDEC tool available at https://dec.vermont.gov/water-investment/cwi/grants/resources can be used to calculate cost effectiveness following the Act 76 Guidance methodology.

Table 5-4 Typical Cost-Effectiveness of Stormwater Treatment Practices

Practice Type	BMP	Estimated Cost-Effectiveness ($/kg-P removed)	
		BMP	Practice
Infiltration Practices	Surface Infiltration	$27,500	$35,000
	Subsurface Infiltration	$32,500	
	Infiltration Trench	$32,500	
	Rain Garden (no underdrain)	$37,500	
Filtering Practices	Gravel Wetland	$77,500	$95,000
	Constructed Wetlands	$65,000	
	Grass Conveyance Swale	$132,500	
	Rain Garden (with underdrain)	$87,500	
	Sand Filter	$115,000	
Ponds	Wet Pond	$65,000	$180,000
	Extended Dry Detention Pond	$297,500	

Table 5-5 Estimated Cost-Effectiveness of Phosphorus Removal for Natural Resource Projects and Stormwater Best Management Practices

Projcet Class	Project Type	Practice	Cost-Effectiveness ($USD/kg TP/yr)
Natural Resource / Re-Connection Project	Floodplain Restoration	Berm Removal	$ 4,519
Natural Resource / Re-Connection Project	Buffers	Buffers	$ 6,142
Natural Resource / Re-Connection Project	Corridor easement	Corridor easement	$ 13,103
Natural Resource / Re-Connection Project	Floodplain Restoration	Create Flood Bench	$ 27,229
Stormwater Best Management Practice	Infiltration Practices	Surface Infiltration	$ 27,558
Natural Resource / Re-Connection Project	Dam removal	Medium ROR Dam	$ 29,626
Natural Resource / Re-Connection Project	Floodplain Restoration	Lower Floodplain	$ 30,902
Stormwater Best Management Practice	Infiltration Practices	Subsurface Infiltration	$ 33,069
Stormwater Best Management Practice	Infiltration Practices	Infiltration Trench	$ 33,069
Natural Resource / Re-Connection Project	Floodplain Restoration	Raise Channel	$ 35,768
Stormwater Best Management Practice	Infiltration Practices	Rain Garden (no underdrain)	$ 38,581
Natural Resource / Re-Connection Project	Dam removal	Medium Breached Dam	$ 43,682
Natural Resource / Re-Connection Project	Dam removal	Small ROR Dam	$ 45,236
Stormwater Best Management Practice	Filtering Practices	Constructed Wetlands	$ 66,138
Stormwater Best Management Practice	Ponds	Wet Pond	$ 66,138
Stormwater Best Management Practice	Filtering Practices	Gravel Wetland	$ 77,161
Stormwater Best Management Practice	Filtering Practices	Rain Garden (with underdrain)	$ 88,184
Stormwater Best Management Practice	Filtering Practices	Sand Filter	$ 115,742
Stormwater Best Management Practice	Filtering Practices	Grass Conveyance Swale	$ 132,276
Stormwater Best Management Practice	Ponds	Extended Dry Detention Pond	$ 297,621

Comparing the cost-effectiveness of P removal between natural resource restoration projects and stormwater best management practices (Table 5-6 and Table 5-7) illustrates that most natural resource projects are a more cost-effective way to remove phosphorus from streams and increase channel stability. For example, berm removal to reconnect floodplains is the most cost-effective approach (~$4,500 per kilogram of P removed). Berm removal is so cost effective due to the potential reconnection of large areas of river corridor and floodplain for a small excavation footprint of a trapezoidal berm. Stormwater practices typically are 6 to 60 times more expensive (Table 5-6) or could cost between $20,000 and $300,000 more to remove a kilogram of P (Table 5-7).

The cost comparison illustrates that many of the floodplain restoration practices (i.e., lowering the floodplain, raising the channel, or creating flood benches) have a similar cost-effectiveness to stormwater infiltration practices (i.e., surface infiltration, subsurface infiltration, infiltration trenches, and rain gardens without underdrains). The ratio of cost effectiveness ranges between 0.9 and 1.4 (Table 5-6) and the cost difference is between -$3,300 to $11,000 (Table 5-7).

The cost effectiveness review illustrates that both buffer plantings and protecting river corridors through easements are cost effective ways to remove P from streams. These findings support the well-documented facts that vegetated riparian buffers are natural mechanisms that filter runoff and create stable banks and channels. Buffer plantings are 4.5 to nearly 50 times more cost effective at P removal than stormwater practices. Protecting river corridor easements to simply allow the channel to have the space it needs to achieve a stable planform is 2 to 20 times more cost effective than stormwater practices.

Interestingly, extended dry detention ponds, one of the most common stormwater treatment practices, are the least cost-effective way to remove P. A straight comparison of using practices is complicated by the fact that some locations such as developed urban areas require stormwater best management practices to treat concentrated urban runoff. This analysis shows that one must pay a premium to use traditional stormwater practices and that natural resource restoration projects should be prioritized wherever space exists since they are so much more cost effective at removing P and stabilizing channels.

This analysis is conservative in that operation and maintenance costs are not directly considered. This is another area where natural resource projects out-perform stormwater best management practices. Restored floodplains typically need much less maintenance than stormwater practices.

The cost effectiveness of natural resource projects presented here is based solely on the FFI phosphorus load reduction credits. The total cost effectiveness would also reflect the flood resiliency and habitat co-benefits of natural resources projects.

Table 5-6 Cost-Effectiveness Comparison (Ratio) Between Natural Resource and Stormwater Treatment Practices

		Stormwater BMP Cost Multiplier over Natrual Resource Projects (Stormwater $US/lb TP / NR $US/lb TP)										
		Infiltration Practices				Filtering Practices					Ponds	
NR Project Type	NR Practice	Surface Infiltration	Subsurface Infiltration	Infiltration Trench	Rain Garden (no underdrain)	Gravel Wetland	Constructed Wetlands	Grass Conveyance Swale	Rain Garden (with underdrain)	Sand Filter	Wet Pond	Extended Dry Detention Pond
Floodplain Restoration	Berm Removal	6.1	7.3	7.3	8.5	17.1	14.6	29.3	19.5	25.6	14.6	65.9
	Lower Floodplain	0.9	1.1	1.1	1.2	2.5	2.1	4.3	2.9	3.7	2.1	9.6
	Raise Channel	0.8	0.9	0.9	1.1	2.2	1.8	3.7	2.5	3.2	1.8	8.3
	Create Flood Bench	1.0	1.2	1.2	1.4	2.8	2.4	4.9	3.2	4.3	2.4	10.9
Dam removal	Small ROR Dam	0.6	0.7	0.7	0.9	1.7	1.5	2.9	1.9	2.6	1.5	6.6
	Medium ROR Dam	0.9	1.1	1.1	1.3	2.6	2.2	4.5	3.0	3.9	2.2	10.0
	Medium Breached Dam	0.6	0.8	0.8	0.9	1.8	1.5	3.0	2.0	2.6	1.5	6.8
Buffers		4.5	5.4	5.4	6.3	12.6	10.8	21.5	14.4	18.8	10.8	48.5
Corridor easement		2.1	2.5	2.5	2.9	5.9	5.0	10.1	6.7	8.8	5.0	22.7

Table 5-7 Cost-Effectiveness Comparison ($US Difference) Between Natural Resource and Stormwater Treatment Practices

			Stormwater BMP Cost Comparison to Natrual Resource Projects (Stormwater $US/lb TP - NR $US/lb TP)										
			Infiltration Practices				Filtering Practices					Ponds	
NR Project Type	NR Practice	NR Practice Cost ($US/lb TP)	Surface Infiltration	Subsurface Infiltration	Infiltration Trench	Rain Garden (no underdrain)	Gravel Wetland	Constructed Wetlands	Grass Conveyance Swale	Rain Garden (with underdrain)	Sand Filter	Wet Pond	Extended Dry Detention Pond
Floodplain Restoration	Berm Removal	$ 4,519	$ 23,039	$ 28,550	$ 28,550	$ 34,062	$ 72,642	$ 61,619	$ 127,757	$ 83,665	$ 111,223	$ 61,619	$ 293,102
	Lower Floodplain	$ 30,906	-$ 3,344	$ 2,167	$ 2,167	$ 7,679	$ 46,259	$ 35,236	$ 101,374	$ 57,282	$ 84,840	$ 35,236	$ 266,719
	Raise Channel	$ 36,277	-$ 8,211	-$ 2,699	-$ 2,699	$ 2,812	$ 41,393	$ 30,370	$ 96,508	$ 52,416	$ 79,973	$ 30,370	$ 261,853
	Create Flood Bench	$ 27,229	$ 328	$ 5,840	$ 5,840	$ 11,351	$ 49,932	$ 38,909	$ 105,047	$ 60,955	$ 88,512	$ 38,909	$ 270,392
Dam removal	Small ROR Dam	$ 45,236	-$ 17,679	-$ 12,167	-$ 12,167	-$ 6,656	$ 31,925	$ 20,902	$ 87,040	$ 42,948	$ 70,505	$ 20,902	$ 252,385
	Medium ROR Dam	$ 29,626	-$ 2,069	$ 3,443	$ 3,443	$ 8,954	$ 47,535	$ 36,512	$ 102,650	$ 58,558	$ 86,115	$ 36,512	$ 267,995
	Medium Breached Dam	$ 43,854	-$ 16,124	-$ 10,613	-$ 10,613	-$ 5,101	$ 33,479	$ 22,456	$ 88,594	$ 44,502	$ 72,060	$ 22,456	$ 253,939
Buffers		$ 6,142	$ 21,416	$ 26,927	$ 26,927	$ 32,439	$ 71,019	$ 59,996	$ 126,134	$ 82,042	$ 109,600	$ 59,996	$ 291,479
Corridor easement		$ 18,345	$ 14,454	$ 19,966	$ 19,966	$ 25,477	$ 64,058	$ 53,035	$ 119,173	$ 75,081	$ 102,638	$ 53,035	$ 284,518

5.2 FLOOD RESILIENCY

Enhanced flood resiliency for Vermont communities can also be realized by restoring stream and floodplain connectivity. Connected river corridors and floodplains reduce the risk of damage from flood inundation and erosion. Restoration is critical in light of increased intensity and magnitude of precipitation events recorded in the Northeast (Guilbert et al., 2014; Guilbert et al., 2015) that have led to increasing frequency of high flows impacting stream channels (Collins, 2009; Armstrong et al., 2012).

Since the 1970's USGS gauges in our region indicate higher flows are taking place and this trend has been observed in Vermont (Schiff et al., 2015a) (e.g., Figure 5-6).

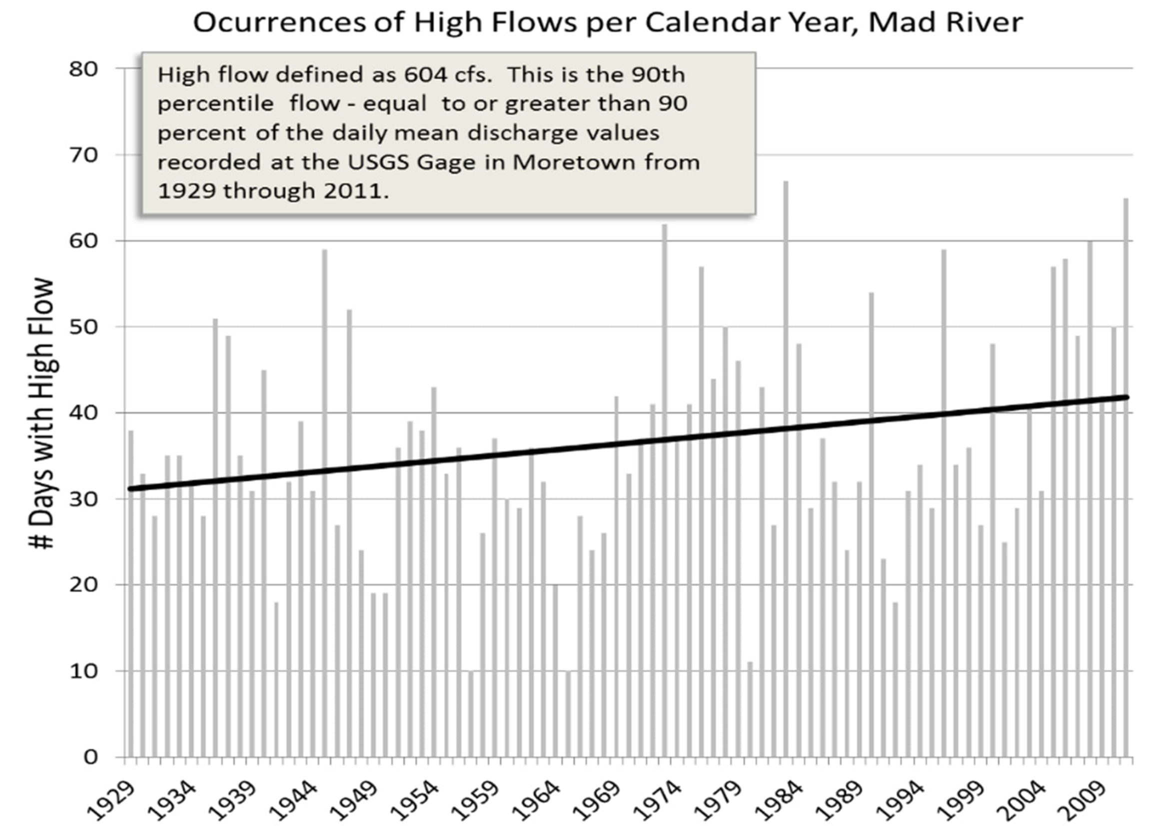


Figure 5-6 Increasing trend of frequency of days experiencing high-magnitude discharges over record from 1929 through 2011 in the Mad River.

5.2.1 REDUCTION OF INUNDATION-RELATED DAMAGES

Increased floodwater storage on floodplains and in riparian wetlands has the potential to decrease down-stream flood peaks in optimal settings (Watson et al., 2016). The potential cost savings through avoided damages can be realized near, upstream, and downstream of reconnection projects as flood water depths tend to be shallower. A review of hydraulic modeling used to design Vermont floodplain reconnection projects over the last decade suggests that larger reconnection areas lead to greater flood depth reductions that extend further up- and downstream from the project site. In this case, it would follow that the larger the reconnection project, the larger the flood damage reduction.

Note that not all settings will realize a reduction in downstream flood peaks or flood depths (e.g., Worley et al., 2022). Generally, reconnection of floodplains will be more effective for larger reconnection project footprints on lowland reaches with low gradients (e.g., less than 0.1 %). The behavior of flood peaks and stages in the downstream direction will vary with floodplain and river width, depth, and incision (Bhowmik, 1984).

FEMA HAZUS documentation (FEMA, 2012, 2013) suggests that common damage reduction levels are 4% per foot of flood reduction (Figure 5-7). Vermont modeling of reconnection projects suggests that a common flood reduction level for reconnection projects is 2 feet (0.5 to 3 feet).

For planning purposes, we estimated the percent hazard reduction for reconnection projects due to flood inundation based on the project size: small (< 1 acre), medium (1 to 5 acres), and large (> 5 acres). Hazard reduction varies with channel slope as flatter channels tend to flood deeper leading to more inundation damage and greater potential risk reduction. Reconnection projects decrease the hazard for small and moderate floods more than larger floods that tend to inundate large floodplain areas.

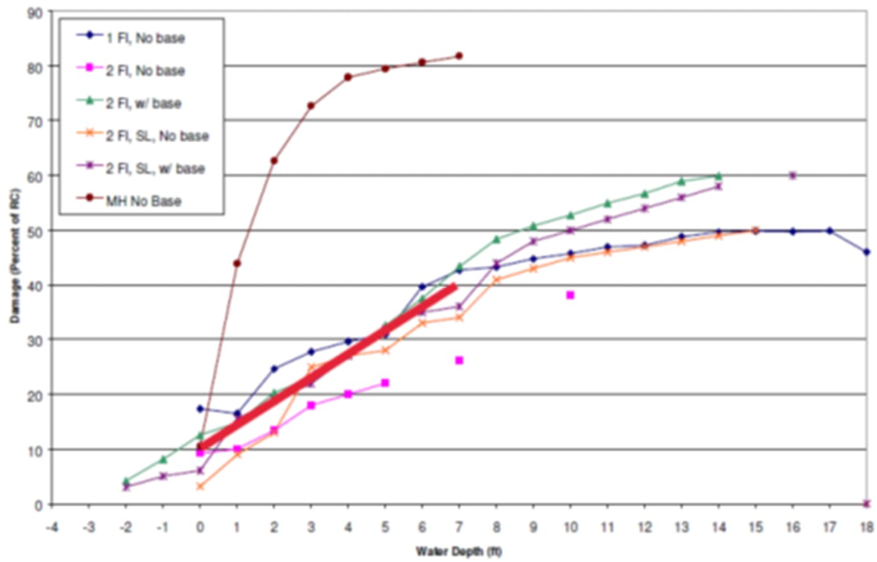


Figure 5-7 FEMA Depth-Damage Curves and Composite (Red)

Based on past flood data and reconnection projects, the predicted inundation risk will decrease between 0% and 20% of the total cost of improved property and infrastructure in the estimated 500-year floodplain (Table 5-8) (Appendix P). The extent of the damage reduction will likely vary from approximately 1,500 feet for smaller projects to nearly 6,000 feet for larger projects in lower valley settings.

An example along the Mad River in Waitsfield indicates that inundation risk reduction due to a 3.8-acre reconnection project could avoid $325,000 in future damages due to a single large flood event (Figure 5-8). The extent of the inundation damage reduction is not assumed to extend longitudinally beyond a headwater river corridor subunit.

Table 5-8 Inundation Hazard Reduction

Building Inundation Hazard Reduction (slope ≤ 0.5%)

	Percent Hazard Reduction				Spatial Extent of Hazard Reduction				
Reconnection Project Size	≤10 year	25-50 year	> 50 year		Upstream 2	Upstream1	SubUnit	Downstream1	Downstream2
< 1 ac	10%	5%	0%		0	0	1	0	0
1-5 ac	15%	10%	5%		0	1	1	1	0
> 5 ac	20%	15%	10%		0.5	1	1	1	0.5
	High	**Medium**	**Low**	**rd Potential**					

Building Inundation Hazard Reduction (slope > 0.5%)

	Percent Hazard Reduction				Spatial Extent of Hazard Reduction				
Reconnection Project Size	≤10 year	25-50 year	> 50 year		Upstream 2	Upstream1	SubUnit	Downstream1	Downstream2
< 1 ac	5%	0%	0%		0	0	1	0	0
1-5 ac	10%	5%	0%		0	0.5	1	0.5	0
> 5 ac	15%	10%	5%		0	0.5	1	0.5	0

Infrastructure Inundation Hazard Reduction (slope ≤ 0.5%)

	Percent Hazard Reduction				Spatial Extent of Hazard Reduction				
Reconnection Project Size	≤10 year	25-50 year	> 50 year		Upstream 2	Upstream1	SubUnit	Downstream1	Downstream2
< 1 ac	2%	0%	0%		0	0	1	0	0
1-5 ac	4%	2%	0%		0	1	1	1	0
> 5 ac	6%	4%	2%		0.5	1	1	1	0.5

Infrastructure Inundation Hazard Reduction (slope > 0.5%)

	Percent Hazard Reduction				Spatial Extent of Hazard Reduction				
Reconnection Project Size	≤10 year	25-50 year	> 50 year		Upstream 2	Upstream1	SubUnit	Downstream1	Downstream2
< 1 ac	0%	0%	0%		0	0	1	0	0
1-5 ac	2%	0%	0%		0	0.5	1	0.5	0
> 5 ac	4%	4%	2%		0	0.5	1	0.5	0

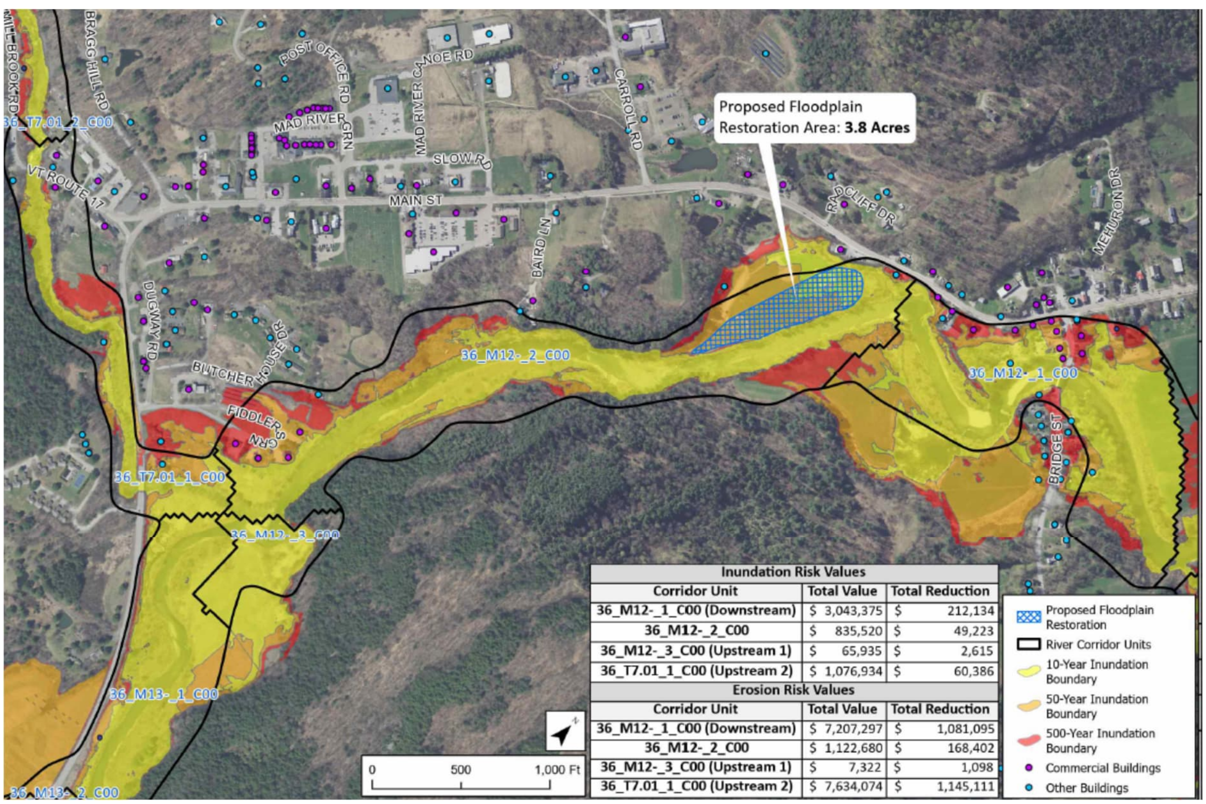


Figure 5-8 Damage Reduction Example

5.2.2 REDUCTION OF EROSION-RELATED DAMAGES

Restoring floodplain connection in reaches that have undergone human-induced incision and encroachment will reduce specific stream power in the restored reach leading to reduced bank and channel erosion. Reconnection projects lead to erosion risk reduction that can reduce the cost of future potential damages. In the Lake Champlain Basin, erosion risk reduction potential is larger than inundation risk reduction since erosion tends to lead to greater damage and often complete destruction of buildings or infrastructure.

Improved property is often preferentially located in river corridors and floodplains based on historic development patterns along rivers. As an initial indicator of vulnerability, the amount of infrastructure in each corridor subunit and 500-year floodplain was estimated (See Appendix P). This value sets the stage for flood and erosion damages and potential savings due to reconnection projects.

Erosion (and deposition) risks are largely a function of a channel's sediment regime (Kline, 2010). For example, coarse equilibrium and fine deposition (CEFD) and transport (TR) reaches tend to have low erosion risk. Confined source transport (CST), unconfined source and transport (UST) and deposition (DEP) reaches tend to have high erosion risk. Fine sediment transport and course (sediment) deposition (FSTCD) reaches have moderate to high erosion risk depending of the degree of later meander connectivity (LMC). Sediment regime classes were used for initial erosion risk assignment (Table 5-9).

Table 5-9 Erosion Risk and Sediment Regime Class (Kline, 2010)

CEFD / TR	FSTCD - LMC ≤ 20% disconnected	CST / UST / FSTCD - LMC > 20% disconnected / DEP
LOW	MODERATE	HIGH

Rules were created to refine the initial erosion risk based on stream power modeling and channel network setting. If moderate risk sites have specific stream power estimates in the 60 to 300 watts per square meter range where erosion is most common (Magilligan, 1992; Knighton, 1999) and a network indicator of increased erosion vulnerability (i.e., near a confluence, have undersized crossings, or have a large slope decrease), the site erosion risk is increased to high. If high erosion risk sites do not have any of the power or network indicators, they are reduced to moderate risk, otherwise they remain high.

Two erosion hazard flags were developed, one for small flood events and one for large flood events. The small flood hazard is triggered when the 10-year flood has a channel specific stream power greater than 60 W/m2. The large flood hazard is triggered when the 100-year flood has a channel specific stream power greater than 300 W/m2 (personal communication, S. Lawson).

In the headwaters, sediment regime and stream power data are not widely available, so erosion risk was determined based on slope and lateral meander connectivity (See Appendix P). The extent of the erosion damage reduction is not evaluated longitudinally beyond the headwater subunit.

Based on past flood data and reconnection projects, the predicted erosion risk will decrease between 5% and 50% of the total cost of improved property and infrastructure in the river corridor (Table 5-10) (See

Appendix P). The extent of the damage reduction will likely vary from approximately 1,500 feet for smaller projects to nearly 5,000 feet for larger projects in lower valley settings.

Table 5-10 Erosion Hazard Reduction

	Percent Hazard Reduction			Spatial Extent of Hazard Reduction				
Reconnection Project Size	High Damage Potential	Moderate Damage Potential	Low Damage Potential	Upstream 2	Upstream1	SubUnit	Downstream1	Downstream2
< 1 ac	20%	10%	5%	0	0	1	0	0
1-5 ac	30%	15%	10%	0	1	1	1	0
> 5 ac	50%	25%	15%	0	1	1	1	1

An example along the Mad River in Waitsfield indicates that erosion hazard reduction due to a 3.8-acre reconnection project could avoid $2,400,000 in future damages due to a single large flood event (See Figure 5-8).

5.2.3 TRACKING RESILIENCY

A scoring system has been developed in FFI to track the resiliency gains as floodplains become reconnected and naturalized. Infrastructure and property in river corridors and floodplains are prone to flood and erosion damages. The more vulnerable property in these hazardous areas, the less resilient the setting (Table 5-11).

Table 5-11 Resiliency Scoring

Value of vulnerable property and infrastructure in Corridor / Floodplain(US$)	Vulnerability Rank
>1,000,000	High
500,000 to 1,000,000	Moderate-High
300,000 to 500,000	Moderate
100,000 to 300,000	Moderate-Low
<100,000	Low

As reconnection projects are completed that reduce flood (0% to 20%) and erosion (5% to 50%) hazards, the amount of vulnerable infrastructure and property value decreases and resiliency increases. As reconnection projects increase in a river corridor, floodplain, and even small watershed; the flood resiliency of the area will increase from low to moderate to high. Note that residual risk will always remain in river corridors and floodplains as these areas are dynamic locations where stream processes and uplands interact.

5.3 HABITAT

Restored instream, riverbank, and floodplain habitat will be instrumental in maintaining biodiversity and the unrestricted movement of organisms – both up- and downstream within the river network and laterally between the floodplain and upland natural communities (Ward et al., 1999). Enhanced habitats will support adaptation to a changing climate that includes both increased frequency and magnitude of precipitation and flooding events, but also increased temperatures and frequency of dry spells/drought (Betts, 2011; Guilbert et al., 2014).

Vermont assessment protocols have been developed for instream habitat (Schiff et al., 2008a), riparian corridors (Sorenson and Zaino, 2018), and natural community mapping (Thompson et al., 2019). Future work funded by the Lake Champlain Basin Program (2022-2025) and The Nature Conservancy (2021-2022) will be building on these protocols leveraging remote sensing resources and new data collected on amphibian and mammal indicator species occupancy to map instream and floodplain habitat mosaics and evaluate their connectivity to upland natural communities under both existing and restored conditions.

5.3.1 AQUATIC ORGANISM PASSAGE

Future FFI work under LCBP project.

5.3.2 INSTREAM COVER MOSAICS

Future FFI work under LCBP project.

5.3.3 FLOODPLAIN HABITAT MOSAICS AND LATERAL RIVERSCAPE MIGRATION

Future FFI work under LCBP project.

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APPENDIX A

GLOSSARY

Acronyms

App – Application

DEC – Vermont Department of Environmental Conservation

FEA – Fitzgerald Environmental Associates, LLC

FFI – Functioning Floodplain Initiative

FM – Fluvial Matters, LLC

GIS – Geographic Information System

HUC – Hydrologic Unit Code

SEI – Stone Environmental, Inc.

SLR – SLR Consulting

SMRC – South Mountain Research and Consulting

SSP – Specific stream power

TMDL – Total Maximum Daily Load

TNC – The Nature Conservancy

TRPT – Vermont Transportation Resilience Planning Tool

UVM – University of Vermont

VCGI – Vermont Center for Geographic Information

VEM – Vermont Emergency Management

VTACCD – Vermont Agency of Commerce and Community Development

VTANR – Vermont Agency of Natural Resources

VTrans – Vermont Agency of Transportation

WID – DEC Water Infrastructure Division

WPD – Watershed Project Database

Glossary of Terms

Aggradation – A progressive buildup or raising of the channel bed and floodplain due to sediment deposition. The geologic process by which streambeds are raised in elevation and floodplains are formed. Aggradation indicates that stream discharge and/or bed-load characteristics are changing. Opposite of degradation.

Alluvial – Deposited by running water.

Avulsion – A change in channel course that occurs when a stream suddenly breaks through its banks, typically bisecting an overextended meander arc. An avulsion is often triggered by excessive deposition during a flood that reduces the channel area where flood water can be carried leading to a rapid channel relocation. Avulsions are often hazardous damaging infrastructure and properties by excessive erosion.

Bank stability – The ability of a streambank to counteract erosion or gravity forces.

Bankfull discharge – The stream discharge corresponding to the water stage that overtops the natural banks. This flow occurs, on average, about once every 1 to 2 years and given its frequency and magnitude is responsible for the shaping of most stream or river channels, and effectively transporting a large amount of sediment over the long term.

Bankfull width – The width of a river or stream channel between the highest banks on either side of a stream in a non-incised setting, typically containing the 1.5- to 2-year flood.

Bar – An accumulation of alluvium (usually gravel or sand) caused by a decrease in sediment transport capacity on the inside of meander bends or in the center of an overwide channel.

Base flow – The portion of stream flow that is drawn from natural watershed storage source and not runoff following precipitation.

Berms – constructed mounds of dirt, earth, gravel, or other fill built parallel to the stream banks designed to keep flood flows from entering the adjacent floodplain. Berms were historically used to protect property near channels but are now not allowed as we know that they confine flood flows, actually increase risk, and create a false sense of safety.

Boundary resistance – The ability of a stream bed or bank to withstand the erosional forces of the flowing water at varying intensities. Under natural conditions boundary resistance is increased due to larger sediment sizes and vegetation (roots).

Braided – A stream channel pattern characterized by flow in several channels typically made of coarse sediment that are dynamic and regularly change course during flooding. Braiding often occurs when sediment loading is too large to be carried by a single channel for the given flow and channel slope.

Buffer – A strip of vegetation such as forest or unmowed perennials between waterways and land uses such as agriculture or urban development designed to provide streambank boundary resistance, slow flood velocities in the near-bank region, and to slow runoff and filter pollution before it reaches the surface water resource. Buffers tend to be static and equal width such as 50 feet on either side of the channel.

Catchment – A small watershed typically consisting of a local drainage network in the headwaters or a stream reach with a length around 0.5 miles.

Channel – An area that contains continuously or periodically flowing water that is confined by banks and a streambed.

Channel slope – The inclination of the channel bottom, measured as the elevation drop per unit length of channel or percent.

Channelization – The process of changing the natural path of a waterway, usually through straightening and armoring with rock or walls.

Confluence – The meeting or junction of two or more streams; also, the place where these streams meet.

Conservation – The preservation of lands to protect the natural process or means of achieving recovery of viable populations.

Culvert – A structure that conveys a stream under a road that has fill over it. Culverts are typically closed pipes, closed boxes, open boxes, or open arches. Culverts have historically been sized through hydraulic modeling of water, and are now sized through both hydraulic modeling and bankfull width of the channel to be able to pass sediment and wood during floods.

Degradation – A progressive lowering of the channel bed due to scour. Degradation is an indicator that the stream's gradient, discharge, and/or sediment load is changing.

Deposition – The accumulation of sediment and wood that leads to the formation of bars and floodplains. Deposition at structures during flood events may lead to overtopping and structure failure.

Drainage area – The total surface area upstream of a point on a stream that drains toward that point.

Drainage basin – The total area of land from which water drains into a specific river.

Entrenchment Ratio – The width of the floodprone area divided by the bankfull width that indicates how broad the floodplain is.

Equilibrium Condition – The state of a river reach in which the input of energy (flow of water and slope of channel) is in balance with the resistance of the river bed (sediment size). Natural river reaches in equilibrium without human impacts tend towards a most stable state where predictable channel forms are maintained over the long term under varying flow conditions.

Erosion – Wearing away of the banks, channel bed, road embankment and structure abutments/footings due to high-velocity flows moving material downstream.

Floodplain – Land adjacent to a river that is regularly flooded. The 100-year floodplain that is often regulated by FEMA is the floodplain that has a 1% chance in a given year of being inundated, or is typically flooded once in 100 years.

Floodplain Function – Flood water access of floodplains that spreads flood width and decreases flood velocity and stream power. Floodplain access reduces erosion, increases sediment deposition and storage, and allows for nutrient uptake.

Floodprone Width – The width of flooding at two (2) times the maximum depth of the bankfull channel, typically assumed to be about the 50-year flood depth that is used for calculating entrenchment ratio.

Flow – The measure of the volume of water passing a point in a stream over a given time, usually expressed in cubic feet per second (cfs).

Fluvial Geomorphology – The study of river form and processes, and how rivers and their landforms interact over time.

Functioning Floodplain Initiative – The system to evaluate and improve the hydrologic connectivity of Vermont's rivers and floodplains toward a dynamic equilibrium to achieve the water quality, flood resiliency, and habitat benefits.

Geographic information system (GIS) – A computer program that stores spatial data, facilitates spatial analysis, and allows for data presentation in maps and tables.

Geomorphology – A branch of physiography and geology that deals with the form of the earth, the general configuration of its surface, and the changes that take place due to erosion of the primary elements and the buildup of erosional debris.

Grade Control – A fixed feature on the streambed that controls the bed elevation at that point, effectively fixing the bed elevation from potential incision. Natural grade control consists of bedrock or large wood spanning the channel. Manmade grade control consists of weirs and bed armoring.

Gradient – The slope, or vertical drop per unit of horizontal distance, typically measured in % or foot/foot.

Headcut – A sharp change in slope, almost vertical, where the streambed is being eroded from downstream to upstream.

Headwater – Referring to the source of a stream or river. Often used to describe small channels with stream order 2 or lower.

High-Gradient Streams – Steeper streams that may have cascade, step/pool, or riffle/pool bedforms. Most of the streams in Vermont are high-gradient streams.

Hydraulic Radius – The cross-sectional area of a stream divided by the wetted perimeter.

Hydrograph – A curve showing stream flow over time. Hydrographs are used to show the rise, peak, and decline of a flood.

Hydrologic Unit Code (HUC) – A numeric code that defines a distinct watershed or river basin. The more digits in the HUC, the smaller the drainage.

Hydrology – The study of the water of the earth, its occurrence, circulation and distribution, its chemical and physical properties, and its interaction with its environment, including its relationship to living things.

Incised River – A river that erodes its channel and cuts down reducing its connection to its floodplain. Incised rivers tend to be excessively erosive and prone to causing flood damage. Post-flood dredging may also result in an incised river.

Incision Ratio – The low bank height divided by the bankfull maximum depth that indicates the level of vertical floodplain connection. An incision ratio of 1.0 to 1.2 indicates a good connection, while an incision ratio larger than 1.5 indicate a loss of connection that is likely to result in an increase in erosion and channel degradation.

Intermittent Stream – Any nonpermanent flowing drainage feature having a definable channel and evidence of scour or deposition.

Inundation – Submergence of a habitable structure, a stream crossing or low spot in the road due to rising floodwaters.

Large Wood – Also known as large woody debris (LWD). Pieces of trees at least 6 feet long and 1 foot wide contained, at least partially, within the bankfull area of a channel.

Low-Gradient Streams – Streams that have low slope and typically appear slow moving and winding.

Mainstem – The principal channel of a drainage system into which other smaller streams or rivers flow.

Mass Failure – The downslope movement of earth caused by gravity. Includes but is not limited to landslides, rock falls, debris avalanches, and creep. It does not however, include surface erosion by running water. It may be caused by natural erosional processes, or by natural disturbances (e.g., earthquakes or fire events) or human disturbances (e.g., mining or road construction).

Meander – The bend or winding of a stream channel, usually in an erodible alluvial valley.

Median Gran Size (D50) – The median grain size of a sediment sample that falls in the middle of the distribution of size or mass of particles.

Natural Flow – The flow past a specified point on a natural stream that is unaffected by stream diversion, storage, import, export, return flow, or change in use caused by modifications in land use.

Outfall – The mouth or outlet of a river, stream, lake, drain or sewer.

Perennial Streams – Streams that flow continuously.

Probability of Exceedance – The probability that a random flood will exceed a specified magnitude in a given period of time.

Reach – A section of stream having relatively uniform physical attributes, such as valley confinement, valley slope, sinuosity, dominant bed material, and bed form, as determined in geomorphic assessment. An individual stretch of stream that has beginning and ending points defined by identifiable features such as where a tributary confluence changes the channel character or order.

Recurrence Interval – An estimation of the probability of a flood event of a given size occurring based on measurements of the historic flow record, expressed in years or exceedance probability (percentage).

Reference Stream Type –Observations of the natural channel form and process that would be present in the absence of anthropogenic impacts to the channel and the surrounding watershed.

Relief – Elevation difference between two or more features.

Resilience – The ability of a system, in this case a river and floodplain, to function naturally upon disturbance such as floods or droughts.

Restoration – The return of an ecosystem to a close approximation of its condition prior to disturbance.

Riparian – Located on the banks of a stream or other body of water.

Riparian Buffer – Riparian buffer is the width of naturally vegetated land adjacent to the stream between the top of the bank (or top of slope, depending on site characteristics) and the edge of other land uses. The buffer is often designated by a direct setback from the top of the bank. A buffer is largely undisturbed and consists of the trees, shrubs, groundcover plants, duff layer, and naturally uneven ground surface. The buffer serves to protect the water body from the impacts of adjacent land uses.

Riparian Vegetation -- The plants that grow adjacent to a wetland area such as a river, stream, reservoir, pond, spring, marsh, bog, meadow, etc., and that rely upon the hydrology of the associated water body.

Riprap – Rock or other material with a specific mixture of sizes referred to as a "gradation," used to stabilize streambanks or riverbanks from erosion or to create habitat features in a stream.

River Corridor – The space required by a river to maintain natural dynamic equilibrium with stable stream dimension, pattern, profile, and sediment regime through meandering down a valley. In Vermont, this includes the meander belt that is a function of the geomorphic stream type (e.g., 6 bankfull channel widths for riffle-pool channels) plus a 50-foot buffer. The river corridor is broken into subunits for FFI.

River Stage – The elevation of the water surface above a known or arbitrary datum.

Riverine – Relating to, formed by, or resembling a river including tributaries, streams, brooks, etc.

Runoff – Water that flows over the ground and reaches a stream because of rainfall or snowmelt. River flow is runoff in terms of the hydrologic cycle where water travels from mountains to ocean.

Scour – The erosive action of running water in streams that excavates and carries away material from the bed and banks. Scour may occur in both earth and solid rock material and can be classed as general, contraction, or local scour.

Sediment – Soil or mineral material transported by water or wind and deposited in streams or other bodies of water.

Sedimentation – Deposition of sediment.

Siltation – The deposition or accumulation of fine soil particles.

Sinuosity – The ratio of channel length to direct down-valley distance. Also may be expressed as the ratio of down-valley slope to channel slope.

Slope – The ratio of the change in elevation over distance.

Slope Stability – The resistance of a natural or artificial slope or other inclined surface to failure by mass movement, geotechnical forces, or hydraulic forces.

Specific Stream Power – Stream power dived by the bankfull channel width to normalize by unit length of channel. See Stream power definition. Specific stream power range of 100 to 300 Watts per square meter are where the most erosion damages tend to occur when resistance is not very high.

Stone – Rock or rock fragments used for construction.

Straightening – The removal of meander bends, often done in towns and along roadways, railroads, and agricultural fields for increased use of land or for historic log drives.

Stream Banks – The top of bank is the point where an abrupt change in slope is evident, and where the stream is generally able to overflow the banks and enter the adjacent floodplain during flows at or exceeding the average annual high water.

Stream Channel – Water flowing in a natural, small channel that is normally wetted and provides a substrate that supports aquatic organisms.

Stream Order – A hydrologic system of stream classification where each small unbranched perennial tributary is a 1st order stream. Two first-order streams join to make a second-order stream. A third-order stream has only first-and second-order tributaries, and so forth.

Stream Power – The ability of a stream to do work as it flows down-gradient, causing the environment to be erosional or depositional. The power works on the bed and banks that resist the erosion.

Streambank Armoring – The installation of concrete walls, gabions, stone riprap, and other large erosion resistant material along stream banks.

Streambank Erosion – The removal of soil from streambanks by flowing water.

Streambank Stabilization – The lining of streambanks with riprap, matting, vegetation, or other measures intended to control erosion.

Streamflow – The rate at which water passes a given point in a stream or river, usually expressed in cubic feet per second (cfs).

Surface Water – All waters whose surface is naturally exposed to the atmosphere, for example, rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.

Total Maximum Daily Load – A plan for restoring impaired waters that identifies the maximum amount of a pollutant that a body of water can receive while still meeting water quality standards. For this project mostly referring to the Phosphorus TMDL for Lake Champlain.

Tributary – A stream that flows into another stream, river, or lake.

Valley – A large geologic feature that contains a river channel and floodplains, and dictates geomorphic stream type, expected channel stability, and habitat.

Valley Confinement – The ratio of valley width to channel width. Unconfined channels (confinement of 4 or greater) flow through broader valleys and typically have higher sinuosity and area for floodplain. Confined channels (confinement of less than 4) typically flow through narrower valleys.

Valley Wall – The side of a valley that begins where the topography transitions from the gentle-sloped valley floor to steep terrain. The distance between valley walls is used to calculate the valley confinement.

Vulnerability – The likelihood of damage resulting from inundation, erosion, or deposition.

Water Quality – The chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.

Watershed – An area of land whose total surface drainage flows to a single point in a stream.

Wetland – Areas adjacent to a stream with sufficient hydrology to have hydric soils and hydrophytic vegetation (e.g., cattails, sedges, rushes, willows or alders).

APPENDIX B

COMPANION DATA SOURCES FOR FFI PROJECT DEVELOPMENT

Companion Data Sources for FFI

1. **ANR Atlas –https://anrmaps.vermont.gov/websites/anra5/**
    - Rivers Layers – contains
        - Stream Geomorphic Assessment (SGA) data
        - Dams
        - FEMA map information
        - Statewide River Corridor Layer
        - River Corridor easement sites
        - River Scientists, Floodplain Managers, and River Management Engineers District Maps
    - Fish & Wildlife Layer
        - Stream Crossing Data
    - Base Map layers
        - VT Culverts
        - Bridge & Culvert Inventory
        - Stormwater (Stormwater Infrastructure; Hydrologically Connected Road)
2. **Stream Geomorphic Assessment (SGA) – River Corridor Plans and Final Reports - https://anrweb.vt.gov/DEC/SGA/finalReports.aspx**
        - SGA Database - https://anrweb.vt.gov/DEC/SGA/projects.aspx (provides specific reach/segment data)
3. **Wetland Inventory Map https://anrmaps.vermont.gov/websites/WetlandProjects/default.html**
4. LIDAR
5. Google Earth – Current / Historic /Street Views
6. Bing Imagery – Current / Street Views
7. VT Center For Geographical Information (VCGI) 1962 Aerial Imagery - https://vcgi.vermont.gov/data-release/1962-aerial-imagery-now-available-statewide-non-georeferenced
8. Vermont landcover data and maps - https://geodata.vermont.gov/pages/land-cover
9. Lake Champlain Basin Lidar-Informed Flood Inundation Layer - https://vcgi.vermont.gov/data-release/lake-champlain-basin-lidar-informed-flood-inundation-layer-now-available

APPENDIX C

WEB APPLICATION USER STORY EXERCISE

Web Application User Story Exercise

A user story exercise was conducted to collect information from a wide range of stakeholders and potential application users. We received 65 user stories, 13 from the internal project team and 52 from stakeholders across 18 categories based on their organization/role (Figure C1). These included stories from all ‘primary’ user groups. Stakeholders were asked to provide input in the form of ‘stories’ as to what type of application user they were, what tasks they wanted to perform using the application, and what they wanted to achieve based on this task. Categories of information were identified based on initial review of stakeholder user stories, including overall user focus, planning focus, tracking completed projects/progress/results, spatial extent of interest, application map visualization, attributes of interest (data requirements), connection to other databases/tool, map base layers. Based on the compiled user stories, we identified common elements within categories to generate prioritized lists of user requirements.

Figure C1. Word cloud based on number of user stories from different organization/roles.

Most users were interested in using the application for project planning versus evaluation of project outcomes (75% and 25%, respectively). Of those interested in project planning, approximately 60% of those wanted to generate a list of prioritized project and approximately 17% wanted to find locations to apply a certain type of project. Of those users who expressed interest in project outcomes, approximately 56% were interested specifically in phosphorus (P) reductions achieved while approximately 44% were interested in understanding how much floodplain reconnection was achieved to enhance flood resiliency.

Additional requirements identified through this process included the need for scalability, and the desire to view maps based on project type and project status. Desired attributes are also shown in Figure C2). It was also clear through this exercise that users want the FFI application to connect the Watershed

Projects Database (WPC), which contains information on Clean Water Initiative Program funded projects and potential projects identified through other processes such as Tactical Basin Planning. Most users did not provide specific details on how they want to get to their desired outcome, however primary functionality of the web application will be determined based on data and methodology generated in the FFI Phase 1 and other tasks of Phase 2.

Category	Attributes Identified	Count
Overall User Focus	Planning	34
	Project Outcomes	10
Planning Focus	Return a List of Prioritized Projects	21
	Find Locations to Apply Certain Type of Project	6
	Comparison Chart/s	4
	Export Results (CSV, PDF)	4
	Find Disconnected Floodplains	2
Tracking Completed Projects\Progress\Results	P-Reduction Achieved	5
	Progress on Reconnecting Floodplain	4
Spatial Extent of Interest	Sub-Corridor/Reach	11
	Watershed	9
	Tactical Basin	4
	Town/Municipality	3
	Sub Watershed	1
	Parcel	1
Application Map Visualization	View Map of Project by Type	14
	View of Projects by Status (assuming this relies on WPD Connection)	6
	View Reaches by Stream Connectivity Score	3
Attributes of Interest (Data Requirements)	Phosphorus Reduction Potential	21
	Flood Resiliency Benefits	13
	Co-benefits	12
	Reconnection Potential	11
	Cost	10
	Feasibility Score	6
	Connectivity Scores	2
	Project Status	2
	Avoided Damages	2
	Protection Level	1
	Land Usage	1
	Landowners/partners	1
	Habitat	3
Connection to Other Databases\Tools	DEC's Watershed Project Database (WPD)	6
	DEC's buffer gap application	1
	ANR Atlas	1
	TRPT	1
Map Baselayers	Imagery	1
	LIDAR	1
	Parcel Boundaries	1

Figure C2. Desired application attributes.

APPENDIX D

DATA DETAILS

River, River Corridor, and Watershed Data

Data	Source and Format	Data Use±	Comments
2019 Draft River Corridor	VTDEC - Shapefile	RC_D, F, RC_P	Available Statewide for Watersheds >2 SQ MI
HUC 12 Watersheds	USGS - Shapefile	RC_D, ST_D	Available Statewide
Stream Centerlines	SLR/FEA - Shapefile	RC_D, F, RC_P, IR, ST_D, ST_P	Available Statewide, SGA-NHD Hybrid (Adapted from Schiff et al., 2015b)
Unbumped Unclipped River Corridor	VTDEC - Shapefile	RC_D	Available Statewide for Watersheds >2 SQ MI

± F = Feasibility, IR = Incision Ratio, RC_D = River Corridor Departure/Attainment, RC_P = River Corridor Project Selection/Prioritization, ST_D = Stream Connectivity Departure/Attainment, ST_P = Stream Connectivity Project Selection/Prioritization

Land Cover and Environmental Data

Data	Source and Format	Data Use±	Comments
LiDAR Digital Elevation Model	VCGI - Raster	IR	Available Statewide
National Land Cover Database	US MRLC - Raster	ST_D	Available Nationwide
NRCS Soils	NRCS - Shapefile	RC_P	Available Statewide
Quebec Province Crop Data	Institut de la statistique du QC - Shapefile	ST_D	Available for Province
AgTile-US Layer	(Valayamkunnath et al., 2020)	RC_D, F, RC_P, ST_D	Available Nationwide
UVM SAL LULC 2016 and Derivatives	UVM/VCGI - Raster and Shapefiles	RC_D, F, RC_P, ST_D	Available Statewide

± F = Feasibility, IR = Incision Ratio, RC_D = River Corridor Departure/Attainment, RC_P = River Corridor Project Selection/Prioritization, ST_D = Stream Connectivity Departure/Attainment, ST_P = Stream Connectivity Project Selection/Prioritization

Land Ownership, Conservation, and Regulation Data

Data	Source and Format	Data Use±	Comments
ACT 250 Permits	VCGI - Shapefile	RC_D	Available Statewide
Designated Downtown	VCGI - Shapefile	F	Available Statewide
Designated New Town Center	VCGI - Shapefile	F	Available Statewide
Designated Village Centers	VCGI - Shapefile	F	Available Statewide
FEMA Floodways & SFHA	FEMA - Shapefile	RC_D	
Parcel Boundaries	VCGI - Shapefile	RC_D, F, RC_P	Available Statewide
River Corridor Bylaws	VTDEC - Table	RC_D, RC_P	Joined to Town Boundaries
River Corridor Easement	VCGI - Shapefile	RC_D	Available Statewide
RPC Digitized SFHA	RPCs - Shapefile	RC_D	ACRPC, LCPC, NRPC, NVDA
Vermont Significant Wetlands Inventory (VSWI)	VCGI - Shapefile	RC_D, F, RC_P	Available Statewide
VSWI Advisory Layer	VCGI - Shapefile	RC_D, RC_P	VTDEC (as available by Town)
VT Protected Lands Database	VCGI - Shapefile	RC_D	Available Statewide

± F = Feasibility, IR = Incision Ratio, RC_D = River Corridor Departure/Attainment, RC_P = River Corridor Project Selection/Prioritization, ST_D = Stream Connectivity Departure/Attainment, ST_P = Stream Connectivity Project Selection/Prioritization

Other Data

Data	Source and Format	Data Use±	Comments
Dam Inventories	VTDEC & FERC - Tables	ST_D, ST_P	Available Statewide
Railroads	VCGI - Shapefile	RC_D, F	Available Statewide

Data	Source and Format	Data Use±	Comments
Road Centerlines	VTrans, NYDOT, Statistics Canada - Shapefiles	ST_D	Available for State/Province
SGA - Phase II Data, Structure Inventory, FIT	VTDEC - Tables and Shapefiles	RC_P, ST_D, ST_P	Available for Phase II SGA Assessments
TRPT Crossings Data	SLR/FEA, VTrans – Shapefile (Schiff et al., 2018)	ST_D, ST_P	Available Statewide

± F = Feasibility, IR = Incision Ratio, RC_D = River Corridor Departure/Attainment, RC_P = River Corridor Project Selection/Prioritization, ST_D = Stream Connectivity Departure/Attainment, ST_P = Stream Connectivity Project Selection/Prioritization

APPENDIX E

UNIT OF ANLAYSIS NAMING CONVENTION AND DISSOVLING OF SMALL UNITS

Naming

The statewide river corridor was tagged with SGA ID (Phase 1 and 2, if available) and VHD REACHCODE based on the segment or reach with the largest corridor overlap. Sub-units of a given segment or reach were numbered sequentially from downstream to upstream using the drainage area in the corridor shape-file provided by VTDEC (See Figure 3-2, center frame). The final unique ID (FFID) assigned to the river corridor (C) after dissolving small sub-units follows the convention below.

SGA ID Available: SGAID_SUB-UNIT NUMBER_SCALE (e.g., 36_M14-_1_C00)

No SGA ID Available: VHD REACHCODE_SUB-UNIT NUMBER_SCALE (e.g., 02010005000044_6_C00)

If the corridor for a segment or reach is not divided into sub-units, the sub-unit number is 0. The naming convention includes placeholders for floodplains (F) (e.g., 36_M14-_1_0F0) and upland habitat areas (U) (e.g., 36_M14-_1_00U).

Combing units of analysis such as the river corridor and floodplain would have a unique identification with C and F (e.g., 36_M14-_1_CF0). If the unit of analysis included the corridor, floodplain, and upland area, a U would be added to the identifier (e.g., 36_M14-_1_CFU).

Eliminating Small Units

Some very small units existed that are not meaningful for floodplain planning. Geoprocessing rules were developed to eliminate the small set of small sub-units that. The following sub-units were dissolved.

- Sub-units that were not intersected by a stream centerline;
- Sub-units that were less than 5-acres in size and less than 10% of the total corridor area for a given reach or segment

These sub-units were dissolved into the largest adjacent sub-unit with the same SGA reach or segment ID (if available). If no SGA ID was available, the VHD REACHCODE was used to dissolve sub-units into the corridor area for the same reach.

APPENDIX F

CONNECTIVITY METHOD DETAILS

Functioning Floodplain Initiative
To Reconnect VT Rivers - Data & Mapping Evaluation
Mike Kline -- October 23, 2018

(Last Updated April 18, 2022)

This project is to create a method for evaluating existing data and creating publicly accessible maps to support a cogent strategy for restoring and protecting the physical integrity (i.e., connectivity) of rivers, riparian areas, and floodplains. Connectivity mapping in Vermont will be part of a larger Functioning Floodplain Initiative to make us safer during floods, improve water quality, and sustain the multitude of fish and wildlife species that depend on healthy river systems. "Reconnect Vermont Rivers" is further described in a separate paper.

This partial, draft method is broken into two sections attempting to capture four types of connectivity:

1. **Floodplain Connectivity** (Lateral and Vertical) **–** a stream's vertical access the floodplain during flooding; floodwater's unconstrained access to the lateral extents of a forested natural floodplain; and a channel's freedom to meander in the river corridor.

2. **Stream Connectivity** (Longitudinal and Temporal) – upstream and downstream flowage of sediment, woody debris, and aquatic organisms; and the natural volume and variation of stream flow; and

For each type of connectivity, a similar list of questions is posed:

- **Which rivers/streams and what percentage of the** river corridor/floodplain **are (dis)connected in a given watershed due to existing constraints or stressors?**
- **What is the opportunity to readily achieve connectivity in each reach and in the watershed? How should connectivity be scored to support a strategic restoration and protection plan?**
- **When a project is completed to restore or protect connectivity, how is that project scored and credited to the existing connectivity scores to track progress at the reach and watershed scales?**
- **What are the highest priority reconnection projects?**
- **What research could support or enhance policies/programs to restore and protect connectivity?**

What follows is a method for evaluating existing data to answer the above questions for floodplain and stream connectivity. *Connectivity and Project/Practice Map Layers* have been developed for the Lake Champlain Basin to: a) assess floodplain connectivity for river reaches and watersheds over time; b) conduct strategic project planning; c) support project funding proposals; and d) communicate progress. Methods are being implemented in a web-based tool to prioritize and visualize proposed reconnection projects to track progress towards implementing the Lake Champlain TMDL and naturalizing river-floodplain interactions to reduce flood and erosion risks and enhance riparian habitats. State and federal river managers, watershed groups, other NGOs, academia, and watershed planners are the primary audiences for these FFI tools, that will also be shared with the general public.

1. Floodplain Connectivity

1.1. Which rivers/streams and what percentage of river corridor/floodplain are laterally/vertically disconnected in a segment, reach, or watershed due to existing encroachments and valley features (u) that confine or constrain meander[1] and channel slope adjustments commensurate with least erosive, equilibrium conditions?

For each geomorphic river reach/segment find the adjacent land areas where it has become highly unlikely to restore lateral connectivity for an equilibrium planform and functioning floodplains.

1.1.1. Calculate the area of the full river corridor (RC) (2019 unbumped/unclipped) polygons (RC_{full} acres)

1.1.2. The mapped statewide river corridor (RC(x) acres) already engenders some loss of lateral space due to the bumping and clipping of state highways and railroads (& other development) and in consideration of valley walls. To see how much lateral "meander" (m) space was lost in this process, subtract the acreage the mapped from the full river corridor:

$RC_{m\text{-}disconnect1}$ acres = RC_{full} acres – RC(x) acres

1.1.3. To understand what further lateral connections would be lost due to additional hard constraints in the mapped statewide river corridor for which a) channel management would likely be pursued in the near term, and b) behind / between which development infill (in many cases) would be permitted under the current social-political system[2], identify the areas of additional hard constraints in GIS and buffer areas around them. Hard constraints include items such as local roads, railways, clusters of buildings, and active croplands with and without ditch networks, and tile drains that are unlikely to be removed. These items have impediment-to-constraint-removal scores $\geq$ 3 (1=minimum constraint and 5=maximum constraint based on technical, social, and cost considerations). See additional documentation for impediment-to-constraint-removal scoring as well as hard constraint area determinations.

$RC_{m\text{-}disconnect2}$ acres = Additional hard constraint areas as identified and buffered in GIS

Therefore, the percent of mapped statewide river corridor that is disconnected and not readily[3] available for lateral reconnection is:

[1] In this context meander is used as a shorthand for on-going lateral adjustments of the channel or adjustments associated the evolution of a straightened river channel. It is NOT used to imply that all natural streams and rivers in a watershed will have single thread meandering channels.

[2] VTDEC, 2017. "Exception to the River Corridor No Adverse Impact Standard for Improvements between Existing Improvements" App. A of Flood Hazard Area and River Corridor Protection Procedure. Vermont Department of Environmental Conservation, Watershed Management Division, Montpelier, VT.

[3] "Readily" in this context means that lateral connectivity is achievable without removing hard constraints that typically serves as impediments to reconnection due to the current social, technical, and financial setting. Note that soft constraints, and even some hard constraints, will be present in the opportunity phase of this analysis as past history has shown that reconnection projects have taken place in both locations as opportunities arise.

$RC_{m\text{-}disconnect}$ % = $RC_{m\text{-}disconnect2}$ acres / RC(x) acres

1.1.4. The total laterally-disconnected river corridor in a watershed can be summed.

$RC_{m\text{-}disconnect\text{-}total}$ acres = $\sum RC_{m\text{-}disconnect1}$ acres + $\sum RC_{m\text{-}disconnect2}$ acres

$RC_{m\text{-}disconnect\text{-}total}$ % = $RC_{m\text{-}disconnect\text{-}total}$ acres / $\sum RC_{full}$ acres

Note that the local catchment drainage divides embedded in the 2019 corridor during its development will be used for display during the departure analysis to see a more detailed spatial breakdown of hard constraints. Departure scoring, however, will take place at the geomorphic segment, geomorphic reach, and watershed scale.

1.2. The target condition is a river corridor and floodplain that is fully connected both laterally and vertically to the river or stream channel, has robust protections (e.g., conservation easements, zoning restrictions) so the land remains open for river processes to take place in the future, and is covered in woody vegetation. How do the current conditions depart from this ideal setting?

1.2.1. Evaluating lateral connectivity starts with calculating the percentage of the mapped statewide river corridor that is not encroached upon by existing hard constraints. River corridor (RC) acres that may be available for lateral meander expression within the river reach:

$RC_{m\text{-}connect}$ acres = RC(x) acres – $RC_{m\text{-}disconnect2}$ acres

Percent of the statewide mapped RC that is laterally connected and may yet be protected:

$RC_{m\text{-}connect}$ % = ($RC_{m\text{-}connect}$ acres / RC(x) acres) * 100

Rank the river corridor in a category of lateral meander (m) connectivity (Table 1)

Table 1: Assigning a lateral meander connectivity rank.

$RC_{m\text{-}connect}$ %	Lateral Meander Connectivity Rank
90 – 100	Full
75 – 89	Moderate
36 – 74	Low
0 – 35	Constrained

1.2.2 Rivers meander across the landscape over long periods of time seeking out the most stable state that is least erosive and provides the highest level of public safety and environmental quality. Ideally, river corridors are protected in perpetuity to reduce risks and maximize water quality and habitat. The degree of RC protection is determined to be no protection (NP), moderate protection (MP), and robust protection (RP) based on overlap of protection areas (Table 2) and RC(x) in GIS. A multiplier is then used to give a reach/segment an area-weighted protection score and a protection rank is then assigned (Table 4).

Table 2: Assigning a level of protection.

Level of Protection	Items	Multiplier
Robust (RP)	River corridor easement	1
Moderate (MP)	FEMA floodways Class 1 or 2 mapped VSWI wetlands Municipally adopted river corridor / FEH bylaws Act 250 parcels Wetlands on the advisory layer Conserved lands	0.5
Low (LP)	Federal lands Municipal lands State Lands Special flood hazard area	0.25
None (NP)	All other areas	0

RP acres = the RC(x) area of the segment/reach with robust protections as derived from GIS.

MP acres = the RC(x) area of the segment/reach with moderate protections as derived from GIS.

LP acres = the RC(x) area of the segment/reach with low protections as derived from GIS.

NP acres = the RC(x) area of the segment/reach without protections:

NP = RC(x) acres – RP acres – MP acres – LP acres

PRT Score = [(1 * RP) + (0.5 * MP) + (0.25 * LP) + (0 * NP)] * 100 / RC(x) acres

Table 3: Assigning a level of protection rank to each segment/reach.

PRT Score	Level of Protection Rank
76 – 100	High
51 – 75	Moderate
26 – 50	Limited
0 – 25	Mostly Absent

1.2.3 Lateral connectivity interacts with a functioning riparian forest because woody vegetation provides resistance to erosion in the near-bank area leading to more stable channels; capture of sediment and nutrients to maintain good water quality; and large wood inputs to create and maintain habitat. A woody buffer rank is assigned based on the percent of wood vegetation within a 50-foot buffer along both banks of the river (Table 4).

BFR_{50} acres = 50-foot buffer area on both sides of the river/stream channel from GIS in RC(x).

$BFR_{50\text{-woody-veg}}$ acres = area of trees, saplings, and shrubs in BFR_{50} acres

$BFR_{50\text{-woody-veg}}$ % = ($BFR_{50\text{-woody-veg}}$ acres / BFR_{50} acres) * 100

Table 4: Assigning a woody buffer rank.

$BFR_{50\text{-woody-veg}}$ %	**Woody Buffer Rank**
76 – 100	Full
51 – 75	Moderate
26 – 50	Limited
0 – 25	Mostly Absent

1.2.4 Sum the scores for lateral meander connectivity, the level of protection, and the woody buffer to calculate a lateral river corridor connectivity score ($RC_{mbp\text{-connect}}$ Score). The scores have been weighted to highlight the importance of lateral connectivity and to create a maximum possible score of 100 points. The weighting is as follows:

- 0.50 for lateral meander connectivity;
- 0.35 for the level of protection;
- 0.15 for the woody buffer; and

$RC_{mbp\text{-connect}}$ Score = (0.50 * $RC_{m\text{-connect}}$ %) + (0.35 * PRT Score) + (0.15 * $BFR_{50\text{-woody-veg}}$ %)

Table 5: Assigning a lateral river corridor connectivity rank ($RC_{mbp\text{-connect}}$ Rank) to each segment/reach.

$RC_{mbp\text{-connect}}$ Score	**$RC_{mbp\text{-connect}}$ Rank**
76 – 100	Full
51 – 75	Moderate
26 – 50	Limited
0 – 25	Mostly Absent

1.2.5 While meander expression is a primary factor in floodplain connectivity, another major component is the degree to which floodwaters have access to the adjacent floodplain at the annual or bi-annual flood stage (i.e., vertical connectivity), as described by the incision ratio. Common incision ratio ranges are provided for informational purposes (Table 6). If it exists for the reach/segment, the human-elevated floodplain (HEF) incision ratio[4] is used in the calculation to

[4] Kline, M., C. Alexander, S. Pytlik, S. Jaquith, and S. Pomeroy, 2009. Vermont Stream Geomorphic Assessment Protocol Handbooks: Remote Sensing and Field Surveys Techniques for Conducting Watershed and Reach Level Assessments (Http://Www.Anr.State.Vt.Us/Dec/Waterq/Rivers/Htm/Rv_Geoassesspro.Htm). Vermont Agency of Natural Resources, Department of Environmental Conservation, Division of Water Quality, River Management Program, Waterbury, VT.

capture the loss of vertical connectivity due to constraints built by humans such as a berm or road embankment. If IR_{HEF} does not exist, the incision ratio calculated from the recently abandoned floodplain (RAF) will be used. Note that if IR_{HEF} exists, the IR_{RAF} will be used as an indicator of reconnection opportunity and credit in future steps.

Table 6: Incision ratio ranges and associated longitudinal score deduction.

Incision	**Incision Ratio[5]**
Minor	IR < 1.3
Moderate	1.3 ≤ IR < 1.5
High	1.5 ≤ IR < 2.0
Severe	IR ≥ 2.0

1.2.6 The existing lateral/vertical river corridor connectivity score[6] for a river reach/segment is:

$RC_{existing-connect}$ Score = $RC_{mbp-connect}$ Score / Incision Ratio

Table 7: Assigning a Lateral-Vertical River Corridor Connectivity Rank

$RC_{existing-connect}$ Score	**Lateral-Vertical River Corridor Connectivity Rank**
90 – 100	Full
75 – 89	Moderate
36 – 74	Low
0 – 35	Constrained

Recall that this score answers the question of how close the segment/reach is to the target condition of a river corridor and floodplain that is fully connected both laterally and vertically to the river or stream channel, that has robust protections so the land remains open for river processes to take place in the future, and that is covered in forest.

1.3. Floodplain Connection Attainment and Departure at the Segment/Reach or Watershed Scale

Once the current connectivity conditions have been assessed, how should connectivity be scored at the segment/reach scale and the watershed scale to support a strategic restoration and protection plan for preserving river corridor meander space from further encroachment, restoring woody riparian buffers and floodplains, and maintaining robust land protection? This step consists of an accounting of floodplain connectivity attainment and departure. The attainment indicates the current connectivity condition, with larger values indicating a site is closer to the target condition. The departure is the opposite of attainment with larger values indicating more departure from the target condition. Departure is one factor that defines the opportunity to improve connectivity.

[5] If the incision ratio for a reach is not measured, it will be approximated via LIDAR and GIS. Note that the minimum IR is 1.0.
[6] The maximum score is 100 / 1.0 = 100 (fully connected).

1.3.1 At the watershed scale the total lateral-vertical river corridor connectivity **attainment score** may be obtained by summing the scores of all assessed segments/reaches in a watershed.

$RC_{existing\text{-}connect\text{-}total}$ Score = $\sum RC_{existing\text{-}connect}$ Score

1.3.2 The **attainment percentage** for the watershed that indicates the average segment/reach attainment score is calculated as the watershed total attainment for lateral-vertical connectivity of the river corridor divided by the total watershed potential for lateral-vertical connectivity. The larger the attainment score the closer to the target conditions.

Attainment % = ($RC_{existing\text{-}connect\text{-}total}$ Score / $RC_{potential\text{-}connect\text{-}total}$ Score) * 100

where

$RC_{potential\text{-}connect\text{-}total}$ Score = $\sum$ 100 * (number of segments/reaches)

since 100 is the maximum potential lateral-vertical river corridor connectivity score indicating full lateral and vertical connectivity with robust protections with a minimum 50-foot buffer of woody vegetation.

1.3.3 At the segment/reach scale, the **departure score** is the maximum potential score minus the existing connectivity.

$RC_{departure\text{-}connect}$ Score = 100 – $RC_{existing\text{-}connect}$ Score

1.3.4 At the watershed scale, the total departure for improving lateral-vertical river corridor connectivity may be obtained by summing the scores of all assessed segments/reaches in a watershed.

$RC_{departure\text{-}connect\text{-}total}$ Score = $\sum RC_{departure\text{-}connect}$ Score

1.3.5 The **departure percentage** for the watershed that indicates the average segment/reach departure score is calculated as the watershed total departure for lateral-vertical connectivity of the river corridor divided by the total watershed potential for lateral-vertical connectivity. The larger the departure score the further from the target conditions and thus the more potential for connectivity projects exists.

Departure % = ($RC_{departure\text{-}connect\text{-}total}$ Score / $RC_{potential\text{-}connect\text{-}total}$ Score) * 100

1.4 The implementation of restoration/protection projects is often a function of connectivity constraints such as infrastructure and private property. Also, fewer and larger parcels simplify project coordination and implementation. How likely is a restoration/protection project to take place that will improve connectivity in each segment/reach and the watershed while considering constraints with varying levels of technical/social/cost impediments to removal? In other words, how complicated is it to implement a connectivity project.

1.4.1 The feasibility of implementing restoration/protection projects to reconnect river corridors and floodplains is largely a function of existing physical constraints and the level of technical/cost/social impediment to constraint removal. See additional documentation for impediment to constraint removal ranking, where 1 is a minimum impediment such as a fallow field where a project would have a high likelihood of taking place, and 5 is a maximum impediment such as the presence of a neighborhood where a project is less likely to occur. Past projects have occurred in areas even with hard constraints (rank > 3) and thus we include these in the opportunity analysis for reconnection projects, although their likelihood of implementation is lower than where soft constraints exist that are easier to remove.

A constraint removal feasibility score has been assigned for each impediment-to-constraint-removal rank (Table 9 and Figure 1). The scores can be conceptualized as a probability of constraint removal informed by past reconnection and protection projects implemented in Vermont and best professional judgement. In an adaptive management context, these relative weightings could be modified in the future in response to possible changes (e.g., policies, incentive programs, socioeconomic trends).

Table 9: Constraint Removal Feasibility Score

Impediment to Constraint Removal Rank	**Constraint Removal Feasibility Score**
0	1.00
1	0.90
2	0.75
3	0.50
4	0.10
5	0.05

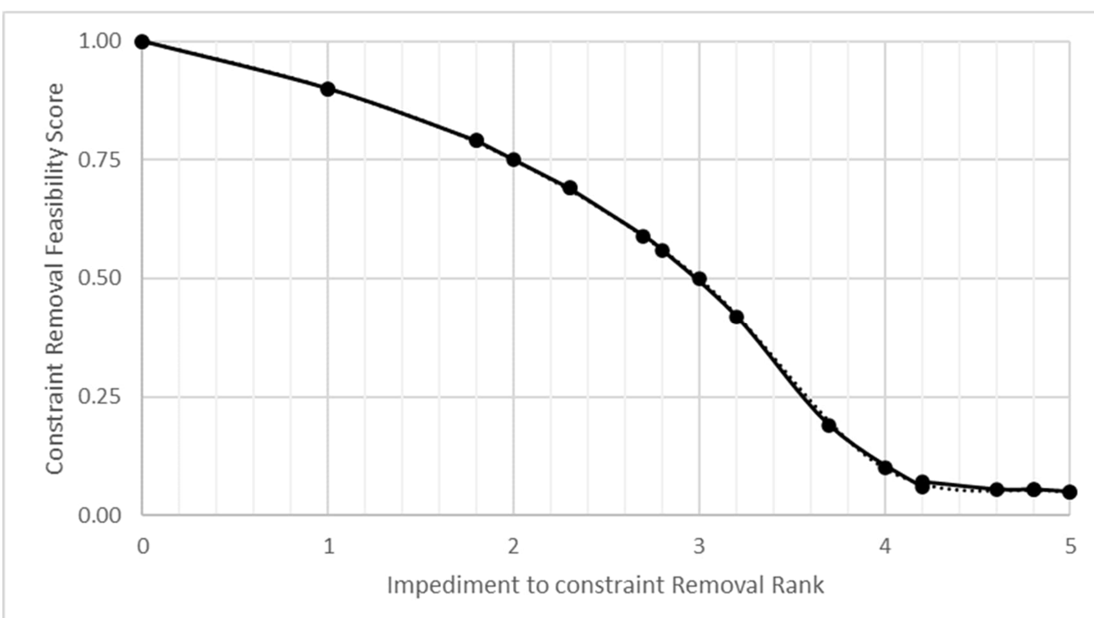

Figure 1: Relationship between Constraint Removal Feasibility Score and Impediment to Constraint Removal Rank

The constraint removal feasibility score for a given segment/reach is calculated as the sum of the products of project area and the assigned constraint removal feasibility score (Table 9), and thus consists of an area weighted average normalized by the area of the state river corridor.

$RC_{constraint\text{-}feasibility}$ Score = 50 * (∑ (Constraint Removal Feasibility Score * Area Acres) / RC(x))

At a segment/reach scale, the maximum constraint removal feasibility score as moderated by technical/social/cost is 50 if the impediment to constraint removal score for the entire corridor and floodplain area is 0. The minimum score is 2.5 if the connectivity project feasibility score is 0.05 for the entire river corridor (50 * 0.05 * area / area = 50 * 0.05 = 2.5).

1.4.2 The number and size of parcels influence connectivity project feasibility. Implementing projects on fewer parcels is easier in terms of coordination and local permitting. Larger parcels also work better for some projects such as river corridor easements. The number of parcels is addressed here and the size of parcels is addressed in project type feasibility screening.

Table 10: Parcel Feasibility Rank and Score

Number of Parcels within Subunit	Rank	Score
One to two	High	50
Three to four	Medium	25
Five or more	Low	10

At a segment/reach scale, the maximum parcel feasibility score is 50 and the minimum is 10.

1.4.3 The total connectivity project feasibility score is the sum of the constraint feasibility score and the parcel feasibility score.

$RC_{connect\text{-}feasibility}$ Score = $RC_{constraint\text{-}feasibility}$ Score + $RC_{parcel\text{-}feasibility}$ Score

At a segment/reach scale, the maximum connectivity project feasibility score is 100 and the minimum is 12.5.

1.4.4 At the watershed scale the total connectivity project feasibility score may be obtained by summing the scores of all assessed segments/reaches in a watershed.

$RC_{connect\text{-}feasibility\text{-}total}$ Score = ∑ $RC_{connect\text{-}feasibility}$ Score

Feasibility % = ($RC_{connect\text{-}feasibility\text{-}total}$ Score / $RC_{potential\text{-}connect\text{-}total}$ Score) * 100

1.5 When a project is completed to restore or protect connectivity with varying levels of permanent protections and woody vegetation, how is that project scored and credited to the existing connectivity scores for tracking progress at the segment/reach and watershed scales?

Credit for a project is assigned based on how much it adds towards achieving the target of a fully connected corridor and floodplain that has robust protections and is covered in woody vegetation. Project size, improvement in the segment/reach/watershed context, level of protection, and land cover dictate the value of implementing a reconnection project. Each of these factors is considered below to credit a completed project.

To calculate the project score:

1.5.1 Re-evaluate the reach with the restoration or protection practice(s) in place using steps 1.2.1 through 1.2.6 described above ($RC_{project\text{-}connect}$). The revised score calculated in step 1.5.1 would then be applied to the segment/reach and used in the watershed analysis if the practice treated the entire segment/reach.

1.5.2 However, often a restoration or protection project treats only a portion of the segment/reach. In this case, determine the percentage of the corridor or floodplain area treated by the practice. For example:

A 20-acre easement within a 100-acre river corridor would treat 20% of the reach.

Calculate the project's connectivity value by subtracting the existing lateral/vertical connectivity $RC_{existing\text{-}connect}$ (from step 1.2.6) from the lateral/vertical connectivity achieved in the segment/reach because of the project ($RC_{project\text{-}l/v\text{-}connect}$), and multiply by the percent of the corridor or floodplain area treated.

Project connectivity value = % corridor/floodplain treated * ($RC_{project\text{-}l/v\text{-}connect} - RC_{existing\text{-}connect}$)

1.5.3 The existing lateral/vertical connectivity score for the segment/reach ($RC_{existing\text{-}connect}$ Score) can then be revised by adding the project's calculated lateral/vertical connectivity value (Project connectivity value). The watershed score may be updated by summing the scores for the segments/reaches.

1.5.4 The connectivity opportunity score ($RC_{opportunity\text{-}connect}$ Score) for the segment/reach can be reduced by the Project connectivity value to show that the segment/reach moved closer towards the target condition. The watershed score may be updated by summing the scores for the segments/reaches.

1.5.5 Update the percent attainment and percent departure/opportunity scores.

1.6 What are the highest priority floodplain reconnection projects?

Refer to the latest spreadsheet that identifies the likely project approach based on the given connectivity departure; the type of project to implement based on departure levels, stream geomorphology, constraint removal feasibility, wetlands, channel size, or corridor protection status; and project prioritization based on departure levels, stream geomorphology, protection status, number of parcels, parcel size, wetlands, and steam size.

2. Stream Connectivity

2.1. Which rivers/streams and what percentage of stream lengths are longitudinally/temporally (dis)connected in a given watershed due to existing upstream-downstream barriers that disrupt flow, sediment, and woody debris regimes and the passage of aquatic organisms?

Overall stream network connectivity is a function of both longitudinal and temporal connectivity. Longitudinal connectivity is important for the downstream movement of water, sediment, large wood, coarse particulate organic matter, nutrients and ice; for the upstream and downstream movement of fish and other aquatic organisms; and for the up- and downstream movement of wildlife. Temporal (i.e., hydrological) connectivity is measured by the frequency and duration that floodplains activate to support a variety of ecosystem functions and services. River channels, corridors, and floodplains may become longitudinally disconnected by infrastructure in and across the channel and floodplain (i.e., dams, weirs, culverts, bridges, roads, and railroads). These longitudinally fragmented channels can become unstable due to excessive sedimentation upstream and lack of sediment downstream of barriers. Temporal disconnection may result from excessive storage behind large dams and regulated release of impounded water. Disturbance of the natural flow regime may also occur due to undersized bridges and culverts; water diversions; excessive runoff from impervious cover; artificial extension of the river network by the road or farm ditch network; and accelerating agricultural runoff in tile drains.

The target condition for stream connectivity is full longitudinal and temporal connectivity. This includes the absence of obsolete dams and functioning dams that alter the timing of flow and transport of materials. Bridges and culverts that constrict the channel do not exist and are at least equal to the bankfull channel width. Floodplains are not artificially constricted by fills so that they can convey flood flows. The natural frequency and duration of floodplain inundation exists in a well-connected system. The target for stream connectivity includes low levels of impervious cover, ditching, and tile drains that do not alter overland flow generation and hydrograph timing.

In summary, a properly functioning stream network has full longitudinal and temporal connectivity amongst the backdrop of natural breaks in connectivity (e.g., waterfalls and bedrock outcrops) and seasonal and annual variations in flow. Flow variation has increased in the past several decades with larger floods, more intense storms, and longer periods of low flow due to changing climate. Connected floodplains and streams are important to dampen the influence of changing flow and sediment regimes associated with climate change.

Longitudinal connectivity is reduced by the number of and size of barriers across the stream network. Temporal connectivity is reduced by large structures that store flood waters, or withdrawals and bypass structures that divert water. Temporal connectivity can be artificially altered by land use conversions that increase the magnitude, flashiness, and frequency of flood flows. *The reduction of stream connectivity is initially identified here on each SGA reach, but typically also evaluated* ***in floodplains*** *at the multi-reach and watershed scales.*

The following table indicates deductions to longitudinal connectivity (i.e., movement of sediment, movement of large wood, resulting channel stability) and temporal connectivity (i.e., flow timing in channel and floodplain inundation frequency) associated with manmade barriers and water diversions.

Table 11: Deductions to Longitudinal and Temporal Connectivity Score from Instream Structures

Barrier	Longitudinal	Temporal	AOP
Large Flood Control Dam	-90	-100	-100
Large Peaking Hydro Dam	-90	-100	-100
Large Run of River (ROR) Dam	-80	-40	-100
Medium Peaking Hydro Dam	-70	-90	-100
Medium ROR Dam	-50	-20	-100
Medium Breached Dam	-40	-20	-100
Small Intact ROR Dam	-30	-20	-100
Small Breached Dam	-20	-10	-80
Bridge (Wbkf>100%)	-10	-10	0
Bridge (50%≥Wbkf≥100%)	-30	-20	-10
Bridge (Wbkf<50%), shallow channel (< 2%)	-40	-30	-20
Bridge (Wbkf<50%), steep channel (≥ 2%)	-20	-10	-30
Culvert (Wbkf>100%)	-10	-20	-20
Culvert (50%≥Wbkf≥100%), shallow	-50	-30	-30
Culvert (50%≥Wbkf≥100%), steep	-30	-10	-40
Culvert (Wbkf<50%), shallow	-80	-40	-60
Culvert (Wbkf<50%), steep	-50	-20	-80
Permitted Surface Withdrawal, no structure	-10	-10	-10
Permitted Surface Withdrawal, with a structure	-50	-10	-70
Groundwater Withdrawal	-10	-10	-10

An incised channel with limited active floodplain also contributes to longitudinal and temporal disconnection as channels become more dominated by sediment transport rather than having an even distribution of sediment transport and storage reaches. Vertical disconnection leads to deficit in connectivity based on the degree of incision (Table 12).

Table 12: Deductions to Longitudinal and Temporal Connectivity Score due to Incision

Incision	Incision Ratio[7]	Longitudinal Score Deduction	Temporal Score Deduction
Minor	IR < 1.3	0	0
Moderate	1.3 ≤ IR < 1.5	-10	-5
High	1.5 ≤ IR < 2.0	-20	-8
Severe	IR ≥ 2.0	-30	-10

2.1.1 The existing longitudinal connectivity score[8] for a river reach is

$$LONG_{existing\text{-}connect}\ \text{Score} = 100 - \sum (\text{Deductions to Longitudinal Connectivity Score})$$

Table 13: Longitudinal Connectivity Rank

[7] If the incision ratio for a reach is not measured, it will be approximated via LIDAR and GIS. Note that the minimum IR is 1.0.

[8] The maximum score is 100 to indicate fully connected and 0 indicates fully disconnected. (No negative scores.)

$LONG_{existing\text{-}connect}$ Score	Longitudinal Connectivity Rank
80 – 100	Connected
41 – 79	Partially Disconnected
0 – 40	Fragmented

2.1.2 Temporal disconnectivity is represented here by instream structures (Table 11), channel incision (Table 12), and changes to watershed land cover. Structures in a channel (e.g., dams and culverts) alter the natural magnitude and frequency of flood pulses and low flows. These changes influence material movement, channel stability, and habitat. Incised channels alter the timing of flows due to loss of floodplain connection.

Changes to watershed land cover such as road networks, impervious cover, agricultural fields, and ditch networks also alter natural flows through changes to overland runoff patterns. To address impacts of watershed-scale land cover change on temporal connectivity, roads are used as a proxy for hydrologic alteration associated with developed lands. With their alteration of overland hydrology due to impervious cover along road networks, ditches along gravel roads, and drainage infrastructure along paved roads,.

Changes to the timing of flows originating from agricultural lands are represented here by crop or hay lands that coincide with poorly drained soils (i.e., SSURGO drainage category) and low slope per Valayamkunnath et al. (2020). This layer will be used in conjunction with the UVM SAL land cover data to identify contiguous crop and hay fields with a small-area threshold of 0.5 acres.

$TEMP_{existing\text{-}chstructures} = 100 - \sum$ (Deductions to Temporal Connectivity due to structures)

Table 14: Temporal Connectivity Rank Due to Structures in the Stream Channel

$TEMP_{existing\text{-}chstructure}$ Score	Temporal Connectivity Rank due to Structures
80 – 100	Connected
41 – 79	Partially Disconnected
0 – 40	Fragmented

$TEMP_{existing\text{-}dev\text{-}rds}$ = Road Length / Subwatershed Area (HUC12) [miles / square miles]

Table 15: Temporal Connectivity Impact Due to Developed Lands Represented by Roads

$TEMP_{existing\text{-}dev\text{-}rds}$	Temporal Connectivity Impact Rank due to Development
0 – 2.0	Low
2.1 – 5.0	Moderate

5.1 – 7.0	High
> 7.0	Extreme

$TEMP_{existing\text{-}ag}$ % = Agricultural Area / Subwatershed Floodplain Area (HUC12)

Table 16: Temporal Connectivity Impact Due to Agricultural Lands

$TEMP_{existing\text{-}ag}$ %	**Temporal Connectivity Impact Rank due to Agriculture Land**
0 – 10	Low
10 – 25	Moderate
25 – 50	High
> 50	Extreme

The impact of agricultural lands on the magnitude and timing of flows, or temporal connectivity, will increase if available mapping suggests tile drains exist in the catchment. *The TEMPexisting-ag % will be doubled to indicate stronger temporal impacts due to agricultural runoff associated with tile drains if the mapping shows the likelihood of tile drains on a field larger than 0.5 acres.*

Convert $TEMP_{existing\text{-}dev\text{-}rds}$ and $TEMP_{existing\text{-}ag}$ % to scores out of 100 maximum based on the range of values.

$TEMP_{existing\text{-}dev\text{-}rds}$ Score = 100 – ($TEMP_{existing\text{-}dev\text{-}rds}$ / MAX $TEMP_{existing\text{-}dev\text{-}rds}$) * 100

$TEMP_{existing\text{-}ag}$ Score = 100 – ($TEMP_{existing\text{-}ag}$ % / MAX $TEMP_{existing\text{-}ag}$ %) * 100

Scores for structures, developed lands proxy, and agricultural lands are combined using the following equation to get the temporal connectivity score that has a reach maximum of 100.

$TEMP_{existing\text{-}connect}$ Score = (0.40 * $TEMP_{existing\text{-}chstructures}$) + (0.30 * $TEMP_{existing\text{-}dev\text{-}rds}$) + (0.30 * $TEMP_{existing\text{-}ag}$)

Table 17: Temporal Connectivity Rank

$TEMP_{existing\text{-}connect}$ Score	**Temporal Connectivity Rank**
80 – 100	Connected
41 – 79	Partially Disconnected
0 – 40	Fragmented

Note that $TEMP_{existing\text{-}connect}$ Score will be set to 0, indicating maximum temporal disconnection, as an override for large flood control or peaking hydroelectric dams with storage, and for medium hydroelectric dams that severely alter longitudinal connectivity, temporal connectivity, and AOP.

2.1.3 Stream connectivity results from the combination of longitudinal and temporal connectivity.

$STREAM_{existing\text{-}connect}$ Score = (0.6 * $LONG_{existing\text{-}connect}$ Score) + (0.4 * $TEMP_{existing\text{-}connect}$ Score)

Table 18: Stream Connectivity Rank

$STREAM_{existing\text{-}connect}$ Score	**Stream Connectivity Rank**
80 – 100	Connected
41 – 79	Partially Disconnected
0 – 40	Fragmented

2.1.4 Stream Connectivity Attainment and Departure at the Watershed Scale

The level of stream connectivity is best evaluated across the stream network at a watershed or basin scale. This step consists of an accounting of stream connectivity attainment and departure scoring. The attainment indicates the current connectivity condition, with larger values indicating a reach is more connected. The departure is the opposite of attainment with larger values indicating more departure from the target condition. Departure is one factor that defines the opportunity to improve connectivity.

At the watershed scale the total stream connectivity **attainment score** may be obtained by summing the scores of all reaches in a watershed.

$STREAM_{existing\text{-}connect\text{-}total}$ Score = $\sum$ $STREAM_{existing\text{-}connect}$ Score

2.1.5 The **attainment percentage** for the watershed is calculated as the watershed total attainment for longitudinal connectivity divided by the total watershed potential for longitudinal connectivity. The larger the attainment score the closer to the target conditions.

Attainment % = ($STREAM_{existing\text{-}connect\text{-}total}$ Score / $STREAM_{potential\text{-}connect\text{-}total}$ Score) * 100

where

$STREAM_{potential\text{-}connect\text{-}total}$ Score = $\sum$ 100 * (number of reaches)

since 100 is the maximum potential stream connectivity score – 50 for longitudinal connectivity and 50 for temporal connectivity.

2.1.6 At the reach scale, the **departure score** is the maximum potential score minus the existing connectivity.

$STREAM_{departure\text{-}connect}$ Score = 100 – $STREAM_{existing\text{-}connect}$ Score

2.1.7 At the watershed scale, the total departure for improving longitudinal connectivity may be obtained by summing the scores of all reaches in a watershed.

$STREAM_{departure\text{-}connect\text{-}total}$ Score = $\sum$ $STREAM_{departure\text{-}connect}$ Score

2.1.8 The **departure percentage** for the watershed is calculated as the watershed total departure for stream connectivity divided by the total watershed potential. The larger the departure score the more disconnection and thus the more potential for connectivity projects exists.

Departure % = ($STREAM_{departure\text{-}connect\text{-}total}$ Score / $STREAM_{potential\text{-}connect\text{-}total}$ Score) * 100

2.2. When a project is completed to restore or protect longitudinal or temporal connectivity, how is that project scored and credited to the existing longitudinal connectivity scores for tracking progress at the reach and watershed scales?

Credit for a project is a function of how much it adds towards achieving the target of a full stream connectivity. Benefits from stream connectivity restoration projects tend to influence the reach scale and larger.

To calculate the project score:

2.3.1 Re-evaluate the attainment score with the stream restoration practice(s) in place using step 2.1 ($STREAM_{project\text{-}connect}$) for the river reach (2.1.1) and watershed (2.1.4).

2.3.2 The existing stream connectivity score for the reach ($STREAM_{existing\text{-}connect}$ Score) can then be revised by updating the project's calculated connectivity value ($STREAM_{project\text{-}connect}$), moving the value closer or to a full score of 100. The watershed score may be updated by summing the scores for the reaches.

2.3.3 Update the percent attainment and percent departure/opportunity scores.

2.3. What are the highest priority longitudinal and temporal reconnection projects?

Refer to the latest spreadsheet that identifies the likely project approach based on the given connectivity departure and project prioritization based on the number of barriers on the reach, stream geomorphology, and structure geomorphic compatibility.

APPENDIX G

DESKTOP INCISION RATIO ESTIMATION METHOD

MEMORANDUM

To: Floodplain Connectivity Working Group
From: Evelyn Boardman and Evan Fitzgerald, CPESC/CFM
Re: Measuring Incision Ratio with LiDAR Elevation Data
Date: June 2, 2021

1.0 Introduction

Incision ratio (IR) is calculated by dividing the height of the recently abandoned floodplain (RAF) by maximum bankfull depth (VT ANR 2009). While IR data exist for areas of past Phase 2 Stream Geomorphic Assessments (SGAs), there are no IR estimates in areas lacking SGA. IR is the key measurement for assessing vertical floodplain connectivity. Therefore, we sought to combine estimates of bankfull depth derived from watershed size with estimates of RAF height derived from a high-resolution LiDAR DEM to estimate IR statewide.

We considered using a focal polygon created from a buffer off of the LiDAR Digital Elevation Model (DEM) to calculate elevation statistics about the area around the channel. We anticipated this would generate inconsistent results due to inaccuracies in the VHD and channel width causing the buffer to pick up on valley walls or stream banks. We explored using Height Above Nearest Drainage (HAND) tools to extract river and RAF elevations from the LiDAR DEM. This method seemed useful for mapping drainage networks and floodplains, but appeared to be very computationally intensive to create a hydrologically coherent DEM and drainage network from which a method for classification of top of bank/RAF would still need to be developed and related to bankfull depth. Similarly, we considered creating a cost-distance raster based on variables such as elevation and slope, but anticipated the same necessity to develop a method to extract the values needed to calculate the incision ratio.

The following approach uses the Vermont LiDAR DEM and stream network to estimate incision ratio at discrete cross-sections. This approach allows us to use previously computed watershed areas to estimate bankfull depth and analyze the cross section to estimate the height of the RAF.

2.0 SGA Data and Bankfull Depth Determination

In order to determine the maximum bankfull depth, we first examined statewide Phase 2 SGA data to evaluate the applicability of Vermont Regional Hydraulic Geometry Curves (HGC) to the estimation of mean bankfull depth statewide (VT ANR, 2006). Overall, the power function predicting mean bankfull depth using watershed area for all B and C-type streams classified as Good or Reference for geomorphic condition is very similar to the equation established in the 2006 HGC.

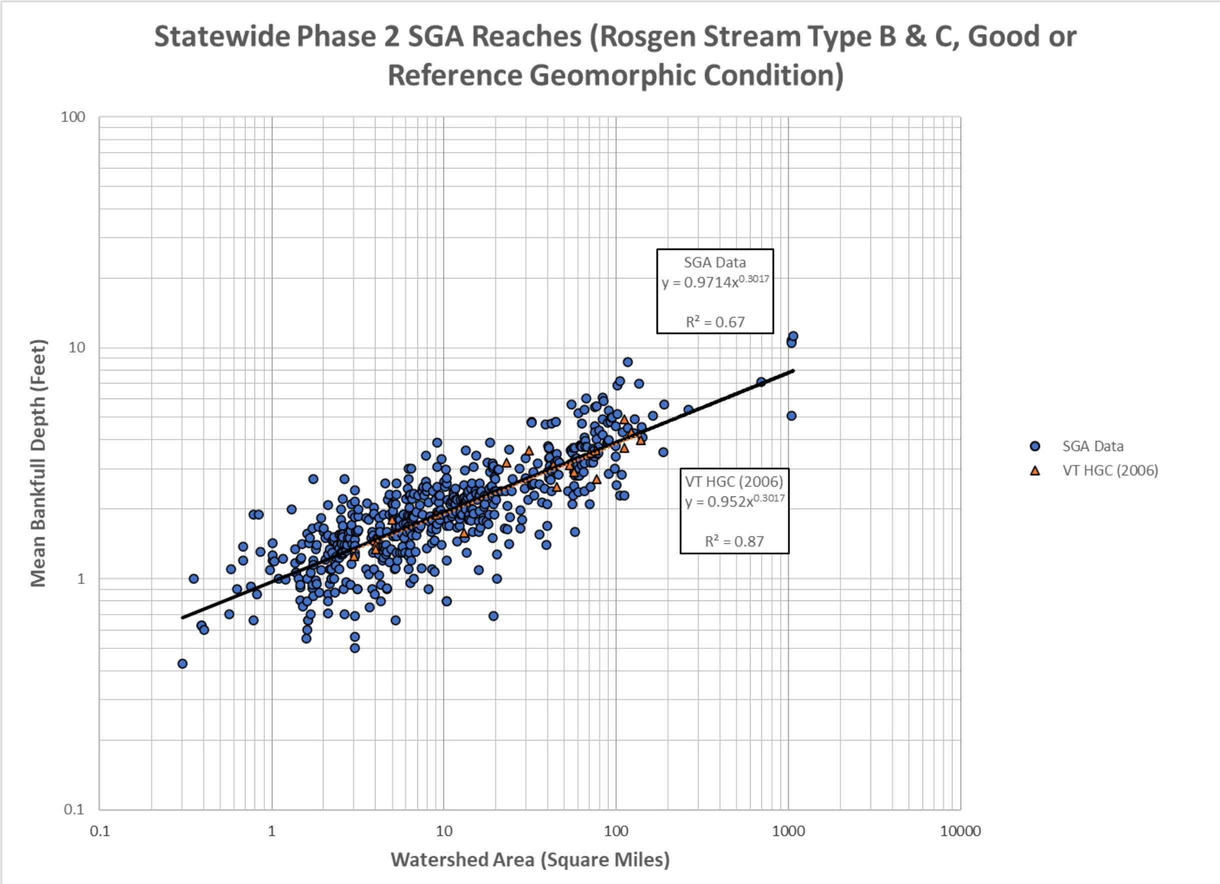

Figure 1.1: Comparison of the relationship between watershed area and mean bankfull depth between the VT HGC (2006) with Statewide Phase 2 SGA Data for Rosgen B and C-type Channels in Good or Reference Geomorphic Condition.

Next, we compared SGA measurements of mean and maximum bankfull depth in the statewide Phase 2 SGA to determine an approach to estimate maximum bankfull depth using HGC predictions of mean bankfull depth . For B and C type streams, the ratio of mean bankfull depth to maximum bankfull depth was approximately 2:3 (Figure 1.2). We estimated maximum bankfull depth applying the HGC equation (Equation 1) to watershed area from the Vermont River Sensitivity Coarse Screen rivers layer then applying the power function relating mean and maximum bankfull depth (Equation 2) shown in Figure 1.3 (Schiff et al., 2015).

Equation 1	$d = 0.96a^{0.3}$	$d = mean\ bankfull\ depth\ (ft)$ $a = drainage\ area\ (mi^2)$
Equation 2	$y = 1.6532d^{0.8503}$	$y = maximum\ bankfull\ depth\ (ft)$ $d = mean\ bankfull\ depth\ (ft)$
Equation 3	$y = 1.6532(0.96a^{0.3})^{0.8503}$	$y = maximum\ bankfull\ depth\ (ft)$ $a = drainage\ area\ (mi^2)$

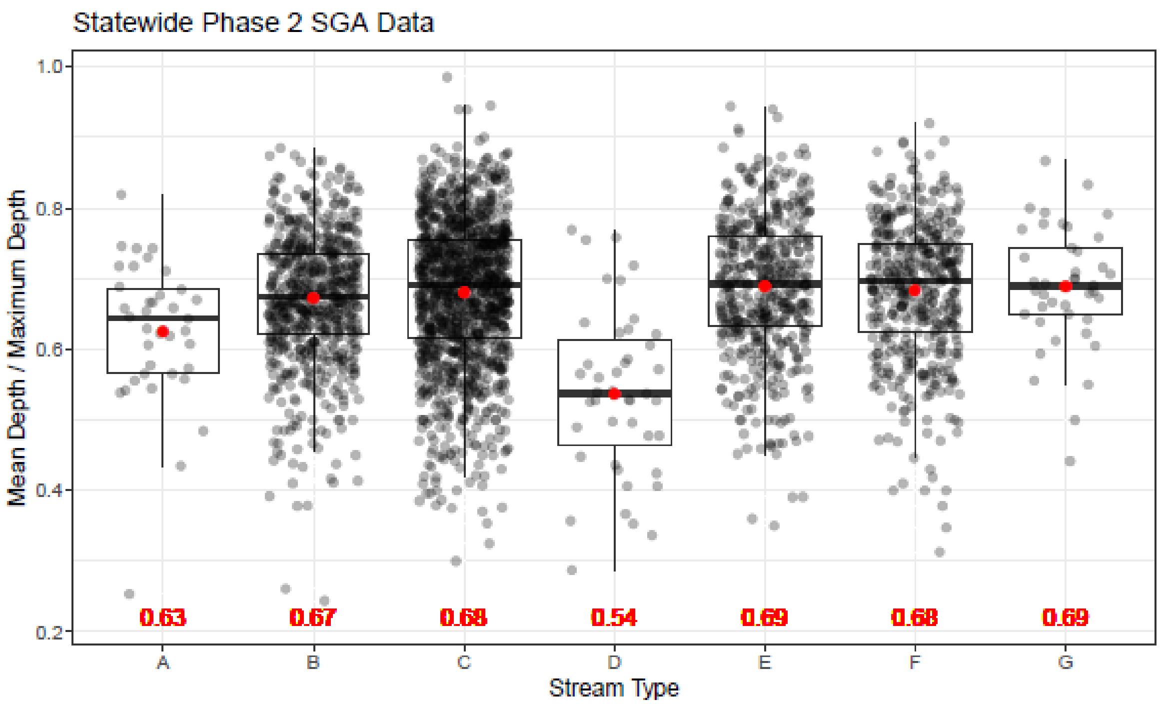

Figure 1.2 : Ratio of mean to maximum bankfull depth from Phase 2 SGA database for different Rosgen stream types. The mean ratio is shown in red.

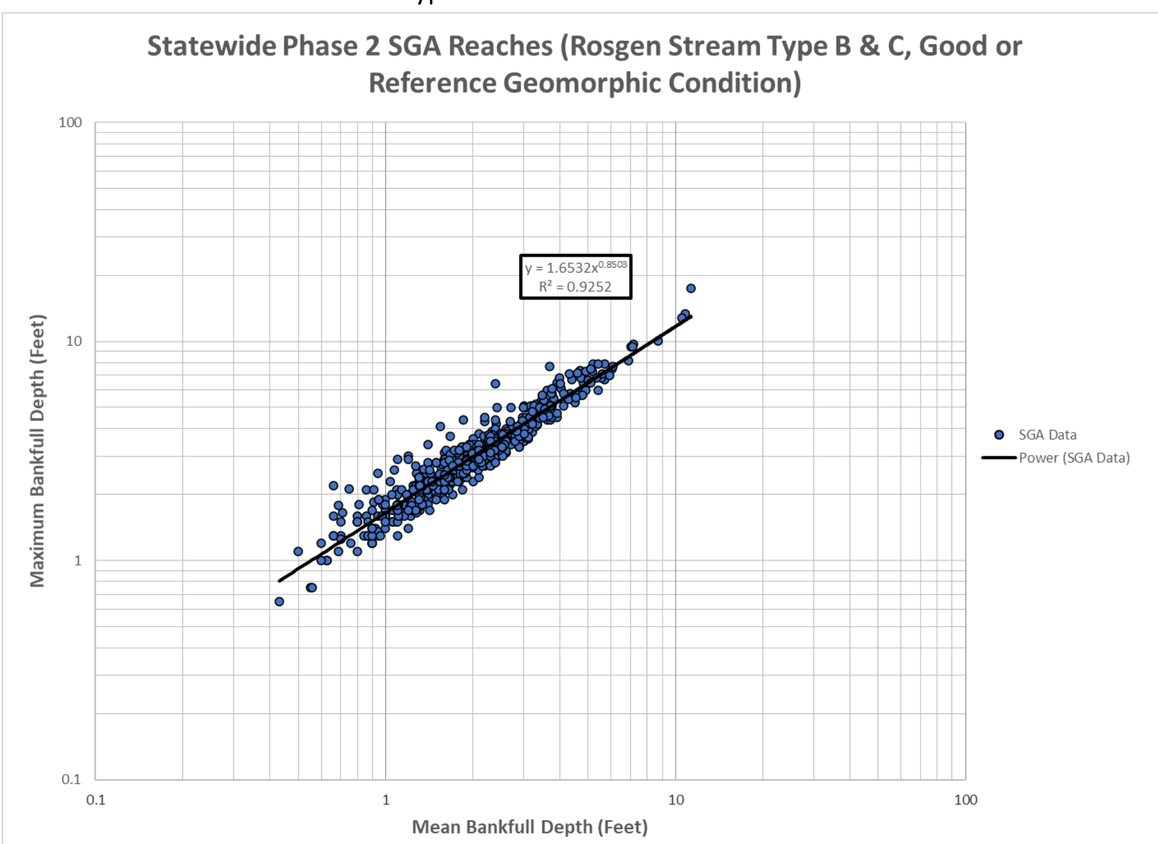

Figure 1.3 : Power function relating mean and maximum bankfull depth from the Phase 2 SGA database for Rosgen Stream Types B and C in Good or Reference Geomorphic Condition.

2.0 RAF and Incision Ratio Determination

The RAF, as outlined in the VT Phase 2 SGA Handbook, should be an area that is or was floodplain at high flows within the past 200 years or so (2009). Parameters given in the description include:

a) The RAF will typically be within 1 bankfull width of the bankfull channel.
b) The RAF will never be less than the maximum bankfull depth.
c) The RAF should not be a high abandoned terrace with an elevation more than 3 times the bankfull depth.

Cross-Sections

We limited incision ratio estimation to channel centerlines for the State River Corridor, indicating they have a drainage area of two square miles or greater. For smaller drainage area headwater streams, the VHD stream centerlines are less accurate and the lower channel depth makes channel and floodplain detection in the LiDAR digital elevation model (DEM) less accurate.

We drew cross sections parallel to the VHD every 200-meters along each segment or reach in the Lake Champlain Basin. The sections extended 100-meters on either side of VHD (200-meters long). We filtered out cross-sections that met the following conditions from the analysis:

a) Cross-sections with in 50-meters of a reach/segment break or tributary confluence;
b) Cross-sections within 20-meters of a road crossing;
c) Cross-sections that intersect the stream network more than once (generally indicating poor cross-section alignment or a confluence).

We then split the stream into “A” and “B” banks based on the minimum elevation value for the cross section (currently, the cross sections are not drawn directionally, so the banks may not correspond to “River Left” and “River Right”).

Recently Abandoned Floodplain (RAF) Estimation

We estimated the height of the RAF by estimating top-of-bank locations using the orthogonal distance between bankfull and a location on the cross sections for each bank. This method was based on a similar approach used to delineate seacliff tops from LiDAR DEMs in southern California (Palaseanu-Lovejoy et al. 2016). We did not evaluate RAF on banks with less than five (5) elevation points.

We drew the line for orthogonal distance analysis between bankfull depth, estimated as the sum of the minimum elevation of the cross-section (estimated channel bottom) and the estimated maximum bankfull depth (Equation 3). We then searched half a bankfull width’s distance beyond the maximum orthogonal point. If the ground elevation rose more than half a maximum bankfull depth, the point was eliminated. This parameter was included to select floodplains that were at least half of the bankfull width and not a narrow shelf or step.

Incision Ratio Estimation

We calculated incision ratio based on as the LiDAR estimated RAF divided by the estimated maximum bankfull depth (Equation 3). If both RAF points were eliminated on a cross-section due to the half bankfull width criteria discussed above, the incision ratio was set equal to one due to steep slopes with no floodplain above the estimated bankfull depth. If both points remained on a cross-section, the minimum RAF was selected. If incision ratio was greater than 3, the incision ratio was set equal to one to filter out high abandoned terraces.

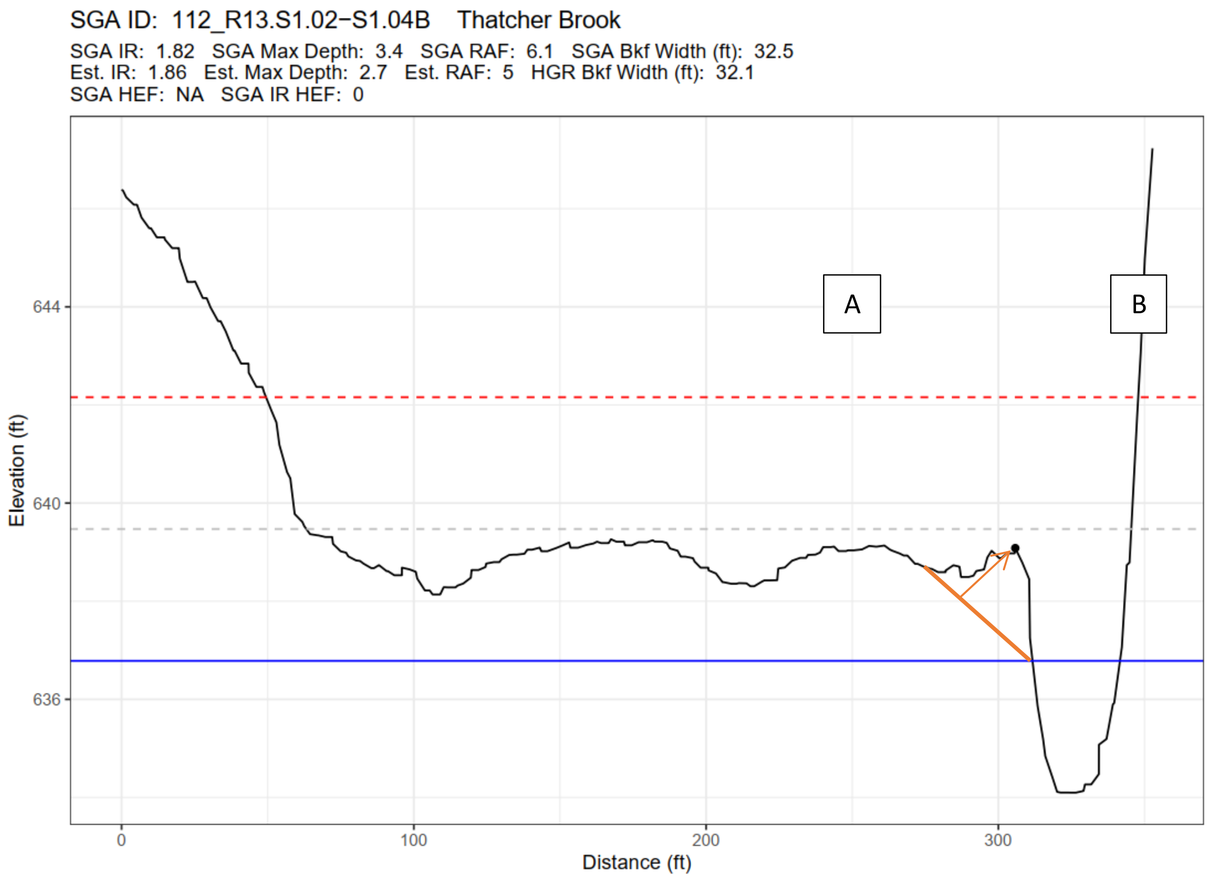

Figure 2.1: LiDAR cross-section with calculated maximum depth shown in blue and lines for calculating orthogonal distance with the minimum and maximum distance lines in orange.

For reaches and segments with multiple cross-sections, we took the median incision ratio value. The median was used instead of the average due to the overrides to the continuous incision ratio value that sets the incision ratio equal to 1. Approximately 80% of stream segments in the Lake Champlain Basin with a river corridor returned an incision ratio result. Reaches and segments without a result were most often due to a lack of cross-sections or low relief due to ponded water in a wetland complex (e.g. Dead Creek and lower Otter Creek).

We redrew cross-sections on the approximately 20% of stream segments and reaches with no LiDAR incision ratio estimate. For these cross-sections we used 50-meter spacing and relaxed the criteria for cross-section distance to a reach/segment break or tributary confluence to 20-meters. Following incision ratio reanalysis, 95.5% of stream segments in the Lake Champlain Basin with a river corridor had a LiDAR incision ratio estimate.

SGA incision ratio data were available for 42% of stream segments in the Lake Champlain Basin with a river corridor. These included some stream segments that did not return a LiDAR incision ratio estimate, improving coverage to 95.9% of stream segments. We discarded five (5) values for having an incision ratio less than 1 or greater than 10. When joined to the river corridor, 97% of Sub-Units had either an SGA or LiDAR incision ratio estimate.

3.0 Constraints and Limitations

This method relies of the VHD stream centerline for determining the location of the channel. Closely cropped cross sections prevent the identification of areas far from the channel being identified as RAFs. If the VHD line is more than 1.5-2 bankfull widths away from the stream channel, the cross section will not have enough information to determine RAF and is discarded. This filtering could be further refined by either increasing the number of x,y,z points required on one side of the channel or by filtering out x,y,z points over 1 or 2 bankfull widths from the bankfull elevation for cross sections where the VHD is not in the channel.

Some characteristics of the LiDAR DEM make the elevations less descriptive than field measurements. The wavelengths of light used to collect the Vermont LiDAR data do not accurately map channel bottoms where the water is more than a foot or so deep. Therefore, adding bankfull depth to the minimum elevation of the stream channel may overestimate the depth due to water in the channel, especially in slack water areas and impoundments. Additionally, LiDAR measurements can also capture less detail under dense vegetative cover and along steep slopes. We feel limiting the streams evaluated to those with drainage areas greater than 2 square miles helped eliminate cases where steep headwater streams might lack the resolution need to evaluate the elevation of the stream bottom and RAF. Channels with small drainage areas are also more likely to have an A-type channel and an inaccurate stream centerline.

4.0 Future Work

- Explore stratification of bankfull depth regressions by slope and drainage area.
- Explore whether backwatered areas or pools are affecting RAF estimates and if a correction factor is needed. Backscatter of the LiDAR on the water surface may cause the minimum elevation of the DEM to be higher than the actual channel bottom. In these areas, calculating the RAF height by taking the difference between the RAF elevation and the minimum channel elevation may underestimate the true value. This would also result in underestimation of the incision ratio.
- Field-validate the incision ratio estimates to refine the method.

5.0 References

Palaseanu-Lovejoy, M., J. Danielson, C. Thatcher, A. Foxgrover, P. Barnard, J. Brock, and A. Young, 2016. Automatic Delineation of Seacliff Limits using Lidar-derived High-resolution DEMs in Southern California. *Journal of Coastal Research*, Special Issue, No. 76, pp.162-173.

Schiff, R., J. C. Louisos, E. Fitzgerald, J. Bartlett, and L. Thompson, 2015. The Vermont River Sensitivity Coarse Screen. Prepared by Milone & MacBroom for the Vermont Land Trust and its conservation partners, Waterbury, VT.

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VTANR, 2009. Vermont Stream Geomorphic Assessment Protocol Handbooks: Remote Sensing and Field Surveys Techniques for Conducting Watershed and Reach Level Assessments (Http://Www.Anr.State.Vt.Us/Dec/Waterq/Rivers/Htm/Rv_Geoassesspro.Htm). Acquired via the internet May 17, 2007. Vermont Agency of Natural Resources, Department of Environmental Conservation, Division of Water Quality, River Management Program, Waterbury, VT.

APPENDIX H

FLOODPLAIN RECONNECTION PROJECT TYPE SELECTION AND PRIORITIZATION

Last updated on: 9/14/2020
Last updated by: Roy/Evan/Evelyn

PROJECT SELECTION (2nd set of filters to identify the applicable project types within each approach.)

ID	APPROACH	PROJECT	IR (RAF, Field)	IR (RAF, Estimate)	IR (HEF, Field)	Lateral Meander Connectivity Rank	Connectivity Project Feasibility Score	Signficant Wetlands or Hydric Soils Present and Land Use Not Natural	Berm Present	Disconnected Flood Chute Present	4th Order or Smaller	River Corridor Bylaws Not in Place
1	No Action	No Action						None	None			
2	Restore lateral-vertical connectivity	Lower floodplain[a]	H, S (or)	H, S, no data (and)		F, M (and)	≥ 75					
3	Restore lateral-vertical connectivity	Reconnect flood chute[b]	M, H, S (and)			F, M (and)	≥ 75 (and)			X		
4	Restore lateral-vertical connectivity	Create flood bench[c]	M, H, S (or)	M, H, S, no data (and)		L, C (and)	< 75					
5	Restore lateral-vertical connectivity	Restore channel slope and pattern[d]	H, S (or)	H, S, no data (and)		F, M (and)	≥ 75					
6	Restore lateral-vertical connectivity	Restore channel roughness [e]	Mi, Mo (or)	Mi, Mo, no data (and)		F, M, L (and)	≥ 75					
7	Restore lateral-vertical connectivity	Raise channel [f]	H, S (or)	H, S, no data (and)		F, M (and)	≥ 75 (and)				X	
8	Restore lateral-vertical connectivity	Remove berm[g]	Mi (and)		H, S (and)	F, M (and)	≥ 75 (and)		X			
9	Restore lateral-vertical connectivity	Restore wetland[h]	Mi, Mo (or)	Mi, Mo, no data (and)		F, M (and)	≥ 75 (and)	X				
10	Constraint removal	Remove major constraint[i]				C (and)						
11	Constraint removal	Remove minor constraint[j]				M, L, C (and)						
12	Protection	Implement river corridor easement				F, M						
13	Protection	Conserve wetlands (e.g., NRCS Wetland Reserve)				F, M (and)		X				
14	Protection	Adopt river corridor bylaws										x
15	Revegetation	Plant woody 50-foot buffer										
16	Revegetation	Plant woody river corridor / floodplain				F, M						
17	Revegetation	Plant woody floodplain (beyond corridor)				F, M						

Incision	Incision Ratio[4]
Minor	IR < 1.3
Moderate	1.3 ≤ IR < 1.5
High	1.5 ≤ IR < 2.0
Severe	IR ≥ 2.0

$RC_{m\text{-}connect}$ %	Lateral Meander Connectivity Rank
90 – 100	Full
75 – 89	Moderate
36 – 74	Low
0 – 35	Constrained

NOTES

[a]Lowering the floodplain is a full or nearly full lowering of the floodplain surface in an incised setting (i.e., many bankfull channel widths, river corridor width, floodplain width - depending on valley confinement and entrenchment ratio).

[b]Flood chutes mapped during Stream Geomorphic Assessments and accessible through Feature Indexing Tool GIS coverage. Flood Chutes assumed to be disconnected when Incision Rank is moderate or greater.

[c]Benches are smaller floodplain reconnetion practices (i.e, 1 or 2 bankfull channel widths) typically implemented in areas with lateral constraints such as infrastructure or confined/entrenched settings (i.e., low confinement or entrnechment ratios).

[d]Restore channel slope and planform means creating meanders and floodplain and riparian features on incised and straightened channels (e.g., rock weirs, log vanes, constructed riffles, adding boulders, etc.)

[e]Restore channel roughness means creating bed features to diversify hydraulic patterns, promote aggradation, and improve habitat complexity (e.g., large wood additions, beaver dam analogs, large wood chop & drop, engineered log jams, etc.)

[f]Channel raising is typically implemented on smaller rivers (e.g., 4th order and smaller, on steeper reaches).

[g]Berm/constraint removal can be full or partial lowering or breaching. Berms mapped during Stream Geomorphic Assessments and accessible through Feature Indexing Tool GIS coverage.

[h]Wetlands mapped on Vermont Significant Wetlands Inventory or with NRCS Hydric Soils, and Land Cover Not Forest or Shrub/Scrub.

[i]Major constraint = impediment to removal score ≥ 3.

[j]Minor constraint = impediment to removal score < 3.

Level of Incision Rank: Mi = Minor, Mo = Moderate, H = High, S = Severe

Lateral Meander Connectivity Rank: F = Full; M = Moderate; L = Low; C = Constrained

Level of ProtectionRank: H = High, M = Moderate, L - Limited, MA = Mostly Absent

Connectivity Project Feasibility Score: The probability of constraint removal where 100 is very likely such a for minor constraints and 0 is not likely such as for major constraints.

Last updated on: 9/14/2020
Last updated by: Roy/Evan/Evelyn

PROJECT PRIORITIZATION (3rd set of filters to identify the likely project priority.)

Mainstem Mad River is 5th order. Should we change 4th to 5th o

ID	APPROACH	PROJECT	Priority Level	Lateral Meander Connectivity Rank	IR (RAF, Field)	IR (RAF, Estimate)	IR (HEF, Field)	Level of Protection Rank	SGA Bank Erosion	SGA Channel Straightening	SGA Aggradation Score	SGA Planform Score	SGA Sensitivity	Connectivity Project Impediment Score	Signficant Wetlands or Hydric Soils Present and Land Use Not Natural	Berm Present	Disconnected Flood Chute Present	4th Order or Smaller River	Shrubs or trees present	
1	No Action	No Action																		
2	Restore lateral-vertical connectivity	Lower floodplain	High	F (and)	S (or)	S (and)		H, M (and)			F, P (or)	F, P (or)	H, VH, Ex							No Lows
			Low	M (and)	H (or)	H (and)		L, MA (and)			R, G (and)	R, G (and)	VL, L, M							Add low
3		Reconnect flood chute	High	F (and)	Mo (or)	Mo														
			Low	M (and)	S (or)	S														
4		Create flood bench	High	L (and)	H, S (or)	H, S (and)												X		No Highs
			Low	C (and)	M (or)	M														order
5		Restore channel slope and planform	High	F (and)				H (and)		H, E (or)		F, P (or)						X		No Highs
			Low	M (and)				M (and)		L (and)		R, G (and)								Removed
6		Restore channel roughness	High	F, M (and)				H, M (and)				R, G (and)						X		Removed
			Low	L (and)				L, MA												
7		Raise channel	High	F (and)	S (or)	S (and)		H, M												No Lows
			Low	M (and)	H (or)	H (and)		L, MA												
8		Remove berm	High	F (and)	Mi (or)	Mi (and)	S (and)	H, M												No exam
			Low	M (and)	Mi (or)	Mi (and)	H (and)	MA												
9		Restore wetland	High	F (and)	Mi (or)	Mi														
			Low	M (and)	Mo (or)	Mo														
10	Constraint removal	Remove major constraint	High		Mi, Mo (or)	Mi, Mo (and)				H, M										No Highs
			Low		H, S (or)	H, S (and)				L										
11		Remove minor constraint	High	M (and)	Mi, Mo (or)	Mi, Mo										X (override)				
			Low	L (and)	H, S (or)	H, S														
12	Protection	Implement river corridor easement	High	F (and)	Mo, H, S (and)	Mo ,H, S (and)		MA, L, M (and)			F, P (or)	F, P (or)	H, VH, Ex							Remove pr
			Low	M (and)	Mi	Mi					R, G (and)	R, G (and)	VL, L, M							
13		NRCS Wetland Reserve	High	F (and)				MA												
			Low	M																
14		Adopt river corridor bylaws	High	F (and)				MA												Yes to re
			Low	M																
15	Revegetation	Plant woody 50-foot buffer	High	F (and)	Mi, Mo (or)	Mi, Mo (or)	Mi, Mo (and)	H (and)	L, M											No Lows
			Low	C (and)	H, S (or)	H, S (or)	H, S (and)	MA (and)	M, H							X (override)				constrain
16		Plant woody river corridor	High	F (and)	Mi, Mo (or)	Mi, Mo (or)	Mi, Mo (and)	H												No Lows
			Low	M (and)	H, S (or)	H, S (or)	H, S (and)	MA								X (override)				
16		Plant woody floodplain (beyond corridor)	High																Yes	
			Low																No	

% Bank Erosion
- Low (<5%)
- Moderate (5-20%)
- High (>20%)

% Straightening
- Low (<5%)
- Moderate (5-20%)
- High (20-50%)
- Extreme (>50%)

Note: River Corridor Planning Guide to identify sediment regimes uses 50% straightening to distinguish between orange (>50) and red reaches

APPENDIX I

STREAM RECONNECTION PROJECT TYPE SELECTION AND PRI-ORITIZATION

Last updated on: 2/16/2021
Last updated by: Roy

PROJECT TYPES

Select project if one or more of these is present on a reach.

Barrier	**Present**	**Absent**
Remove Large Flood Control Dam	√	X
Remove/Convert Large Peaking Hydro Dam	√	X
Remove Large Run of River (ROR) Dam	√	X
Remove/Convert Medium Peaking Hydro Dam	√	X
Remove Medium ROR Dam	√	X
Remove Medium Breached Dam	√	X
Remove Small Intact ROR Dam	√	X
Remove Small Breached Dam	√	X
Replace Bridge (Wbkf>100%)	√	X
Replace Bridge (50%>Wbkf>100%)	√	X
Replace Bridge (Wbkf<50%), shallow channel (< 2%)	√	X
Replace Bridge (Wbkf<50%), steep channel (> 2%)	√	X
Replace Culvert (Wbkf>100%)	√	X
Replace Culvert (50%>Wbkf>100%), shallow	√	X
Replace Culvert (50%>Wbkf>100%), steep	√	X
Replace Culvert (Wbkf<50%), shallow	√	X
Replace Culvert (Wbkf<50%), steep	√	X
Remove Re-Permit Diversion / Withdrawal	√	X
Remove Groundwater Extraction (commercial, wells)	√	X
Stabilize Headcut in Perennial Streami	√	X
Stabilize Gully	√	X
Stabilize Gully w-Treatment of Stormwater	√	X
Disconnect Municipal or Private Road Ditch	√	X
Treat Legacy Forest Trail/Road Drainage	√	X

Last updated on: 2/19/2020
Last updated by: Evan/Roy

Last updated on: 2/19/2021
Last updated by: Roy and Evan

PH1: Less barriers on reach = larger priority?
PH2: Network recovery lengths?

PROJECT PRIORITIZATION (filters to identify the likely project priority.)

ID	PROJECT	Priority Level	Only dam on reach	More than 3 bridges/culverts on reach	RGA Sensitivity	Gemorphic Compatibility	Only extraction	Taller than 3x bankfull depth	Extends stream network	Active erosion
1	No Action									
2	Remove Large Flood Control Dam	High	Y and		Extreme/Very High					
		Low								
3	Remove/Convert Large Peaking Hydro Dam	High	Y and		Extreme/Very High					
		Low								
4	Remove Large Run of River (ROR) Dam	High	Y and		Extreme/Very High					
		Low								
5	Remove/Convert Medium Peaking Hydro Dam	High	Y and		Extreme/Very High					
		Low								
6	Remove Medium ROR Dam	High	Y and		Extreme/Very High					
		Low								
7	Remove Medium Breached Dam	High	Y and		Extreme/Very High					
		Low								
8	Remove Small Intact ROR Dam	High	Y and		Extreme/Very High					
		Low								
9	Remove Small Breached Dam	High	Y and		Extreme/Very High					
		Low								
10	Replace Bridge (Wbkf>100%)	High			Extreme/Very High and	Incompatible				
		Low		Y						
11	Replace Bridge (50%>Wbkf>100%)	High			Extreme/Very High and	Incompatible				
		Low		Y						
12	Replace Bridge (Wbkf<50%), shallow channel (< 2%)	High			Extreme/Very High and	Incompatible				
		Low		Y						
13	Replace Bridge (Wbkf<50%), steep channel (> 2%)	High			Extreme/Very High and	Incompatible				
		Low		Y						
14	Replace Culvert (Wbkf>100%)	High			Extreme/Very High and	Incompatible				
		Low		Y						
15	Replace Culvert (50%>Wbkf>100%), shallow	High			Extreme/Very High and	Incompatible				
		Low		Y						
16	Replace Culvert (50%>Wbkf>100%), steep	High			Extreme/Very High and	Incompatible				
		Low		Y						
17	Replace Culvert (Wbkf<50%), shallow	High			Extreme/Very High and	Incompatible				
		Low		Y						
18	Replace Culvert (Wbkf<50%), steep	High			Extreme/Very High and	Incompatible				
		Low		Y						
19	Remove Re-Permit Diversion / Withdrawal	High			Extreme/Very High and		Y			
		Low								
20	Remove Groundwater Extraction (commercial, wells)	High			Extreme/Very High and		Y			
		Low								
21	Stabilize Headcut in Perennial Stream	High			Extreme/Very High					
		Low								
22	Stabilize Gully	High			Extreme/Very High and			Y or	Y or	Y
		Low								
23	Stabilize Gully w-Treatment of Stormwater	High			Extreme/Very High and			Y or	Y or	Y
		Low								
24	Treat Legacy Forest Trail/Road Drainage	High			Extreme/Very High and				Y or	Y
		Low								
25	Backwater Culvert with Weir or Other Approach	High		Y and	Extreme/Very High and	Compatible				
		Low								
26	Place Baffles in Culvert	High		Y and	Extreme/Very High and	Compatible				
		Low								

Table 7.2 Phase 2 Stream Sensitivity Ratings based on existing stream type, condition and departure.

Stream Type Group	Existing Geomorphic Stream Type[1]	Sensitivity: Reference or Good Condition	Sensitivity: Fair-Poor Condition in Major Adjustment	Sensitivity: Poor Condition, Represents a Stream Type Departure
1	A1, A2, B1, B2	Very Low	Very Low	Low
2	C1, C2	Very Low	Low	Moderate
3	G1, G2	Low	Moderate	High
4	F1, F2	Low	Moderate	High
5	B3, B4, B5	Moderate	High	High
6	B3c, C3, E3	Moderate	High	High
7	C4, C5, B4c, B5c	High	Very High	Very High
8	A3, A4, A5, G3, F3	High	Very High	Extreme
9	G4, G5, F4, F5	Very High	Very High	Extreme
10	D3, D4, D5	Extreme	Extreme	Extreme
11	C6, E4, E5, E6	High	Extreme	Extreme

Category Name	Screen Score	Threshold Conditions	Description of structure-channel geomorphic compatibility
Fully compatible	$20<GC\leq25$	n/a	Structure fully compatible with natural channel form and process. There is a low risk of failure. No replacement anticipated over the lifetime of the structure. A similar structure is recommended when replacement is needed.
Mostly compatible	$15<GC\leq20$	n/a	Structure mostly compatible with current channel form and process. There is a low risk of failure. No replacement anticipated over the lifetime of the structure. Minor design adjustments recommended when replacement is needed to make fully compatible.
Partially compatible	$10<GC\leq15$	n/a	Structure compatible with either current form or process, but not both. Compatibility likely short term. There is a moderate risk of structure failure and replacement may be needed. Re-design suggested to improve geomorphic compatibility.
Mostly incompatible	$5<GC\leq10$	% Bankfull Width + Approach Angle scores ≤ 2	Structure mostly incompatible with current form and process, with a moderate to high risk of structure failure. Re-design and replacement planning should be initiated to improve geomorphic compatibility.
Fully incompatible	$0\leq GC\leq5$	% Bankfull Width + Approach Angle scores ≤ 2 **AND** Sediment Continuity + Erosion and Armoring scores ≤ 2	Structure fully incompatible with channel and high risk of failure. Re-design and replacement should be performed as soon as possible to improve geomorphic compatibility.

APPENDIX J

PREDICTED SEDIMENT REGIME CLASS ASSIGNMENT RULE SET

Predicted Sediment Regime Class Assignment Rule Set (Draft)

Sediment regime classifications (Section 4.2) for each geomorphic reach or segment are relied upon in the FFI to screen lower valley reaches for flood erosion hazards (see Section 5.2.2 and Flood Resiliency Methods spreadsheet V13). These classifications were originally proposed by Kline (2010) as part of the River Corridor Planning guidance (see Tables J2 and J3 reproduced from this guidance) and have been vetted in the peer-reviewed literature (Underwood et al., 2021).

Need for a Sediment Regime Class Rule Set

Sediment regime classes (SRCs) are dependent upon several reach-scale parameters (Tables J1, I2, and I3) collected during stream geomorphic assessments (SGA) following VTANR protocols (VTANR, 2009). Ideally, SRCs are assigned after Phase 2 SGA is performed, because field-based assessments provide a more comprehensive and representative estimate of these parameters than desktop assessments (Phase 1 SGA). However, not all reaches in the Vermont portion of the Lake Champlain Basin have been assessed through Phase 2 SGA. Of those that have, SRC assignments exist for only a subset, and these classifications are recorded in watershed-specific river corridor plans and do not exist in the online SGA database. For these reasons, the FFI Development Team generated a rule set to assign provisional SRC assignments to geomorphic reaches based on available Phase 1 and/or Phase 2 SGA data, as well as select FFI connectivity parameters. Sediment regime classes were then tagged to FFI corridor sub-units of lower valley reaches to screen for erosion hazards (Section 5.2.2) where SRCs were re-classed into erosion damage potential categories of Low, Moderate and High (Figure J1).

CEFD / TR	FSTCD - LMC ≤ 20% disconnected	CST / UST / FSTCD - LMC > 20% disconnected / DEP
LOW	MODERATE	HIGH

Figure J1. Erosion Damage Potential by Sediment Regime Class

Development of a Sediment Regime Class Rule Set

To support development and testing of a SRC rule set, we compiled a training data set of 135 reach/segment observations from Phase 2 SGA where SRC classifications had been assigned by experts following guidance in Kline (2010). Of this total, 110 observations were sourced from Underwood et al. (2021) for reaches located within the Lake Champlain Basin. These were supplemented with SRCs for 25 Mad River reaches, a pilot watershed of the FFI.

We then performed a feature selection exercise to identify reach-scale parameters that have meaning for discerning between SRCs. A starting point for important features relied on the findings of Underwood and others (2021) that had identified Phase 1 and Phase 2 SGA parameters important in driving SRC membership; we also explored the addition of new metrics developed during the FFI project. A final listing of input parameters is provided in Table J1.

Table J1. Sourcing of parameters used in provisional Sediment Regime Classifications.

Parameter	Abbrev in Rule Set chart	Abbrev in Logic	Data Source DMS Ph 1 SGA	DMS Ph 2 SGA	FFI Database
Impoundment	I	I	Step 5.1	Step 4.5	
Impoundment Location	IL	IL	--	Step 4.5	
Valley Confinement	VC	VC	Step 2.10	Updated	
Incision Ratio	IR	IR	--	Step 2.8	lidar-derived; see App. G
Channel SSP at Q2	SSP_{Q2}	Q	--	--	derived from probHAND data sets; see Section 4.3 and App. X
Valley Slope	S	Slp	Step 2.3	--	
Width to Depth ratio	W/D	WD	--	Step 2.6	
Percent Straightening	pSTR	pSTR	Step 5.4	Updated	
Alluvial Fan presence	Alluv Fan	AF	Step 3.1	Updated	
Lateral Meander Connectvity Score	LMC	LMC	--	--	Section 1.2.1; App. F Connectivity Methods Details

DMS = Data Management System, VTANR Stream Geomorphic Assessment data, https://anrweb.vt.gov/DEC/SGA/Default.aspx

SGA = Stream Geomorphic Assessment, VTANR protocols, Kline et al. 2009, https://dec.vermont.gov/watershed/rivers/river-corridor-and-floodplain-protection/geomorphic-assessment

Updated = VTANR SGA protocols call for Phase 1 values to be updated based on field-based observations from Phase 2, either through manual database changes or upload of Feature Indexing Tool data, or both.

We carried out feature selection and rule set development by iteratively running various rule sets constructed of the input variables in Table J1, and comparing resulting classifications to existing, expert-assigned classifications for the training data set. Our objectives were to minimize misclassifications while also maximizing the number of reaches that could ultimately be assigned provisional SRCs in the LCB (i.e., rely on data that might be sourced only from remote sensing methods). The final rule set used inputs in Table J1 and applied them according to the logic illustrated in the decision tree of Figure J2.

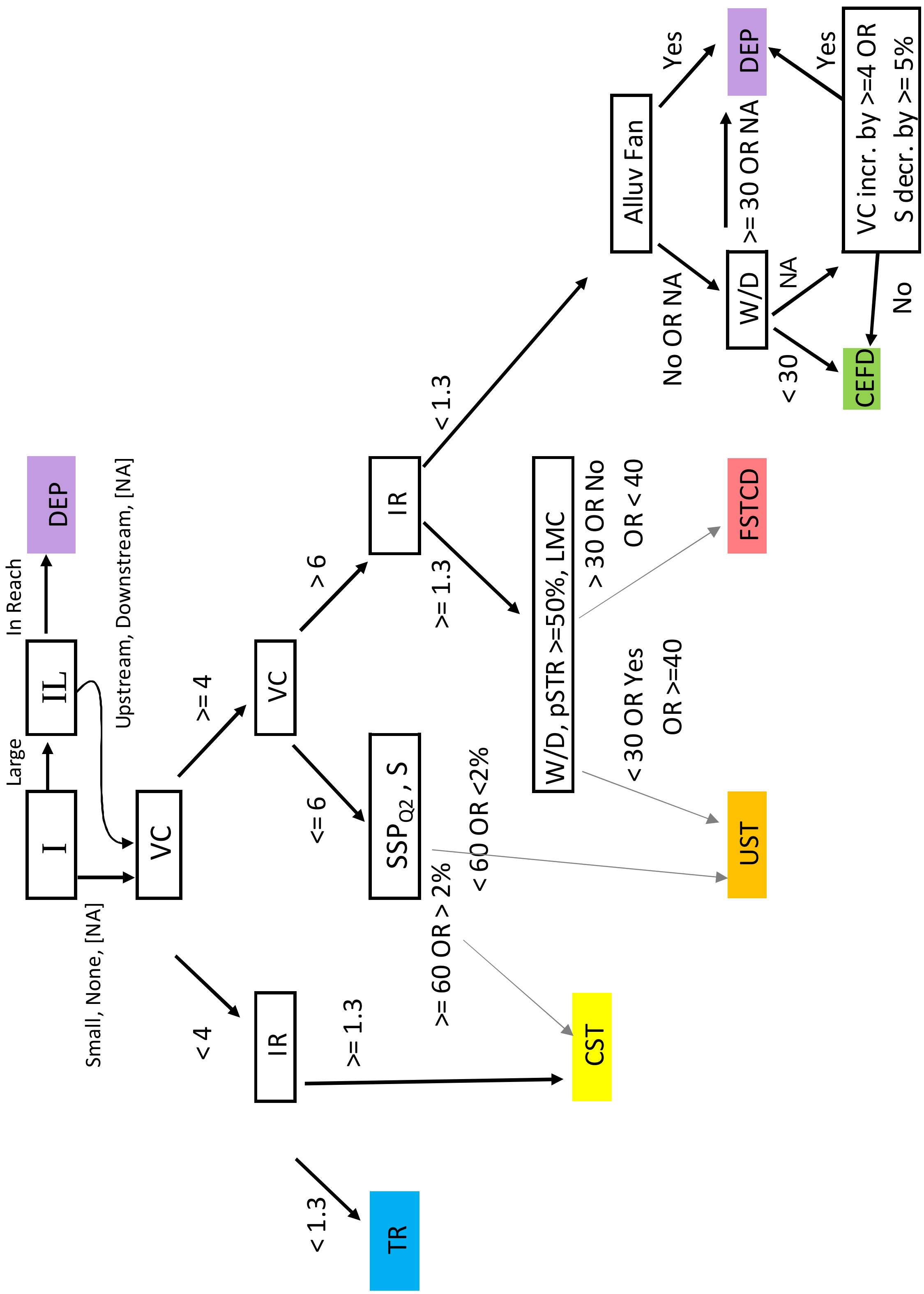

Figure J2. Graphical display of Rule Set used for provisional Sediment Regime Classifications.

Performance of Rule Set

Flood Erosion Damage Potential		n	Class	Rule Set Assigned: TR	CST	UST	FSTCD	CEFD	DEP	Percent Correct	Percent Correct w/in 1 class
LOW		20	TR	**14**	5				1	70%	95%
HIGH		5	CST	1	**4**					80%	100%
HIGH	Expert	39	UST	2	18	**16**	1	2		41%	90%
MOD	Assigned	32	FSTCD		11	8	**11**	1	1	34%	63%
LOW		37	CEFD	3	3	3		**19**	9	51%	76%
HIGH		2	DEP		1				**1**	50%	50%
		135									

Figure J3. Confusion matrix illustrating the performance of the rule set on n=135 reaches/segments with existing, expert-assigned Sediment Regime Classes.

Discussion

TR and CST have higher percent correct classifications (70%, 80%) than the remaining four SRCs (ranging from 34% to 51%). Discerning between UST, FSTCD and CEFD is difficult with the current rule set and its reliance on parameter values that can be remotely sensed and do not require field measurement. However, correct classifications increase for five out of the six SRCs when considering correctness within one class to either side of the correct class (ranging from 63% to 100%). Classifications are mostly conservative, meaning that a majority of the misclassifications went to an equal or higher Erosion Damage Potential class. CST is the exception, in that 20% (1 out of 5) of the observations in that category were misclassified to a much lower Erosion Damage Potential (i.e., from High to Low).

Despite the limitations of this rule set for classification, it represents a transparent and standardized approach suitable for assignment of provisional SRCs to the vast majority of Lake Champlain Basin reaches in Vermont to support screening and planning-level phases of project selection and prioritization within the FFI. As projects are vetted with landowners and proceed through design and construction phases, we anticipate that geomorphic assessments will be conducted, including an updated assignment of SRC, which itself will inform a revised assessment of Erosion Damage Potential (Table J1) and screening of erosion hazards to update the flood resiliency benefit of a given project.

Future Work

Sediment regime classifications could be improved through additional analysis in a future phase of FFI, including:

- *Increasing the number of observations in the training data set.* At present the training data set (n=135) has very few numbers in the categories of CST (n=5) and DEP (n=2). Additional expert-assigned SRCs could be populated from existing River Corridor Plans, many of which are accessible here: https://anrweb.vt.gov/DEC/SGA/finalReports.aspx.

- *Exploring random forest or boosted regression tree methods of classification.* These more robust methods for feature selection and classification would be expected to refine thresholds in parameter values that define membership in Sediment Regime Classes, and result in greater accuracy of classifications.

- *Continuing to update the SGA data set and associated geospatial data sets upon which the FFI database relies.* As new SGA data are collected, and reaches are segmented, this new data will offer greater spatial resolution of SRCs. Phase 1 reaches are often longer than Phase 2 reaches/segments and may span substantial changes in valley confinement and/or slope – features that would cause a reach to be segmented during a field-based Phase 2 SGA. Expanded SGA data sets would be expected to yield greater accuracy in SRCs, both in terms of greater accuracy of input data when values are sourced from field measurements rather than remote sensing; and in terms of allowing for additional inputs to the rule sets (or machine learning methods) once more comprehensive field-based measurements are acquired. For example, two sets of provisional SRC classifications could be generated: one based on only remotely-sensed or Phase 1 SGA data, and a second more robust set of classifications relying on additional inputs sourced from field observations in Phase 2 SGA.

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Table J2. Sediment Regime Class – Description and Color Coding (excerpted from Kline, 2010, p.43)

Sediment Regime	Narrative Description
Transport	Steeper bedrock and boulder/cobble cascade and step-pool stream types; typically in more confined valleys, do not supply appreciable quantities of sediments to downstream reaches on an annual basis; little or no mass wasting; storage of fine sediment is negligible due to high transport capacity derived from both the high gradient and/or natural entrenchment of the channel.
Confined Source and Transport	Cobble step pool and steep plane bed streams; confining valley walls, comprised of erodible tills, glacial lacustrine, glacial fluvial, or alluvial materials; mass wasting and landslides common and may be triggered by valley rejuvenation processes; storage of coarse or fine sediment is limited due to high transport capacity derived from both the gradient and entrenchment of the channel. Look for streams in narrow valleys where dams, culverts, encroachment (roads, houses, etc.), and subsequent channel management may trigger incision, rejuvenation, and mass wasting processes.
Unconfined Source and Transport	Sand, gravel, or cobble plane bed streams; at least one side of the channel is unconfined by valley walls; may represent a stream type departure due to entrenchment or incision and associated bed form changes; these streams are not a significant sediment supply due to boundary resistance such as bank armoring, but may begin to experience erosion and supply both coarse and fine sediment when bank failure leads to channel widening; storage of coarse or fine sediment is negligible due to high transport capacity derived from the deep incision and little or no floodplain access. Look for straightened, incised or entrenched streams in unconfined valleys, which may have been bermed and extensively armored and are in Stage II or early Stage III of channel evolution.
Fine Source and Transport & Coarse Deposition	Sand, gravel, or cobble streams with variable bed forms; at least one side of the channel is unconfined by valley walls; may represent a stream type departure due to vertical profile and associated bed form changes; these streams supply both coarse and fine sediments due to little or no boundary resistance; storage of fine sediment is lost or severely limited as a result of channel incision and little or no floodplain access; an increase in coarse sediment storage occurs due to a high coarse sediment load coupled with the lower transport capacity that results from a lower gradient and/or channel depth. Look for historically straightened, incised, or entrenched streams in unconfined valleys, having little or no boundary resistance, increased bank erosion, and large unvegetated bars. These streams are typically in late Stage III and Stage IV of channel evolution.
Coarse Equilibrium (in = out) & Fine Deposition	Sand, gravel, or cobble streams with equilibrium bed forms; at least one side of the channel is unconfined by valley walls; these streams transport and deposit coarse sediment in equilibrium (stream power—produce as a result of channel gradient and hydraulic radius—is balanced by the sediment load, sediment size, and channel boundary resistance); and store a relatively large volume of fine sediment due to the access of high frequency (annual) floods to the floodplain. Look for unconfined streams, which are not incised or entrenched, have boundary resistance (woody buffers), minimal bank erosion, and vegetated bars. These streams are Stage I, late Stage IV, and Stage V.
Deposition	Silt, Sand, gravel, or cobble streams with variable and braided bed forms; at least one side of the channel is unconfined by valley walls; may represent a stream type departure due to changes in slope and/or depth resulting in the predominance of transient depositional features; storage of fine and coarse sediment frequently exceeds transport**. Floodplains are accessed during high frequency (annual) floods. Look for unconfined streams, which are not incised or entrenched, have become significantly over-widened, and if high rates of bank erosion are present, it is offset by the vertical growth of unvegetated bars. These regimes may be located at zones of naturally high deposition (e.g., active alluvial fans, deltas, or upstream of bedrock controls), or may exist due to impoundment and other backwater conditions above weirs, dams and other constrictions.

** Use of the "Deposition" regime characterization may be rare, but valuable as a planning tool, where the reach is storing far more than it is transporting during some defined planning period. The extreme example would be that of an impounded reach where all of the course and a great percentage of the fine sediments are being deposited, rather than transported downstream. This man-made condition may change, thereby changing the sediment regime, but is not likely over the period at which the corridor plan will be used.

Table J3. Phase 2 SGA parameters useful in classifying Sediment Regime Class (excerpted from Kline, 2010, p.44)

Sediment Regime	Delimiting criteria related to sediment supply, transport, and storage	Stage of Channel Evolution Geomorphic Condition	Common Existing Stream Type	Natural Valley Type
Transport	Bedrock gorge = yes	Stage I or V Good-Ref	A1, A2, B1, B2 G1,G2, G3 F1, F2, F3	NC, SC, NW
	Incision ratio < 1.3	Stage I or V Good-Ref	A3, B3, B4	NC, SC, NW
Confined Source and Transport	Incision ratio > 1.3	Stage II-IV Fair-Good	A3, B3*	NC, SC, NW
	Incision ratio > 1.3	Stage II-IV Fair-Good	A4, A5 B4*, B5*	Any Type
Unconfined Source & Transport	Bank armor > 50% Straightening > 50% W/d < 30 Incision ratio > 1.3	Stage II - III Poor-Fair	G3, G4, G5 F3, F4, F5	NW, BD, VB
		Stage II - III Poor-Fair	E3, E4, E5 C3, C4, C5 B3c, B4c, B5c	NW, BD, VB
Fine Source & Transport and Coarse Deposition	Bank armor < 50% W/d > 30** Incision ratio > 1.3	Stage II-IV Poor-Fair	E3, E4, E5 C3, C4, C5 B3c, B4c, B5c F3, F4, F5	NW, BD, VB
	Bank armor < 50% Incision ratio > 1.3	Stage II-IV Poor-Fair	D3, D4, D5	NW, BD, VB
Coarse Equilibrium (in = out) & Fine Deposition	Incision ratio < 1.3	Stage I -V Fair-Good-Ref	D3, D4, D5	NW, BD, VB
	W/d < 30 Incision ratio < 1.3	Stage I -V Fair-Good-Ref	C2, C3, E3	NW, BD, VB
	W/d < 30 Incision ratio < 1.3	Stage I -V Fair-Good-Ref	C4, C5 E4, E5	NW, BD, VB
Deposition	Incision ratio = 1.0 Backwater from downstream constriction, weir, dam, etc.	Stage IId	C4, C5, C6	BD, VB
	Incision ratio = 1.0 Active alluvial fan	Stage IId	D3, D4, D5	BD, VB

* B streams with the slope of a C stream, or a Bc stream type, in an unconfined valley setting (NW, BD, VB) should be classified as having a sediment regime as either "unconfined source and transport" or a "fine source and transport & course deposition" depending on other delimiting criteria.

** Depositional Features may include multiple channel avulsions and multiple chute cut-offs

APPENDIX K

SPECIFIC STREAM POWER AS AN INDICATOR OF EROSION

At any point in the river, discharge (Q), friction slope (S_f) and the unit weight of water (γ) combine to generate the Total Stream Power available to erode channel boundaries (Bull, 1979) (Figure K1). In order to compare in-channel stream power at various locations across or within watersheds, Total Stream Power is normalized by the channel width (w), to define the Specific Stream Power. In practice, the friction slope of the stream is typically approximated by substituting the water surface slope, or channel bed slope (Fonstad, 2003).

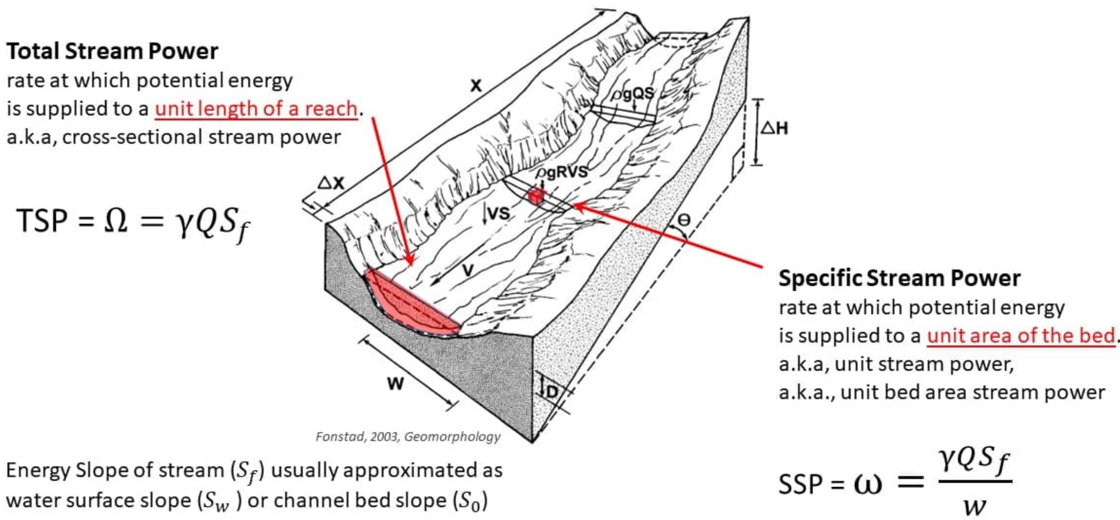

Figure K1. Illustration of channel dimensions used in calculating Total Stream Power and Specific Stream Power, modified after Fonstad (2003).

In general, SSP increases from the headwaters to the mid-point of the watershed as discharge grows with increasing drainage area; SSP then begins to decline with distance downstream as channel slopes decline, despite continued increase in drainage area (Schumm, 1984). In a study of Vermont stream channels of various sizes (denoted by Strahler stream order), MMI / FEA found that Specific Stream Power peaks in 3rd order streams (Figure K2).

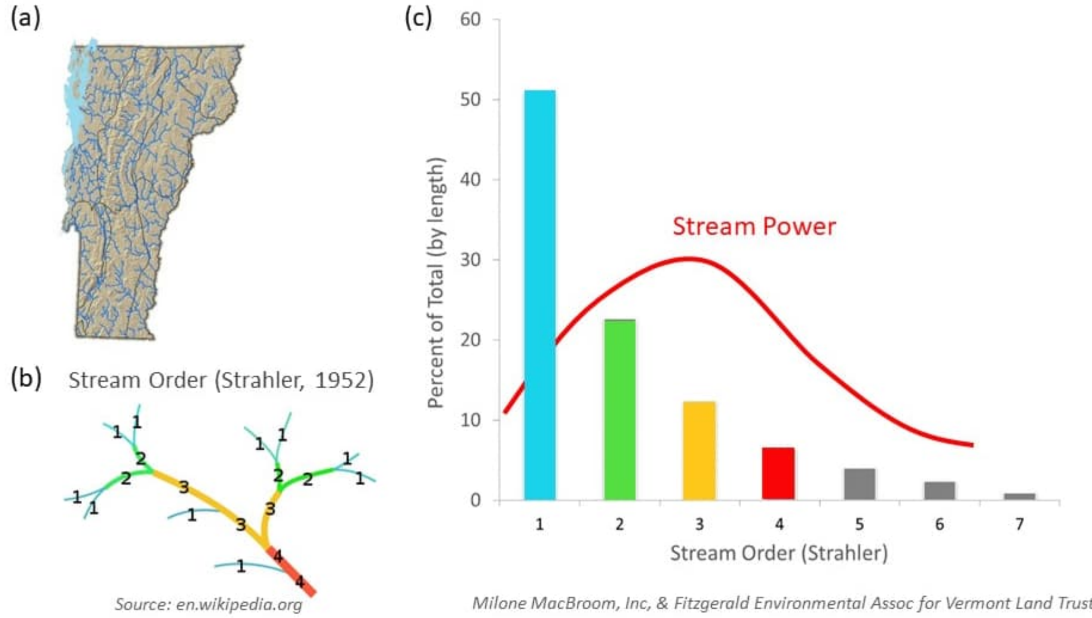

Figure K2. Based on mapping of SSP along statewide river networks (a), first and second order stream channels (b) comprise 75 % of the river network. SSP values peak in third order streams (c). Source: Milone & MacBroom and Fitzgerald Environmental for Vermont Land Trust.

The pattern displayed in Figure K2 for the aggregate of Vermont streams, is consistent with an idealized downstream trend in SSP for a given watershed (Magilligan, 1992). However, in reality, SSP varies in complex and nonlinear ways in most watersheds, due to changing lithology and variable patterns in tributary confluences (Fonstad, 2003; Magilligan, 1992).

We can easily calculate and map the SSP available to the channel to perform erosion; however, there is a critical threshold of stream power which must be exceeded to actually move sediment or debris. This critical stream power is a function of the nature of channel boundaries, including sediment sizes, cohesive strength of soils, and degree of stabilizing vegetative cover. When available stream power exceeds the critical stream power, sediment and debris are mobilized and the channel bed and banks are eroded (Bull, 1979).

In general, coarse-grained sediments exhibit greater resistance to movement than fine-grained sediments due to their mass and << physical set up - incipient motion conditions >> (Figure K3). Petit and others (2005) also found that headwaters (<20km2) exhibit higher values of critical SSP, due to resistance offered by bedforms (e.g., boulder steps) in addition to their typically more coarse-grained bed materials (e.g., boulders, bedrock)

For gravel-bed rivers (64 to 2 mm), previous research has defined a SSP threshold of 300 Watts/m2 associated with major channel adjustment (Magilligan, 1992). Research has also defined a stability threshold of approximately 35 Watts/m2, where channels experiencing greater than this threshold are erosion-dominated and channels with SSP less than this threshold tend to be deposition-dominated (Bizzi and Lerner, 2013; Brookes, 1987).

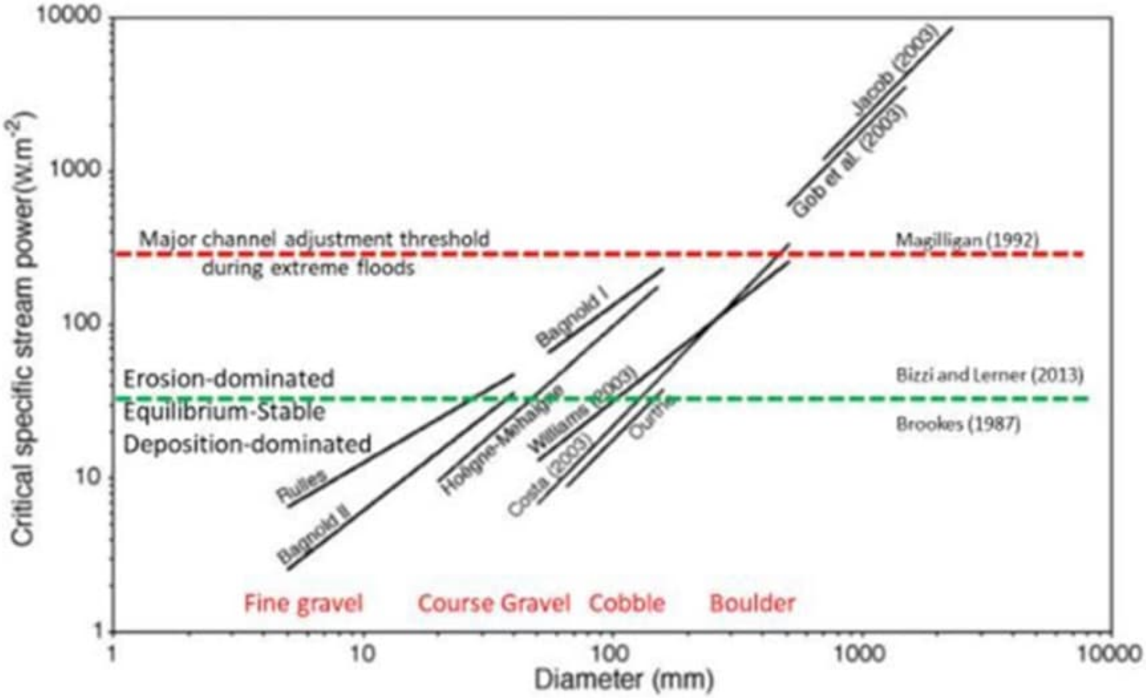

Figure K3. Relationships between critical specific stream power and median diameter of channel bed particles; modified after Petit et al 2005). Annotated with grain size classifications and thresholds for gravel-bed rivers (after Magilligan, 1992; Bizzi and Lerner, 2013; Brookes, 1987).

Lisenby and Fryirs found that on a catchment scale, most of the channel adjustment occurs in reaches where upstream drainage area comprises between 10 and 60 % of the total drainage area (i.e., mid-order channels). (Importantly, this is for Australia and more arid climate). They call this a "Window of Opportunity" for channel management aimed at reducing water quality and habitat impacts.

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APPENDIX L

SKETCHES OF EXAMPLES OF ACTIVE FLOODPLAIN RESTORATION APPROACHES

A typical channel-floodplain cross section in Lower Valley rivers of Vermont (Fig. L1a) includes alluvial sediments that fill the valley, flanked by bedrock-controlled valley walls. Soils develop on a thin veneer of glacial till on the valley side slopes (not pictured). Within the valley there may be elevated terraces of glacial origin, either from outwash or lake-bottom sediments, such as the glaciolacustrine terrace indicated in Figure L1a. Often, due to a history of channel and floodplain manipulations and deep valley accretions from deforestation, the river channel is incised below the alluvial floodplain, and relatively high-frequency storms (e.g., storm with 2-year recurrence interval) are contained within the channel and no longer spill out onto the floodplain.

Common restoration techniques used to reconnect an incised channel with its floodplain include:

- Flood Chute Lowering (Fig. L1b) – flood chutes or side arms of the river channel convey flood waters during annual or higher-magnitude flood peaks. In a depositional reach, the upstream end of these natural features may become blocked with sediment and debris from erosion occurring in upstream reaches. Flood chute lowering can reconnect these side arms to lessen water elevations and velocities within the main channel during flooding events.

- Berm Removal (Fig. L1c) - earthen berms have traditionally been constructed along streambanks to prevent floodwaters from impacting adjacent land uses including agriculture or built infrastructure. Materials are often sourced from channel dredging activities. Berm removal can include full or partial lowering or breaching.

- Flood Bench (Fig. L1d) - benches are smaller-scale floodplain reconnection practices (i.e, 1 or 2 channel widths) typically implemented in areas with lateral constraints such as nearby buildings or roads. This technique is also used in steeper-gradient settings more closely confined by valley walls. Elevation lowering may target the 2-year flood, or a higher-stage, lower frequency design storm.

- Floodplain Lowering (Fig. L1e) – In areas with fewer lateral constraints, larger-scale lowering of the floodplain may be possible across more than 2 channel widths, usually targeting the 2-year flood elevation.

Often more than one of the above techniques are implemented in combination, followed by establishment of naturally-vegetated buffers (Fig. L1f).

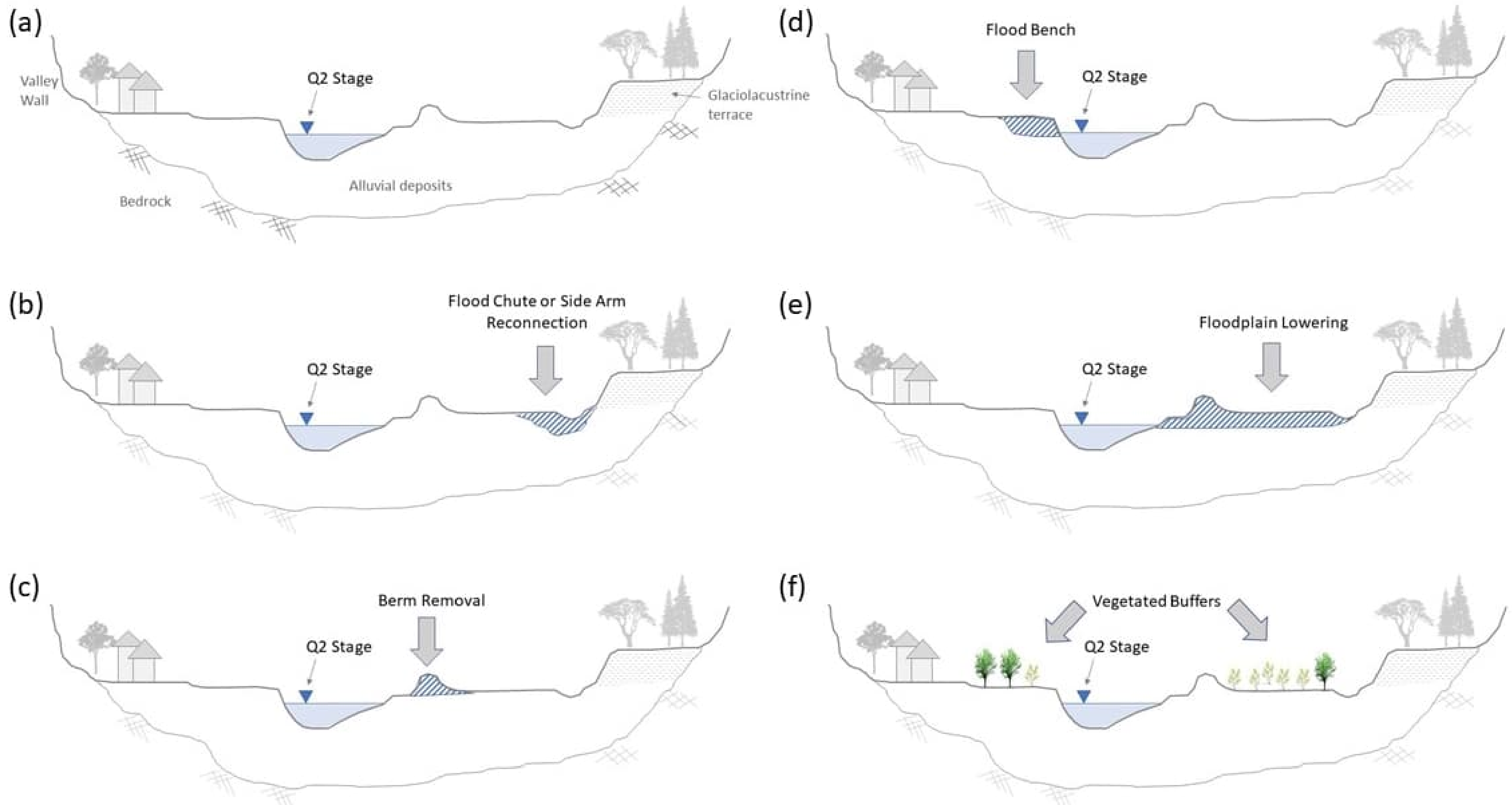


Figure L1. Floodplain reconnection alternatives for incised channels in unconfined Lower Valley settings that are (a) typically characterized by alluvial valley fill, may include: (b) flood chute (or side-arm channel) reconnection; (c) berm removal; (d) flood benching; (e) floodplain lowering; and (f) planting of naturally-vegetated buffers, or combinations of the above.

APPENDIX M

PHOSPHORUS LOAD ALLOCATIONS AND STREAM AND FLOOD-PLAIN PROJECT CREDITING BASED ON THE LAKE CHAMPLAIN TMDL AND VERMONT FUNCTIONING FLOODPLAIN METHODS TO ACHIEVE STABLE STREAMS (FOR INCLUSION IN THE VTDEC STANDARD OPERATING PROCEDURES FOR TRACKING & AC-COUNTING OF NATURAL RESOURCES RESTORATION PRO-JECTS)

PHOSPHORUS LOAD ALLOCATIONS AND STREAM AND FLOODPLAIN PROJECT CREDITING BASED ON THE LAKE CHAMPLAIN TMDL AND VERMONT FUNCTIONING FLOODPLAIN METHODS TO ACHIEVE STABLE STREAMS

Version 2.1

Prepared for:

Watershed Management Division

and Water Investment Division

Vermont Department of Environmental Conservation

June 15, 2023

CONTENTS

APPENDICES

1. ALLOCATION AND CREDITING FROM THE TMDL, PROCESS-BASED DERIVATION OF PHOSPHORUS BASE LOADS

Under the Lake Champlain TMDL, the baseline phosphorus (P) load attributed to stream instability has been allocated to TMDL sub-basins – one or more that make up each HUC 12 watershed in the Lake Champlain Basin (Figure 1 and Appendix A). P base load allocations at the sub-basin level are needed for TMDL tracking and accounting of P load reductions resulting from resource management and projects implemented at the reach or sub-reach scale. Allocating P base loads to river channels at a sub-basin scale recognizes that stream processes, channel evolution trajectories, and stream stability largely operate over geomorphic stream reaches at the watershed scale rather than at individual sites.

> *The erosion control "practice" in this TMDL context is not actually a BMP in the conventional sense. Given that channel erosion control projects (such as bank stabilization) in one part of a stream system can have destabilizing effects on other parts of the system, the goal in this case was to estimate the phosphorus reduction associated with bringing an entire stream reach to a more stable geomorphic condition. Following years of detailed geomorphic assessments, VT DEC has classified a large subset of Vermont streams according to channel evolution model (CEM) stages I through V. Streams in CEM stages I and V are typically fairly stable systems close to equilibrium conditions; stage II and III streams are generally unstable and eroding; and stage IV streams are usually in between stable and unstable conditions (Tetra Tech, 2015a, b).*

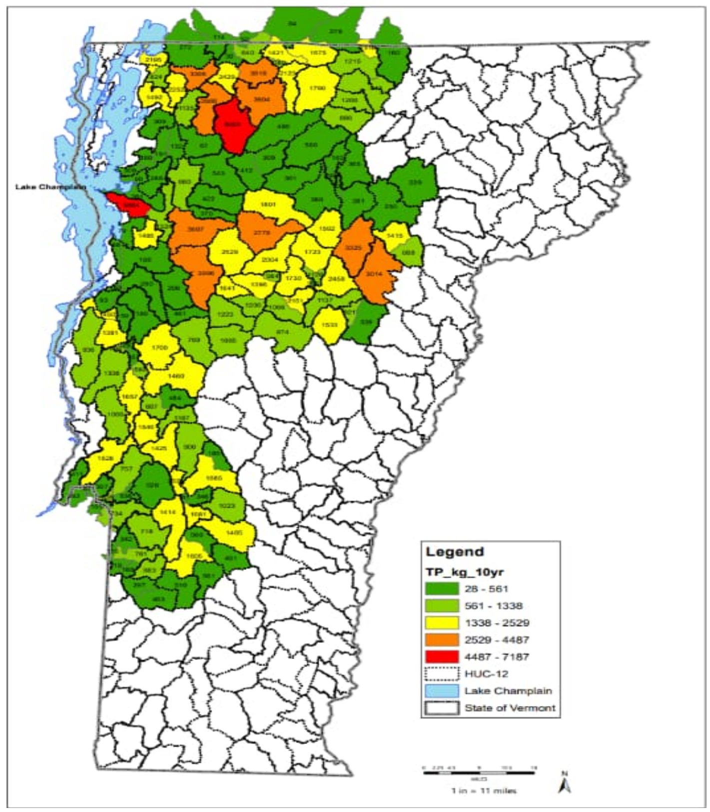


Figure 1. Lake Champlain Sub-basin phosphorus load allocations (Source: VTANR).

Floodplain (vertical and lateral) and stream (longitudinal and temporal) connectivity[1] (or the lack thereof) are a reflection of ongoing channel evolution processes and stream dynamic equilibrium. Structures, channelization, and land use practices in the river corridor or floodplain may result in disconnectivity, creating an unnatural imbalance between erosion and deposition processes. This imbalance in stream networks leads to a loss of ecosystem services and habitat,

[1] **Vertical connectivity** is a measure of a stream's access to its floodplain at bankfull flows (~Q1.5) and represented by the incision ratio, which is a measure of bed degradation or downcutting. The **lateral connectivity** is characterized by the available space in the river corridor that is free of physical constraints to river movement; land protections such as river corridor easements; and natural riparian vegetation. **Longitudinal connectivity** is the upstream/downstream connection across the stream network and is important for the downstream movement of water, sediment, large wood, coarse particulate organic matter, nutrients, and ice; for the upstream and downstream movement of fish, aquatic organisms, and wildlife. **Temporal connectivity** is the resulting timing of flood flows accessing floodplains based on watershed hydrology and the flow characteristics within the stream network as measured by the magnitude, frequency, and duration of flows.

including reduced inundation-related storage processes in natural wetland and floodplain features, increased flood vulnerability, stream channel instability, and degraded riparian habitat.

To restore and protect stream and floodplain connectivity, a project and channel evolution crediting system has been developed, facilitated by downscaling of the TMDL sub-basin P base load allocation to the geomorphic sub-unit, segment, or reach scale (Schiff et al., 2023). The P allocation and crediting system described below recognizes that projects implemented to improve stream and floodplain connectivity will affect stream processes and nutrient loading occurring at both site and sub-basin scales and may therefore be awarded multiple P load reduction credits depending on erosion-reduction, deposition, and inundation processes affected by the project. P load reduction credits are achieved through two key mechanisms: 1) improving stream stability; and 2) enhancing storage (Figure 2). Stream stability and storage may be restored through the removal of constraints and protection of the natural processes that work toward equilibrium conditions, and/or through the physical removal of legacy sediments that overburden historic floodplains and contribute to channel incision. A given restoration project may include one or more of these components. This connectivity-based framework for P base load allocation and crediting is predicated on the understanding that restoring connectivity will increase stream equilibrium and therefore reduce net P loading to Lake Champlain. Ongoing river and floodplain research is revealing a gradient of connected settings that differentially influence P storage and retention. As research products become available, they will be integrated to further inform project priorities and crediting.

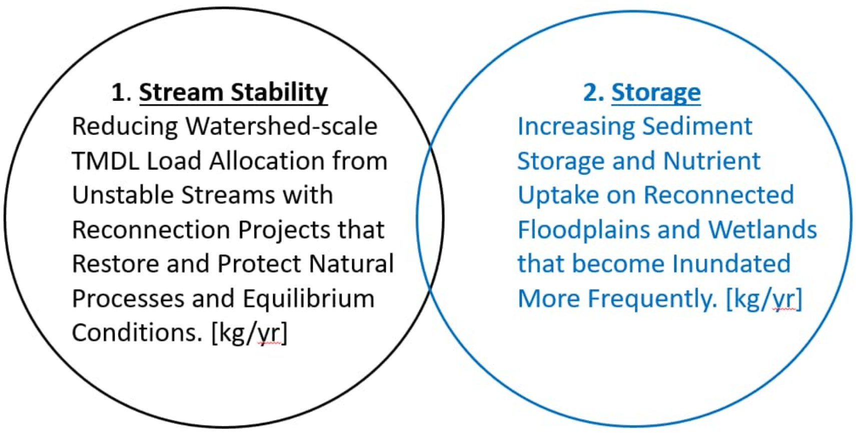


Figure 2. Two methods for achieving P load reduction credit with projects to restore and protect floodplain and stream connectivity.

The FFI stream stability allocation and crediting system recognizes the relative contribution of different types of connectivity departure at the watershed scale and credits projects and natural resource management for contributing to the restoration and protection of stream processes that affect both reach-scale stability and equilibrium beyond the project site to the watershed as a whole. As watershed-scale stability increases and the HUC 12 P base load decreases, a lower allocation is redistributed down to the reach scale, meaning that an individual project completed later in time would be reducing an increment of a lower remaining base load, and therefore be awarded a lower P credit[2]. To keep the initial award of project credits static (i.e., with no reallocation of a smaller base load) would imply that all the benefits of a project are accrued at the project site at one time (i.e., erosion/deposition are only influenced by connectivity within the reach as affected by in-reach projects). Base loads and credits get lower as equilibrium in the watershed is achieved because stream processes operate to

[2] These are the initial credits that, once awarded with the completion of the project, would remain unchanged over time. To illustrate this, if the HUC 12 base load recorded in the FFI starts out at 500 lbs/yr and then a buffer project in that watershed is awarded a 2 lbs/yr credit, that buffer project credit would remain the same as an annual credit over time. If, after couple years, the HUC 12 base load has been lowered in the FFI to 475 lbs/yr, and that lower value were reallocated to the stream reach scale (as described in Section 2), a similar buffer project in a reach with similar connectivity departure might be awarded a 1.9 lbs/yr credit, which would remain the same as an annual credit over time. It should be noted that, because departure scores are being reduced in reaches where projects are being completed, allocations would also shift to remaining reaches where projects have not been done (where departures are still higher), and therefore, as a net effect, the credits in the reach where this second buffer project is being proposed may be very close to those before reallocation.

affect equilibrium at larger scales. In other words, as the base load allocation value decreases due to completed projects and ongoing management that facilitates passive restoration, the FFI approach will shift the remaining nutrient load within the HUC 12 to reaches with the greatest remaining connectivity departure. If a watershed were to become near fully connected and protected at or near equilibrium conditions, it would be less cost effective to intervene with restoration projects there, compared with doing projects in another watershed where greater systemic instability remains.

2. STREAM STABILITY P BASE LOAD ALLOCATIONS

Stream stability base loads are allocated in three major steps. The first step involves splitting the base load between headwaters and lower valley reaches within each HUC 12, the rationale for which is described below in Section 2.1. The second stage allocates the base load among river corridor subunits using connectivity scoring considering their relative contribution to the departure or imbalance of stream-floodplain processes that drive sediment and nutrient loading at the watershed scale (Sections 2.2). This allocation creates awareness and rewards for restoring and protecting all types of connectivity in the watershed in order to achieve the overall desired base load reduction. It discourages further disconnections that may occur were there no categorical allocation (i.e., nothing to lose), and allocations were only made to the current sources of loading. It promotes active restoration and conservation projects, as well as natural resource management programs that prevent backsliding. For instance, technical and regulatory assistance programs successfully minimize the further loss of active and passive restoration potential, when there is a broader public awareness of the functions and values that connected streams and floodplains may be serving. The third step in the allocation process (Section 2.3) gives weight to the size of a river corridor and the degree of connectivity departure within the corridor. This brings an emphasis to a site scale and rewards those practitioners that create projects to address the most significant current-day departures.

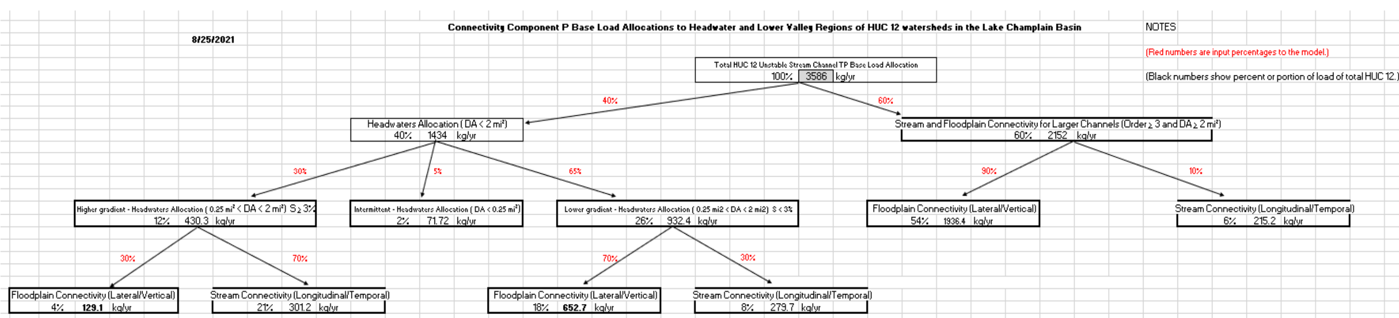


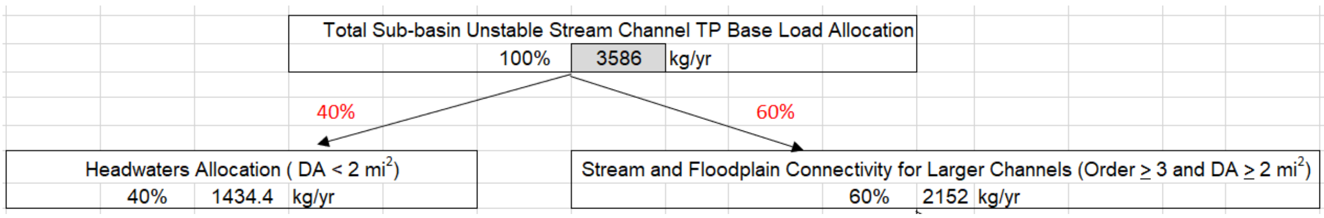
Figure 3. Overall HUC 12 base P load allocations to connectivity components in headwater types and lower valley streams.

The overall stream stability P load allocation process has been set up to split the HUC 12 base load down to stream and floodplain components of connectivity within headwater types and for lower valley streams. Throughout the description of this process (Sections 2.1 to 2.3), enlarged snippets of the splitting process depicted in Figure 3 will be used to illustrate the text. In this example, a base load calculated for a HUC 12 in the Mad River valley from the TMDL subbasins it contains, is entered into the very top of the load splitting tree and all the connectivity component allocations are computed.

2.1 HEADWATERS VS LOWER VALLEY REGIONS AT THE HUC12 SCALE

Each HUC 12 P unattenuated base load allocation is determined from the Lake Champlain TMDL sub-basin allocations (Figure 1). The HUC 12 load is then divided between the headwater region (i.e., drainage area (DA) < 2 sq. mi. or stream order ≤ 2) and the lower valley region composed of larger streams and rivers (i.e., DA ≥ 2 sq. mi. or stream orders ≥ 3).

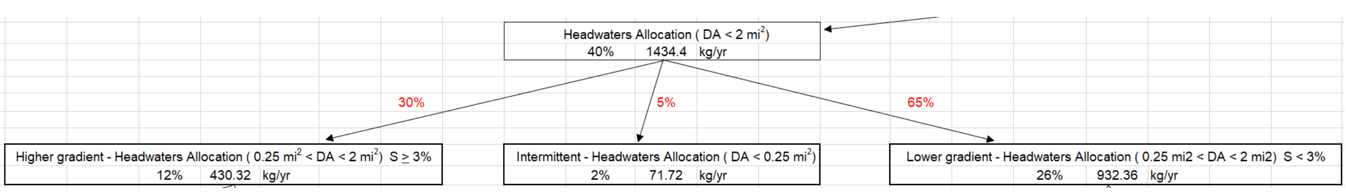
Although the headwaters contain a much higher percentage of the overall stream miles in a HUC 12 (i.e., typically around 75%), they are allocated a lower percentage of the base load compared to the lower valley streams. This nonproportional allocation is primarily because the greater width and depth of P-rich alluvium in floodplains in lower valley settings indicate a cumulative volume that is greater than the floodplain volumes from headwater regions (Tockner and Stanford, 2002). The 60-40% TP base load allocation split between larger channels and headwater is applied consistently across all HUC12s, but may be adjusted in outlier situations based on the percent of headwater drainage areas in the HUC12 and the overall connectivity of lower valley or headwater streams. For example, if a HUC 12 with a high P base load consists of very few lower-valley reaches that are fairly well connected to their floodplains and a much higher percentage of headwater drainages, then a higher percentage of the HUC 12 load may be assigned to the headwaters.



To provide a finer-scale allocation, the headwater region of each HUC 12 watershed is further divided into three parts with weighted allocation of P base load (Table 1, page 10). Larger headwater streams are split into two types depending on whether channel slope is greater or less than 3 percent[3]. Steeper headwaters (type 1) are awarded a lower percentage of the headwater region allocation (30%), because much smaller areas are typically available in these narrower valleys for floodplain development. Stream connectivity projects in steeper headwaters (e.g., upsizing crossing structures), particularly those with greater sediment bed loads, may be more important to stability in the overall stream network. The lower gradient headwaters (type 2) are given a larger percentage of the headwater region allocation (65%) because (as with lower valley streams) they would typically be expected to have wider valleys and floodplain features important to channel stability and sediment storage. Floodplain connectivity projects to reduce instability and increase storage in lower gradient headwaters will be more cost-effective with a higher allocation.

Headwater allocations are further weighted by the area of river corridor in types 1 or 2 relative to all the corridor acres in the combination of types 1 and 2. The weighting recognizes that some watersheds may be very steep or very low gradient and, for example, it would not make sense to give a large 65% allocation to 2 or 3 lower gradient reaches in an otherwise steep headwaters where the other 30 or 40 reaches are in a headwater type 1 category (>3% slope).

The headwater type 3 (assumed to be largely comprised of intermittent streams) is given a very small allocation



[3] The 3% gradient was chosen from published literature (Montgomery and Buffington, 1997) as a conservative channel slope cutoff with the intent of capturing the important pockets of floodplain, in the headwaters type 2 category, that begin forming as a stream shifts from a step-pool, sediment transport stream (narrow valley Rosgen stream type "B") to a riffle-pool, sediment deposition stream (broader valley Rosgen stream type "C").

to support projects that restore temporal connectivity (e.g., land use conversions, gully stabilization), thereby leading to improved stream stability of down-valley perennial streams. Specific allocations for lateral, vertical, and longitudinal connectivity departures have not been made to intermittent headwater stream channels.

2.2 STREAM AND FLOODPLAIN CONNECTIVITY ALLOCATIONS AT THE HUC 12 SCALE

Allocations to each of the lower valley and headwater regions are then further split between floodplain connectivity (vertical/lateral) and stream connectivity (longitudinal/temporal) bins using FFI methods (Schiff et al., 2023). While all components of connectivity exert some influence on the full complement of forces affecting dynamic channel equilibrium (Figure 4), floodplain *lateral-vertical* connectivity has a greater influence over reach scale hydraulic factors (i.e., slope, depth, and boundary resistance), while stream *longitudinal-temporal* connectivity has a greater influence over watershed scale inputs (i.e., discharge and sediment supply). Therefore, the P base load allocation process is started by: a) Assigning greater lateral and vertical connectivity base loads to lower gradient stream reaches, with wider valleys and abandoned floodplains, where connectivity projects may be critical for restoring and protecting site-specific channel slope and depth; and b) Assigning greater longitudinal and temporal connectivity base loads to steeper headwater stream reaches where connectivity projects may be critical for restoring natural watershed inputs (i.e., flow, sediment, and debris regimes) within the stream network.

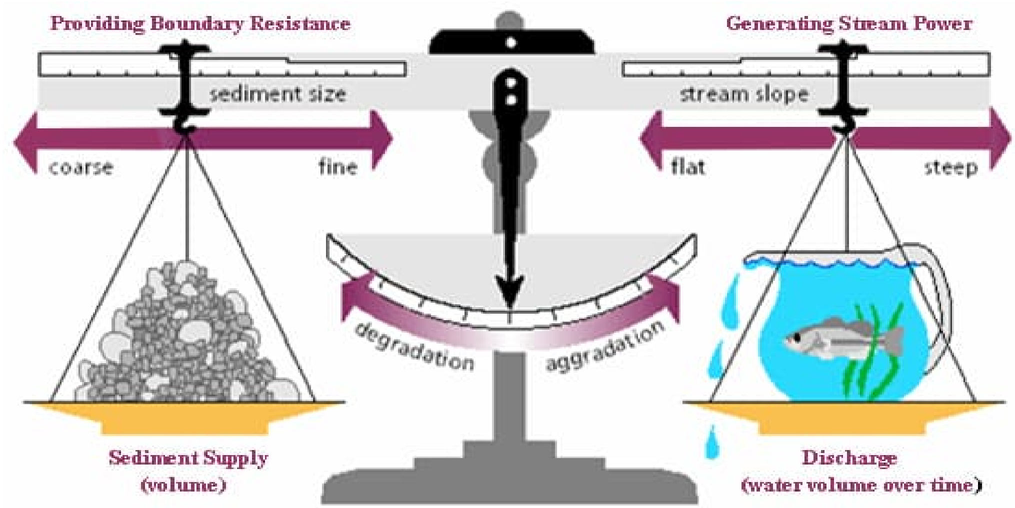


Figure 4. Lane's Balance of Sediment Supply & Sediment Size with Slope & Discharge (Lane, 1955)

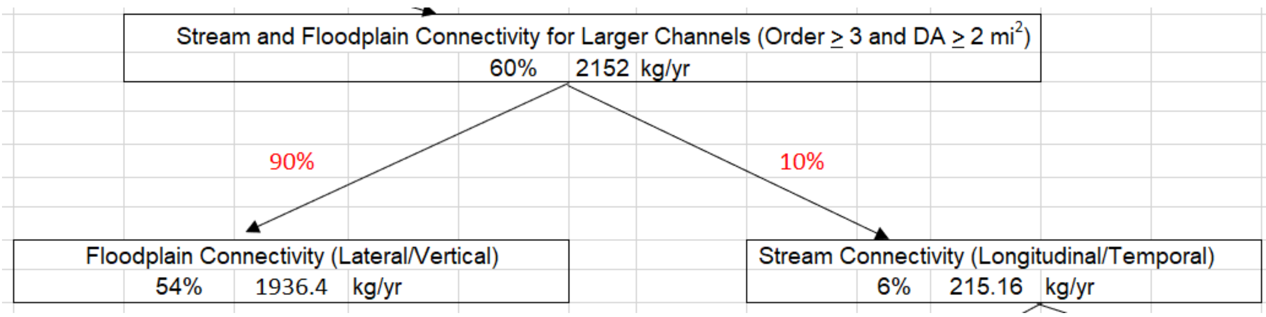
2.2.1 LOWER VALLEY STREAM AND FLOODPLAIN ALLOCATIONS

For lower valley streams, and consistent across all HUC 12s, the allocation is largely assigned to floodplain connectivity, with only a small percentage of the load assigned to stream connectivity. See the red percentages for the P allocation split across each level. This distribution is based upon the following assumptions.

- Departures in vertical and lateral connectivity are the primary drivers of stream instability and P loading in lower valley reaches[4]. Floodplain encroachments, and channel manipulations cause reach-scale slope and depth increases that lead to enhanced channel velocities and shear stresses and erosion of non-cohesive bed and bank sediments and P during floods.

[4] Hereafter, the term stream "reach" is used in this document as short hand for the stream sub-units, geomorphic-based stream segments and reaches used to break up the stream network in the FFI (see FFI User Manual, Fig. 2-1).

- The cumulative impact of longitudinal and temporal departures in connectivity from upstream hydrologic alterations may drive some channel instability, but local, within-reach stream connectivity departures would have a minor impact on equilibrium conditions, unless considered cumulatively or where a larger stream is impounded behind a dam. Crossings on larger streams and rivers are typically bridges, which are less likely than culverts to create a longitudinal discontinuity in the sediment regime.

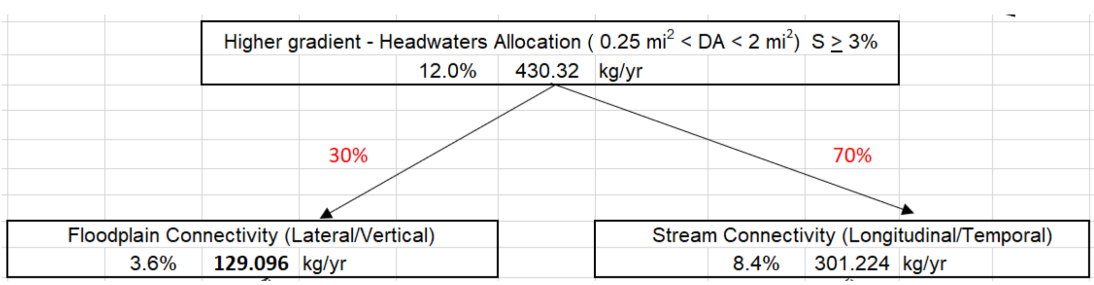


2.2.2 HEADWATER TYPE STREAM AND FLOODPLAIN ALLOCATIONS

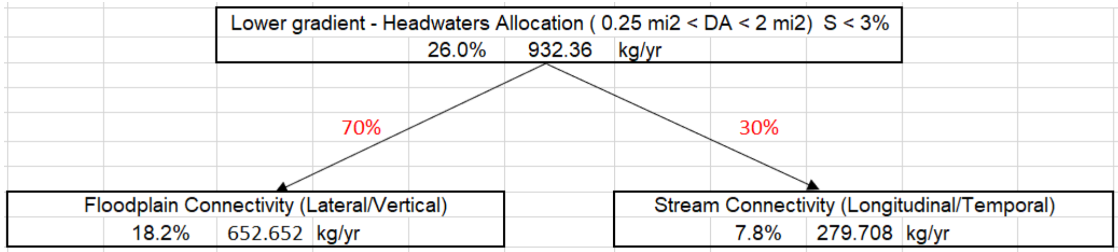
Allocations between stream and floodplain connectivity have been set up differently depending on which headwater type a stream has been attributed:

- Intermittent Stream Headwaters: The 2% allocation of P load from the HUC 12 base load to the intermittent stream headwater type is not further allocated between stream and floodplain connectivity. The small allocation to streams draining less the 0.25 sq mi (assumed intermittent) is for crediting the land use conversions or practices that result in the restoration of temporal connectivity. The vertical stabilization of gullies in intermittent or ephemeral streams may be considered for P load reduction credits from the land use sector in which it is located.

- Higher Gradient Headwater Streams: consistent across all HUC 12s, the allocation favors stream connectivity over floodplain connectivity due to: 1) The greater prevalence and destabilizing effects of undersized culverts, dams, ditching and impervious cover expected in steeper headwaters; 2) The greater dominance of transport over deposition processes expected in steeper headwaters; and 3) The relatively smaller areal extent of floodplains and greater degree of channel boundary resistance.



- Lower Gradient Headwater Streams: consistent across all HUC 12s, the allocation favors floodplain connectivity over stream connectivity. Lower gradient headwater streams, particularly in the Lake Champlain Valley, beaver influenced streams, or high-elevation wetlands may be a source of fine sediments and have significant floodplain features that are often laterally and vertically disconnected. The floodplain connectivity allocation in lower gradient headwaters streams (70%) is less than lower valley streams (90%) because the floodplain dimensions (width and depth) are proportionately lower in these settings.



Summary of HUC12 P base load allocations

The percentages of the HUC 12 base load allocated to floodplain and stream connectivity departures (rounded to the nearest tenth of a percent) are summarized below[5] (Table 1). These percentages would typically be the same for all HUC 12s. Because each HUC 12 allocation process would start with a different base load calculated from TMDL sub-basin loads, the application of these percentages would result in different connectivity component allocations from one HUC 12 to another.

Table 1. HUC 12 P base load allocations based on floodplain and stream connectivity

Higher Gradient Headwater—12%	**Lower Gradient Headwaters—26%**
Floodplain—3.6% Stream—8.4%	Floodplain—18.2% Stream—7.8%

Lower Valley Streams and Rivers—60%
Floodplain—54% Stream—6%

2.3 CONNECTIVITY ALLOCATIONS TO RIVER CORRIDOR SUBUNITS

This last stage of the process involves an area-weighted allocation from the floodplain or stream connectivity assigned loads (Section 2.2) based on the overall subunit floodplain or stream connectivity departure (Schiff et al., 2023). This final allocation, used for project and passive channel evolution crediting, is based on the following formula:

> [(Subunit Departure Score X Subunit River Corridor Acres) / Sum of Lower Valley or Headwater Type Subunit (Departure Score X River Corridor Acres)] X Lower Valley or Headwater Type Floodplain or Stream Connectivity Allocation.

Mad River subunit M10_2_C00	**HUC 041504030504 - Lower valley subunits**
Subunit departure score = 68.32	Sum of departure scores x RC acres = 60,227
Subunit RC acres = 33.76	Floodplain connectivity allocation = 1,936.4 kg/yr

Mad River subunit M10_2_C00 allocation = [(68.32 x 33.76)/60,227] x 1,936.4 kg/yr = **74.2 kg/yr**

Figure 5. Example of a HUC 12 floodplain connectivity allocation to a lower valley Mad River subunit.

HUC 12 loads assigned to stream and floodplain connectivity (Section 2.2) are also allocated to stream reaches based on overall subunit departure scores (Schiff et al., 2023) and weighted by the corridor area in the reach as a percentage of the corridor area within the entire lower valley or headwater type portion of the HUC 12.

[5] These summary tables do not include the 2 percent of the HUC 12 base load allocated to intermittent headwaters.

Table 2. Estimated incision ratios for headwater streams

Channel Slope	Lateral Connectivity Score	Default Incision Ratio
> 3%	0 – 100	1.25
< 3%	51 – 100	1.25
	0 – 50	1.5

While the same allocation process is used for higher-gradient and lower-gradient headwater streams (0.25 < DA < 2 square miles), the sparseness of field-measured incision ratio data (i.e., a measure of bed degradation or downcutting relative to the floodplain surface) in headwaters, used in assessing vertical connectivity, has necessitated the creation of default values for incision (Table 2). These are generated using relationships between measured incision ratio data and lateral connectivity departures. [Note: These default values will be updated as field-measured values become available and as further analysis of Vermont stream geomorphic data (Kline et al., 2009) from headwaters takes place.]

3. PROJECT CREDITING

Projects are awarded P load reduction credits for (1) the components of connectivity restored and protected (i.e., affecting stream stability); and (2) the nutrient storage achieved through restored floodplain and wetland function (see Figure 2). Stream stability credits will be awarded at the completion of the project development stage and will not change over time. Sediment/TP storage credits will change over time depending on the anticipated and verified change in floodplain connectivity and storage rates (Appendix B).

Groups of project types and practice are credited for the two types of P load reductions with all of the anticipated credit provided up front (Appendix B). Credits are calculated in the FFI web application, or from simulated values at the HUC-12 subwatershed scale.

Appendix C describes how sediment regime types (Kline, 2010; Underwood et al., 2020), floodplain deposition, and wetland storage would be used to adjust allocations, project crediting, and prioritization. Appendix D includes an analysis of the subunit data across the Basin to generate median P load reduction credits (kg/acre) for some of the more common projects.

3.1 PROJECT P LOAD REDUCTION CREDITING FOR STREAM STABILITY

Floodplain and stream connectivity projects affect ongoing stream processes at both the reach and watershed scales. Therefore, once awarded, P load reduction credits against the TMDL subbasin loads for stream stability (kg/yr or lb/yr) remain constant over time and are directly proportional to the increase in floodplain and/or stream connectivity score achieved by the project when it was completed. It is important to note that projects such as buffer plantings and those that disperse concentrated runoff (i.e., restore temporal connectivity) are awarded P load reduction credits because of their effects on stream stability. However, these project types may also be awarded credits in the development, agriculture, and forest sectors because they treat overland runoff and erosion. P load reductions and crediting related to overland runoff and erosion are not defined in this methodology.

3.1.1 FLOODPLAIN CONNECTIVITY PROJECTS

Consistent with the goal of achieving least-erosive conditions, in vertical-laterally connected streams with naturally vegetated buffers, natural sediment regime processes (see Appendix D), and protected corridors, the project crediting system will:

- Credit projects that remove hard constraints in the river corridor such that lateral channel migration may occur and the stream has more space to establish a meander planform and channel slope more consistent with equilibrium conditions.
- Credit projects that restore and protect viable 50'+ naturally vegetated buffers and reduce channel migration to a more natural rate along vertically connected, near-equilibrium stream reaches (Appendix D). Where the stream reach is vertically disconnected, the load reduction credit would be lower, because the lateral stability typically afforded by a naturally vegetated buffer is compromised by the depth of bank scour in the incised channel, resulting in a lower connectivity score. NOTE: while a 50' naturally vegetated buffer created on an incised channel would get a lower "credit" for reducing the P loading associated with stream instability, any buffer project would get a P load reduction credit for its role in slowing and infiltrating overland runoff from adjacent lands as part of a separate Watershed Project practice.
- Award all available P credits for addressing floodplain connectivity to the cost-effective practices of river corridor, wetland, and floodplain protection. The easement would get the lateral-protection P credits, and, because the channel evolution process would progress unimpeded (i.e., work done by the river), the project would be awarded credits for lateral meander, vertical, and naturally vegetated buffer connectivity that support stream stability (i.e., equilibrium and least erosive conditions).
- Credit projects that raise the streambed, open a flood chute, or remove a berm from the P load associated with the vertical connectivity departure for that reach. These projects would receive additional P load reduction credit for an increment of the annual P <u>storage</u> gained through renewed floodplain and wetland inundation processes (i.e., load reduction #2, from Figure 2).
- Projects that include berm removal or the construction of a floodplain through excavation would be awarded two types of P load reduction credits:
  - An annual P storage credit due to the restored inundation process (#2 in Figure 2); and
  - A stream stability credit for the acres where sediment was removed to achieve vertical connectivity and the efficiency associated with the endpoint of channel evolution process used in the TMDL to calculate base load reductions for channel stability. These removed channel evolution sediments are accounted for in the FFI crediting process as the project's floodplain (lateral-vertical) connectivity P load reduction credit and contribute to reach and watershed scale equilibrium.

  Like other connectivity projects, constructed floodplains contribute to channel stability and storage at both the reach and watershed scale and are credited from the stream process-based P load allocation that's been established to achieve the Lake Champlain TMDL. However, these active restoration projects can be expensive, and co-benefits for flood damage reductions and habitat functions should be considered as further incentive for their implementation.

3.1.2 STREAM CONNECTIVITY PROJECTS

Consistent with the goal of achieving least-erosive conditions, in longitudinal-temporally connected streams with natural sediment regime processes (Appendix C), the project will be awarded P load credits from stream reach allocations proportional to the departure scores listed in the FFI User Guide (Schiff et al., 2023) for structures and land drainage features that affect stream connectivity, and will:

- Credit projects, such as enlarging culverts and removing or establishing operational changes at dam or diversion structures, that restore the natural hydrology (i.e., temporal connectivity) and the longitudinal connectivity of stream processes (i.e., and the quantity, size, sorting, and distribution on sediments and debris). Severely undersized culverts on a low to moderate gradient stream may significantly disrupt the upstream to downstream flow of flood water and materials and create vertical channel instability well beyond the site of the stream crossing.

- o Credit practices that reduce the erosion that occurs when a road or agricultural drainage ditch deepens into a gully before entering a perennial stream. These projects principally involve the treatment of stormwater (i.e., disconnecting a length of road drainage or acres of agricultural land drainage) and would be eligible for a temporal connectivity load reduction credit. Stabilization of a gully and head-cuts formed by a perennial stream would receive additional stream stability credits for increasing vertical and longitudinal connectivity. Gullies that headcut into adjacent floodplains, may increase both coarse and fine sediment loads, depress groundwater levels, and adversely affect wetland hydrology. These changes, in turn, also affect stream stability by aggrading the downstream channel bed. See Appendix B for further description of stream stability crediting for Gully projects.
- o Many practices that address departures in longitudinal and temporal connectivity also have a positive impact on vertical and lateral connectivity and receive credits accordingly.

3.2 PROJECT P LOAD REDUCTION CREDITING FOR FLOODPLAIN AND WETLAND STORAGE

Most projects that restore connectivity between channel and floodplains improve the natural storage function of floodplains that will allow for attenuation of sediment during improved floodplain inundation and increased nutrient load attenuation (Opperman et al., 2010; Van Appledorn et al., 2019).

Limited sampling at recently completed floodplain reconnection sites along the Dog River, Lamoille River, and Black Creek has indicated a storage potential of 15 to 40 pounds of P per acre per year in the year(s) immediately following reconnection (unpublished empirical project data by UVM and SLR following several single event floods of an estimated 2- to 10-year recurrence interval). A literature review of floodplain restoration indicates that the longer term storage of nutrients on a floodplain drops 50% from initial reconnection values (Gellis et al., 2009) . Recent research out of the University of Vermont indicates that moderately to well-connected Vermont floodplains may store between 0.2 and 30 pounds of P per acre per year (Diehl et al., 2021).

These empirically documented deposition rates, are similar to values predicted using methods from other regions. A potential of 26 pounds P per acre per year deposited on the floodplain was estimated following the Chesapeake Bay Program floodplain crediting methods (CSN, 2020), and based on site-specific sediment and flow data, for a proposed floodplain restoration project on Potash Brook in South Burlington, VT (unpublished project data prepared by Fitzgerald Environmental in 2021).

More research is needed in Vermont to refine these expected P storage values and understand the fate of deposited material and future storage potential, and emerging research on floodplain and wetland processes will be used to help prioritize FFI projects. In the meantime, initial storage values have been proposed for project crediting of reconnection projects (Table 3). The existing and proposed level of floodplain connectivity must be estimated to select the improvement in P storage achieved by a floodplain reconnection project. A 50% reduction of the initial credit in P storage potential for floodplains, over the lifespan of the credit, has been implemented in the table below, based on research indicating a drop off in floodplain storage following the first year of (re)connectivity (Gellis et al., 2009).

Table 3. Estimated P load reduction due to improved floodplain storage indicated by a change in floodplain connectivity (high, moderate, and low refer to floodplain connectivity scores).

	Default TP Storage Credits (lb/ac/yr)*		
	Low to High	**Low to Moderate**	**Moderate to High**
Initial	**20**	**15**	**10**
Future (50%)	**10**	**7**	**5**

*To be updated by project specific measurements or future research.

Floodplains deposit, store, and release sediment and nutrients that were sourced from the upstream watershed. For this reason, it is anticipated that DEC will eventually assign the storage credit to the load and waste load sectors located upstream of a floodplain storage site and distributed based on the contribution of a) regulated vs. non-regulated loads, and b) the percent sector contribution to the base load as reported in the TMDL for each Lake Champlain subbasin (EPA, 2016). For now, the storage credit will be allocated to the channel stability sector and get credited along with reconnection projects.

4. P LOAD REDUCTIONS ACHIEVED THROUGH WATERSHED MANAGEMENT AND NATURAL CHANNEL EVOLUTION

The Vermont Phase 1 Lake Champlain Phosphorus TMDL Implementation Plan (2016) explains in great detail how DEC's River, Floodplain, and Wetland programs have been enhanced to provide the regulatory and technical assistance and public outreach needed to meet the TMDL required load reductions for stream stability. The Plan states that:

> *New public policies have put the DEC Rivers and Wetland programs in the vanguard of implementing avoidance-centric approaches to watershed restoration by protecting floodplain, wetland, and riparian features where natural fluvial process enhances and sustains water, sediment, and nutrient storage.*

DEC conducts stream geomorphic assessments (SGAs) to document the status of stream processes and equilibrium conditions, as Vermont's rivers adjust in response to both human and natural stressors. The FFI framework is being developed to track the many restoration and protection projects that have become more prevalent in recent years to mitigate for past human encroachments and practices, remove constraints, and support the channel evolution process toward equilibrium and least-erosive conditions. But natural events like floods also function to remove overburden constraints and accelerate the channel evolution process. During flood recovery efforts, new public policies ensure that eroded constraints are not always replaced (e.g., FEMA buyouts), or are replaced with more geomorphically-compatible structures (e.g., upsized culverts). Limits on post-flood channel dredging, windrowing, berming and armoring are also in place, so that flood-accelerated channel evolution gains are preserved.

To capture these flood-induced changes in stream and floodplain connectivity that may not be framed as a specific restoration or protection project, per se, functionality has been built into the FFI framework to document the P load reduction credits resulting from these flood-induced changes and acceleration of the natural channel evolution process. Post-flood SGAs have become a priority of the DEC, and after the completion of an updated assessment, River Scientists will be able to enter new and revised connectivity data from field observations into the FFI and calculate changes in P loading (lbs/yr) associated with the flood-driven natural evolution of stream channels and their improved floodplain connections.

At the conclusion of an SGA, changes in the acres of (lateral) meander, protection, and buffer connectivity, subunit-scale changes in incision ratio, and changes in structures affecting longitudinal and temporal connectivity within a HUC 12 watershed would be entered in the FFI and changes in connectivity component departures (Section 2.3) would be translated into a P load reduction from the natural channel evolution observed in the field[6].

[6] Changes in HUC 12 connectivity scores and P load reductions from natural channel evolution would not change the P load credits awarded to projects in the SGA assessed reaches that are already in the design or implementation phase of completion. Channel evolution during floods creates connectivity that is additive and complementary to the connectivity achieved or anticipated through projects. For instance, the connectivity-based credits awarded to an easement (that protects lateral

These stream stability load reductions are reported out of the FFI for TMDL tracking by the DEC. The FFI reporting will enable the DEC to discern P load reductions made as result restoration and protection projects from those achieved through flood-driven processes and proper resource management that minimizes post-flood channelization.

5. DATA INPUTS, OUTPUTS, AND TRACKING WITHIN AND BETWEEN THE FFI AND THE WATERSHED PROJECT DATABASE

Data inputs, outputs, and tracking within and between the FFI and Watershed Project Database (WPD) are outlined and explained diagrammatically in Appendix E. Fundamentally, the FFI is storing and tracking reach-based connectivity scores (i.e., acres and connectivity components) and P allocations at the reach and HUC 12 scales. The WPD is tracking project-specific data in conjunction with the DEC's overall accounting for TMDL P load reductions for the stream stability sector[7]. Potential projects generated in FFI planning tools with connectivity and P load reduction credits (i.e., stream stability and floodplain storage credits) are exported out of the FFI and imported into the WPD where they are tracked from project development through design and implementation. Once a project is complete, the as-built subunit- or reach-based connectivity acres/scores would be revised in the FFI, and HUC 12 stream stability P base load allocations would be updated in the FFI to reset connectivity and subunit P allocations.

Project "dots," placed on FFI mapped stream subunits and reaches, would allow the user to see where projects are underway or completed. By clicking on the dot, the FFI user would see a brief project description and a link giving them access to the project in the WPD where more detailed project data is being stored and tracked.

meander and buffer connectivity and anticipates vertical connectivity) stay in place and remain unchanged after a flood; however, if a post-flood assessment verifies that acres of newly connected floodplain have formed in the easement reach, then additional credits for new storage processes may be awarded following the assessment. Assessment-documented changes to connectivity and subsequent crediting would be made in non-project reaches or in project reaches where the project type did not anticipate channel evolution and therefore receive front-loaded credits.

[7] Separate from the FFI, the overall accounting for TMDL load reductions for the channel stability sector would involve subtracting the cumulative annual project load reduction credits from the original TMDL stream stability base load for each HUC 12 and Lake Segment. The annual load reduction credits would include lbs/yr credits awarded to projects based on project connectivity scores and the stream stability sector portion of the lbs/yr awarded for restored floodplain storage.

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Appendix A

Excerpted From:

Lake Champlain BMP Scenario Tool: Requirements and Design. Prepared by Tetra Tech Inc. for U.S. EPA, Region 1. (April, 2015) (pp. 27-30) and correspondence with Eric Perkins (US EPA, VT TMDL Coordinator, Water Quality and Wetlands Protection Section)

Streambank Erosion BMPs

The erosion control "practice" in this TMDL context is not actually a BMP in the conventional sense. Given that channel erosion control projects (such as bank stabilization) in one part of a stream system can have destabilizing effects on other parts of the system, the goal in this case was to estimate the phosphorus reduction associated with bringing an entire stream reach to a more stable geomorphic condition. Following years of detailed geomorphic assessments, VT DEC has classified a large subset of Vermont streams according to channel evolution model (CEM) stages I through V. Streams in CEM stages I and V are typically fairly stable systems close to equilibrium conditions; stage II and III streams are generally unstable and eroding; and stage IV streams are usually in between stable and unstable conditions.

As the term channel evolution implies, stream systems naturally evolve over time from one stage to another, starting with stage I (stable) and progressing through the unstable stages (II and III) and eventually back to the more stable stage (V). Then the cycle begins again. However, human development in a watershed can significantly affect the timing of this evolution and the severity of erosion during the unstable stages. For example, encroachments into stream floodplains (such as houses or roads) can speed up the transition from stage I to II and can dramatically increase erosion during stages II and III. Likewise, actions like preventing floodplain encroachment, reestablishing stream access to floodplains, and properly sizing stream culverts can reduce the severity of erosion (and flooding) for reaches at stage II or III and can speed up the evolution to stage IV and ultimately to stages V and I. The erosion control practice simulated for TMDL purposes represents the transition from the phosphorus loading levels associated with the less stable stages II and III to the more stable stages I and V. The TMDL does not assume or prescribe a set method for achieving this transition. The appropriate actions will be determined at the implementation stage based on the unique characteristics of each reach.

Streambank Erosion BMP Efficiency

The efficiency factor used in the Scenario Tool is based on the results of a separate analysis that compared SWAT-modeled loads from eroding reaches to loads from more stable reaches as follows. Available channel evolution stage classifications for the HUC12 basins in the Vermont portion of the basin were compared to the HUC12 channel loads generated by SWAT. (Note that channel evolution stage classification data were not available for all SWAT-modeled HUC12s.) This was accomplished by intersecting the VT DEC CEM GIS layer with the SWAT model HUC12 sub-basins. The Vermont geomorphic assessment process typically results in the identification of multiple small reaches at different CEM stages within each larger HUC-12. Because SWAT estimates phosphorus loads by HUC-12 reach, it was necessary to aggregate the CEM data up to the HUC-12 reach scale. To do this, the total length associated with each CEM stage in a HUC12 was calculated and the HUC12 was assigned the stage with the greatest length. For example, if a HUC12 contained 10 reaches at various CEM stages and stage III was dominant (based on total length), then the HUC12 was designated as stage III. The process of assigning a HUC12 to a particular dominant CEM stage reduced the total number of Lake Champlain basin reaches with CEM stage data from 1,528 to 105. The reduction efficiency was calculated by computing the difference between median loads from HUC12 stream reaches in stages II and III to those in stages I and V. The aggregation process resulted in no HUC12 reaches designated as stage V because stage V was not dominant in any of the few HUC12 reaches containing stage V reaches. Therefore, the reduction efficiency ultimately was calculated based on the comparison of “unstable” stage II and III reaches (combined) with “stable” stage I reaches (Figure 1). Stage IV reaches were not used in this analysis because such reaches are at an “in between” stage of stability. The reduction efficiency calculated using this approach was 55 percent. This percentage was derived from a weighted average of the reductions calculated for stage II and stage III (Table 13), and it takes into account that a much higher number of HUC12 reaches are at stage III than at stage II (49 versus 11).

Because data were not available for the entire basin, CEM stage was designated for only 105 of the 187 HUC12 sub-basins in the Vermont portion of the Lake Champlain basin. To estimate the potential phosphorus reduction associated with applying the 55 percent efficiency factor more broadly, there was a need for a way to identify the larger group of highly eroding HUC12 reaches throughout the basin that are likely dominated by CEM stages II and III even though actual CEM data are lacking. An analysis of all HUC12 loads (distributed into four quartile groups) compared with loads from HUC12s having an assigned CEM stage found that the three quartiles above the 25th percentile loading group were dominated by reaches at stages III and II (see Table 14). Based on this alignment, stream reaches in HUC12 sub-basins in the phosphorus loading groups above the 25th percentile are assumed to be predominantly at CEM stages III and II. Accordingly, the Scenario Tool was configured to allow application of the stream channel erosion control “practice” to reaches above the 25th percentile (loading rates) throughout the Vermont portion of the basin.

This reduction efficiency factor provides a way to estimate the total load that may ultimately be reduced (in part through natural stream evolution) primarily at the HUC8, large-basin scale. At the implementation stage, the HUC12s above the 25th loading percentile may certainly be looked at to identify enhancement opportunities, but EPA recognizes that most implementation work would be driven by actual field assessments (as is the case for the other phosphorus source categories as well).

Summary from Eric Perkins (EPA) in correspondence with VT DEC:

“Loading rates (from unstable streams) were modeled using a customized SWAT routine, as described in the SWAT report. The loading rates are by HUC-12 reach, there’s no areal loading rate. I worked with DEC Rivers Program and Tetra Tech to then match stream channel evolution model (CEM) status info with loading rates, so that we could understand the estimated P reduction if a stream reach goes from an unstable class like CEM III to an equilibrium class, like CEM I. So, the plan was not to track P reductions associated with individual shoreline or streambank stabilization projects, but rather to track overall improvement in a reach (as a result of a combination of practices implemented). If VT river scientists determine that a combination of practices has changed a reach from class III to I, for example, or even part way there, the P reduction could be estimated based on the assumed percentage change between those classes (applying that percent reduction to the baseline load for the reach). This was the original plan. I’ll just add for context that VTDEC felt this overall approach was superior to the approach used in the Chesapeake in part because the Chesapeake approach doesn’t easily take into account the impacts an individual streambank project may have on other parts of the stream system – as you know, stabilizing a bank in one spot can make erosion worse downstream etc., depending how well the project is integrated with an overall stream system restoration plan. And Vermont is in the rare position to have sufficient stream geomorphic assessment data to evaluate progress over time at the reach level in many or most cases. From a tracking standpoint, the intent was for DEC to keep track of projects done in each HUC-12 reach, and then maybe every 5 years (or perhaps longer, depending on activity in a particular reach), the DEC rivers scientist that covers the applicable reach would do an assessment of progress towards equilibrium conditions. If it is found that a reach is about half-way toward CEM I, for example, then credit would be given for one half of the difference between the baseline load and the estimated load associated with attaining CEM I.“

Appendix B

P Crediting and Tracking for Stream and Floodplain Connectivity Projects

The following tables describing P load reductions over time strictly follow the expected pattern as a stream project reach might evolve toward dynamic equilibrium. A crediting system that followed the same timeframes would require many resources dedicated to project monitoring and administrative tasks. Therefore, from years of assessing channel evolution processes in Vermont, streams evolve to their least erosive form over time, therefore <u>*DEC will award these anticipated stream stability P reduction credits starting at the completion of a project*</u>.

Projects with similar patterns of P load reductions and credits are grouped below, and tables are provided for each group to show P load reductions for year 1, years 2-40, and years 41 and beyond associated with stream stability and floodplain storage. Guidance is also provided on FFI crediting approaches. Where the type and design of a project cannot always anticipate additional stream stability and storage credits, project monitoring will be needed to document load reductions and the award of additional credits for new floodplain function—stream stability and storage credits.

Smaller dots • and larger triangles ▼ are used to show the type and relative size of a connectivity credits that would likely be awarded for different project types over time. Some groups include large projects where certain practice types typically occur concurrently (e.g., floodplain lowering and corridor protection). Separate project group credits may be applied if they happen to occur concurrently such as the removal of a small dam that includes an easement to protect the newly created floodplain, where the project would get the credits described in Groups 2 and 6 below.

The following tables and group descriptions are a guide for developing projects in the FFI Planning Tool. Each dot • or triangle ▼ indicates the required calculation input. Using Table 2.1 *Data Inputs for Phosphorus Crediting Calculations* in the FFI User Guide in combination with the group tables below, the proponent of a project to remove a berm and restore and protect a floodplain on previously ditched and drained agricultural land (described below in Group 1A), for example, would prepare the following data for calculating stream stability and storage phosphorus credits for entry into the FFI calculation input page to complete Project Planning.

<table>
<tr><th colspan="8">Year 1 Stream Stability – project to restore and protect a floodplain on previously ditched and drained Ag land</th></tr>
<tr><th>Meander
(unconstrained)</th><th>Protection
(robust)</th><th>Buffer
(50 ft)</th><th>Vertical Change
(new Incision Ratio)</th><th>Longitudinal
Structure Δ</th><th>Structure Δ
for flows</th><th>Developed
drainage Δ</th><th>Agricultural
drainage Δ</th></tr>
<tr><td></td><td>•</td><td>•</td><td>▼</td><td></td><td></td><td></td><td>•</td></tr>
<tr><td></td><td>Acres</td><td>Acres</td><td>Acres w/ new Incision ratio</td><td></td><td></td><td></td><td>Acres of new flow storage</td></tr>
<tr><td colspan="4">▼</td><td colspan="4">Year 1 Storage – existing and project (future) connectivity rank and restored floodplain acres</td></tr>
</table>

If a P reduction credit is not calculated for a project site using the FFI web application, the simulated P reduction values in a given HUC 12 watershed should be used (Appendix D). Common reasons that a credit cannot be calculated include the presence of a structure such as a small culvert that is not in the FFI database and thus cannot get a stream connectivity credit if it is enlarged to a bankfull width structure. A credit cannot be calculated if a P base load allocation is not available, particularly in headwaters, and thus simulated values can be used to estimate a potential credit.

Group 1: **A. Floodplain and channel restoration;**
B. Large/medium dam removal

Group 1A	Year 1								Years 2 - 40								Years ≥ 41							
Stream Stability[8]	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
		•	•	▼				•		•	•	▼				•		•	•	▼				•
Storage	▼								•								•							

Group 1B	Year 1								Years 2 - 40								Years ≥ 41							
Stream Stability	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
		•	•	▼	▼	▼		•		•	•	▼	▼	▼		•		•	•	▼	▼	▼		•
Storage	▼								•								•							

Steam Stability – These large restoration projects would get credits for vertical reconnection, lateral protection, and riparian buffer. If functioning, forested floodplain is being restored on lands that had been drained for agricultural production, the project would get a temporal connectivity credit for the acres converted that remain constant over time. Large and medium-sized dam removal projects that significantly restore longitudinal and temporal (structural) connectivity would get these credits which would remain constant over time.

Storage – these projects would all restore inundation and storage processes and get a per acre P storage credit that would be higher in year one. Starting in year two, storage would be awarded a lower value (reflecting a lower efficiency) that would then remain constant over time.

Group 2: **Remove small intact Run-Of-River or breached dam**

Group 2	Year 1								Years 2 - 40								Years ≥ 41							
Stream Stability	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
		•	•	▼	▼	▼				•	•	▼	▼	▼				•	•	▼	▼	▼		
Storage	▼								•								•							

Steam Stability – Small dam removal projects would get credits for vertical reconnection, lateral protection, and riparian buffer. If functioning, forested floodplain is being restored on lands that had been drained for agricultural production, the project would get a temporal connectivity credit for the acres converted that remain constant over time. Small and breached dam removal projects that significantly restore longitudinal and temporal (structural) connectivity would get these credits and they would remain constant over time. Small dam removals (Group 2) get the same type of credits as large dam removals (Group 1), but are likely to involve far fewer acres of reconnection and therefore receive less P load reduction credits.

Storage – these projects would all restore inundation and storage processes and get a per acre P storage credit that would be higher in year one. Starting in year two, storage would be awarded a lower value (reflecting a lower efficiency) that would then remain constant over time.

[8] Stream stability connectivity components: M=meander; P=protection; B=buffer; V=vertical; L=longitudinal; S=structure (temporal); D=development (temporal); and A=agriculture (temporal)

Group 3: **Reconnect flood chute; Remove berm;**
Create flood bench; or Raise channel

Group 3	Year 1								Years 2 - 40								Years ≥ 41							
Stream Stability	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
			•	▼							•	▼							•	▼				
Storage	▼								•								•							

Steam Stability – Projects that create floodplain access would get a vertical connectivity and a riparian buffer credit. Floodplain connectivity credits remain constant over time.

Storage – these projects would typically restore inundation and storage processes (with some berm removals being the exception) and get a per acre P storage credit that would be higher in year one. Starting in year two, storage would be awarded a lower value (reflecting a lower efficiency) that would then remain constant over time.

Group 4: **Restore channel roughness; or**
Large wood addition (e.g., chop and drop, or beaver analog)

Group 4	Year 1								Years 2 - 40								Years ≥ 41							
Stream Stability	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
				▼								▼								▼				
Storage	•								•								•							

Steam Stability – Channel roughness and wood addition projects have the potential to significantly alter channel hydraulics and result in aggradation of sediments and debris that restore floodplain function and channel stability. Wood addition projects with elements designed to span the channel will change the vertical profile in Year 1, and therefore would receive ongoing vertical floodplain reconnection credits starting in Year 1. Projects consisting of wood additions along the stream banks or clusters of mid-channel wood and rock (i.e., typically for habitat enhancement but not channel spanning), may create sufficient roughness and turbulence to initiate the aggradation process and floodplain reconnection. Should this process occur, the project would get a vertical connectivity credit that may increase over time. Crediting for non-channel spanning wood addition projects would necessitate monitoring.

Storage – If/when floodplain reconnection occurs the project would get a per acre P load storage credit.

Group 5: **Remove hard constraint to meander migration**

Group 5	Year 1								Years 2 - 40								Years ≥ 41							
Stream Stability	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
	▼	•							▼	•							▼	•						
Storage	•								•								•							

Steam Stability – Removing hard constraints and protecting the land from future development, that would otherwise result in stream channelization, armoring and expected channel disequilibrium, would get credit for lateral protection and meander connectivity that would remain constant over time.

Storage – If the project occurs on lands where the stream and floodplain are vertically connected, the project would receive a per acre P storage credit where removal of the hard constraint has opened access to the previously-isolated natural floodplain.

Group 6: **River corridor easement**

Group 6	Year 1								Years 2 - 40								Years ≥ 41							
Stream Stability	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
		•	•	▼						•	•	▼						•	•	▼				•
Storage									•								•							

Steam Stability – River corridor easement projects would get a lateral connectivity credit for protection and buffer that would remain constant over time. Easements would also get front-loaded credits for anticipated vertical connectivity. In some reaches where easements are being completed, vertical connectivity may already exist (i,e., therefore, new vertical connectivity credits would not be awarded, only lateral), on others it would be anticipated to occur over time given the easement conditions limiting any new channel of river corridor encroachments.

Storage – As floodplains reform through the channel evolution process, project monitoring may indicate the per acre P storage credits are warranted.

Group 7: **Adopt a river corridor bylaw; or**
Conserve wetlands (e.g., NRCS Wetland Reserve)]

Group 7	Year 1								Years 2 - 40								Years ≥ 41							
Stream Stability	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
		•								•								•						
Storage																								

Steam Stability – Providing a moderate level of protection, i.e., little or no new structural encroachment, where there was little or no protection, would garner a small lateral protection connectivity credit. The benefit of river corridor bylaws would be the cumulative credits awarded for protecting stream reaches throughout a municipality. Wetland conservation, without any restoration practices, is included in this group, because protecting an already functioning wetland would assure a modest benefit to stream stability over time, there may be no additional increase stream stability as a result.

Storage – No new storage would be anticipated for simple administrative constraints (e.g., legal agreements) to conserve a functioning wetland. In the case of both river corridor bylaws and wetland conservation, however, any change on channelization or drainage maintenance practices stemming from the change in land use, may enhance stream processes where floodplain formation, inundation, and storage functions would increase over time.

Group 8: **A. Plant 50-foot natural vegetation buffer ; or**
B. Plant natural vegetation within the entire river corridor or floodplain

Group 8A	Year 1								Years 2 - 40								Years ≥ 41							
Stream Stability	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
			•								•								•					
Storage																								

Group 8B	Year 1								Years 2 - 40								Years ≥ 41							
Stream Stability	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
			•					•			•					•			•					•
Storage									•								•							

Steam Stability – Planting natural vegetation within a 50' riparian buffer would receive a lateral connectivity credit. Projects that involve the revegetation of the entire width of the river corridor or floodplain would also be awarded temporal connectivity credits where the land use is converted form drained agricultural to forested land cover. [Note: To incentivize these projects and reduced monitoring and administrative expense, buffer projects would begin receiving the full credit associated with a mature buffer upfront upon completion of the planting.]

Storage – Along with infiltrating and storing water (i.e., decreasing peak stream flows), inundation processes would be affected within a revegetated river corridor/floodplain, thereby increasing sediment/P storage. A modest storage credit may be anticipated for plantings in the corridor/floodplain outside the 50-ft buffer.

Group 9: **A. Replace bridges and culverts – bankfull span and/or steep slope; or**
B. Replace bridges and culverts – undersized and/or shallow slope]

Group 9A	Year 1								Years 2 - 40								Years ≥ 41							
Stream Stability	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
					•	•							•	•							•	•		
Storage																								

Group 9B	Year 1								Years 2 - 40								Years ≥ 41							
Stream Stability	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
				•	▼	•						•	▼	•						•	▼	•		
Storage									•								•							

Steam Stability – Bridges and culverts affect longitudinal and temporal flows in the channel, the floodplain, or both. Crossings with span lengths at or near channel bankfull width mostly affect larger flood flows and their replacement would be awarded only modest longitudinal and temporal credits. Minor breaks in the natural connectivity of flows may also occur at structures crossing steeper sloped channels, and credits would be awarded accordingly. The replacement of undersized crossings, especially culverts and structures that impound flood flows and disrupt sediment transport, would receive higher longitudinal connectivity credits. If replacement of the severely undersized culvert changes sediment regime processes above and below the crossing, the downstream deposition result in the restoration of vertical connectivity then stream stability credit may be awarded.

Storage – If floodplains reform or reconnect through the channel evolution process, the project would receive per acre P storage credits.

Group 10: **Stabilize Headcut in Perennial Stream; or**
Stabilize Gully (with perennial flow)]

Group 10	Year 1								Years 2 - 40								Years ≥ 41							
Stream Stability	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
				•	▼							•	▼							•	▼			
Storage																								

Steam Stability – Headcut and/or gully stabilizations are unique, because the objective is to try and arrest the erosion process at the project site, and, in-so-doing promote equilibrium at the reach and watershed scale. These projects may be awarded a modest vertical connectivity credit where the structure reduces the channel incision ratio and a more significant longitudinal credit.

Storage – no new storage would be anticipated with a headcut or gully stabilization project.

Group 11: **Removal of ditch and tile drainage from Wetlands;**
Stabilize gully w-treatment of stormwater;
Disconnect municipal or private road ditch; or
Treat legacy forest trail/road drainage]

Group 11	Year 1								Years 2 - 40								Years ≥ 41							
Stream Stability	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
							•	•							•	•							•	•
Storage	▼								•								•							

Steam Stability – The restoration of wetlands and projects that divert and infiltrate stormwater from developed or agricultural lands, that would otherwise enter a drainage ditch, form a gully, and enter a perennial stream, would be credited for restoring the temporal connectivity of the watershed.

Storage – Wetland restoration would be credited for increasing P storage. Other stormwater treatment projects would not create new storage—related to flood inundation process—and would not be awarded storage credits.

Group 12: **Remove or re-permit stream diversions or water withdrawals; or**
Remove groundwater extraction (commercial, wells)]

Group 12	Year 1								Years 2 - 40								Years ≥ 41							
Stream Stability	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
					•	•							•	•							•	•		
Storage																								

Steam Stability – Removing or changing the operation of structures that divert surface or subsurface flows from the stream would be awarded credits for improving longitudinal and temporal connectivity that would begin in year 1 and continue unchanged over time.

Storage – No new storage—related to flood inundation process—would be anticipated with a project that minimize temporal disconnections due to diversions and withdrawals.

Data Collected to Adjust FFI and Monitor Connectivity, Fluvial Processes, and Project Effectiveness

The purpose of this section is to describe the project reporting that may be important for recalibrating P allocations and project credits awarded in the FFI planning tools for stream stability and storage crediting. This is not intended to be O&M monitoring, although, for projects involving the placement of structures, there may be overlaps and efficiencies gained by combining both types of monitoring. Crediting for several of the project groups described above could change based on project monitoring. Where possible, notes were added to indicate opportunities to front load credits to reduce monitoring burdens, based on the current body of evidence for how these project sites evolve. If such an award system were adopted, the assessment of these variables would help to further validate or fine-tune upfront awards and connectivity scoring in the FFI.

The following data would be used to adjust P award metrics and track connectivity in the FFI as described in the table below.

Variables used to assess stream stability and storage:

1. Buffer viability and acres
2. Incision ratio
3. Floodplain acres
4. Sediment regime departure and channel evolution stage
5. Evidence of floodplain storage

	Year 1	Year 5	Year 10	Every 10 years thereafter
Group 1 Lg. floodplain excavations	As built data to confirm initial credits.	Report on buffer viability and evidence of FP storage	Report on buffer maturity and evidence of FP storage	Report on five monitoring variables[9]
Group 2 Sm. floodplain excavations	As built data to confirm initial credits.	Report on buffer viability and evidence of FP storage	Report on buffer maturity and evidence of FP storage	Report on five monitoring variables
Group 3 Floodplain reconnection	As built data to confirm initial credits.	Report on buffer viability and evidence of FP storage	Report on buffer maturity and evidence of FP storage	Report on five monitoring variables
Group 4 Wood addition	As built data to confirm credits and possible removal credits.	Report on channel evolution and evidence of FP storage.	Is aggradation, FP reconnection and storage occurring warranting new vertical and storage credits?	Report on five monitoring variables and accrue further credits for new floodplain function
Group 5 Constraint removal	As built data to confirm credits and possible removal credits.	Where appropriate, report on new FP storage	Is new laterally accessible FP eligible for storage credit?	
Group 6 RC Easement	Easement documentation	Report on channel evolution stage and evidence of floodplain storage	If floodplain connectivity did not exist, has FP begun to reform	Report on five monitoring variables and accrue further credits for new floodplain storage
Group 7 RC bylaws and wetland protect	Bylaw[10] or easement documentation			
Group 8 Nat. vegetation buffers	As built data to confirm initial credits.	Report on buffer viability and evidence of FP storage	Report on buffer maturity.	

[9] Where floodplains have been restored, balanced erosion and deposition processes may be affecting channel evolution and equilibrium process in adjacent reaches, which could be documented for stream stability crediting.

[10] If new structures are placed in the river corridor or a municipality votes to remove bylaw/zoning protections for river corridors, then floodplain connectivity scores would decrease and base loads would increase in the affected HUC 12s, putting more pressure on the need for other restoration and protection projects to achieve the TMDL reductions.

Group 9 Stream crossings	As built data to confirm credits and possible vertical credits.		Has stream profile changed with new FP connectivity warranting new vertical and storage credits	
Group 10 Headcuts and gullies	As built data to confirm credits and possible vertical and/or removal credits.		Is grade control maintaining longitudinal connectivity (and credit)?	
Group 11 Stormwater infiltration	As built info to confirm initial credits.			
Group 12 Water diversions	As built info to confirm initial credits.			

Phosphorus load reduction crediting of projects that include stream alterations and bank stabilization practices (armoring and bioengineering)

The FFI P load reduction crediting system is based on whether a practice results in gains in floodplain and stream connectivity that promote channel evolution and equilibrium process. The system was devised to account for reductions in the watershed-scale load, uniquely modeled for unstable streams in the Lake Champlain TMDL, and not for site-scale stream stabilizations (i.e., those practices that cause the stream to depart from, further depart from, or impede the attainment of equilibrium conditions).

> The erosion control "practice" in this TMDL context is not actually a BMP in the conventional sense. Given that channel erosion control projects (such as bank stabilization) in one part of a stream system can have destabilizing effects on other parts of the system, the goal in this case was to estimate the phosphorus reduction associated with bringing an entire stream reach to a more stable geomorphic condition. "The plan was not to track P reductions associated with individual shoreline or streambank stabilization projects, but rather to track overall improvement in a reach (as a result of a combination of practices implemented). If the DEC determines that a combination of practices has changed a reach from (channel evolution) class III to I, for example, or even part way there, the P reduction could be estimated based on the assumed percentage change between those classes (applying that percent reduction to the baseline load for the reach)." (Excerpts from EPA Clake Champlain TMDL in Appendix A).

The following provides further detail, including the existing Vermont policy, guidelines, and principles that were relied on to develop a crediting approach for projects that include a streambank stabilization practice.

<u>Existing Vermont Policy</u> defining the standards for stream and river restoration:

- It is the policy of the State to promote and protect the natural maintenance and natural restoration of dynamic equilibrium conditions and to minimize fluvial erosion hazards (Stream Alteration Rule §27-102a).

- In Vermont Law 10 V.S.A. §1422(14) "Equilibrium condition" means the width, depth, meander pattern, and longitudinal slope of a stream channel that occurs when water flow, sediment, and woody debris are transported by the stream in such a manner that it generally maintains dimensions, pattern, and slope without unnaturally aggrading or degrading the channel bed elevation.

- Properties within river corridors are highly vulnerable to fluvial erosion hazards. Stream alterations implemented to protect these properties may affect the balance of stream processes and the distribution of erosion and deposition elsewhere along the corridor (i.e., alterations to stop erosion in one place may increase erosion in another place). Stream alterations that change the course, current, or cross-section of a stream and that cause the stream to significantly depart from or further depart from its equilibrium condition, or that alter the connectivity of the stream in its vertical and horizontal dimensions, increase risks to aquatic life, riparian property, and public safety (Stream Alteration Rule §27-102b).

- The State issues stream alteration permits to address emergencies and threats to life, public health, and safety or the threat of severe damage to existing improved property and may impede the attainment and maintenance of equilibrium conditions, recognizing that such alterations may potentially result in or significantly contribute to (fluvial erosion and) damage to fish life, wildlife, or the rights of riparian owners. (Stream Alteration Rule §27-102c)

- The implementation of Vermont's General Water Quality and Antidegradation policies require the protection of existing uses and high quality water and ensure the protection of designated water uses such as aquatic habitat, which, in part, consists of physical structures maintained through stream processes and flow characteristics (Vermont Water Quality Standards, 2022).

- Vermont's (EPA approved) Phase 1 Lake Champlain TMDL Implementation Plan (2016) committed to achieving equilibrium conditions through restoration and protection measures that promote and protect channel evolution. The following excerpt from the "Preventing Adverse River Channel Modifications" section of the Plan:

> Widespread and historic stream channelization (i.e., entrenchment with dredging, berming, straightening, and armoring practices) has resulted in increased erosion and therefore increased sediment and nutrient loading. Land drainage activities and structural controls such as riprap may prevent flooding and erosion at one site, but increase erosion downstream and contribute to destabilizing the stream system. These activities increase the power of floods thereby increasing stream bed and bank erosion, property damages, and risks to public safety. Valley streams and rivers in the Champlain drainage were, by nature, evolving to a least erosive, equilibrium condition where sediment erosion and deposition (storage) are in balance. Now, due to channelization, they function primarily as transport (or non-storage) streams. The floodplain deposition of fine sediment, so critical to nutrient retention, has been drastically reduced (>50%) throughout the Lake Champlain Basin. Stream alteration activities that result in conditions that depart from, further depart from, or impede the attainment of an equilibrium condition should be limited.

- VT DEC has adopted methods for the award and tracking of P load reduction credits, that will be assigned to river and floodplain restoration and protection projects based on gains in connectivity and geomorphic equilibrium, consistent with the load allocation and channel evolution-based methods established in the EPA's TMDL and state's TMDL Implementation Plan.

Principles and guidelines for P load reduction crediting of stream alterations in the FFI based on Vermont adopted policies:

a. The effects of stream alterations on water quality cannot be determined on a site by site basis, rather on how they singularly or cumulatively affect stream processes (i.e., erosion and deposition) and channel evolution at the reach and watershed scales over time.

b. Streams in channel evolution stages II-IV, which describes 75% of Vermont rivers and streams (Kline and Cahoon, JAWRA, 2010), are prone to downcutting and/or widening (VT ANR River Corridor Planning Guide, 2010). Bank armoring alone (i.e., including hard rock rip rap as well as softer bank revetments using root wads and log vanes) is not likely to reduce erosion risks on a stream that is prone to downcutting and widening as the rock and wood will be undermined (Vermont Standard River Management Principles and Practices, 2014).

c. While the permitting of stream alterations such as bank armoring may be necessary to protect public safety and property, cumulatively stream alterations have resulted in significant departures in natural stream processes, working toward equilibrium conditions, and have contributed to stream instability and the impairment of waterbodies such as Lake Champlain and Lake Memphremagog (e.g., ~21% of the Lake Champlain Basin P loads).

d. A bank armoring project that would <u>not</u> cause a stream to depart from, further depart from, or impede the attainment of equilibrium conditions, is one where the eroding stream segment has or could in the future evolve to the dimensions, pattern, and slope consistent with maintaining the natural channel bed elevation (relative to its active floodplain at bankfull stage). An example would be the limited armoring of an eroding streambank located at or very near the edge of the stream's meander belt within the river corridor, where the stream may still maintain or evolve to a least erosive, geomorphic equilibrium, with remaining space to establish and recruit native riparian vegetation, between the edge of the meander belt and the outside edge of the river corridor (see figure and diagram below).

e. A water quality restoration project, that includes a bank armoring practice, would not receive P load reduction credits, unless the armoring meets this test (defined in c. above) and includes other instream, riparian, and floodplain restoration and protection practices that increase connectivity and manage the stream toward an equilibrium condition. It is the gains in lateral and vertical connectivity of these other practices that result in the P load reduction credits for the overall project.

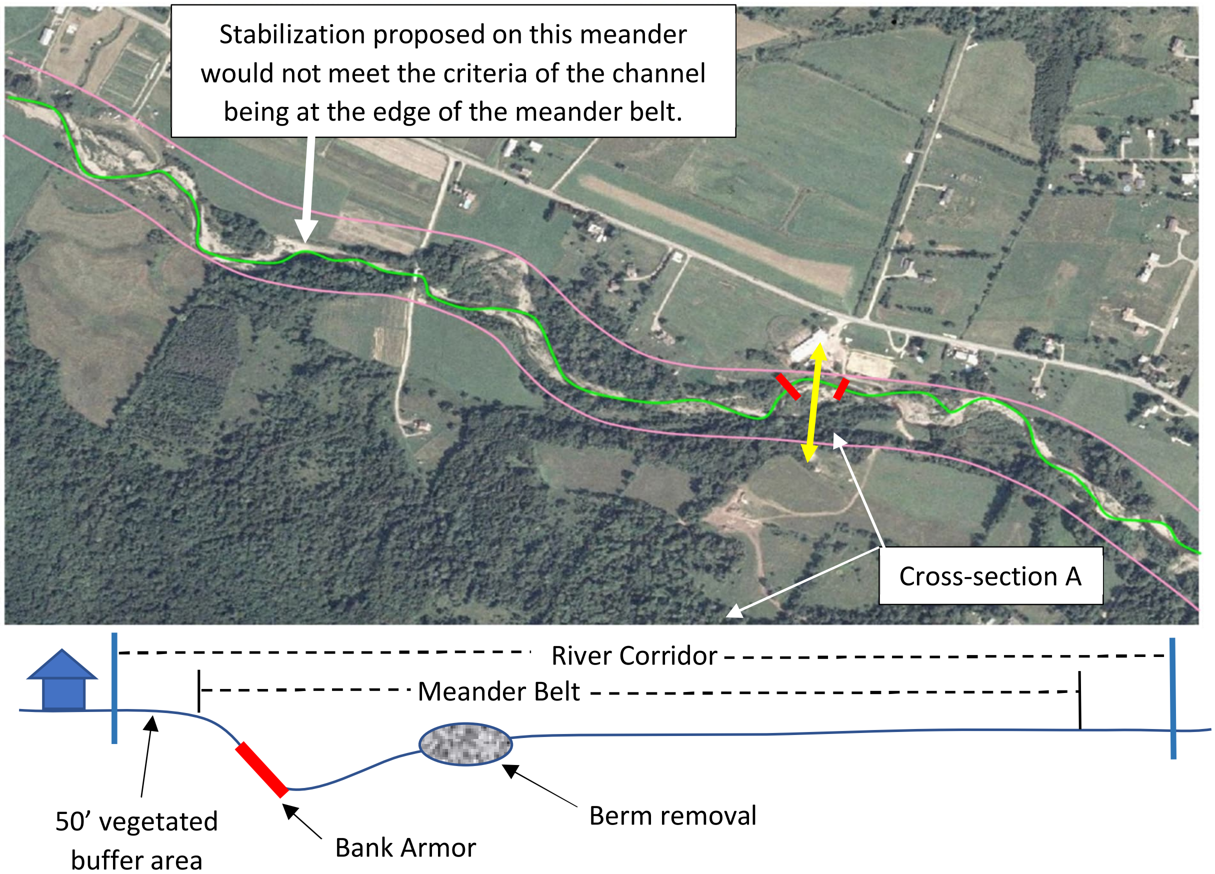
f. Clean water projects target nutrient and sediment pollution reductions to improve water quality of Vermont's waterbodies over the long term. While measured water quality parameters are the ultimate indicator of progress, it will take time for Vermont's waters to realize the benefits of clean water projects" (VT DEC, Watershed Investment Division, 2022). Vermont's tracking and accounting of river restoration projects defines practices eligible for load reduction credits, as developed through the FFI, and are based on these guidelines and principles. The Vermont Clean Water Initiative supports practices that are eligible for P load reduction credits because they maintain or improve water quality over the long term.

The FFI currently follows the above policy and guidelines and provides the opportunity to calculate P load reduction credits consistent with the following example.

Described here is a hypothetical, Vermont Clean Water-funded project, that includes a bank stabilization practice to protect private or public infrastructure and investments. This example includes the removal of a berm to restore floodplain storage and reduce erosive stream power, a river corridor easement to protect natural stream processes and channel evolution into the future, the planting of a 50-foot riparian buffer, and a bank armoring component (located between the red tick marks in the figure below). In this case, the bank stabilization practice, being used to protect a nearby building, is located at or very near the edge of the stream's meander belt, with a space remaining to establish a minimum 50-foot wide buffer of native riparian vegetation between the edge of the meander belt and the outside edge of the river corridor.

Unlike the berm removal, easement, and buffer components, the bank armor does not get a separate credit for reducing reach and watershed-scale P loads, because, while it doesn't impede the achievement of equilibrium, it does not increase connectivity and promote channel evolution in a river segment that was historically straightened. The bank stabilization may have public funding support as part of a larger reach scale effort to restore stream equilibrium. In many cases, assisting a landowner with their need to address erosion hazards (i.e., bank erosion moving toward their home) will gain their support of other project components that increase lateral connectivity (berm removal, corridor easement, 50 ft buffer), vertical connectivity (berm removal), and equilibrium conditions over time.

In conclusion, while a bank armoring project (including soft armoring such as bioengineered revetments) may be eligible for a Stream Alteration Permit, it will not be considered as a stand-alone practice that increases lateral and vertical connectivity. While acknowledging historic, cumulative impacts, the FFI and the FFI P load reduction planning tools are neutral with respect to bank stabilizations, neither awarding them P load reduction credit or accounting for them as instream encroachments that necessarily, over the long term, cause an increase on loading.


Stabilization proposed on this meander would not meet the criteria of the channel being at the edge of the meander belt.
Cross-section A
River Corridor
Meander Belt
50' vegetated buffer area
Bank Armor
Berm removal

Appendix C

Incorporation of Process-Based Research into Connectivity-based P Allocations and Project Prioritization

Work is ongoing to integrate results of processed-based research from stream channels, floodplains and wetlands into the FFI framework for connectivity-based P allocations and project prioritization. At present, the mapping layers for each spatial data set will be overlain on FFI mapping layers to further guide and prioritize stream and floodplain reconnection projects.

Stream-based Sediment Regime Departure Types

Sediment regime departure (SRD) classifications (Underwood, 2021; Kline, 2009) are used to refine vertical connectivity P load allocations to stream reaches and to set priorities for projects designed to address floodplain (lateral and vertical) and stream (longitudinal/temporal) connectivity departures.

TR	Transport
DEP	Depositional
CEFD	Course Equilibrium Fine Deposition
CST	Confined Source and Transport
UST	Unconfined Source and Transport
FSTCD	Fine Source and Transport Course Deposition

- **Vertical connectivity**:
  - ✓ Incised streams (CST, UST, and FSTCD types), in lower valley settings, are assigned higher percentages of the vertical connectivity allocation (by reliance on departure scoring methods that consider Incision Ratio) due to the expected increased rate of fine sediment erosion from these reaches. Where vertical connectivity can be re-established in these SRD types, the channel evolution that would otherwise result in very high P loading, would be reduced significantly.
  - ✓ Stable, equilibrium reaches (IR = 1.0) get no vertical connectivity allocation.
  - ✓ Lowering the incision ratio by restoring floodplains increases the value of lateral meander, protection, and buffer connectivity scores and stream stability load reduction credits, e.g., a buffer planted on connected floodplain (IR =1.0) would get a greater buffer P load credit than a buffer planted on a moderate to severely incised stream (IR > 1.5).
- **Lateral connectivity (meander freedom space):**
  - ✓ Incised streams (UST and FSTCD types) are rated as higher priorities for projects that remove river corridor constraints to reestablish meander space. Where lateral connectivity is re-established, the unstable channel evolves in an unconstrained corridor resulting in channel slopes commensurate with least-erosive equilibrium conditions, and lower P loading rates.
  - ✓ Lateral connectivity projects are lower priorities in the river corridors of equilibrium and vertically stable reaches, recognizing that there may be some lateral constraint removal that is cost effective.
- **Protection of lateral connectivity**:
  - ✓ Protecting the processes that create meanders and floodplains, particularly along incised UST and FSTCD types, is assigned the highest priority. Where river corridors remain open and protected, channel evolution and vertical reconnection will result in stable channel slopes commensurate with least-erosive equilibrium conditions, greater flow and material storage, and lower P loading rates. CST streams, while incised, are moderate priorities for easement projects, because of the lower potential for sediment and P storage in steeper, confined settings.
  - ✓ Depositional, equilibrium and vertically stable reaches are lower priority for river corridor easements, however, there may be great value in the long-term protection of existing floodplain storage

on the floodplains adjacent to larger DEP and CEFD streams that may be threatened by future stream or floodplain encroachment.

- **Laterally connected naturally vegetated buffers**:
  - ✓ High priority is assigned to naturally vegetated buffer restoration projects along depositional (DEP) and equilibrium streams (CEFD) where natural vegetation has a significant influence over the rate of natural channel migration.
  - ✓ Low priority is given to the restoration of a narrow (≤ 50') buffer along incised and evolving SRD types, because, as a standalone practice, root depths would be insufficient to stabilize bank materials. Reestablishing natural vegetation within the entre river corridor of CST, UST, and FSTCD, however, would be a priority, as the river shore and floodplain forest communities would evolve with the incised stream over time.
- **Longitudinal Connectivity:**
  - ✓ Maintaining existing natural, longitudinal connectivity in any SRD type is important, because disruption of sediment and debris regimes may bring about erosion and depositional processes that increase vertical disconnections and significantly effect stream stability and P loading.
  - ✓ High priority is given to the replacement of moderate to severely undersized stream crossings or the removal of derelict dams that result in significant upstream deposition and downstream bed erosion during floods. The depositional (DEP) SRD type is particularly sensitive to vertical instability due to breaks in longitudinal connectivity.
- **Temporal Connectivity**
  - ✓ Maintaining existing natural, temporal connectivity in any SRD type is important, because disruption of the hydrologic regimes may bring about erosion and depositional processes that increase vertical disconnections and significantly effect stream stability and P loading.
  - ✓ High priority is given to the water quality certification of water withdrawals and diversions or the treatment of urban, road, or agricultural stormwater that result in significant changes in stream processes during floods. Smaller CEFD and DEP streams (DA ≤ 2 sq.ml.) are particularly sensitive to vertical instability due to changes in temporal connectivity.

Floodplain Deposition

Provisional results of research on floodplain sediment and P deposition during 2019 and 2020 (Diehl et al., 2021) indicate that the estimated pounds of P per acre per year varies across Lake Champlain Basin floodplains as a function of valley width, energy (i.e., ssp= specific stream power), and vertical connectivity (as measured by incision ratio (IR).

- Narrow-valley < 25 x W_{bkf} vs. Wide-valley > 25 x W_{bkf}
- Well-connected (IR<1.3) vs. moderately-connected (1.3 < IR <1.9)
- Energy: Low SSP (<10 Watts/m^2; generally gradients <0.001) vs. Med SSP (10-300 Watts/m^2).

	Well Connected		Moderately Connected	
	Low Energy	Medium Energy	Low Energy	Medium Energy
Narrow Valley	7.7	17.5	3.4	5.4
Wide Valley	14.6	26.2	13.1	18.5

Results from the 2021 season will be compiled in coming months to further define the range of expected sediment and P deposition and to help characterize the uncertainty in P deposition estimates across space and over time (and inform uncertainty in P credits allocated to floodplain storage). Statistical models generated in Diehl et al. (2021) will be updated with these new data, and can be used to guide prioritization of floodplain reconnection sites and to optimize P attenuation in connected (or reconnected) floodplains.

Wetland Storage

P cycling in riparian wetlands is a complex process with many governing variables. Preliminary research findings from Roy and Wiegman (separate LCBP project) indicate that:

- Soluble reactive P (SRP) release can offset some of the P deposited in many riparian wetland sites, especially during winter/early spring floods when there is more plant litter subject to decomposition, and especially in sites where influent river SRP concentrations are relatively low to begin with.
- Across sites, preliminary data suggest decreasing SRP release from soils with time since farming.
- Certain soil metrics (e.g., Soil P Storage Capacity) predict soluble P loss risk from soils well.

Additional data collected in 2021 is presently being analyzed to build on the evidence base for proxies that can be used to estimate the SRP release risk for candidate floodplain restoration sites and compare this loss risk to anticipated deposition of sediment-bound P. These findings will be used, along with floodplain attenuation estimates above, to guide prioritization of floodplain reconnection sites to maximize P attenuation and minimize SRP release from connected (or reconnected) floodplains.

Appendix D

Stream Stability P Load Reduction Simulated Credits for Common Stream and Floodplain Connectivity Projects

Median values for P load reduction credits for the stream stability sector were estimated using the FFI Phase 1 dataset for floodplain and stream connectivity for streams with a watershed area of 2 square miles or greater (Table D1). For each simulated project, the data were filtered to select those subunits meeting the required minimum conditions for the practice (Table D2).

The simulated typical Vermont projects represent a range of potential values across the Lake Champlain Basin and vary based on the stream or floodplain's degree of departure from target conditions and the stream stability load allocation to the HUC12 watershed in which the project is located (Figure D1). Beyond this initial estimate, actual crediting for individual projects will be calculated and tracked within the final FFI web application during project planning and implementation.

In direct drainage watersheds where the stream stability loads are incorporated into the loads of other sectors (i.e., no direct load allocation has been made to the stream stability sector), the North and Lake Champlain simulation median credits provide appropriate values for crediting stream and floodplain connectivity projects, given their similarities in land use and natural settings to direct drainages (i.e., topography, soils, precipitation patterns). Proposed P-credit values for the direct drainage watersheds are presented in Table D3.

Detailed simulation results, including the number of simulated projects and mean and median P load reductions, are presented in Table D4.

Table D1. Median P Load Reduction Credits for Common Stream and Floodplain Connectivity Projects

Project Type (Appendix B)	Simulated Project	Median P Reduction Credit	P Credit Units
1A, 3	Floodplain Restoration with Buffer Revegetation	1.6	lb/ac/yr
1A, 3	Floodplain Restoration with Buffer Revegetation and Easement	2.1	lb/ac/yr
1B	Large/medium dam removal with floodplain restoration	2.0	lb/ac/yr
2	Small/medium intact ROR or breached dam removal with floodplain restoration	2.1	lb/ac/yr
4	Wood addition in 1st and 2nd order streams with vertical reconnection	1.7	lb/ac/yr
4	Wood addition in 3rd and 4th order streams with vertical reconnection	0.6	lb/ac/yr
5	Remove hard constraint	1.1	lb/ac/yr
6	Passive Restoration - Easement and Buffer Revegetation	0.7	lb/ac/yr
7	Adopt Corridor Bylaws	0.2	lb/ac/yr
8A	Buffer Revegetation	0.6	lb/ac/yr
9B	Replace Culverts - Undersized with Shallow Slope	2.0	lb/culvert/yr
10	Stabilize Gully on Perennial Stream	2.6	lb/project/yr

Table D2. Criteria for simulations of stream and floodplain connectivity P load reduction credits.

Project Type (Appendix B)	Simulated Project	Simulated Project Components	Subset Filtering Criteria
1A, 3	Floodplain Restoration with Buffer Revegetation	1/3 acre buffer 1 acre floodplain lowering (IR = 1)	IR > 1.3 ≥ 1/3 acre unvegetated ≥ 1 acre Unconstrained
	Floodplain Restoration with Buffer Revegetation and Easement	1/3 acre buffer 1 acre easement 1 acre floodplain lowering (IR = 1)	IR > 1.3 ≥ 1/3 acre unvegetated ≥ 1 acre without Robust Protection ≥ 1 acre Unconstrained
1B	Large/medium dam removal with floodplain restoration	Remove large or medium dam Normalize by impoundment area Add median floodplain restoration with buffer revegetation credit	LARGE_FLOOD_DAM LARGE_PEAKING_DAM LARGE_ROR_DAM MED_PEAKING_DAM
2	Small/medium intact ROR or breached dam removal with floodplain restoration	Remove small or medium dam Normalize by impoundment area Add median floodplain restoration with buffer revegetation credit	MED_ROR_DAM MED_BREACHED_DAM SMALL_ROR_DAM SMALL_BREACHED_DAM
4	Wood addition in 1st and 2nd order streams with vertical reconnection	1 acre floodplain reconnection (IR =1)	IR > 1.3 Stream Order 1-2 Subunit Area ≥ 1 acre
4	Wood addition in 3rd and 4th order streams with vertical reconnection	1 acre 50% IR improvement	IR > 1.3 Stream Order 3-4 Subunit Area ≥ 1 acre
5	Remove hard constraint	0.5 acre constraint removal	≥ 0.5 acre Constrained
6	Passive Restoration - Easement and Buffer Revegetation	1 acre easement (robust protection) 1/3 acre buffer	IR 1.2 - 1.8 ≥ 1 acre unvegetated Non-Ag Lateral Connectivity ≥ 90% ≥ 1 acre without Robust or Moderate Protection
7	Adopt Corridor Bylaws	Low or No Protection Converted to Moderate Protection	> 0 acre with Low or No Protection
8A	Buffer Revegetation	1 ac buffer	IR 1.2 - 1.8 ≥ 1 acre unvegetated Non-Ag Lateral Connectivity ≥ 90% ≥ 1 acre without Robust or Moderate Protection
9B	Replace Culverts - Undersized with Shallow Slope	Convert to Bankfull Structure	Culvert Type = <50% BKF Width, Shallow Slope
10	Stabilize Gully on Perennial Stream	Add 30 to Long and Temp Deductions	Number of Gullies ≥ 1

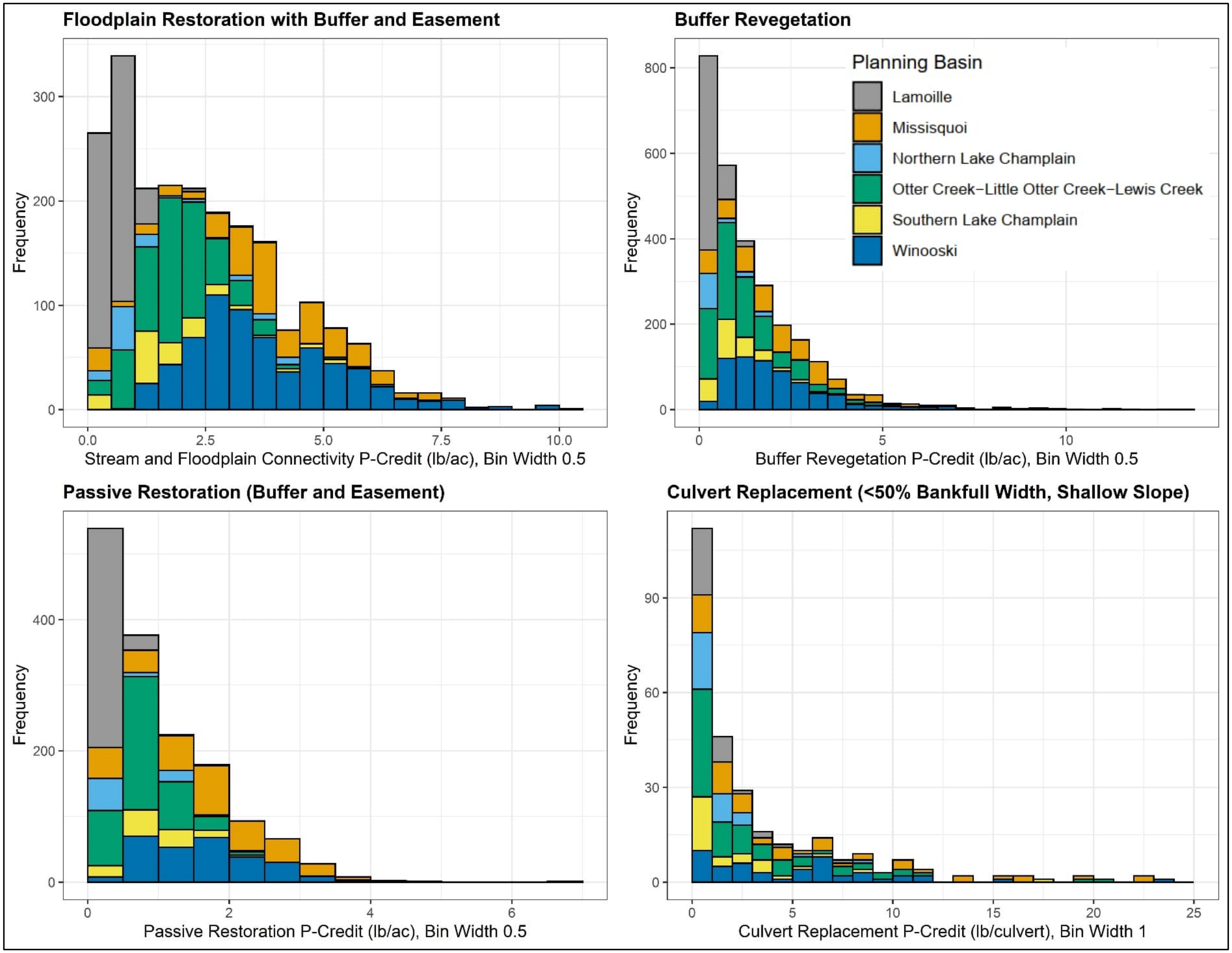
Table D3. Estimated Median P load reduction credits for simulated stream and floodplain connectivity projects.

Project Type (Appendix B)	Simulated Project	Northern Lake Champlain	Southern Lake Champlain	P Credit Units
1A, 3	Floodplain Restoration with Buffer Revegetation	0.7	1.2	lb/ac/yr
1A, 3	Floodplain Restoration with Buffer Revegetation and Easement	0.9	1.5	lb/ac/yr
1B	Large/medium dam removal with floodplain restoration	0.7	1.5	lb/ac/yr
2	Small/medium intact ROR or breached dam removal with flood-plain restoration	0.8	1.2	lb/ac/yr
4	Wood addition in 1st and 2nd order streams with vertical reconnection	1.2	2.8	lb/ac/yr
4	Wood addition in 3rd and 4th order streams with vertical reconnection	0.3	0.5	lb/ac/yr
5	Remove hard constraint	0.5	1.0	lb/ac/yr
6	Passive Restoration - Easement and 1/3 acre Buffer Revegetation	0.4	0.8	lb/ac/yr
7	Adopt Corridor Bylaws	0.2	0.3	lb/ac/yr
8A	Buffer Revegetation	0.3	0.8	lb/ac/yr
9B	Replace Culverts - Undersized with Shallow Slope	1.4	2.7	lb/culvert/yr
10	Stabilize Gully on Perennial Stream	1.1	4.2	lb/project/yr

Table D4. Complete results summary for simulated stream and floodplain connectivity projects.

Project Type (Appendix B)	Simulated Project	Basin Plan:	Lamoille	Missisquoi	Northern Lake Champlain	Otter Creek-Little Otter Creek-Lewis Creek	Southern Lake Champlain	Winooski	Overall
1A, 3	Floodplain Restoration with Buffer Revegetation (lb/ac/yr)	mean	0.5	2.9	1.1	1.4	1.4	2.9	1.9
		median	**0.4**	**2.9**	**0.7**	**1.4**	**1.2**	**2.7**	**1.6**
		n	*496*	*338*	*88*	*506*	*134*	*663*	*2225*
	Floodplain Restoration with Buffer Revegetation and Easement (lb/ac/yr)	mean	0.6	3.9	1.5	1.9	1.9	3.8	2.5
		median	**0.6**	**3.8**	**0.9**	**1.9**	**1.5**	**3.4**	**2.1**
		n	*481*	*335*	*87*	*495*	*133*	*648*	*2179*
1B	Large/medium dam removal with floodplain restoration (lb/ac/yr)	mean	0.7	3.5	0.7	2.6	1.5	3.1	2.2
		median	**0.6**	**3.3**	**0.7**	**2.0**	**1.5**	**3.0**	**2.0**
		n	*4*	*5*	*1*	*11*	*2*	*14*	*37*
2	Small/medium intact ROR or breached dam removal with floodplain restoration (lb/ac/yr)	mean	0.8	4.7	0.8	2.4	1.5	12.7	6.4
		median	**0.4**	**3.3**	**0.8**	**1.5**	**1.2**	**4.7**	**2.1**
		n	*8*	*10*	*3*	*18*	*10*	*38*	*87*
4	Wood addition in 1st and 2nd order streams (lb/ac/yr)	mean	0.4	1.9	1.2	1.3	2.5	2.3	1.7
		median	**0.3**	**1.8**	**1.2**	**1.3**	**2.8**	**1.9**	**1.7**
		n	*28*	*68*	*6*	*45*	*16*	*45*	*208*
4	Wood addition in 3rd and 4th order streams (lb/ac/yr)	mean	0.2	1.2	0.4	0.6	0.6	1.3	0.8
		median	**0.2**	**1.1**	**0.3**	**0.5**	**0.5**	**1.1**	**0.6**
		n	*485*	*334*	*108*	*439*	*157*	*597*	*2120*
5	Remove hard constraint (lb/ac/yr)	mean	0.4	2.3	0.9	1.2	1.3	2.4	1.5
		median	**0.3**	**2.2**	**0.5**	**1.0**	**1.0**	**2.1**	**1.1**
		n	*1215*	*994*	*309*	*1616*	*448*	*1557*	*6139*
6	Passive Restoration - Easement and 1/3 Acre Buffer Revegetation (lb/ac/yr)	mean	0.3	1.8	0.8	0.8	1.0	2.1	0.9
		median	**0.3**	**1.9**	**0.4**	**0.8**	**0.8**	**2.1**	**0.7**
		n	*197*	*123*	*18*	*194*	*57*	*43*	*635*
7	Adopt Corridor Bylaws (lb/ac/yr)	mean	0.1	0.5	0.3	0.3	0.4	0.7	0.4
		median	**0.1**	**0.5**	**0.2**	**0.3**	**0.3**	**0.7**	**0.2**
		n	*971*	*595*	*137*	*1124*	*313*	*562*	*3702*
8A	Buffer Revegetation (lb/ac/yr)	mean	0.3	1.9	0.6	0.9	0.9	2.1	1.0
		median	**0.2**	**1.8**	**0.3**	**0.8**	**0.8**	**2.0**	**0.6**
		n	*197*	*123*	*18*	*194*	*57*	*43*	*635*
9B	Replace Culverts - Undersized with Shallow Slope (lb/culvert/yr)	mean	1.3	7.5	1.4	4.2	2.7	5.7	4.3
		median	**0.5**	**3.6**	**0.8**	**2.2**	**1.4**	**5.7**	**2.0**
		n	*32*	*56*	*31*	*69*	*27*	*43*	*258*
10	Stabilize Gully on Perennial Stream (lb/project/yr)	mean	1.6	7.5	1.0	0.2	4.8	1.8	1.5
		median	**0.7**	**6.9**	**1.1**	**0.2**	**4.2**	**1.2**	**2.6**
		n	*5*	*6*	*7*	*2*	*6*	*25*	*51*

Figure D1. Sample histograms of P-credits for simulated stream and floodplain connectivity projects.

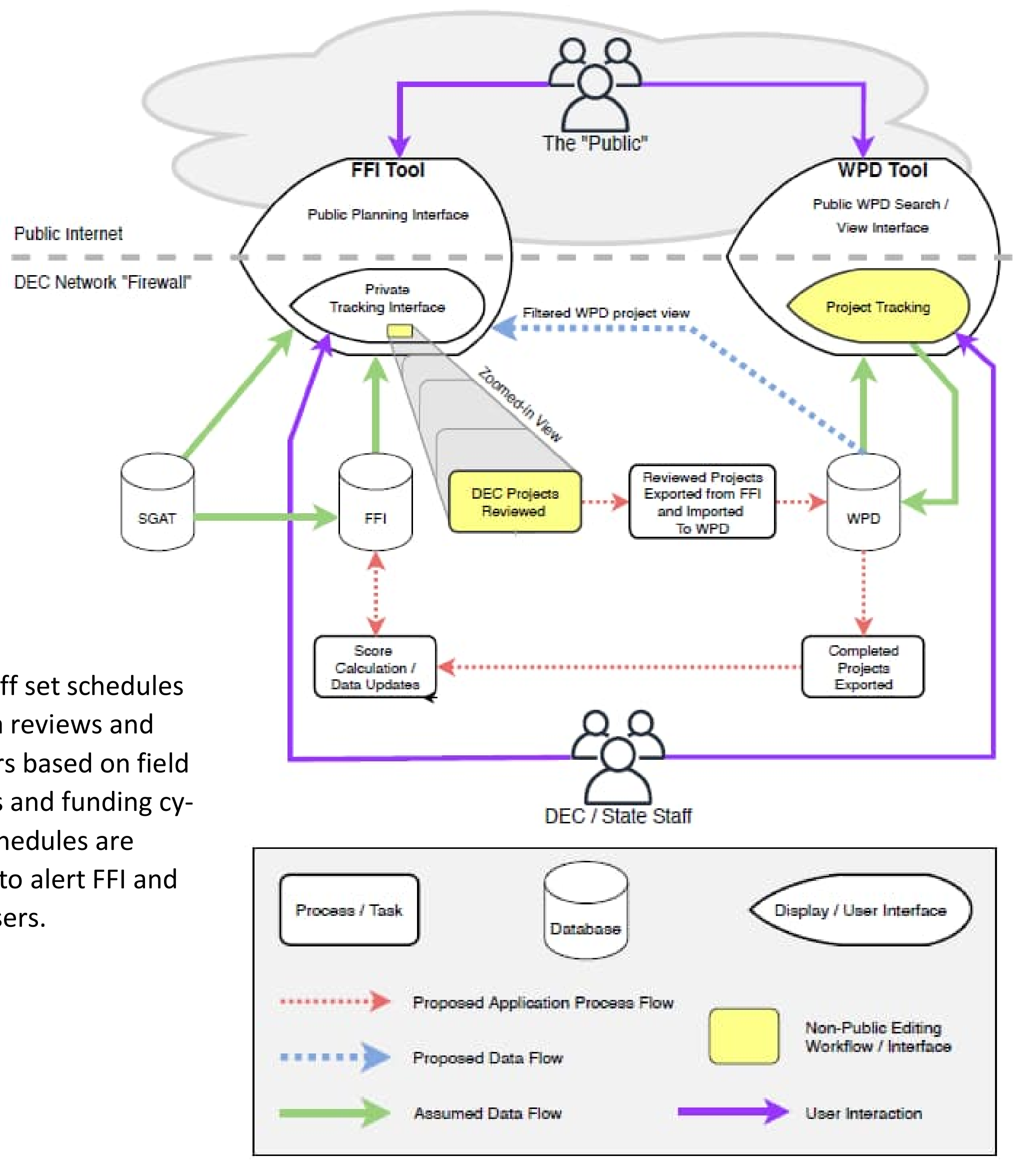


Appendix E

Data Inputs, Outputs, and Tracking Within and Between FFI and WPD

Data inputs, outputs, and tracking within and between DEC's FFI and WPD databases are outlined and explained here with the following set of graphics. Fundamentally, the FFI is storing and tracking reach-based connectivity scores (i.e., acres and connectivity components) and P allocations at the stream reach/subunit and HUC 12 scales. The WPD is tracking project-specific connectivity and P credits. Potential projects generated in FFI planning tools with connectivity and P load reduction credits (i.e., channel stability and floodplain storage credits) are exported out of the FFI and imported into the WPD where they are tracked from project development through design and implementation. Once a project is complete, the as-built subunit- or reach-based connectivity acres/scores would be revised in the FFI, and HUC 12 stream stability P base load allocations would be updated in the FFI to reset connectivity and reach/subunit P allocations.

Project "dots," placed on FFI mapped stream subunits and reaches, would allow the user to see where projects are underway or completed. By clicking on the dot, the FFI user would see a brief project description and a link giving them a window to the project data stored and tracked in the WPD..



DEC staff set schedules for data reviews and transfers based on field seasons and funding cycles. Schedules are posted to alert FFI and WPD users.

Data Flow and Tracking within and between the FFI and WPD

FFI Inputs and Tracking

Revisions to FFI data (w-versions saved for tracking), based on WPD outputs, stream geomorphic assessments, and new base-data (e.g., LiDAR) to update:

- Lateral-vertical scores (acres and incision ratios)
- Longitudinal and temporal scores
- HUC 12 P Base Loads
- New project "dots" where projects are underway/completed

WPD outputs – FFI inputs

- New project "dots" with:
  - Brief project descriptions
  - Link into WPD for user to view estimated/ revised/scheduled connectivity and P load credits assigned to the projects
- Data from completed projects to update subunit connectivity acres and scores
- Revised HUC 12 stream stability base loads to refresh reach allocations (SGAs & projects)

FFI outputs – WPD inputs

Projects with stream stability (incl. advanced removal) and storage P credits to be reviewed and approved by DEC for WPD entry. Data to include:

- Type and Subunit/Reach ID
- Initial connectivity acres and credits
- P load reduction credits, for each practice set, over time
  - Stream stability (equilibrium)
  - Storage (yr1, yr2 and beyond)

WPD Project Crediting, Monitoring, and Tracking

Table of projects at different phases of development, design, and implementation, with:

- Adjustments to storage P credits after design phase
- Schedule for stream stability P load credits over time
- Schedule for P storage credits and assignment of credits to different TMDL Sectors, incl. stream stability sector
- Project monitoring requirements

DEC staff are the gatekeepers of data flow between the FFI and the WPD. They would determine schedules for outputs/inputs between the two tracking systems, perhaps influenced by scheduled rounds of project funding and reporting and the field seasons established for monitoring and assessment. The key to understanding the following outline is that the FFI tracks stream reach/subunit P allocations and connectivity scores, and the WPD tracks project P and connectivity credits.

FFI Inputs and Tracking

Annual Revisions (versions of FFI data saved for tracking and reporting), based on WPD outputs (see below), stream geomorphic assessments, or new base data (e.g., new LiDAR).

- Lateral constraint acres
- Protected river corridor acres
- Natural riparian buffer acres
- Subunit incision ratio/acres
- Longitudinal disconnections/credits
- Temporal disconnections/credits
- HUC 12 Base Loads
- New project "dots" to view data in WPD

Note that stream geomorphic assessments are separate from project monitoring and will likely document significant changes in connectivity over time at the reach scale rather than the site-scale. An example would be assessments that take place after a flood event that result in channel evolution and changes in stream and floodplain connectivity. Documented reach-scale changes in connectivity are entered into the FFI following the SGA and the resulting changes in stream stability base loads are noted and tracked by DEC as natural channel evolution credits (i.e., programmatic vs. project-related base load reductions).

FFI outputs – WPD inputs

Project proponents (e.g., project grantees) would obtain from the FFI the stream stability and storage P credits for review and approval by DEC for WPD entry

- Project location/Subunit ID
- Project type (including which types of connectivity restored/protected)
- Connectivity acres and scores for:
    - Each practice set
    - Project as a whole
- Provisional P load reduction credits, for each practice set, over time (yr1, yr5, yr10, 20, 30), for
    - Stream stability (equilibrium)
    - Floodplain/wetland Storage

WPD Project Crediting, Monitoring, and Tracking

Table of projects at different phases of development, design, implementation, and post-implementation performance, with

- Adjustments to storage P credits after design and implementation phase using more precise field-based surveys of floodplain/wetland characteristics (affecting estimated storage credit).
- Schedule for assignment of P storage credits to different TMDL Sectors (provisionally output from FFI, but likely to change through project development, design and implementation)
    - Developed lands (with breakout to Vtrans, others?)
    - Agricultural lands
    - Forest lands

    - Stream stability
- Schedule for stream stability P load credits (less likely to change from the FFI output). The administration of the schedule could take one of these two forms:
    - Pre-awarded and retracted if design specifications and monitored targets are not met, or
    - Awarded on scheduled years as determined with monitoring
- Project monitoring requirements to determine credit awards/retainment over time

WPD outputs – FFI inputs (circling back around to the top)

- New project "dots" for projects that have been awarded funding with:
    - Brief project descriptions indicating practice type and types of connectivity restored/protected
    - Link into WPD for user to view more detail including project phase and the estimated/revised/scheduled connectivity and P load credits assigned to the project
- Data from completed projects and monitoring reports that justify updates to subunit or reach connectivity acres and scores in the FFI
- Revised HUC 12 P base loads to refresh subunit (Lateral-Vertical) and reach (Longitudinal-Temporal) allocations

APPENDIX N

SIMULATED P CREDITS FOR COMMON RECONNECTION PROJECTS IN THE LAKE CHAMPLAIN BASIN

Connectivity Project Credit Simulations

Median values for P load reduction credits for the stream stability sector were estimated using the FFI Phase 2 dataset for floodplain and stream connectivity for headwater and lower valley streams. These simulations exclude floodplain storage crediting. For each simulated project, the data were filtered to select those subunits meeting the required minimum conditions for the practice (Table N1).

Median results for each HUC12 are presented in Table N2. For HUC12 watersheds with no project sites to simulate after applying the subset filtering criteria or no separate P allocation to the stream stability sector, the basin median was used.

Table N1 Criteria for simulations of stream and floodplain connectivity P load reduction credits.

Simulated Project	Simulated Project Components	Subset Filtering Criteria
Floodplain Restoration with Buffer Revegetation and Easement	1/3 acre buffer 1 acre easement (robust protection) 1 acre floodplain lowering (IR = 1)	IR > 1.3 ≥ 1/3 acre unvegetated ≥ 1 acre Unconstrained ≥ 1 acre without Robust Protection
Floodplain Restoration with Buffer Revegetation	1/3 acre buffer 1 acre floodplain lowering (IR = 1)	IR > 1.3 ≥ 1/3 acre unvegetated ≥ 1 acre Unconstrained
Remove Hard Constraint	0.5 acre constraint removal	≥ 0.5 acre Constrained
Passive Restoration - Easement and Buffer Revegetation	1/3 acre buffer 1 acre easement (robust protection)	IR 1.2 - 1.8 ≥ 1 acre unvegetated Non-Agricultural Lateral Connectivity ≥90% ≥ 1 acre without Robust or Moderate Protection
Restore Wetland	Reduce Agricultural Acres and Tile Drained Acres by 1 Sum credit by HUC12	N/A
Adopt Corridor Bylaws	Low or No Protection Converted to Moderate Protection	> 0 acre with Low or No Protection
Plant 50-Foot Riparian Area	1 acre buffer	IR 1.2 - 1.8 ≥ 1 acre unvegetated Non-Agricultural Lateral Connectivity ≥90% ≥ 1 acre without Robust or Moderate Protection
Replace Undersized Bridge	Convert to Bankfull Structure	Bridge Type = <50% BKF Width, Shallow or Steep Slope or Bridge Type = 50-100% BKF, Shallow or Steep Slope
Replace Undersized Culvert	Convert to Bankfull Structure	Culvert Type = <50% BKF Width, Shallow Slope or Steep Slope
Large/medium dam removal with floodplain restoration	Remove large or medium dam Normalize by impoundment area Add median floodplain restoration with buffer revegetation credit	LARGE_FLOOD_DAM LARGE_PEAKING_DAM LARGE_ROR_DAM MED_PEAKING_DAM

Small/ medium intact ROR or breached dam removal with floodplain restoration	Remove small or medium dam Normalize by impoundment area Add median floodplain restoration with buffer revegetation credit	MED_ROR_DAM MED_BREACHED_DAM SMALL_ROR_DAM SMALL_BREACHED_DAM
Stabilize Gully on Perennial Stream	Add 30 to Longitudinal and Temporal Deductions	Number of Gullies > 1

Note that variability exists around the median values for both HUC-12s and Vermont Planning Basins (Figure N1), and thus they should only be used for crediting when a credit calculation is not possible in the FFI web application. For example, the median simulated P credit for a typical floodplain reconnection in the Lamoille River Basin is 0.2 kg/ac/yr while the maximum value in the dataset of 506 simulated projects is 1.7 kg/ac/yr. Use of the FFI web application P credit tool will provide a more accurate estimate of P credits for a specific project site with a base load allocation.

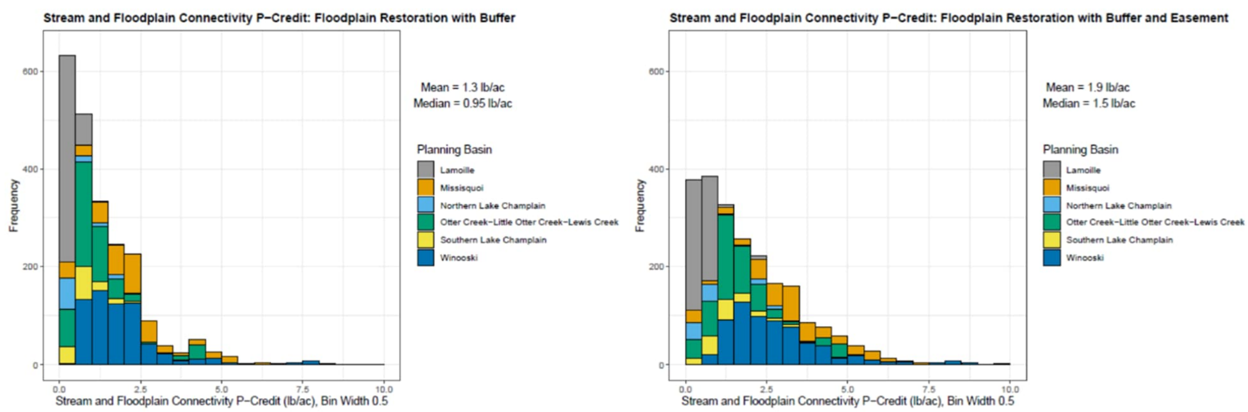


Figure N1 Simulated Median Credit Values for Stream Stability Sector Projects by Vermont Planning Basin

Table N2 Simulated Median Credit Values for Stream Stability Sector Projects by HUC12 Watershed (Reported in Kilograms)

(See next page.)

Simulated Median Credit Values (Reported in Kilograms)
Stream Stability Sector Projects

			Protection (kg/ac)			Channel, Floodplain, and Wetland Restoration (kg/ac)								Revegetation (kg/ac)			Constraint Removal (kg/ac)		Dam Removal (kg/ac)								Bridge and Culvert Replacement or Retrofit (kg/structure)														Stabilization (kg/project)		
Basin	HUC12	Name	Implement River Corridor Easement	Adopt River Corridor Bylaws	NRCS Wetland Reserve	Create Flood Bench	Lower Floodplain	Raise Channel	Reconnect Flood Chute	Remove Berm	Restore Channel Roughness and Wood	Restore Channel Slope	Restore Wetland	Plant 50-Foot Riparian Area	Plant Floodplain Outside of Corridor	Plant River Corridor Outside of 50-Foot Riparian Area	Remove Major Constraint	Remove Minor Constraint	Remove/ Convert Large Peaking Hydro Dam	Remove/ Convert Medium Peaking Hydro Dam	Remove Large Flood Control Dam	Remove Large Run of River Dam	Remove Medium Breached Dam	Remove Medium Run of River Dam	Remove Small Breached Dam	Remove Small Intact Run of River Dam	Replace Bridge (50%>Wbkf >100%)	Replace Bridge (No Wbkf Data)	Replace Bridge (Wbkf >100%)	Replace Bridge (Wbkf<50%), shallow channel (<2%)	Replace Bridge (Wbkf<50%), steep channel (>2%)	Replace Culvert (50%>Wbkf>100%), shallow channel (<2%)	Replace Culvert (50%>Wbkf>100%), steep channel (>2%)	Replace Culvert (No Wbkf Data), shallow channel (<2%)	Replace Culvert (No Wbkf Data), steep channel (>2%)	Replace Culvert (Wbkf>100%)	Replace Culvert (Wbkf<50%), steep channel (>2%)	Replace Culvert (Wbkf<50%), shallow channel (<2%)	Place Baffles in Culvert	Backwater Culvert with Weir or Other Approach	Stabilize Gully	Stabilize Gully with Treatment of Stormwater	Stabilize Headcut in Perennial Stream
Lamoille	043001050101	Headwaters Lamoille River	0.08	0.03	0.08	0.15	0.15	0.15	0.15	0.15	0.10	0.15	0.01	0.04	N/A	N/A	0.09	0.09	0.32	0.32	0.32	0.32	0.26	0.26	0.26	0.26	0.27	0.27	N/A	0.27	0.27	0.48	0.48	0.48	0.48	N/A	0.48	0.48	0.48	0.48	0.24	0.24	0.24
	043001050102	Hardwick Lake Dam-Lamoille River	0.06	0.03	0.06	0.14	0.14	0.14	0.14	0.14	0.09	0.14	0.00	0.05	N/A	N/A	0.08	0.08	0.32	0.32	0.32	0.32	0.26	0.26	0.26	0.26	0.32	0.32	N/A	0.32	0.32	0.34	0.34	0.34	0.34	N/A	0.34	0.34	0.34	0.34	0.24	0.24	0.24
	043001050103	Wild Branch	0.13	0.05	0.13	0.32	0.32	0.32	0.32	0.32	0.22	0.32	0.01	0.09	N/A	N/A	0.15	0.15	0.32	0.32	0.32	0.32	0.26	0.26	0.26	0.26	0.50	0.50	N/A	0.50	0.50	2.09	2.09	2.09	2.09	N/A	2.09	2.09	2.09	2.09	0.24	0.24	0.24
	043001050104	Elmore Branch-Lamoille River	0.15	0.04	0.15	0.32	0.32	0.32	0.32	0.32	0.22	0.32	0.01	0.18	N/A	N/A	0.15	0.15	0.32	0.32	0.32	0.32	0.26	0.26	0.26	0.26	0.51	0.51	N/A	0.51	0.51	3.06	3.06	3.06	3.06	N/A	3.06	3.06	3.06	3.06	0.24	0.24	0.24
	043001050105	Green River	0.70	0.22	0.70	1.08	1.08	1.08	1.08	1.08	0.88	1.08	0.01	0.08	N/A	N/A	0.78	0.78	0.32	0.32	0.32	0.32	0.26	0.26	0.26	0.26	3.15	3.15	N/A	3.15	3.15	3.73	3.73	3.73	3.73	N/A	3.73	3.73	3.73	3.73	0.24	0.24	0.24
	043001050106	Ryder Brook-Lamoille River	0.11	0.04	0.11	0.21	0.21	0.21	0.21	0.21	0.14	0.21	0.01	0.07	N/A	N/A	0.11	0.11	0.32	0.32	0.32	0.32	0.26	0.26	0.26	0.26	0.27	0.27	N/A	0.27	0.27	0.56	0.56	0.56	0.56	N/A	0.56	0.56	0.56	0.56	0.24	0.24	0.24
	043001050107	Kenfield Brook-Lamoille River	0.09	0.03	0.09	0.20	0.20	0.20	0.20	0.20	0.15	0.20	0.00	0.07	N/A	N/A	0.07	0.07	0.32	0.32	0.32	0.32	0.26	0.26	0.26	0.26	0.22	0.22	N/A	0.22	0.22	0.53	0.53	0.53	0.53	N/A	0.53	0.53	0.53	0.53	0.24	0.24	0.24
	043001050201	Headwaters Browns River	0.15	0.05	0.15	0.36	0.36	0.36	0.36	0.36	0.27	0.36	0.01	0.07	N/A	N/A	0.16	0.16	0.32	0.32	0.32	0.32	0.26	0.26	0.26	0.26	0.36	0.36	N/A	0.36	0.36	1.04	1.04	1.04	1.04	N/A	1.04	1.04	1.04	1.04	0.24	0.24	0.24
	043001050202	Browns River	0.27	0.05	0.27	0.42	0.42	0.42	0.42	0.42	0.31	0.42	0.01	0.33	N/A	N/A	0.25	0.25	0.32	0.32	0.32	0.32	0.26	0.26	0.26	0.26	1.75	1.75	N/A	1.75	1.75	2.22	2.22	2.22	2.22	N/A	2.22	2.22	2.22	2.22	0.24	0.24	0.24
	043001050301	Gihon River	0.16	0.06	0.16	0.33	0.33	0.33	0.33	0.33	0.22	0.33	0.01	0.08	N/A	N/A	0.18	0.18	0.32	0.32	0.32	0.32	0.26	0.26	0.26	0.26	0.29	0.29	N/A	0.29	0.29	0.93	0.93	0.93	0.93	N/A	0.93	0.93	0.93	0.93	0.24	0.24	0.24
	043001050302	North Branch Lamoille River	0.14	0.05	0.14	0.29	0.29	0.29	0.29	0.29	0.18	0.29	0.01	0.14	N/A	N/A	0.16	0.16	0.32	0.32	0.32	0.32	0.26	0.26	0.26	0.26	0.85	0.85	N/A	0.85	0.85	2.02	2.02	2.02	2.02	N/A	2.02	2.02	2.02	2.02	0.24	0.24	0.24
	043001050303	Brewster River-Lamoille River	0.11	0.03	0.11	0.22	0.22	0.22	0.22	0.22	0.17	0.22	0.01	0.13	N/A	N/A	0.10	0.10	0.32	0.32	0.32	0.32	0.26	0.26	0.26	0.26	0.25	0.25	N/A	0.25	0.25	1.55	1.55	1.55	1.55	N/A	1.55	1.55	1.55	1.55	0.24	0.24	0.24
	043001050304	Seymour River-Lamoille River	0.10	0.02	0.10	0.17	0.17	0.17	0.17	0.17	0.12	0.17	0.00	0.10	N/A	N/A	0.08	0.08	0.32	0.32	0.32	0.32	0.26	0.26	0.26	0.26	0.09	0.09	N/A	0.09	0.09	0.74	0.74	0.74	0.74	N/A	0.74	0.74	0.74	0.74	0.24	0.24	0.24
	043001050305	Stones Brook-Lamoille River	0.02	0.01	0.02	0.04	0.04	0.04	0.04	0.04	0.03	0.04	0.00	0.01	N/A	N/A	0.02	0.02	0.32	0.32	0.32	0.32	0.26	0.26	0.26	0.26	0.14	0.14	N/A	0.14	0.14	0.14	0.14	0.14	0.14	N/A	0.14	0.14	0.14	0.14	0.24	0.24	0.24
	043001050306	Lamoille River	0.14	0.05	0.14	0.33	0.33	0.33	0.33	0.33	0.25	0.33	0.00	0.12	N/A	N/A	0.23	0.23	0.32	0.32	0.32	0.32	0.26	0.26	0.26	0.26	0.10	0.10	N/A	0.10	0.10	2.39	2.39	2.39	2.39	N/A	2.39	2.39	2.39	2.39	0.24	0.24	0.24
Missisquoi	043001070101	Headwater Missisquoi River	0.73	0.32	0.73	1.60	1.60	1.60	1.60	1.60	1.16	1.60	0.03	0.17	N/A	N/A	0.93	0.93	1.80	1.80	1.80	1.80	1.79	1.79	1.79	1.79	0.86	0.86	N/A	0.86	0.86	6.79	6.79	6.79	6.79	N/A	6.79	6.79	6.79	6.79	2.73	2.73	2.73
	043001070102	Snider Brook-Missisquoi River	0.86	0.29	0.86	1.48	1.48	1.48	1.48	1.48	0.96	1.48	0.03	0.68	N/A	N/A	0.83	0.83	1.80	1.80	1.80	1.80	1.79	1.79	1.79	1.79	2.41	2.41	N/A	2.41	2.41	6.79	6.79	6.79	6.79	N/A	6.79	6.79	6.79	6.79	2.73	2.73	2.73
	043001070103	Mineral Spring Brook-Missisquoi River	0.38	0.14	0.38	0.67	0.67	0.67	0.67	0.67	0.50	0.67	0.01	0.26	N/A	N/A	0.41	0.41	1.80	1.80	1.80	1.80	1.79	1.79	1.79	1.79	1.10	1.10	N/A	1.10	1.10	4.66	4.66	4.66	4.66	N/A	4.66	4.66	4.66	4.66	2.73	2.73	2.73
	043001070104	Jay Branch	1.54	0.48	1.54	3.14	3.14	3.14	3.14	3.14	2.17	3.14	0.03	0.82	N/A	N/A	1.68	1.68	1.80	1.80	1.80	1.80	1.79	1.79	1.79	1.79	2.41	2.41	N/A	2.41	2.41	6.79	6.79	6.79	6.79	N/A	6.79	6.79	6.79	6.79	2.73	2.73	2.73
	043001070106	Mud Creek	0.08	0.03	0.08	0.15	0.15	0.15	0.15	0.15	0.11	0.15	0.03	0.03	N/A	N/A	0.08	0.08	1.80	1.80	1.80	1.80	1.79	1.79	1.79	1.79	0.08	0.08	N/A	0.08	0.08	0.65	0.65	0.65	0.65	N/A	0.65	0.65	0.65	0.65	2.73	2.73	2.73
	043001070107	Beetle Brook-Missisquoi River	0.40	0.44	0.40	1.44	1.44	1.44	1.44	1.44	1.12	1.44	0.03	0.15	N/A	N/A	1.24	1.24	1.80	1.80	1.80	1.80	1.79	1.79	1.79	1.79	3.71	3.71	N/A	3.71	3.71	6.79	6.79	6.79	6.79	N/A	6.79	6.79	6.79	6.79	2.73	2.73	2.73
	043001070206	Leavit Brook-Missisquoi River	3.27	0.30	3.27	1.62	1.62	1.62	1.62	1.62	1.23	1.62	0.03	1.23	N/A	N/A	0.86	0.86	1.80	1.80	1.80	1.80	1.79	1.79	1.79	1.79	2.41	2.41	N/A	2.41	2.41	6.79	6.79	6.79	6.79	N/A	6.79	6.79	6.79	6.79	2.73	2.73	2.73
	043001070209	Outlet Sutton River	0.63	0.20	0.63	1.62	1.62	1.62	1.62	1.62	1.23	1.62	0.00	0.36	N/A	N/A	1.65	1.65	1.80	1.80	1.80	1.80	1.79	1.79	1.79	1.79	2.41	2.41	N/A	2.41	2.41	6.02	6.02	6.02	6.02	N/A	6.02	6.02	6.02	6.02	2.73	2.73	2.73
	043001070210	Lucas Brook-Missisquoi River	0.74	0.26	0.74	1.48	1.48	1.48	1.48	1.48	1.21	1.48	0.04	0.91	N/A	N/A	0.76	0.76	1.80	1.80	1.80	1.80	1.79	1.79	1.79	1.79	2.41	2.41	N/A	2.41	2.41	6.79	6.79	6.79	6.79	N/A	6.79	6.79	6.79	6.79	2.73	2.73	2.73
	043001070301	Headwaters Trout River	0.27	0.12	0.27	1.30	1.30	1.30	1.30	1.30	1.04	1.30	0.03	0.36	N/A	N/A	0.71	0.71	1.80	1.80	1.80	1.80	1.79	1.79	1.79	1.79	2.41	2.41	N/A	2.41	2.41	6.79	6.79	6.79	6.79	N/A	6.79	6.79	6.79	6.79	2.73	2.73	2.73
	043001070302	Outlet Trout River	1.58	0.27	1.58	2.25	2.25	2.25	2.25	2.25	1.77	2.25	0.02	0.36	N/A	N/A	1.38	1.38	1.80	1.80	1.80	1.80	1.79	1.79	1.79	1.79	2.41	2.41	N/A	2.41	2.41	6.79	6.79	6.79	6.79	N/A	6.79	6.79	6.79	6.79	2.73	2.73	2.73
	043001070401	Tyler Branch	0.42	0.18	0.42	1.97	1.97	1.97	1.97	1.97	1.60	1.97	0.04	0.16	N/A	N/A	1.17	1.17	1.80	1.80	1.80	1.80	1.79	1.79	1.79	1.79	2.99	2.99	N/A	2.99	2.99	6.79	6.79	6.79	6.79	N/A	6.79	6.79	6.79	6.79	2.73	2.73	2.73
	043001070402	Enosburg Falls-Missisquoi River	2.04	0.22	2.04	1.46	1.46	1.46	1.46	1.46	1.16	1.46	0.03	0.76	N/A	N/A	0.82	0.82	1.80	1.80	1.80	1.80	1.79	1.79	1.79	1.79	2.41	2.41	N/A	2.41	2.41	6.79	6.79	6.79	6.79	N/A	6.79	6.79	6.79	6.79	2.73	2.73	2.73
	043001070403	Goodsell Brook-Missisquoi River	1.03	0.24	1.03	1.76	1.76	1.76	1.76	1.76	1.24	1.76	0.03	1.03	N/A	N/A	0.87	0.87	1.80	1.80	1.80	1.80	1.79	1.79	1.79	1.79	2.41	2.41	N/A	2.41	2.41	6.79	6.79	6.79	6.79	N/A	6.79	6.79	6.79	6.79	2.73	2.73	2.73
	043001070501	Headwaters Black Creek	1.14	0.34	1.14	2.38	2.38	2.38	2.38	2.38	1.60	2.38	0.05	0.80	N/A	N/A	1.60	1.60	1.80	1.80	1.80	1.80	1.79	1.79	1.79	1.79	3.59	3.59	N/A	3.59	3.59	6.79	6.79	6.79	6.79	N/A	6.79	6.79	6.79	6.79	2.73	2.73	2.73
	043001070502	Fairfield River	1.31	0.48	1.31	4.40	4.40	4.40	4.40	4.40	2.96	4.40	0.09	0.49	N/A	N/A	1.88	1.88	1.80	1.80	1.80	1.80	1.79	1.79	1.79	1.79	2.41	2.41	N/A	2.41	2.41	6.79	6.79	6.79	6.79	N/A	6.79	6.79	6.79	6.79	2.73	2.73	2.73
	043001070503	Dead Creek	0.82	0.26	0.82	2.19	2.19	2.19	2.19	2.19	1.41	2.19	0.01	0.31	N/A	N/A	1.13	1.13	1.80	1.80	1.80	1.80	1.79	1.79	1.79	1.79	0.69	0.69	N/A	0.69	0.69	3.55	3.55	3.55	3.55	N/A	3.55	3.55	3.55	3.55	2.73	2.73	2.73
	043001070504	Black Creek	0.71	0.17	0.71	1.47	1.47	1.47	1.47	1.47	1.11	1.47	0.00	0.47	N/A	N/A	0.88	0.88	1.80	1.80	1.80	1.80	1.79	1.79	1.79	1.79	2.41	2.41	N/A	2.41	2.41	6.79	6.79	6.79	6.79	N/A	6.79	6.79	6.79	6.79	2.73	2.73	2.73
	043001070601	McGowan Brook-Missisquoi River	1.24	0.26	1.24	1.43	1.43	1.43	1.43	1.43	0.92	1.43	0.02	1.17	N/A	N/A	0.96	0.96	1.80	1.80	1.80	1.80	1.79	1.79	1.79	1.79	2.41	2.41	N/A	2.41	2.41	6.79	6.79	6.79	6.79	N/A	6.79	6.79	6.79	6.79	2.73	2.73	2.73
	043001070602	Hungerford Brook	1.29	0.47	1.29	2.65	2.65	2.65	2.65	2.65	1.69	2.65	0.02	0.48	N/A	N/A	1.62	1.62	1.80	1.80	1.80	1.80	1.79	1.79	1.79	1.79	1.96	1.96	N/A	1.96	1.96	6.76	6.76	6.76	6.76	N/A	6.76	6.76	6.76	6.76	2.73	2.73	2.73
	043001070603	Outlet Missisquoi River	0.61	0.08	0.61	0.30	0.30	0.30	0.30	0.30	0.21	0.30	0.01	0.31	N/A	N/A	0.29	0.29	1.80	1.80	1.80	1.80	1.79	1.79	1.79	1.79	2.41	2.41	N/A	2.41	2.41	4.78	4.78	4.78	4.78	N/A	4.78	4.78	4.78	4.78	2.73	2.73	2.73
	043001081001	Heawaters Pike River	0.41	0.15	0.41	0.99	0.99	0.99	0.99	0.99	0.78	0.99	0.00	0.15	N/A	N/A	0.55	0.55	1.80	1.80	1.80	1.80	1.79	1.79	1.79	1.79	1.44	1.44	N/A	1.44	1.44	2.86	2.86	2.86	2.86	N/A	2.86	2.86	2.86	2.86	2.73	2.73	2.73
	043001081005	Groat Creek	0.24	0.09	0.24	0.50	0.50	0.50	0.50	0.50	0.32	0.50	0.00	0.20	N/A	N/A	0.32	0.32	1.80	1.80	1.80	1.80	1.79	1.79	1.79	1.79	0.41	0.41	N/A	0.41	0.41	0.98	0.98	0.98	0.98	N/A	0.98	0.98	0.98	0.98	2.73	2.73	2.73
	043001081101	Rock River	0.08	0.04	0.08	0.12	0.12	0.12	0.12	0.12	0.08	0.12	0.00	0.03	N/A	N/A	0.19	0.19	1.80	1.80	1.80	1.80	1.79	1.79	1.79	1.79	1.03	1.03	N/A	1.03	1.03	0.76	0.76	0.76	0.76	N/A	0.76	0.76	0.76	0.76	2.73	2.73	2.73
	043001081102	Carman Brook-Missiquoi Bay	2.60	0.44	2.60	3.02	3.02	3.02	3.02	3.02	2.14	3.02	0.02	0.97	N/A	N/A	2.50	2.50	1.80	1.80	1.80	1.80	1.79	1.79	1.79	1.79	2.41	2.41	N/A	2.41	2.41	6.02	6.02	6.02	6.02	N/A	6.02	6.02	6.02	6.02	2.73	2.73	2.73
Northern Lake Champlain	043001080801	La Platte River	0.09	0.02	0.09	0.17	0.17	0.17	0.17	0.17	0.14	0.17	0.00	0.03	N/A	N/A	0.12	0.12	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.08	0.08	N/A	0.08	0.08	0.46	0.46	0.46	0.46	N/A	0.46	0.46	0.46	0.46	0.13	0.13	0.13
	043001080802	Munroe Brook-Shelburne Bay	0.19	0.03	0.19	0.28	0.28	0.28	0.28	0.28	0.23	0.28	0.00	0.13	N/A	N/A	0.15	0.15	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.45	0.45	N/A	0.45	0.45	0.16	0.16	0.16	0.16	N/A	0.16	0.16	0.16	0.16	0.13	0.13	0.13
	043001080901	Malletts Creek	0.22	0.07	0.22	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.00	0.15	N/A	N/A	0.25	0.25	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.72	0.72	N/A	0.72	0.72	1.11	1.11	1.11	1.11	N/A	1.11	1.11	1.11	1.11	0.13	0.13	0.13
	043001080902	Malletts Bay	0.34	0.15	0.34	0.73	0.73	0.73	0.73	0.73	0.44	0.73	0.00	0.15	N/A	N/A	0.44	0.44	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.93	0.93	N/A	0.93	0.93	0.52	0.52	0.52	0.52	N/A	0.52	0.52	0.52	0.52	0.13	0.13	0.13
	043001081201	Jewett Brook	0.69	0.24	0.69	1.48	1.48	1.48	1.48	1.48	1.30	1.48	0.01	0.31	N/A	N/A	0.92	0.92	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	6.23	6.23	N/A	6.23	6.23	1.95	1.95	1.95	1.95	N/A	1.95	1.95	1.95	1.95	0.13	0.13	0.13
	043001081202	Mill River	0.16	0.05	0.16	0.36	0.36	0.36	0.36	0.36	0.27	0.36	0.00	0.06	N/A	N/A	0.18	0.18	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.35	0.35	N/A	0.35	0.35	1.23	1.23	1.23	1.23	N/A	1.23	1.23	1.23	1.23	0.13	0.13	0.13
	043001081203	Mud Creek	0.19	0.07	0.19	0.38	0.38	0.38	0.38	0.38	0.28	0.38	0.00	0.13	N/A	N/A	0.19	0.19	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.45	0.45	N/A	0.45	0.45	0.62	0.62	0.62	0.62	N/A	0.62	0.62	0.62	0.62	0.13	0.13	0.13
	043001081204	Saint Albans Bay-Lake Champlain	0.19	0.07	0.19	0.38	0.38	0.38	0.38	0.38	0.28	0.38	0.00	0.13	N/A	N/A	0.19	0.19	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.45	0.45	N/A	0.45	0.45	0.62	0.62	0.62	0.62	N/A	0.62	0.62	0.62	0.62	0.13	0.13	0.13
	043001081604	Lake Champlain	0.19	0.07	0.19	0.38	0.38	0.38	0.38	0.38	0.28	0.38	0.00	0.13	N/A	N/A	0.19	0.19	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.45	0.45	N/A	0.45	0.45	0.62	0.62	0.62	0.62	N/A	0.62	0.62	0.62	0.62	0.13	0.13	0.13
	043001090302	Little River-Richelieu River	0.19	0.07	0.19	0.38	0.38	0.38	0.38	0.38	0.28	0.38	0.00	0.13	N/A	N/A	0.19	0.19	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.45	0.45	N/A	0.45	0.45	0.62	0.62	0.62	0.62	N/A	0.62	0.62	0.62	0.62	0.13	0.13	0.13
	043001090303	South River	0.19	0.07	0.19	0.38	0.38	0.38	0.38	0.38	0.28	0.38	0.00	0.13	N/A	N/A	0.19	0.19	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.45	0.45	N/A	0.45	0.45	0.62	0.62	0.62	0.62	N/A	0.62	0.62	0.62	0.62	0.13	0.13	0.13
Otter Creek- Little Otter Creek- Lewis Creek	043001020101	Headwaters Otter Creek	0.11	0.10	0.11	0.62	0.62	0.62	0.62	0.62	0.52	0.62	0.02	0.17	N/A	N/A	0.31	0.31	0.98	0.98	0.98	0.98	0.84	0.84	0.84	0.84	0.84	0.84	N/A	0.84	0.84	2.74	2.74	2.74	2.74	N/A	2.74	2.74	2.74	2.74	0.08	0.08	0.08
	043001020102	Big Branch	0.30	0.37	0.30	1.31	1.31	1.31	1.31	1.31	1.10	1.31	0.02	0.17	N/A	N/A	0.72	0.72	0.98	0.98	0.98	0.98	0.84	0.84	0.84	0.84	1.50	1.50	N/A	1.50	1.50	5.42	5.42	5.42	5.42	N/A	5.42	5.42	5.42	5.42	0.08	0.08	0.08
	043001020103	Homer Stone Brook-Otter Creek	0.21	0.18	0.21	1.04	1.04	1.04	1.04	1.04	0.80	1.04	0.02	0.20	N/A	N/A	0.75	0.75	0.98	0.98	0.98	0.98	0.84	0.84	0.84	0.84	2.50	2.50	N/A	2.50	2.50	6.28	6.28	6.28	6.28	N/A	6.28	6.28	6.28	6.28	0.08	0.08	0.08
	043001020104	Headwaters Mill Creek	0.28	0.07	0.28	0.89	0.89	0.89	0.89	0.89	0.69	0.89	0.01	0.24	N/A	N/A	0.31	0.31	0.98	0.98	0.98	0.98	0.84	0.84	0.84	0.84	1.40	1.40	N/A	1.40	1.40	1.46	1.46	1.46	1.46	N/A	1.46	1.46	1.46	1.46	0.08	0.08	0.08
	043001020105	Mill Creek	0.48	0.11	0.48	0.96	0.96	0.96	0.96	0.96	0.75	0.96	0.01	0.20	N/A	N/A	0.42	0.42	0.98	0.98	0.98	0.98	0.84	0.84	0.84	0.84	1.01	1.01	N/A	1.01	1.01	3.73	3.73	3.73	3.73	N/A	3.73	3.73	3.73	3.73	0.08	0.08	0.08
	043001020106	Cold River	0.37	0.12	0.37	0.92	0.92	0.92	0.92	0.92	0.73	0.92	0.03	0.10	N/A	N/A	0.36	0.36	0.98	0.98	0.98	0.98	0.84	0.84	0.84	0.84	4.56	4.56	N/A	4.56	4.56	3.08	3.08	3.08	3.08	N/A	3.08	3.08	3.08	3.08	0.08	0.08	0.08
	043001020107	East Creek	0.48	0.19	0.48	1.17	1.17	1.17	1.17	1.17	0.90	1.17	0.02	0.25	N/A	N/A	0.65	0.65	0.98	0.98	0.98	0.98	0.84	0.84	0.84	0.84	2.78	2.78	N/A	2.78	2.78	3.08	3.08	3.08	3.08	N/A	3.08	3.08	3.08	3.08	0.08	0.08	0.08
	043001020108	Clarendon River	0.44	0.14	0.44	1.13	1.13	1.13	1.13	1.13	0.72	1.13	0.01	0.06	N/A	N/A	0.71	0.71	0.98	0.98	0.98	0.98	0.84	0.84	0.84	0.84	2.79	2.79	N/A	2.79	2.79	4.38	4.38	4.38	4.38	N/A	4.38	4.38	4.38	4.38	0.08	0.08	0.08
	043001020109	Moon Brook-Otter Creek	1.88	0.20	1.88	4.70	4.70	4.70	4.70	4.70	3.12	4.70	0.02	0.52	N/A	N/A	0.80	0.80	0.98	0.98	0.98	0.98	0.84	0.84	0.84	0.84	1.24	1.24	N/A	1.24	1.24	4.87	4.87	4.87	4.87	N/A	4.87	4.87	4.87	4.87	0.08	0.08	0.08
	043001020201	Headwaters New Haven River	0.30	0.05	0.30	0.81	0.81	0.81	0.81	0.81	0.71	0.81	0.02	0.17	N/A	N/A	0.29	0.29	0.98	0.98	0.98	0.98	0.84	0.84	0.84	0.84	1.81	1.81	N/A	1.81	1.81	1.44	1.44	1.44	1.44	N/A	1.44	1.44	1.44	1.44	0.08	0.08	0.08
	043001020202	Baldwin Creek	0.53	0.17	0.53	1.44	1.44	1.44	1.44	1.44	1.12	1.44	0.02	0.28	N/A	N/A	0.61	0.61	0.98	0.98	0.98	0.98	0.84	0.84	0.84	0.84	2.39	2.39	N/A	2.39	2.39	3.63	3.63	3.63	3.63	N/A	3.63	3.63	3.63	3.63	0.08	0.08	0.08
	043001020203	New Haven River	0.46	0.13	0.46	0.92	0.92	0.92	0.92	0.92	0.66	0.92	0.02	0.18	N/A	N/A	0.50	0.50	0.98	0.98	0.98	0.98	0.84	0.84	0.84	0.84	2.30	2.30	N/A	2.30	2.30	3.88	3.88	3.88	3.88	N/A	3.88	3.88	3.88	3.88	0.08	0.08	0.08
	043001020301	Furnace Brook	0.34	0.10	0.34	0.69	0.69	0.69	0.69	0.69	0.43	0.69	0.01	0.22	N/A	N/A	0.41	0.41	0.98	0.98	0.98	0.98	0.84	0.84	0.84	0.84	1.26	1.26	N/A	1.26	1.26	4.32	4.32	4.32	4.32	N/A	4.32	4.32	4.32	4.32	0.08	0.08	0.08
	043001020302	Bresee Mill Brook-Otter Creek	0.24	0.05	0.24	0.49	0.49	0.49	0.49	0.49	0.37	0.49	0.01	0.34	N/A	N/A	0.22	0.22	0.98	0.98	0.98	0.98	0.84	0.84	0.84	0.84	1.50	1.50	N/A	1.50	1.50	3.11	3.11	3.11	3.11	N/A	3.11	3.11	3.11	3.11	0.08	0.08	0.08
	043001020303	Neshobe River	0.31	0.32	0.31	2.24	2.24	2.24	2.24	2.24	1.38	2.24	0.03	0.32	N/A	N/A	1.46	1.46	0.98	0.98	0.98	0.98	0.84	0.84	0.84	0.84	3.96	3.96	N/A	3.96	3.96	3.08	3.08	3.08	3.08	N/A	3.08	3.08	3.08	3.08	0.08	0.08	0.08
	043001020304	Willow Brook-Otter Creek	0.30	0.09	0.30	0.61	0.61	0.61	0.61	0.61	0.50	0.61	0.02	0.44	N/A	N/A	0.38	0.38	0.98	0.98	0.98	0.98	0.84	0.84	0.84	0.84	1.50	1.50	N/A	1.50	1.50	3.08	3.08	3.08	3.08	N/A	3.08	3.08	3.08	3.08	0.08	0.08	0.08
	043001020305	Leicester River	0.66	0.23	0.66	1.37	1.37	1.37	1.37	1.37	0.84	1.37	0.01	0.25	N/A	N/A	0.83	0.83	0.98	0.98	0.98	0.98	0.84	0.84	0.84	0.84	0.91	0.91	N/A	0.91	0.91	4.64	4.64	4.64	4.64	N/A	4.64	4.64	4.64	4.64	0.08	0.08	0.08
	043001020306	Middlebury River	0.44	0.15	0.44	0.88	0.88	0.88	0.88	0.88	0.71	0.88	0.01	0.17	N/A	N/A	0.52	0.52	0.98	0.98	0.98	0.98	0.84	0.84	0.84	0.84	0.74	0.74	N/A	0.74	0.74	3.97	3.97	3.97	3.97	N/A	3.97	3.97	3.97	3.97	0.08	0.08	0.08
	043001020307	Pleasant Brook-Otter Creek	0.61	0.09	0.61	0.93	0.93	0.93	0.93	0.93	0.69	0.93	0.01	0.37	N/A	N/A	0.45	0.45	0.98	0.98	0.98	0.98	0.84	0.84	0.84	0.84	4.08	4.08	N/A	4.08	4.08	4.21	4.21	4.21	4.21	N/A	4.21	4.21	4.21	4.21	0.08	0.08	0.08
	043001020401	Upper Lemon Fair River	0.28	0.12	0.28	0.64	0.64	0.64	0.64	0.64	0.49	0.64	0.01	0.11	N/A	N/A	0.36	0.36	0.98	0.98	0.98	0.98	0.84	0.84	0.84	0.84	3.02	3.02	N/A	3.02	3.02	1.84	1.84	1.84	1.84	N/A	1.84	1.84	1.84	1.84	0.08	0.08	0.08
	043001020402	Lower Lemon Fair River	0.33	0.13	0.33	0.58	0.58	0.58	0.58	0.58	0.39	0.58	0.01	0.14	N/A	N/A	0.41	0.41	0.98	0.98	0.98	0.98	0.84	0.84	0.84	0.84	4.64	4.64	N/A	4.64	4.64	2.22	2.22	2.22	2.22	N/A	2.22	2.22	2.22	2.22	0.08	0.08	0.08
	043001020501	Dead Creek	0.21	0.09	0.21	0.45	0.45	0.45	0.45	0.45	0.29	0.45	0.02	0.08	N/A	N/A	0.33	0.33	0.98	0.98	0.98	0.98	0.84	0.84	0.84	0.84	1.33	1.33	N/A	1.33	1.33	1.17	1.17	1.17	1.17	N/A	1.17	1.17	1.17	1.17	0.08	0.08	0.08
	043001020502	Otter Creek	0.40	0.10	0.40	0.81	0.81	0.81	0.81	0.81	0.60	0.81	0.01	0.45	N/A	N/A	0.44	0.44	0.98	0.98	0.98	0.98	0.84	0.84	0.84	0.84	1.50	1.50	N/A	1.50	1.50	6.12	6.12	6.12	6.12	N/A	6.12	6.12	6.12	6.12	0.08	0.08	0.08
	043001080401	Headwaters Little Otter Creek	0.05	0.02	0.05	0.11	0.11	0.11	0.11	0.11	0.07	0.11	0.02	0.02	N/A	N/A	0.08	0.08	0.98	0.98	0.98	0.98	0.84	0.84	0.84	0.84	0.08	0.08	N/A	0.08	0.08	0.24	0.24	0.24	0.24	N/A	0.24	0.24	0.24	0.24	0.08	0.08	0.08
	043001080402	Outlet Little Otter Creek	0.08	0.03	0.08	0.18	0.18	0.18	0.18	0.18	0.13	0.18	0.00	0.03	N/A	N/A	0.12	0.12	0.98	0.98	0.98	0.98	0.84	0.84	0.84	0.84	0.27	0.27	N/A	0.27	0.27	0.39	0.39	0.39	0.39	N/A	0.39	0.39	0.39	0.39	0.08	0.08	0.08
	043001080501	Headwaters Lewis Creek	0.14	0.03	0.14	0.27	0.27	0.27	0.27	0.27	0.20	0.27	0.00	0.07	N/A	N/A	0.15	0.15	0.98	0.98	0.98	0.98	0.84	0.84	0.84	0.84	0.27	0.27	N/A	0.27	0.27	1.03	1.03	1.03	1.03	N/A	1.03	1.03	1.03	1.03	0.08	0.08	0.08
	043001080502	Outlet Lewis Creek	0.17	0.05	0.17	0.27	0.27	0.27	0.27	0.27	0.21	0.27	0.02	0.08	N/A	N/A	0.22	0.22	0.98	0.98	0.98	0.98	0.84	0.84	0.84	0.84	1.18	1.18	N/A	1.18	1.18	0.91	0.91	0.91	0.91	N/A	0.91	0.91	0.91	0.91	0.08	0.08	0.08
Southern Lake Champlain	043001010201	Headwaters Mettawee River	0.43	0.12	0.43	0.67	0.67	0.67	0.67	0.67	0.55	0.67	0.01	0.23	N/A	N/A	0.36	0.36	0.96	0.96	0.96	0.96	0.91	0.91	0.91	0.91	1.61	1.61	N/A	1.61	1.61	2.03	2.03	2.03	2.03	N/A	2.03	2.03	2.03	2.03	1.67	1.67	1.67
	043001010202	Flower Brook	0.33	0.14	0.33	2.06	2.06	2.06	2.06	2.06	1.82	2.06	0.03	0.23	N/A	N/A	1.02	1.02	0.96	0.96	0.96	0.96	0.91	0.91	0.91	0.91	1.08	1.08	N/A	1.08	1.08	2.64	2.64	2.64	2.64	N/A	2.64	2.64	2.64	2.64	1.67	1.67	1.67
	043001010203	Wells Brook-Mettawee River	0.61	0.18	0.61	1.16	1.16	1.16	1.16	1.16	0.77	1.16	0.01	0.29	N/A	N/A	0.71	0.71	0.96	0.96	0.96	0.96	0.91	0.91	0.91	0.91	0.82	0.82	N/A	0.82	0.82	3.35	3.35	3.35	3.35	N/A	3.35	3.35	3.35	3.35	1.67	1.67	1.67
	043001010204	Indian River	0.43	0.12	0.43	0.19	0.19	0.19	0.19	0.19	0.17	0.19	0.01	0.23	N/A	N/A	0.07	0.07	0.96	0.96	0.96	0.96	0.91	0.91	0.91	0.91	0.32	0.32	N/A	0.32	0.32	0.69	0.69	0.69	0.69	N/A	0.69	0.69	0.69	0.69	1.67	1.67	1.67
	043001010205	Mettawee River	0.16	0.07	0.16	0.83	0.83	0.83	0.83	0.83	0.57	0.83	0.00	0.06	N/A	N/A	0.20	0.20	0.96	0.96	0.96	0.96	0.91	0.91	0.91	0.91	1.08	1.08	N/A	1.08	1.08	0.59	0.59	0.59	0.59	N/A	0.59	0.59	0.59	0.59	1.67	1.67	1.67
	043001010301	Headwaters Poultney River	0.10	0.10	0.10	0.82	0.82	0.82	0.82	0.82	0.55	0.82	0.01	0.04	N/A	N/A	0.43	0.43	0.96	0.96	0.96	0.96	0.91	0.91	0.91	0.91	2.44	2.44	N/A	2.44	2.44	2.34	2.34	2.34	2.34	N/A	2.34	2.34	2.34	2.34	1.67	1.67	1.67
	043001010302	Finel Hollow Brook-Poultney River	0.39	0.11	0.39	0.77	0.77	0.77	0.77	0.77	0.57	0.77	0.01	0.21	N/A	N/A	0.43	0.43	0.96	0.96	0.96	0.96	0.91	0.91	0.91	0.91	0.49	0.49	N/A	0.49	0.49	2.81	2.81	2.81	2.81	N/A	2.81	2.81	2.81	2.81	1.67	1.67	1.67
	043001010303	Headwaters Castleton River	0.18	0.07	0.18	0.40	0.40	0.40	0.40	0.40	0.28	0.40	0.00	0.09	N/A	N/A	0.25	0.25	0.96	0.96	0.96	0.96	0.91	0.91	0.91	0.91	0.87	0.87	N/A	0.87	0.87	1.35	1.35	1.35	1.35	N/A	1.35	1.35	1.35	1.35	1.67	1.67	1.67
	043001010304	Castleton River	0.73	0.29	0.73	1.74	1.74	1.74	1.74	1.74	1.16	1.74	0.01	0.35	N/A	N/A	1.17	1.17	0.96	0.96	0.96	0.96	0.91	0.91	0.91	0.91	2.87	2.87	N/A	2.87	2.87	1.93	1.93	1.93	1.93	N/A	1.93	1.93	1.93	1.93	1.67	1.67	1.67
	043001010305	Mud Brook-Poultney River	0.51	0.13	0.51	0.97	0.97	0.97	0.97	0.97	0.63	0.97	0.00	0.25	N/A	N/A	0.51	0.51	0.96	0.96	0.96	0.96	0.91	0.91	0.91	0.91	1.08	1.08	N/A	1.08	1.08	3.33	3.33	3.33	3.33	N/A	3.33	3.33	3.33	3.33	1.67	1.67	1.67
	043001010306	Hubbardton River	0.48	0.16	0.48	0.99	0.99	0.99	0.99	0.99	0.67	0.99	0.01	0.29	N/A	N/A	0.58	0.58	0.96	0.96	0.96	0.96	0.91	0.91	0.91	0.91	5.70	5.70	N/A	5.70	5.70	4.66	4.66	4.66	4.66	N/A	4.66	4.66	4.66	4.66	1.67	1.67	1.67
	043001010307	Poultney River-Head of Lake Champlain	0.45	0.14	0.45	0.82	0.82	0.82	0.82	0.82	0.64	0.82	0.01	0.24	N/A	N/A	0.62	0.62	0.96	0.96	0.96	0.96	0.91	0.91	0.91	0.91	1.08	1.08	N/A	1.08	1.08	2.91	2.91	2.91	2.91	N/A	2.91	2.91	2.91	2.91	1.67	1.67	1.67
	043001080104	Charter Brook-Lake Champlain	0.43	0.12	0.43	0.83	0.83	0.83	0.83	0.83	0.57	0.83	0.01	0.23	N/A	N/A	0.44	0.44	0.96	0.96	0.96	0.96	0.91	0.91	0.91	0.91	1.08	1.08	N/A	1.08	1.08	2.60	2.60	2.60	2.60	N/A	2.60	2.60	2.60	2.60	1.67	1.67	1.67
	043001080301	East Creek	0.43	0.12	0.43	0.83	0.83	0.83	0.83	0.83	0.57	0.83	0.01	0.23	N/A	N/A	0.44	0.44	0.96	0.96	0.96	0.96	0.91	0.91	0.91	0.91	1.08	1.08	N/A	1.08	1.08	2.60	2.60	2.60	2.60	N/A	2.60	2.60	2.60	2.60	1.67	1.67	1.67
	043001080304	McKenzie Brook-Lake Champlain	0.43	0.12	0.43	0.83	0.83	0.83	0.83	0.83	0.57	0.83	0.01	0.23	N/A	N/A	0.44	0.44	0.96	0.96	0.96	0.96	0.91	0.91	0.91	0.91	1.08	1.08	N/A	1.08	1.08	2.60	2.60	2.60	2.60	N/A	2.60	2.60	2.60	2.60	1.67	1.67	1.67
	043001080602	Hoisington Brook-Lake Champlain	0.43	0.12	0.43	0.83	0.83	0.83	0.83	0.83	0.57	0.83	0.01	0.23	N/A	N/A	0.44	0.44	0.96	0.96	0.96	0.96	0.91	0.91	0.91	0.91	1.08	1.08	N/A	1.08	1.08	2.60	2.60	2.60	2.60	N/A	2.60	2.60	2.60	2.60	1.67	1.67	1.67
Winooski	043001030101	Headwaters Stevens Branch	0.81	0.35	0.81	2.23	2.23	2.23	2.23	2.23	1.53	2.23	0.01	0.07	N/A	N/A	1.04	1.04	1.57	1.57	1.57	1.57	2.39	2.39	2.39	2.39	1.06	1.06	N/A	1.06	1.06	4.40	4.40	4.40	4.40	N/A	4.40	4.40	4.40	4.40	0.90	0.90	0.90
	043001030102	Jail Branch	0.32	0.16	0.32	1.15	1.15	1.15	1.15	1.15	0.88	1.15	0.04	0.20	N/A	N/A	0.50	0.50	1.57	1.57	1.57	1.57	2.39	2.39	2.39	2.39	0.53	0.53	N/A	0.53	0.53	3.16	3.16	3.16	3.16	N/A	3.16	3.16	3.16	3.16	0.90	0.90	0.90
	043001030103	Stevens Branch	0.20	0.14	0.20	1.33	1.33	1.33	1.33	1.33	0.97	1.33	0.01	0.07	N/A	N/A	0.52	0.52	1.57	1.57	1.57	1.57	2.39	2.39	2.39	2.39	0.50	0.50	N/A	0.50	0.50	2.21	2.21	2.21	2.21	N/A	2.21	2.21	2.21	2.21	0.90	0.90	0.90
	043001030201	Headwaters Winooski River	1.61	0.41	1.61	2.04	2.04	2.04	2.04	2.04	1.58	2.04	0.02	0.28	N/A	N/A	1.33	1.33	1.57	1.57	1.57	1.57	2.39	2.39	2.39	2.39	1.40	1.40	N/A	1.40	1.40	6.11	6.11	6.11	6.11	N/A	6.11	6.11	6.11	6.11	0.90	0.90	0.90
	043001030202	Nasmith Brook-Winooski River	0.85	0.26	0.85	1.36	1.36	1.36	1.36	1.36	1.11	1.36	0.04	0.32	N/A	N/A	0.76	0.76	1.57	1.57	1.57	1.57	2.39	2.39	2.39	2.39	2.14	2.14	N/A	2.14	2.14	5.38	5.38	5.38	5.38	N/A	5.38	5.38	5.38	5.38	0.90	0.90	0.90
	043001030203	Kingsbury Branch	0.90	0.38	0.90	2.30	2.30	2.30	2.30	2.30	1.57	2.30	0.02	0.64	N/A	N/A	1.50	1.50	1.57	1.57	1.57	1.57	2.39	2.39	2.39	2.39	1.55	1.55	N/A	1.55	1.55	3.19	3.19	3.19	3.19	N/A	3.19	3.19	3.19	3.19	0.90	0.90	0.90
	043001030204	Sodom Pond Brook-Winooski River	1.49	0.25	1.49	1.59	1.59	1.59	1.59	1.59	1.25	1.59	0.01	0.56	N/A	N/A	0.75	0.75	1.57	1.57	1.57	1.57	2.39	2.39	2.39	2.39	2.56	2.56	N/A	2.56	2.56	1.30	1.30	1.30	1.30	N/A	1.30	1.30	1.30	1.30	0.90	0.90	0.90
	043001030301	Headwaters North Branch Winooski River	0.28	0.10	0.28	2.84	2.84	2.84	2.84	2.84	2.33	2.84	0.04	0.28	N/A	N/A	1.70	1.70	1.57	1.57	1.57	1.57	2.39	2.39	2.39	2.39	3.15	3.15	N/A	3.15	3.15	6.11	6.11	6.11	6.11	N/A	6.11	6.11	6.11	6.11	0.90	0.90	0.90
	043001030302	North Branch Winooski River	0.51	0.28	0.51	2.41	2.41	2.41	2.41	2.41	2.05	2.41	0.04	0.19	N/A	N/A	1.00	1.00	1.57	1.57	1.57	1.57	2.39	2.39	2.39	2.39	5.34	5.34	N/A	5.34	5.34	6.11	6.11	6.11	6.11	N/A	6.11	6.11	6.11	6.11	0.90	0.90	0.90
	043001030401	Headwaters Dog River	0.14	0.10	0.14	0.59	0.59	0.59	0.59	0.59	0.44	0.59	0.04	0.05	N/A	N/A	0.39	0.39	1.57	1.57	1.57	1.57	2.39	2.39	2.39	2.39	0.55	0.55	N/A	0.55	0.55	2.05	2.05	2.05	2.05	N/A	2.05	2.05	2.05	2.05	0.90	0.90	0.90
	043001030402	Dog River	0.58	0.43	0.58	2.46	2.46	2.46	2.46	2.46	1.76	2.46	0.03	0.22	N/A	N/A	1.44	1.44	1.57	1.57	1.57	1.57	2.39	2.39	2.39	2.39	5.10	5.10	N/A	5.10	5.10	6.11	6.11	6.11	6.11	N/A	6.11	6.11	6.11	6.11	0.90	0.90	0.90
	043001030403	Great Brook-Winooski River	0.43	0.14	0.43	1.07	1.07	1.07	1.07	1.07	0.80	1.07	0.01	0.57	N/A	N/A	0.54	0.54	1.57	1.57	1.57	1.57	2.39	2.39	2.39	2.39	5.58	5.58	N/A	5.58	5.58	2.47	2.47	2.47	2.47	N/A	2.47	2.47	2.47	2.47	0.90	0.90	0.90
	043001030501	Headwaters Mad River	0.51	0.25	0.51	1.34	1.34	1.34	1.34	1.34	1.10	1.34	0.01	0.28	N/A	N/A	0.68	0.68	1.57	1.57	1.57	1.57	2.39	2.39	2.39	2.39	1.20	1.20	N/A	1.20	1.20	5.51	5.51	5.51	5.51	N/A	5.51	5.51	5.51	5.51	0.90	0.90	0.90
	043001030502	Mill Brook-Mad River	0.51	0.25	0.51	1.28	1.28	1.28	1.28	1.28	1.07	1.28	0.01	0.28	N/A	N/A	0.62	0.62	1.57	1.57	1.57	1.57	2.39	2.39	2.39	2.39	5.03	5.03	N/A	5.03	5.03	2.74	2.74	2.74	2.74	N/A	2.74	2.74	2.74	2.74	0.90	0.90	0.90
	043001030503	Shepard Brook	0.51	0.37	0.51	3.79	3.79	3.79	3.79	3.79	2.94	3.79	0.04	0.28	N/A	N/A	2.18	2.18	1.57	1.57	1.57	1.57	2.39	2.39	2.39	2.39	1.26	1.26	N/A	1.26	1.26	6.11	6.11	6.11	6.11	N/A	6.11	6.11	6.11	6.11	0.90	0.90	0.90
	043001030504	Mad River	0.98	0.32	0.98	2.04	2.04	2.04	2.04	2.04	1.65	2.04	0.02	0.19	N/A	N/A	1.06	1.06	1.57	1.57	1.57	1.57	2.39	2.39	2.39	2.39	0.81	0.81	N/A	0.81	0.81	6.11	6.11	6.11	6.11	N/A	6.11	6.11	6.11	6.11	0.90	0.90	0.90
	043001030601	Graves Brook-Winooski River	0.34	0.13	0.34	0.90	0.90	0.90	0.90	0.90	0.63	0.90	0.02	0.27	N/A	N/A	0.41	0.41	1.57	1.57	1.57	1.57	2.39	2.39	2.39	2.39	0.49	0.49	N/A	0.49	0.49	6.11	6.11	6.11	6.11	N/A	6.11	6.11	6.11	6.11	0.90	0.90	0.90
	043001030602	Headwaters Little River	0.25	0.13	0.25	1.28	1.28	1.28	1.28	1.28	1.06	1.28	0.02	0.09	N/A	N/A	0.58	0.58	1.57	1.57	1.57	1.57	2.39	2.39	2.39	2.39	1.09	1.09	N/A	1.09	1.09	4.91	4.91	4.91	4.91	N/A	4.91	4.91	4.91	4.91	0.90	0.90	0.90
	043001030603	Little River	0.77	0.21	0.77	2.07	2.07	2.07	2.07	2.07	1.64	2.07	0.03	0.61	N/A	N/A	0.79	0.79	1.57	1.57	1.57	1.57	2.39	2.39	2.39	2.39	1.20	1.20	N/A	1.20	1.20	6.29	6.29	6.29	6.29	N/A	6.29	6.29	6.29	6.29	0.90	0.90	0.90
	043001030604	Joiner Brook-Winooski River	0.64	0.19	0.64	1.32	1.32	1.32	1.32	1.32	0.99	1.32	0.07	1.39	N/A	N/A	0.78	0.78	1.57	1.57	1.57	1.57	2.39	2.39	2.39	2.39	2.71	2.71	N/A	2.71	2.71	6.11	6.11	6.11	6.11	N/A	6.11	6.11	6.11	6.11	0.90	0.90	0.90
	043001030701	Huntington River	0.35	0.24	0.35	1.84	1.84	1.84	1.84	1.84	1.39	1.84	0.05	0.70	N/A	N/A	0.84	0.84	1.57	1.57	1.57	1.57	2.39	2.39	2.39	2.39	4.01	4.01	N/A	4.01	4.01	6.11	6.11	6.11	6.11	N/A	6.11	6.11	6.11	6.11	0.90	0.90	0.90
	043001030702	Snipe Island Brook-Winooski River	0.51	0.25	0.51	0.94	0.94	0.94	0.94	0.94	0.81	0.94	0.04	0.28	N/A	N/A	0.51	0.51	1.57	1.57	1.57	1.57	2.39	2.39	2.39	2.39	3.33	3.33	N/A	3.33	3.33	5.72	5.72	5.72	5.72	N/A	5.72	5.72	5.72	5.72	0.90	0.90	0.90
	043001030703	Muddy Brook	1.37	0.45	1.37	2.47	2.47	2.47	2.47	2.47	1.83	2.47	0.01	0.52	N/A	N/A	1.75	1.75	1.57	1.57	1.57	1.57	2.39	2.39	2.39	2.39	5.97	5.97	N/A	5.97	5.97	4.34	4.34	4.34	4.34	N/A	4.34	4.34	4.34	4.34	0.90	0.90	0.90
	043001030704	Winooski River	2.27	0.32	2.27	1.54	1.54	1.54	1.54	1.54	1.14	1.54	0.04	1.09	N/A	N/A	1.12	1.12	1.57	1.57	1.57	1.57	2.39	2.39	2.39	2.39	2.34	2.34	N/A	2.34	2.34	6.77	6.77	6.77	6.77	N/A	6.77	6.77	6.77	6.77	0.90	0.90	0.90

APPENDIX O

ESTIMATING THE COST-EFFECTIVENESS OF P REMOVAL FOR NATURAL RESOURCE PROJECTS

Floodplain Restoration Costs
9/21/2021

		Project Management, Administration		Assessment, Design, Permitting		Construction + Bid, Oversight		Operation, Maintenance, Monitoring				Restoration Characteristics						
Floodplain Restoration Project	**Location**	**Year**	**Cost**	**Year**	**Cost**	**Year**	**Cost**	**Year**	**Cost**	**Total Project Cost**	**Total Project Cost (no O&M)**	**Project Type***	**Restored Floodplain Area (Acres)**	**Total Cost per Area (no O&M) ($US/acre)**	**EX Connectivity**	**Change in Estimated TP Retention (lb/ac/yr)**	**Cost per Pound TP (no O&M) ($US/lb TP/yr)**	**Notes**
Lamoille River and Black Creek Floodplain Restoration Project	Johnson, Cambridge, Bakersfield, Fairfield, Fletcher	2006-2008	$ 50,000	2006-2007	$ 50,000	2007-2008	$ 500,000	N/A	$ -	$ 600,000	$ 600,000	Remove Berm	200	$ 3,000	low	20	$ 150	1.3 tons of P associated with sediment on 80 acres of floodplains after flood in a given year (32 lb/ac/yr).
Roaring Branch Floodplain Restoration	Bennington, VT	2008-2012	$ 50,000	2008-2010	$ 60,000	2010-2012	$ 540,000	2010	$ 3,000	$ 653,000	$ 650,000	Lower Floodplain (with Berm Removal)	13	$ 50,000	low	20	$ 2,500	Final part of floodplain restoration completed during Irene recovery.
Dog River Floodplain Restoration	Northfield, VT	2016-2017	$ 50,000	2016	$ 61,025	2017	$ 435,332	N/A	$ -	$ 546,357	$ 546,357	Lower Floodplain (with Berm Removal)	3.1	$ 176,244	low	20	$ 8,812	Included Town park creation. Lots of infrastructure around.
West Branch Flooddplain Restoration	Stowe, VT	2014-2016	$ 25,000	2014-2015	$ 57,500	2015 (PH I) 2016 (PH II)	$ 493,000	N/A	$ -	$ 575,500	$ 575,500	Flood Benches (3)	2.8	$ 205,536	low-moderate	15	$ 13,702	Incised channel setting with linear trail, pedestrian bridges, agricultural land uses in area. Estimated half of all fees associated with flood bench work.
Cambridge Greenway Bridge Floodplain Restoration	Jeffersonville, VT	2015	$ 5,000	2015	$ 5,000	2015	$ 45,000	N/A	$ -	$ 55,000	$ 55,000	Flood Bench	0.3	$ 220,000	low	20	$ 11,000	Associated with bridge project. Estimated flood bench restoration with portion of design and construction fee.
Beecher Hill Brook	Hinesburg, VT	2017-2019	$ 20,000	2017-2018	$ 39,943	2019	$ 361,892	2020	$ 6,000	$ 427,835	$ 421,835	Raise Channel (and Lower Floodplain)	1.3	$ 324,488	low	20	$ 16,224	Linked to garage construction project and stormwater treatment. Act250 added project cost
Whetstone-Melrose	Brattleboro, VT	2017-2019	$ 60,000	2017-2019	$ 105,500	2021	$ 2,340,000	N/A	$ -	$ 2,505,500	$ 2,505,500	Lower Floodplain	4.4	$ 569,432	low-moderate	15	$ 37,962	Includes flood bypass culvert under road, road work, and building demolition.
Whetstone-250 Birge	Brattleboro, VT	2016-2022	$ 50,000	2016-2021	$ 85,200	2022	$ 740,000	N/A	$ -	$ 875,200	$ 875,200	Lower Floodplain	6.2	$ 141,161	low	20	$ 7,058	Urban soils so includes a little extra handling. Includes small wetland restoraton component.
Green River - Neuhauser	Guilford, VT	2019-2020	$ 8,000	2019	$ 12,000	2020	$ 30,000			$ 50,000	$ 50,000	Remove Berm	1.92	$ 26,042	low-moderate	15	$ 1,736	Moderately sized floodplain behind berm
Green River - Rogers	Halifax, VT	2019-2020	$ 8,000	2019	$ 5,000	2020	$ 8,500			$ 21,500	$ 21,500	Remove Berm	0.61	$ 35,246	moderate	10	$ 3,525	Small floodplain
Brewster River - Smugglers Notch Restort	Cambridge, VT	2018-2019	$ 5,000	2018	$ 8,000	2019	$ 8,000			$ 21,000	$ 21,000	Remove Berm	0.33	$ 63,636	low	15	$ 4,242	Small floodplain
Cold River - Ruanes	Clarendon, VT	2015-2021	$ 15,000	2015	$ 10,000	2021	$ 100,000			$ 125,000	$ 125,000	Remove Berm	10.50	$ 11,905	low	20	$ 595	Large floodplain behind berm
Potash Brook - CWD Site	South Burlington, VT	2020-2021	$ 5,000	2020	$ 15,000	2021	$ 90,000			$ 110,000	$ 110,000	Lower Floodplain	0.50	$ 220,000	low	20	$ 11,000	Urban setting
Crosby Brook - Bickfords	Brattleboro, VT	2012-2013	$ 1,800	2012	$ 8,000	2013	$ 12,000			$ 21,800	$ 21,800	Lower Floodplain	0.13	$ 167,692	moderate	10	$ 16,769	Urban setting

Gray text indicates cost estimate.

	PM Cost	ADP Cost	Construction Cost	O&M Cost	Total Project Cost	Total Project Cost (no O&M)	Restored Floodplain Area (Acres)	Total Cost per Area (no O&M)	Change in Estimated TP Retention	Cost per Pound TP (no O&M)	
Minimum	*$ 1,800*	*$ 5,000*	*$ 8,000*	*$ -*	***$ 21,000***	***$ 21,000***	**0.13**	**$ 3,000**	**10**	**$ 150**	*Minimum*
Maximum	*$ 60,000*	*$ 105,500*	*$ 2,340,000*	*$ 6,000*	***$ 2,505,500***	***$ 2,505,500***	**200.00**	**$ 569,432**	**20**	**$ 37,962**	*Maximum*
Average	*$ 25,200*	*$ 37,298*	*$ 407,409*	*$ 1,125*	***$ 470,549***	***$ 469,907***	**17.50**	**$ 158,170**	**17**	**$ 9,663**	*Average*
Standard deviation	*$ 21,778*	*$ 33,150*	*$ 609,280*	*$ 2,232*	***$ 655,008***	***$ 654,976***	**52.68**	**$ 153,440**	**4**	**$ 9,906**	*Standard deviation*

Dam Removal Costs
9/21/2021

		Project Management, Administration		Assessment, Design, Permitting		Construction + Bid, Oversight		Operation, Maintenance				Restoration Characteristics								
Dam Removal Project	Location	Year	Cost	Year	Cost	Year	Cost	Year	Cost	Total Project Cost ($US)	Total Project Cost (no O&M)	Dam Use	Dam Height (feet)	Impoundment Area / Restored Floodplain (Acres)	FFI Barrier Type*	Total Cost per Restored Floodplain Area (no O&M) ($US/acre)	EX Connectivity	Change in Estimated TP Retention (lb/ac/yr)	Cost per Pound TP (no O&M) ($US/lb TP/yr)	Notes
Dufresne Pond Dam	Manchester, VT	2010-2011	$ 12,000	2010-2011	$ 46,000	2011	$ 166,550	N/A	$ -	$ 224,550	$ 224,550	Recreation, Obsolete	12	11.0	Medium ROR dam	$ 20,414	Low	15	$ 1,361	Overtopping and seepage. Needed to replace shallow well. State structure.
Kendrick Pond	Pittsford, VT			2011-2012	$ 35,000	2014	$ 139,796	N/A	$ -	$ 174,796	$ 174,796	Ice, Obsolete	13	1.2	Medium breached dam	$ 145,663	Low	15	$ 9,711	Small job. Sole source bid. No maintenance as channel naturally functioning.
East Burke Dam	East Burke, VT	2016-2019	$ 90,000	2016-2017	$ 77,000	2017	$ 270,000	2019	$ 13,000	$ 450,000	$ 437,000	Saw Mill, Obsolete	13	2.0	Medium breached dam	$ 218,500	Low-Moderate	15	$ 14,567	Long first phase of work not in budget? Erosion repair to tune up bank year 1. admin $35k salary, $15k travel, $40k indirect admin. Pulled 5K from oversight into monitoring.
Rome Dam	Jay, NY			2016-2017	$ 217,000	2018	$ 2,258,000	N/A	$ -	$ 2,475,000	$ 2,475,000	Pulp and Paper Mills, Obsolete	38	5.0	Medium ROR dam	$ 495,000	Low	15	$ 33,000	Large, high hazard dam and NYS GOSR requirements drove cost of project up.
Mill Pond Dam	Colchester, VT	2017-2019	$ 12,000	2017-2019	$ 115,000	2019	$ 498,250	2020	$ 5,079	$ 630,329	$ 625,250	Saw Mill, Obsolete	12	9.0	Medium breached dam	$ 69,472	Moderate-High	5	$ 13,894	Construction felt underfunded. Scaled back sediment removal so more post-construction setting, epsecially in flat, fine-grained system. Needed one repair to stabilize gullies. Site now healing and moving towards EQU.
Camp Wihakowi Dam	Northfield, VT	2017-2020	$ 12,972	2018-2020	$ 60,880	2020	$ 415,631	N/A	$ -	$ 489,483	$ 489,483	Recreation, Obsolete	13	3.3	Medium breached dam	$ 148,328	Low	15	$ 9,889	Act250 added additional costs
Dunklee Pond Dam	Rutland, VT			2019-2020	$ 75,000	2021	$ 340,000	N/A	$ -	$ 415,000	$ 415,000	Ice, Obsolete	10	1.0	Medium breached dam	$ 415,000	Low	15	$ 27,667	In progress. Construction planned for 2021. includes fish passage weir and parklet.
Montague Dam	Post Mills, VT			2020-	$ 55,000	2021	$ 200,000	N/A	$ -	$ 255,000	$ 255,000	Saw Mill, Obsolete	13	0.5	Medium breached dam	$ 510,000	Low-Moderate	15	$ 34,000	53 sq mi
Youngs Brook Dam	West Rutland, VT			2020-	$ 49,400	2022	$ 530,000	N/A	$ -	$ 579,400	$ 579,400	Water Supply, Obsolete	46	2.0	Medium breached dam	$ 289,700	Moderate	10	$ 28,970	
Springfield Reservoir Dam	Weathershfield, VT			2020-2021	$ 55,000	2023	$ 600,000	N/A	$ -	$ 655,000	$ 655,000	Water Supply, Obsolete	49	11.0	Medium ROR dam	$ 59,545	Moderate	10	$ 5,955	Old water supply. Seems like limited storage so list as ROR?
Brownsville/WWVFD Dam	West Windsor, VT	2016-2017	$ 5,000	2016-2017	$ 8,000	2018	$ 25,000	N/A	$ -	$ 38,000	$ 38,000	Snowmaking water withdrawal	6	0.2	Small Intact ROR Dam	$ 236,469	Moderate	10	$ 23,647	35 sq mi watershed
Kidder Hill Dam	Grafton, VT	2018	$ 5,000	2018	$ 9,000	2019	$ 20,000	N/A	$ -	$ 34,000	$ 34,000	Saw Mill, Obsolete	5	0.1	Small Intact ROR Dam	$ 246,840	Moderate	10	$ 24,684	20 sq mi watershed
Windham/Montagna	Windham, VT	2020-2021	$ 5,000	2020-2021	$ 25,000	2019	$ 80,000	N/A	$ -	$ 110,000	$ 110,000	On-stream Ponds	7	0.6	Small Intact ROR Dam	$ 198,394	Low	15	$ 13,226	1 sq mi watershed

Gray text indicates cost estimate as project in progress.

Minimum	*$ 5,000*	*Minimum*	*$ 8,000*	*Minimum*	*$ 20,000*	*Minimum*	*$ -*	***$ 34,000***	***$ 34,000***	*Minimum*	5	0.1	*Minimum*	***$ 20,414***		**5**	***$ 1,361***	*Minimum*
Maximum	*$ 90,000*	*Maximum*	*$ 217,000*	*Maximum*	*$ 2,258,000*	*Maximum*	*$ 13,000*	***$ 2,475,000***	***$ 2,475,000***	*Maximum*	49	11.0	*Maximum*	***$ 510,000***		**15**	***$ 34,000***	*Maximum*
Average	*$ 20,282*	*Average*	*$ 63,637*	*Average*	*$ 426,402*	*Average*	*$ 1,391*	***$ 502,351***	***$ 500,960***	*Average*	18	3.6	*Average*	***$ 234,871***		**13**	***$ 18,505***	*Average*
Standard deviation	*$ 30,962*	*Standard deviation*	*$ 54,414*	*Standard deviation*	*$ 583,097*	*Standard deviation*	*$ 3,760*	***$ 631,272***	***$ 631,288***	*Standard deviation*	15	4.1	*Standard deviation*	***$ 158,139***		**3**	***$ 10,708***	*Standard deviation*

Corridor Easement Costs
9/21/2021
****See recent ANR database for cost per acre of corridor conserved via easement.**

Project	Total Project Cost (no O&M)	Acres Conserved	Total Cost per Conserved Corridor/Floodplain Area (no O&M) ($US/acre)	Estimated Channel Stability Credit (lb/ac/yr)	Cost per Pound TP (no O&M) ($US/lb TP/yr)	Notes
Pekin Brook River Corridor Easement (Armstrong Farm)	$23,800.00	42.0	$ 567	0.70	$809.52	
River Corridor Easements- 2017- Vermont Land Trust	$360,048.00	270.0	$ 1,334	0.70	$1,905.02	
Merck Parcel River Corridor Easement, Nulhegan River	$103,472.00	73.0	$ 1,417	0.70	$2,024.89	
Rock River Corridor Easement- Choiniere Property	$91,015.62	51.0	$ 1,785	0.70	$2,549.46	
Thatcher Brook River Corridor Easement (Roscioli Property)	$26,000.00	12.3	$ 2,114	0.70	$3,019.74	
Barup Farm River Corridor Easement- North Branch Lamoille River	$46,494.00	21.0	$ 2,214	0.70	$3,162.86	
Jeffersonville Easement Acquisition	$4,677.00	2.0	$ 2,339	0.70	$3,340.71	
Nulhegan River Confluence Easements	$19,000.00	7.4	$ 2,568	0.70	$3,667.95	
Stickney River Corridor Easement	$35,796.00	13.6	$ 2,632	0.70	$3,760.08	
River Corridor Easement - 2017 - Lawton	$44,646.00	15.4	$ 2,903	0.70	$4,146.94	
River Corridor Easement - 2017 - Stearns, Wolcott	$31,183.00	10.4	$ 2,998	0.70	$4,283.38	
Chapman Farm River Corridor Easement	$39,186.00	12.8	$ 3,061	0.70	$4,373.44	
Selawsky River Corridor Easement: Wild Branch - Phase 2	$53,080.00	17.0	$ 3,122	0.70	$4,460.50	
Kaiser Farm River Corridor Easement	$42,098.00	12.4	$ 3,395	0.70	$4,850.00	
Second Branch White River Corridor Easement (Wortman Farm)	$65,925.44	18.7	$ 3,525	0.70	$5,036.32	
2020 VLT River Corridor Easement Development & Implementation, Round 2	$198,545.00	56.0	$ 3,545	0.70	$5,064.92	
River Corridor Easement Block Grant 2019 - Nuzzo Lamoille River	$70,945.00	20.0	$ 3,547	0.70	$5,067.50	
Moulton River Corridor Easement	$136,205.36	37.8	$ 3,603	0.70	$5,147.59	
River Corridor Easement Grant - Lewis Creek - Briggs	$137,377.00	37.0	$ 3,713	0.70	$5,304.13	
River Corridor Easement - 2017 - Stearns, Morrisville	$29,757.00	7.9	$ 3,767	0.70	$5,381.01	
River Corridor Easement Grant - Lewis Creek - Clifford	$117,832.00	31.0	$ 3,801	0.70	$5,430.05	
LaPlatte River Corridor Easement (O'Neil Farm)	$173,266.00	44.0	$ 3,938	0.70	$5,625.52	
Clough Farm Corridor Easement	$349,796.00	87.3	$ 4,007	0.70	$5,724.04	
Hurteau River Corridor Easement, Lamoille River	$96,440.00	23.7	$ 4,069	0.70	$5,813.14	
Rogers Farm River Corridor Easement	$170,618.00	38.5	$ 4,432	0.70	$6,330.91	
Black River Corridor Easements	$131,950.00	28.6	$ 4,610	0.70	$6,586.30	
Saxtons River Corridor Easement (Kissel Property)	$42,000.00	9.0	$ 4,667	0.70	$6,666.67	
River Corridor Easement - 2017 - Karlan/Mason	$21,680.00	4.5	$ 4,818	0.70	$6,882.54	
Middle White River Corridor Easement -Freund/Finn Property	$140,782.00	26.8	$ 5,253	0.70	$7,504.37	
Ompompanoosuc River Corridor Easements - Dresser Farm and Odd Dog Farm	$169,194.00	31.6	$ 5,354	0.70	$7,648.91	
Pingree Flats Riparian Corridor Easement	$105,426.00	18.5	$ 5,699	0.70	$8,141.00	
Wild Branch Lamoille River Corridor Easement -McCrumb Property	$71,766.00	12.3	$ 5,835	0.70	$8,335.19	
River Corridor Easement - 2017 - Bettis	$32,195.00	5.5	$ 5,854	0.70	$8,362.34	
Wild Branch River Corridor Easements	$136,539.00	22.5	$ 6,068	0.70	$8,669.14	
Rankin Farm River Corridor Easement	$79,026.00	12.3	$ 6,425	0.70	$9,178.40	
Middle White River Corridor Easement Restoration (Hull Property)	$71,342.00	9.0	$ 7,927	0.70	$11,324.13	
Upper White River Corridor Easement and Buffer Restoration/Planting (Millard Property)	$113,408.00	14.2	$ 7,986	0.70	$11,409.26	
Upper White River Corridor Restoration Project	$108,226.00	13.5	$ 8,017	0.70	$11,452.49	
Jeffersonville Riparian Corridor Easement	$39,286.00	4.2	$ 9,354	0.70	$13,362.59	

ALL PROJECTS

Minimum	***$ 4,677***	*Minimum*	***$ 567***		***$ 810***	*Minimum*
Maximum	***$ 360,048***	*Maximum*	***$ 9,354***		***$ 13,363***	*Maximum*
Average	***$ 95,642***	*Average*	***$ 4,161***		***$ 5,944***	*Average*
Standard deviation	***$ 79,358***	*Standard deviation*	***$ 1,981***		***$ 2,830***	*Standard deviation*

Buffer Costs
9/21/2021

Project	Total Project Cost (no O&M)	Acres Planted	Total Cost per Planted Buffer (no O&M) ($US/acre)	Estimated Channel Stability Credit (lb/ac/yr)	Cost per Pound TP (no O&M) ($US/lb TP/yr)	Notes
Riparian Buffer Stewardship - PMNRCD - Pawlet	$1,795.00	2.70	$ 665	1.42	$468.64	
Irons Property Buffer Planting on the Black River - Albany	$4,297.87	3.27	$ 1,314	1.42	$926.49	
Missisquoi Riparian Buffer Planting - Troy	$2,393.00	1.80	$ 1,329	1.42	$937.14	
Riparian Buffer Stewardship - PMNRCD - West Haven	$1,795.00	1.10	$ 1,632	1.42	$1,150.29	
VT Fish and Wildlife Buffer Planting on the Barton River - Coventry	$2,252.00	1.38	$ 1,632	1.42	$1,150.33	
Missisquoi Riparian Buffer Planting - North Troy 2	$2,393.00	1.20	$ 1,994	1.42	$1,405.71	
Clean Water Planning and Implementation Work Crew (VYCC) - River Planting	$7,284.58	3.10	$ 2,350	1.42	$1,656.45	
The Upper La Platte River Natural Area Floodplain & River Restoration Project	$15,750.00	5.60	$ 2,813	1.42	$1,982.56	
Chop Property Buffer Planting on Memphremagog Direct Tributary - Newport	$4,042.00	1.38	$ 2,929	1.42	$2,064.68	
Mongeon Property Black River Buffer Planting - Albany	$1,231.00	0.42	$ 2,931	1.42	$2,066.06	
Riparian Buffer Stewardship - PMNRCD - West Pawlet	$1,795.00	0.60	$ 2,992	1.42	$2,108.86	
Winooski Trees for Streams 2016 - Joiner Brook R10.S3.02, Bolton	$1,072.50	0.30	$ 3,575	1.42	$2,520.06	
Winooski Trees for Streams 2016 - Lamoille River R01, Milton - Buffer Planting	$1,430.00	0.40	$ 3,575	1.42	$2,520.06	
Winooski Trees for Streams 2016 - Huntington River M09, Huntington - Buffer Planting	$1,787.50	0.50	$ 3,575	1.42	$2,520.06	
Winooski Trees for Streams 2016 - McCabe Brook T1.05, Shelburne - Buffer Planting	$893.75	0.25	$ 3,575	1.42	$2,520.06	
Winooski Trees for Streams 2016 - Lee River T4.03S2.01, Jericho - Buffer Planting	$893.75	0.25	$ 3,575	1.42	$2,520.06	
Winooski Trees for Streams 2016 - Indian Brook M11, Essex Junction - Buffer Planting	$8,222.50	2.30	$ 3,575	1.42	$2,520.06	
Missisquoi Watershed Trees for Streams - North Troy Village	$14,062.50	3.75	$ 3,750	1.42	$2,643.42	
Missisquoi Watershed Trees for Streams - Lamonda-Bakersfield	$7,500.00	2.00	$ 3,750	1.42	$2,643.42	
Missisquoi Watershed Trees for Streams - Moulton	$5,625.00	1.50	$ 3,750	1.42	$2,643.42	
Missisquoi Watershed Trees for Streams - Moulton Section 2	$5,625.00	1.50	$ 3,750	1.42	$2,643.42	
Missisquoi Watershed Trees for Streams - Randal	$5,625.00	1.50	$ 3,750	1.42	$2,643.42	
Missisquoi Watershed Trees for Streams - Fleischer	$1,875.00	0.50	$ 3,750	1.42	$2,643.42	
Missisquoi Watershed Trees for Streams - Branon	$1,875.00	0.50	$ 3,750	1.42	$2,643.42	
Missisquoi Watershed Trees for Streams - Montgomery	$1,875.00	0.50	$ 3,750	1.42	$2,643.42	
Missisquoi Watershed Trees for Streams - Menard	$937.50	0.25	$ 3,750	1.42	$2,643.42	
Winooski Watershed Targeted Riparian Corridor Restoration - Marshfield	$5,855.00	1.50	$ 3,903	1.42	$2,751.50	
Winooski Trees for Streams - 2015, M08, Charlotte	$6,660.00	1.48	$ 4,500	1.42	$3,172.10	
Winooski Trees for Streams - 2015, T02, Northfield	$6,750.00	1.50	$ 4,500	1.42	$3,172.10	
Winooski Trees for Streams - 2015, R14, Middlesex	$4,500.00	1.00	$ 4,500	1.42	$3,172.10	
Winooski Trees for Streams - 2015- Dillenbeck Property, Charlotte	$1,125.00	0.25	$ 4,500	1.42	$3,172.10	
Winooski Trees for Streams - 2015, Unnamed Tributary to Lewis Creek	$4,590.00	1.02	$ 4,500	1.42	$3,172.10	
Winooski River Trees for Streams Riparian Buffer Restoration/Planting - Browns River - Underhill	$1,353.75	0.30	$ 4,512	1.42	$3,180.91	
Winooski River Trees for Streams Riparian Buffer Restoration/Planting - Huntington River- Huntington	$902.50	0.20	$ 4,512	1.42	$3,180.91	
Winooski River Trees for Streams Riparian Buffer Restoration/Planting - Lewis Creek - Charlotte	$9,025.00	2.00	$ 4,513	1.42	$3,180.91	
Winooski River Trees for Streams Riparian Buffer Restoration/Planting - Winooski River - Cabot	$4,512.50	1.00	$ 4,513	1.42	$3,180.91	
Winooski River Trees for Streams Riparian Buffer Restoration/Planting - Browns River - Jericho	$2,256.25	0.50	$ 4,513	1.42	$3,180.91	
Whitney Brook and Black River Riparian Buffer Restoration	$25,448.00	5.38	$ 4,730	1.42	$3,334.31	
Missisquoi Riparian Buffer Planting - North Troy 1	$2,393.00	0.50	$ 4,786	1.42	$3,373.71	
Statewide Trees for Streams/Riparian Buffer Restoration, 2016 - McCrumb	$4,353.00	0.85	$ 5,121	1.42	$3,609.98	
Statewide Trees for Streams/Riparian Buffer Restoration, 2016 - Hurteau	$21,765.00	4.25	$ 5,121	1.42	$3,609.98	
Statewide Trees for Streams/Riparian Buffer Restoration, 2016 - Markie	$20,024.00	3.91	$ 5,121	1.42	$3,610.01	
Statewide Trees for Streams/Riparian Buffer Restoration, 2016 - Roleau	$20,485.00	4.00	$ 5,121	1.42	$3,610.03	
Statewide Trees for Streams/Riparian Buffer Restoration, 2016 - Serrell	$28,167.00	5.50	$ 5,121	1.42	$3,610.04	
Statewide Trees for Streams/Riparian Buffer Restoration, 2016 - Balzano West	$7,170.00	1.40	$ 5,121	1.42	$3,610.15	
Statewide Trees for Streams/Riparian Buffer Restoration, 2016 - Balzano East	$7,170.00	1.40	$ 5,121	1.42	$3,610.15	
Statewide Trees for Streams/Riparian Buffer Restoration, 2016	$64,116.00	12.50	$ 5,129	1.42	$3,615.69	
Green River Corridor Restoration - Implementation	$2,165.00	0.40	$ 5,412	1.42	$3,815.33	
Lewis Brook Riparian Buffer Restoration at Saltis Farm- Poultney VT	$27,778.00	4.60	$ 6,039	1.42	$4,256.75	
Norwich Dam Removal Planting - Charles Brown Brook - Norwich	$2,212.42	0.35	$ 6,321	1.42	$4,455.89	
Work Crew Partnership 2018- VYCC- Buffer Planting	$63,157.86	9.65	$ 6,545	1.42	$4,613.55	
Statewide Trees for Streams, 2015- Lamoille River - Morrisville	$804.00	0.12	$ 6,700	1.42	$4,722.91	
Statewide Trees for Streams, 2015 - Ottauquechee - Woodstock	$5,362.00	0.80	$ 6,702	1.42	$4,724.67	
Statewide Trees for Streams, 2015- Black River - Craftsbury	$2,413.00	0.36	$ 6,703	1.42	$4,724.87	
Statewide Trees for Streams, 2015- Little River, Stowe	$4,491.00	0.67	$ 6,703	1.42	$4,725.01	
Statewide Trees for Streams, 2015 - Saxtons Main Stem - Rockingham	$6,703.00	1.00	$ 6,703	1.42	$4,725.02	
Statewide Trees for Streams, 2015 - Saxtons South Branch - Grafton	$6,703.00	1.00	$ 6,703	1.42	$4,725.02	
Statewide Trees for Streams, 2015 - Mettowee - Pawlet	$8,915.00	1.33	$ 6,703	1.42	$4,725.03	
Statewide Trees for Streams, 2015 - Dog River - Northfield	$8,714.00	1.30	$ 6,703	1.42	$4,725.08	
Statewide Trees for Streams, 2015 - Dead Creek - Bridport	$15,015.00	2.24	$ 6,703	1.42	$4,725.11	
Statewide Trees for Streams, 2015 - Sugar Hollow Brook - Pittsford	$3,352.00	0.50	$ 6,704	1.42	$4,725.73	
Statewide Trees for Streams, 2015 - Kendrick Pond - Pittsford	$3,352.00	0.50	$ 6,704	1.42	$4,725.73	
Statewide Trees for Streams, 2015 - Neshobe River - Brandon	$1,676.00	0.25	$ 6,704	1.42	$4,725.73	
Winooski Watershed Targeted Riparian Corridor Restoration - Crosset Brook Middle School	$5,855.00	0.85	$ 6,888	1.42	$4,855.60	
Statewide Trees for Streams, 2014-2015- Mendon Brook, Rutland	$15,510.00	2.15	$ 7,214	1.42	$5,085.20	
Statewide Trees for Streams, 2014-2015-Union Brook, Northfield	$7,214.00	1.00	$ 7,214	1.42	$5,085.23	
Statewide Trees for Streams, 2014-2015- Lamoille River, Wolcott	$7,214.00	1.00	$ 7,214	1.42	$5,085.23	
Statewide Trees for Streams, 2014-2015- New Haven River, Bristol	$19,983.00	2.77	$ 7,214	1.42	$5,085.29	
Statewide Trees for Streams, 2014-2015- Mettowee River, Pawlet	$8,657.00	1.20	$ 7,214	1.42	$5,085.35	
Statewide Trees for Streams, 2014-2015- Flower Brook, Pawlet	$2,525.00	0.35	$ 7,214	1.42	$5,085.43	
Statewide Trees for Streams, 2014-2015-Poultney River, Poultney	$3,896.00	0.54	$ 7,215	1.42	$5,085.81	
Statewide Trees for Streams, 2014-2015-Wells River, Wells	$361.00	0.05	$ 7,220	1.42	$5,089.46	
Statewide Trees for Streams, 2014-2015- Flower Brook, Pawlet 2	$289.00	0.04	$ 7,225	1.42	$5,092.99	
Little River Agricultural Site Riparian Tree Planting	$55,020.00	7.00	$ 7,860	1.42	$5,540.61	
Lull's Brook Riparian Buffer Restoration	$7,189.91	0.80	$ 8,987	1.42	$6,335.31	
Lafreniere Field Camel's Hump State Park Riparian Planting	$9,070.94	1.00	$ 9,071	1.42	$6,394.21	
River Buffer Restoration in the Memphremagog Basin - Von Stackelberg	$8,158.00	0.86	$ 9,486	1.42	$6,686.82	
River Buffer Restoration in the Memphremagog Basin - Prevost	$6,166.00	0.65	$ 9,486	1.42	$6,686.90	
River Buffer Restoration in the Memphremagog Basin - Irons	$10,435.00	1.10	$ 9,486	1.42	$6,687.05	
Lake Shoreland and River Buffer Restoration in the Memphremagog Basin- 2016	$17,455.00	1.84	$ 9,486	1.42	$6,687.08	
River Buffer Restoration in the Memphremagog Basin - Chop	$26,562.00	2.80	$ 9,486	1.42	$6,687.09	
River Buffer Restoration in the Memphremagog Basin - Vt Fish and Wildlife	$13,281.00	1.40	$ 9,486	1.42	$6,687.09	
Riparian Buffer and Shoreland Restoration in the Memphremagog Basin	$3,092.00	0.28	$ 11,043	1.42	$7,784.24	
Lake/ River Buffer - Memphremagog Basin - Prevost Site, East Charleston	$25,181.00	2.28	$ 11,044	1.42	$7,785.25	
Lake/ River Buffer - Memphremagog Basin - Messier Field Site, Coventry	$12,149.00	1.10	$ 11,045	1.42	$7,785.43	
Lake/ River Buffer - Memphremagog Basin - Chop Site, Newport Town	$4,418.00	0.40	$ 11,045	1.42	$7,785.75	
Lake/ River Buffer - Memphremagog Basin - Woods Site, Island Pond	$2,651.00	0.24	$ 11,046	1.42	$7,786.34	
Winooski Watershed Targeted Riparian Corridor Restoration - Berlin	$5,855.00	0.50	$ 11,710	1.42	$8,254.51	
Winooski Watershed Targeted Riparian Corridor Restoration - Montpelier	$5,855.00	0.50	$ 11,710	1.42	$8,254.51	
Winhall River Riparian Buffer Restoration/Planting	$6,000.00	0.50	$ 12,000	1.42	$8,458.94	
Woody Buffer Block Grant- WUV 2019	$265,152.00	20.00	$ 13,258	1.42	$9,345.44	
Woody Buffer Block Grant- NRCC 2019	$164,848.00	12.20	$ 13,512	1.42	$9,524.86	
Saxton River Riparian Restoration	$4,307.00	0.30	$ 14,357	1.42	$10,120.18	
Second Branch White River Corridor Easement (Wortman Farm)	$65,925.44	4.30	$ 15,331	1.42	$10,807.35	
Riparian Buffer Stewardship - PMNRCD - Dorset	$1,795.00	0.10	$ 17,950	1.42	$12,653.16	
Statewide Trees for Streams, 2014-2015	$168,224.00	9.10	$ 18,486	1.42	$13,031.10	
Wells River Corridor Tree Planting - Wells River - Newbury	$18,534.00	0.85	$ 21,805	1.42	$15,370.39	
Windham County Trees for Streams/Riparian Buffer Restoration	$30,000.00	1.27	$ 23,622	1.42	$16,651.46	
White River Partnership Riparian Planting	$7,178.00	0.20	$ 35,890	1.42	$25,299.28	
Middle White River Corridor Easement -Freund/Finn Property	$140,782.00	3.00	$ 46,927	1.42	$33,079.62	
Upper White River Corridor Easement and Buffer Restoration/Planting (Millard Property)	$113,408.00	1.60	$ 70,880	1.42	$49,964.13	
Birds of Vermont Museum, Huntington Stream Restoration and Gully Remediation	$22,000.00	0.25	$ 88,000	1.42	$62,032.22	
Projects to Address Sediment Sources in the Upper Black River Watershed	$82,185.00	0.80	$ 102,731	1.42	$72,416.45	
Crooked Creek Gully Restoration	$80,000.00	0.50	$ 160,000	1.42	$112,785.86	
River Corridor Easement - Third Branch White River - Bethel	$275,646.00	1.00	$ 275,646	1.42	$194,306.07	

ALL PROJECTS

Minimum	***$ 289***	*Minimum*	***$ 665***	***1.42***	***$ 469***	*Minimum*
Maximum	***$ 275,646***	*Maximum*	***$ 275,646***	***1.42***	***$ 194,306***	*Maximum*
Average	***$ 21,388***	*Average*	***$ 13,769***	***1.42***	***$ 9,706***	*Average*
Standard deviation	***$ 46,558***	*Standard deviation*	***$ 33,211***	***0.00***	***$ 23,411***	*Standard deviation*

SMALLER SITE SPECIFIC PROJECTS

Minimum	***$ 894***	*Minimum*	***$ 665***	***1.42***	***$ 469***	*Minimum*
Maximum	***$ 64,116***	*Maximum*	***$ 6,545***	***1.42***	***$ 4,614***	*Maximum*
Average	***$ 8,789***	*Average*	***$ 3,952***	***1.42***	***$ 2,786***	*Average*
Standard deviation	***$ 13,326***	*Standard deviation*	***$ 1,277***	***0.00***	***$ 900***	*Standard deviation*

Channel Restoration Costs
3/17/2021

		Project Management, Administration		Assessment, Design, Permitting		Construction + Bid, Oversight		Operation, Maintenance				Restoration Characteristics			
Floodplain Restoration Project	**Location**	**Year**	**Cost**	**Year**	**Cost**	**Year**	**Cost**	**Year**	**Cost**	**Total Project Cost**	**Total Project Cost (no O&M)**	**Project Type***	**Restored Corridor Area (acres)**	**Total Cost per Area (no O&M) ($US/acre)**	**Notes**
Adams Brook Channel Restoration	Newfane, VT	2015-2018	$ 5,000	2015-2018	$ 10,000	2018	$ 45,000			**$ 60,000**	**$ 60,000**	**Bed armor removal**	**0.23**	**$ 260,942**	
Green River Karlan-Mason	Guilford, VT	2016-2018	$ 5,000	2016-2018	$ 8,000	2018	$ 45,000			**$ 58,000**	**$ 58,000**	**Channel habitat/stability restoration**	**0.62**	**$ 93,411**	
Pike River Tributary	Berkshire, VT	2019-2020	$ 3,000	2019-2020	$ 10,000	2020	$ 36,000			**$ 49,000**	**$ 49,000**	**Channel habitat/stability restoration**	**0.33**	**$ 148,856**	
Marsh Brook	Franklin, VT	2018-2021	$ 10,000	2018-2021	$ 30,000	2022	$ 200,000			**$ 240,000**	**$ 240,000**	**Channel habitat/stability restoration**	**14.8**	**$ 16,219**	

Gray text indicates cost estimate.

		Minimum	*$ 3,000*		*$ 8,000*		*$ 36,000*		*$ -*	***$ 49,000***	***$ 49,000***			***$ 16,219***	*Minimum*
		Maximum	*$ 10,000*		*$ 30,000*		*$ 200,000*		*$ -*	***$ 240,000***	***$ 240,000***			***$ 260,942***	*Maximum*
		Average	*$ 5,750*		*$ 14,500*		*$ 81,500*		*#DIV/0!*	***$ 101,750***	***$ 101,750***			***$ 129,857***	*Average*
		Standard deviation	*$ 2,986*		*$ 10,376*		*$ 79,114*		*#DIV/0!*	***$ 92,291***	***$ 92,291***			***$ 102,934***	*Standard deviation*

APPENDIX P

ESTIMATING INUNDATION AND EROSION HAZARDS AND BEN-EFITS

Lower Valley Inundation Damage Hazard Reduction

Building Inundation Hazard Reduction (slope ≤ 0.5%)

	Percent Hazard Reduction		
Reconnection Project Size	≤10 year	25-50 year	> 50 year
< 1 ac	10%	5%	0%
1-5 ac	15%	10%	5%
> 5 ac	20%	15%	10%

Spatial Extent of Hazard Reduction				
Upstream 2	Upstream1	SubUnit	Downstream1	Downstream2
0	0	1	0	0
0	1	1	1	0
0.5	1	1	1	0.5

Building Inundation Hazard Reduction (slope > 0.5%)

	Percent Hazard Reduction		
Reconnection Project Size	≤10 year	25-50 year	> 50 year
< 1 ac	5%	0%	0%
1-5 ac	10%	5%	0%
> 5 ac	15%	10%	5%

Spatial Extent of Hazard Reduction				
Upstream 2	Upstream1	SubUnit	Downstream1	Downstream2
0	0	1	0	0
0	0.5	1	0.5	0
0	0.5	1	0.5	0

Infrastructure Inundation Hazard Reduction (slope ≤ 0.5%)

	Percent Hazard Reduction		
Reconnection Project Size	≤10 year	25-50 year	> 50 year
< 1 ac	2%	0%	0%
1-5 ac	4%	2%	0%
> 5 ac	6%	4%	2%

Spatial Extent of Hazard Reduction				
Upstream 2	Upstream1	SubUnit	Downstream1	Downstream2
0	0	1	0	0
0	1	1	1	0
0.5	1	1	1	0.5

Infrastructure Inundation Hazard Reduction (slope > 0.5%)

	Percent Hazard Reduction		
Reconnection Project Size	≤10 year	25-50 year	> 50 year
< 1 ac	0%	0%	0%
1-5 ac	2%	0%	0%
> 5 ac	4%	4%	2%

Spatial Extent of Hazard Reduction				
Upstream 2	Upstream1	SubUnit	Downstream1	Downstream2
0	0	1	0	0
0	0.5	1	0.5	0
0	0.5	1	0.5	0

Notes:

- UVM HAND floodplains used to summarize infrastructure present in each inundation band up to the 0.2% (500-year) flood.
- Excludes bridges for inundation, includes culverts due to abundance of undersized culverts
- Lower valley channels with > 2% slope have no inundation risk reduction applied

Headwater Inunda. on Damage Hazard Reducon

Headwaters Hazard Risk Reduction

	Buildings		Infrastructure	
Reconnection Project Size	<3% Slope	>3% Slope	<3% Slope	>3% Slope
< 1 ac	5%	0%	0%	0%
1-5 ac	10%	0%	2%	0%
> 5 ac	15%	0%	4%	0%

Notes:

- Excludes bridges for inundation, includes culverts due to abundance of undersized culverts
- Headwater channels with > 3% slope have no inundation risk reduction applied

Esma ted Value for Inundao n and Erosion Screening

E911 SITETYPE	Category	Value	Unit
AIR SUPPORT / MAINTENANCE FACILITY	Institutional	$ 21,000	Each
AMBULANCE SERVICE	Institutional	$ 258,850	Each
AUDITORIUM / CONCERT HALL / THEATER / OPERA HOUSE	Institutional	$ 380,350	Each
BANK	Institutional	$ 413,000	Each
BORDER CROSSING	Institutional	$ 232,500	Each
CITY / TOWN HALL	Institutional	$ 836,900	Each
COLLEGE / UNIVERSITY	Institutional	$ 263,800	Each
COMMUNITY / RECREATION FACILITY	Institutional	$ 162,950	Each
COURT HOUSE	Institutional	$ 2,383,250	Each
CULTURAL	Institutional	$ 167,700	Each
DAY CARE FACILITY	Institutional	$ 215,250	Each
EDUCATIONAL	Institutional	$ 206,300	Each
FIRE STATION	Institutional	$ 162,950	Each
HEALTH CLINIC	Institutional	$ 354,400	Each
HISTORIC SITE / POINT OF INTEREST	Institutional	$ 61,400	Each
ICE ARENA	Institutional	$ 4,000,000	Each
LAW ENFORCEMENT	Institutional	$ 575,850	Each
LIBRARY	Institutional	$ 351,200	Each
MUSEUM	Institutional	$ 200,950	Each
NATIONAL GUARD / ARMORY	Institutional	$ 531,400	Each
POST OFFICE	Institutional	$ 147,300	Each
PUMP STATION	Institutional	$ 2,000,000	Each
RAILROAD STATION	Institutional	$ 500,000	Each
SCHOOL K / 12	Institutional	$ 1,726,810	Each
SPORTS ARENA / STADIUM	Institutional	$ 837,200	Each
STATE GARAGE	Institutional	$ 446,350	Each
STATE GOVERNMENT FACILITY	Institutional	$ 638,200	Each
TOWN GARAGE	Institutional	$ 177,100	Each
TOWN OFFICE	Institutional	$ 286,930	Each
TRANSFER STATION	Institutional	$ 64,000	Each
US GOVERNMENT FACILITY	Institutional	$ 906,200	Each
VISITOR / INFORMATION CENTER	Institutional	$ 202,600	Each
WASTEWATER TREATMENT PLANT	Institutional	$10,000,000	Each
CONDOMINIUM	Residential	$ 250,000	Each
MOBILE HOME	Residential	$ 117,000	Each
MULTI-FAMILY DWELLING	Residential	$ 322,500	Each
NURSING HOME / LONG TERM CARE	Residential	$ 365,100	Each
OTHER RESIDENTIAL	Residential	$ 287,063	Each
SEASONAL HOME	Residential	$ 116,800	Each
SINGLE FAMILY DWELLING	Residential	$ 287,063	Each
GATED W/BUILDING	Other	$ 53,800	Each
GATED W/O BUILDING	Other	$ 41,250	Each
SUBSTATION	Other	$ 433,450	Each
ACCESSORY BARN	Commercial	$ 40	per SQFT
ACCESSORY BUILDING	Commercial	$ 40	per SQFT
BREWERY	Commercial	$ 40	per SQFT
COMMERCIAL	Commercial	$ 40	per SQFT
COMMERCIAL CONSTRUCTION SERVICE	Commercial	$ 40	per SQFT
COMMERCIAL FARM	Commercial	$ 40	per SQFT
COMMERCIAL GARAGE	Commercial	$ 40	per SQFT
COMMERCIAL W/RESIDENCE	Commercial	$ 40	per SQFT
FITNESS FACILITY	Commercial	$ 40	per SQFT
GAS STATION	Commercial	$ 40	per SQFT
GOVERNMENT	Commercial	$ 40	per SQFT
GREENHOUSE / NURSERY	Commercial	$ 40	per SQFT
GROCERY STORE	Commercial	$ 40	per SQFT
HOUSE OF WORSHIP	Commercial	$ 40	per SQFT
INDUSTRIAL	Commercial	$ 40	per SQFT
LODGING B&B / HOTEL / MOTEL / INN	Commercial	$ 40	per SQFT
LUMBER MILL / SAW MILL	Commercial	$ 40	per SQFT
MANUFACTURING FACILITY	Commercial	$ 40	per SQFT
MORGUE	Commercial	$ 40	per SQFT
OFFICE BUILDING	Commercial	$ 40	per SQFT
OIL / GAS FACILITY	Commercial	$ 40	per SQFT
OTHER	Commercial	$ 40	per SQFT
OTHER COMMERCIAL	Commercial	$ 40	per SQFT
PHARMACY	Commercial	$ 40	per SQFT
RESIDENTIAL FARM	Commercial	$ 40	per SQFT
REST STOP / ROADSIDE PARK	Commercial	$ 40	per SQFT
RESTAURANT	Commercial	$ 40	per SQFT
RETAIL FACILITY	Commercial	$ 40	per SQFT
STORAGE UNITS	Commercial	$ 40	per SQFT
VETERINARY HOSPITAL / CLINIC	Commercial	$ 40	per SQFT
WAREHOUSE	Commercial	$ 40	per SQFT

Agricultural Land Estimate Value: $2,500/acre

Roads Estimated Value:

Road Type	AOT Class	Value ($/mile)
Forest Roads/Highways, Town Class 4 Roads	4-6, 11-16, 21-25	$1,000,000/mile
Private	8-10	$800,000/mile
Town Roads (including unclassified)	1-3	$1,500,000/mile
State and Federal and Highways/Interstates	20, 30-59	$2,300,000/mile
Excluded (Proposed, Unknown, Trails)	65-88	$0/mile

Bridges and Culverts Estimated Value:

Structure	Width	Value ($/structure)
Culvert	>8 ft	$500,000
Culvert	4 – 8 ft	$200,000
Culvert	<4 ft	$50,000
Bridge*	>60 ft	$3,000,000
Bridge*	40 – 60 ft	$1,500,000
Bridge*	<40 ft	$750,000

*Bridges considered in erosion screen only

Lower Valley Erosion Risk

CEFD / TR	FSTCD - LMC ≤ 20% disconnected	CST / UST / FSTCD - LMC > 20% disconnected / DEP
LOW	MODERATE	HIGH

SCREEN 1 [LOW] (CEFD / TR) >> Automatically set to low erosion damage potential.

SCREEN 2 [MODERATE] (FSTCD - LMC > 80% connected)

Warning Indicators (Raise to HIGH if 2 or more present):

- Excessive Erosion Damage Potential:
  - SSP > 60 W /m2 during Q10 (HAND modeling)
- Excessive Deposition Potenaàl:
  - 1 or more 3rd order confluence areas
  - 1 or more road crossings where structure width less than bankfull width
  - 1 or more 5% or larger slope decreases on adjacent stream reaches/segments

SCREEN 3 [HIGH] (CST / UST / FSTCD - LMC ≤ 80% connected / DEP)

Warning Indicators (Lower to MODERATE if none present):

- Excessive Erosion Damage Potential:
  - SSP > 60- W /m2 during Q10 (HAND modeling)
  - SSP > 300 W /m2 during Q100 (HAND modeling)
- Excessive Deposition Potenaàl:

- 1 or more 3rd order confluence areas
- 1 or more road crossings where structure width less than bankfull width
- 1 or more 5% or larger slope decreases on adjacent stream reaches/segments

Headwaters Erosion Risk

	Lateral Meander Connectivity		
Slope (Existing Bins for High and Low	**<60% (V. Low Connectivity)**	**60-80% (Low Connectivity)**	**≥80% (High Connectivity)**
<3% (Low Gradient)	HIGH	MODERATE	LOW
>3% (High Gradient)	HIGH	HIGH	MODERATE

Erosion Damage Hazard Reducon

	Percent Hazard Reduction		
Reconnection Project Size	**High Damage Potential**	**Moderate Damage Potential**	**Low Damage Potential**
< 1 ac	20%	10%	5%
1-5 ac	30%	15%	10%
> 5 ac	50%	25%	15%

	Spatial Extent of Hazard Reduction*				
Reconnection Project Size	**Upstream 2**	**Upstream1**	**SubUnit**	**Downstream1**	**Downstream2**
< 1 ac	0	0	1	0	0
1-5 ac	0	1	1	1	0
> 5 ac	0	1	1	1	1

*Headwaters reducons` are only applied to the corridor where a project is located (no upstream or downstream effects).