

Appendix F – Utilizing Streambank Stabilization in Water Quality Trading

Last Revised: March 2026

1.0 Introduction

WDNR offers watershed-based alternatives for meeting requirements associated with effluent limits in WPDES permits. These programs include Adaptive Management (AM), Water Quality Trading (WQT) and the statewide Multi-discharger Variance (MDV). This document details the necessary steps for quantifying pollutant reductions achieved from streambank stabilization projects implemented for the above programs. While the steps and examples are specific to WQT projects, similar methods should be used for AM and MDV projects.

Section 283.84(1m)(a), Wis. Stats., requires trades must reduce overall pollutant loading and result in water quality improvement. As such, a project or practice that shifts pollutant loading from one area/source to another does not meet these requirements and would not qualify as a valid credit generation project/practice. For WDNR to assert that this requirement has been met, pollutant reductions must be properly quantified, assigned a trade ratio, and be accompanied by supporting documentation.

Streambank erosion has long been identified as having negative impacts to water quality. The U.S. Environmental Protection Agency lists excessive sediments as a leading problem in our nation's rivers and streams. Unnatural quantities of sediment entering streams can degrade aquatic habitat and alter physical and chemical characteristics of the water. Nutrients associated with soil particles enter the stream and become available to aquatic plants and algae, ultimately contributing to eutrophication of local and downstream waters.

Erosion of streambanks is a naturally occurring process for many waterways, but human impacts can exacerbate erosion. Removal of vegetation, foot or vehicle traffic, and channel modifications can contribute to erosion. Hydrologic alteration of a stream's watershed (such as tiling or paving) can also accelerate streambank erosion. When planning a streambank stabilization project, treatments should aim to correct the cause of erosion. Stabilization projects that do not address the cause of erosion are generally less sustainable and have a higher risk of failure. Simply armoring eroding streambank without addressing sources of excessive hydraulic energy may transfer erosive energy downstream, increasing rates of erosion occurring at those locations. When this occurs, a net reduction in sediment and nutrients entering the waterway is not achieved, and water quality trading credits cannot be generated pursuant to s. 283.84(1m)(a), Wis. Stats. To help account for this issue, projects that do not apply natural channel design principles (i.e. designing and reconnecting the channel to floodplain where appropriate) are subject to an uncertainty factor of four (4).

1.1 Considerations for Project Selection

There has been a growing awareness of fluvial processes and stream restoration principles since publication of the stream classification system of Rosgen (Rosgen, 1994), and with this, interest in projects that might restore natural river functions and processes. However, subsequent reviews of river restoration projects find that many projects commonly failed to meet restoration goals, may actually contribute to habitat degradation, that restoration/streambank stabilization efforts were inappropriate for the specific setting, and/or failed to address

the causes of ecological impairment and restore natural ecological function (Cendrero, et. al., 2022; Lundberg, et. al., 2021; Palmer, et. al., 2010). Streambank stabilization projects that simply serve to “patch” eroding banks may fail to address the underlying causes of streambank erosion and are likely to redirect erosive energy to other parts of the stream. In cases such as this, a “streambank stabilization” project may actually degrade water quality and habitat of the receiving water (FISRWG, 1998). Such a project would fail to meet water quality improvement requirements under s. 283.84(1m)(a), Wis. Stats. and would not be eligible to generate pollutant trading credits.

Streambank erosion, whether natural or anthropogenic, is a symptom reflective of the (im)balance of the geologic and hydraulic/hydrologic driving variables that influence stream stability, fluvial process, and morphology (Figure F1 below, adapted from Lane, 1955; Stone, et. al., 2015). Changes in these driving variables, whether at the local, landscape, or watershed scale, may destabilize the dynamic equilibrium in a graded river and drive fluvial system response to accommodate changing water and sediment regimes in the stream system.

“Graded River”: In a graded river the channel slope has adjusted such that it provides the flow velocity and bed surface texture required to transport the mixed-size load supplied from upstream. The representative water discharge does not affect the equilibrium representative flow velocity, bed shear stress, and bed surface texture. (Bloom, et. al., 2016)

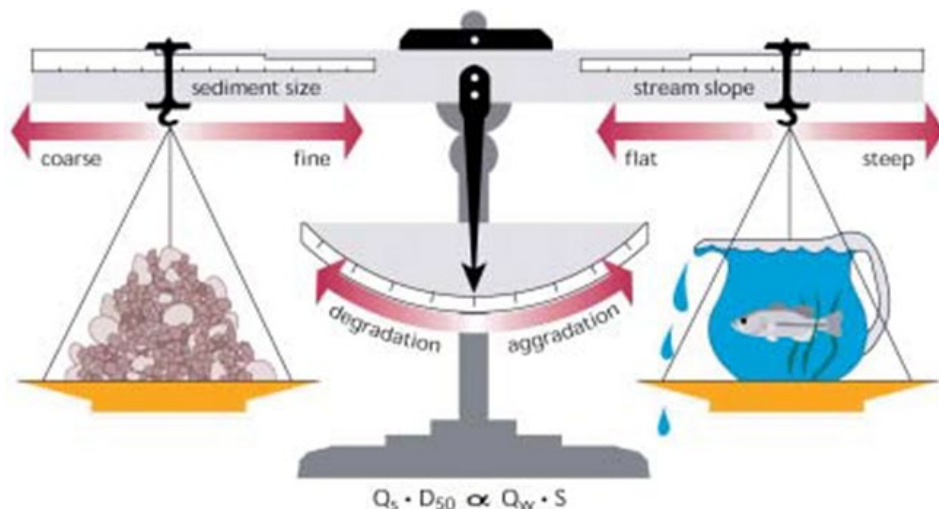
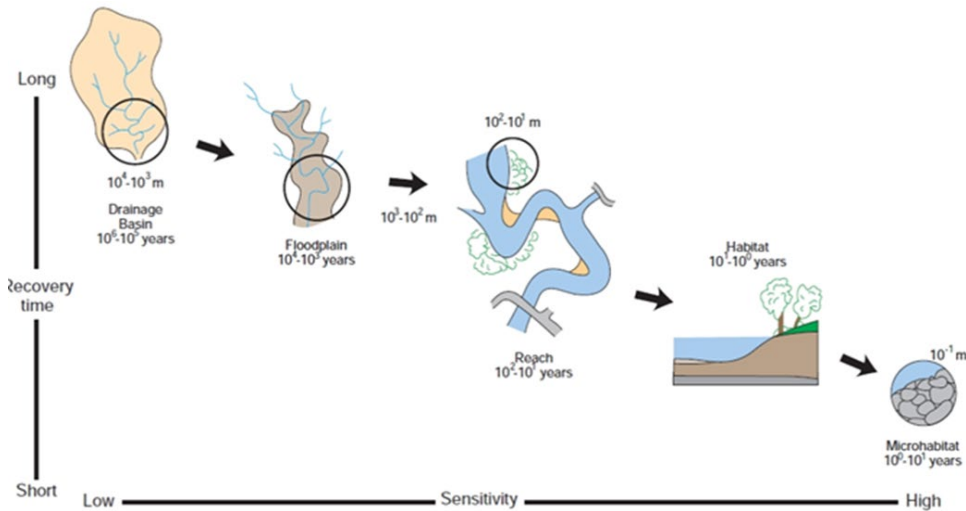


FIGURE F1: THE TRANSPORT OF WATER AND SEDIMENT IN A STREAM IS A DYNAMIC EQUILIBRIUM BETWEEN DRIVING AND RESISTING FORCES (ADAPTED FROM LANE, 1955). CHANGES IN WATERSHED HYDROLOGY THAT SIGNIFICANTLY ALTER WATER AND SEDIMENT LOADING TO STREAMS CAN CAUSE COMPLEX, SYSTEMIC CHANGES THAT MAY INCLUDE STREAMBANK EROSION AS A SYMPTOM.

The spatial scales of perturbations that result in instability for a given stream reach can vary from acute, local, riparian scale to chronic, watershed/basin scale. Similarly, temporal scale perturbations that influence fluvial processes and channel stability can occur in minutes (e.g. landslide, earthquake, etc.), span years (e.g. riparian pastures, transportation projects) or even millennia (e.g. glacial rebound, base-level eustacy) (Figure F2 – below) (Stone, et. al., 2015; NRCS, 2010; FISRWG, 1998; Macklin, 1997; Leopold, et. al., 1995; Frissell, et. al., 1986).



Source: C.A. Frissell and others, "A Hierarchical Framework for Stream Habitat Classification: Viewing Streams in a Watershed Context," Environmental Management, Vol. 10, and SEWRPC.

FIGURE F2: RELATION BETWEEN RECOVERY TIME AND SENSITIVITY TO DISTURBANCE FOR DIFFERENT HIERARCHICAL SPATIAL SCALES ASSOCIATED WITH STREAM SYSTEMS (ADAPTED FROM FRISSELL, 1986).

Streambank erosion is driven by erosive scour of the stream bed (incision) and banks (widening). Basin-scale changes in land use and base-level (e.g. eustatic change in water levels due to lake level fluctuations, glacial rebound, regional wildfires, dam removal, etc.) that significantly alter the water balance of a watershed, and/or receiving water elevation of the stream can trigger local and regional episodes of channel incision, streambank erosion, valley widening, and related fluvial-geomorphic adjustment mechanisms (Stone, et. al., 2010; Riedel, et. al., 2005; Verry, 2000; Fitzpatrick, et. al., 1999; Dunne & Leopold, 1995; Leopold, et. al., 1995). The oversteepening of streambanks by scour of the bank toe can result in undermining and mass/block failure or slumping of streambanks, bluffs, and valley walls into the stream channel. In these situations, systemic driving forces for failure exceed the resisting forces and evolution of the drainage network (e.g scour, meander migration, valley widening, etc.) may likely be a natural phenomenon (Simon & Rinaldi, 2006; Riedel, et. al., 2005; Fitzpatrick, et. al., 1999; Macklin, 1997). Consequently, it is imperative to develop a comprehensive understanding of the nature and (im)balance of fluvial processes at work in any given stream or river, before attempting streambank stabilization (Verry, 2000; Macklin, 1997; Leopold, et. al., 1995).

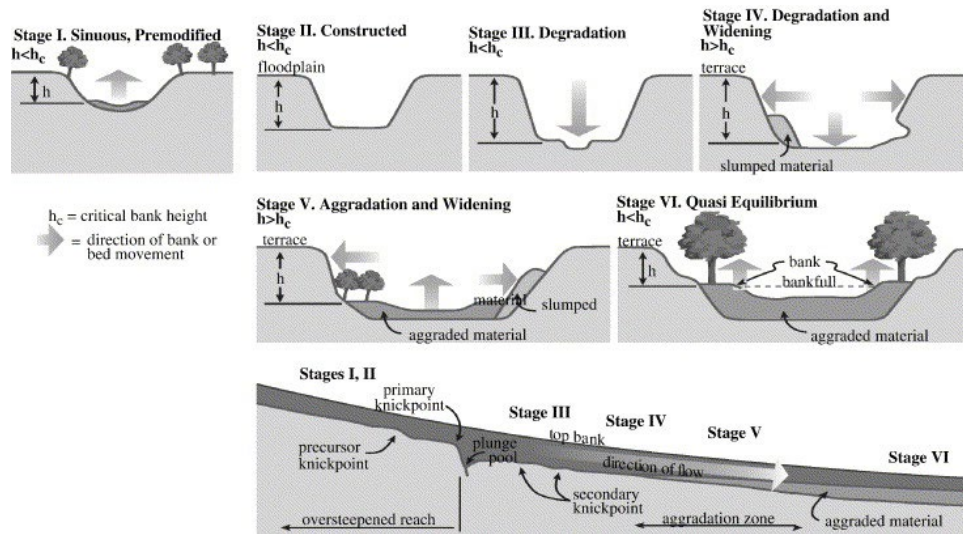


FIGURE F3: STREAM MORPHOLOGY STAGES DEFINED

For example, much of Wisconsin was covered by thick lobes of glacial ice, snow and debris during the quaternary period ~12,000 years ago. Topography of the state, watershed and basin divides, and glacial lakes and ice-melt rivers was profoundly different from contemporary conditions (WGNHS, 2011). With recession of the large mass of glacial ice and debris, and alteration of major drainage basins and pathways (aside from the driftless region), our current day rivers and watersheds are still responding to large driving forces such as isostatic glacial rebound (Riedel, et. al., 2005; Baedke, et. al., 2004; Fitzpatrick, et. al., 1999). The degree of this response varies greatly across our region. Glacial Lake Duluth (modern day Lake Superior) had its shoreline at the equivalent present-day elevation of 1,200 feet above sea level, nearly 600 feet higher than current mean lake level. (Riedel, et. al., 2005). Consequently, watersheds tributary to Lake Superior are still actively growing in response to this eustatic base-level change and the deeply incised valleys and high gradient streams in this region are prone to mass-wasting, landslides, and extensive meander migration and sediment transport as the river systems continue evolving to adapt to geologic drivers (Stone, et. al., 2015; Stone, et. al., 2010; Riedel, et. al., 2005; Verry 2002; Fitzpatrick, 1999). In situations such as this, stabilizing a single streambank amounts to “patching a symptom” and is unlikely to generate lasting or meaningful improvements in water quality. These localized projects will likely transfer excessive hydraulic and erosive energy to locations downstream, and ultimately drive an increase in erosion at those locations (NRCS, 2010; NC State University, 2003).

1.2 Localized Bank Stabilization of Systemic Erosion

Uncertainty Factor: 4

Habitat Adjustment: Not eligible

Given that exacerbated streambank erosion can be a significant source of pollutant loading and habitat degradation in streams and rivers, there can be situations where localized application of streambank stabilization can reduce pollutant loading and improve water quality. Given the potential uncertainty for pollutant reductions using an approach that simply “patches” eroding streambanks, these projects may be used to generate pollutant trading credits, but will have higher uncertainty factor and little to no measurable habitat

benefit. Conversely, holistic stream restoration projects that are designed from a “systems approach” and incorporate natural channel design, address fluvial processes, watershed analyses and incorporate habitat elements, along with bank stabilization, may be used to generate pollutant trading credits and will be awarded lower uncertainty factor and greater habitat benefit. WDNR operations and fisheries staff around the state have specific expertise in designing, installing, and maintaining stream habitat restoration projects. Anyone considering streambank stabilization or restoration projects for permit compliance via water quality trading or adaptive management is strongly encouraged to reach out to WDNR staff early in the planning process to best facilitate a collaborative process that allows for smoother transition from project conception, design, and approval.

Criteria for “Localized Bank Stabilization of Systemic Erosion” category:

- Sites where vertical or near-vertical stabilization measures are used, including walls and sheet pilings
- Sites where rip-rap or other hardening measures are used to maintain a slope greater than 2:1
- High-energy streams where steps for mitigating potential shifting of erosion are not employed
- Other indicators show that shifting of erosion is likely to occur due to the stabilization project

1.3 Integrated Streambank Stabilization for Generating Water Quality Trading Credits

Uncertainty Factor:3

With Habitat Adjustment: 2

Streambank stabilization projects to address very localized/acute cases of bank erosion with directly identifiable causes can be good candidates to reduce pollutant loading to receiving waters, generate pollutant credits, and, if designed properly, may benefit aquatic ecosystems. Some examples of disturbances limited to a local/riparian scale include livestock grazing/traffic across streams, alignment of drainage, transportation, or other infrastructure projects that impeding on local river function, and channel straightening for agricultural drainage. These types of disturbances, and resulting streambank instability, can be relatively simple to address at the local scale and remedied with integrated streambank stabilization practices that not only mitigate bank erosion and pollutant loading, but also provide habitat benefits (WDNR, 2016).

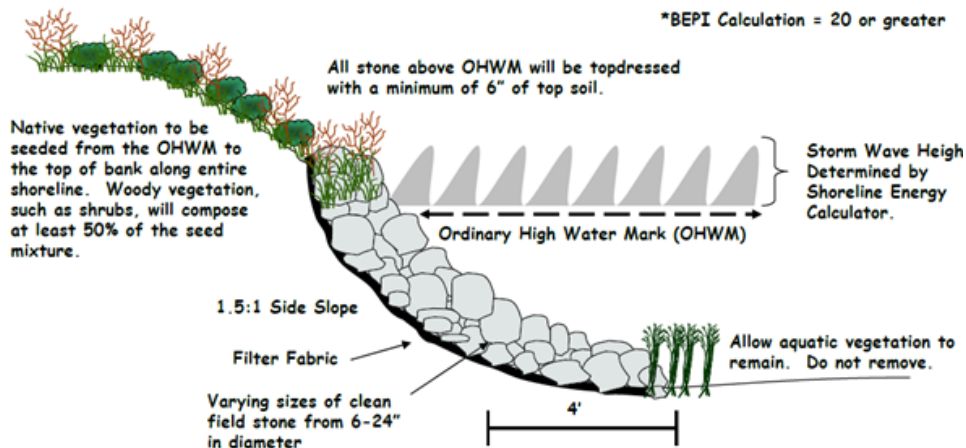


FIGURE F4: AN EXAMPLE CROSS-SECTION OF INTEGRATED STREAMBANK STABILIZATION (WDNR, 2016).

Credits may be generated using “[Integrated Streambank Stabilization](#)” practice standards, where the emphasis is on stopping localized erosion. Allowable practices/settings for WQT eligible streambank projects address acute, localized hydrologic/hydraulic/geotechnical issues that can be remedied with reach-level remediation work. Specifically, streambank erosion is a localized phenomenon in response to a direct, acute cause, that can be corrected/mitigated. Examples include:

- Streambank erosion due to livestock traffic, trampling etc., in riparian grazing, pasture access, or similar agricultural setting (e.g. Stone, et. al., 2010a; Riedel, et. al., 2006)
 - Fencing for livestock exclusion/riparian grazing to protect streambanks from cattle traffic
 - Engineered/stabilized cattle crossing/ford
 - Alternative water supply
 - “Natural” channel design/streambank stabilization following NRCS streambank stabilization standards (NRCS, 2010)
 - Integrated Streambank Protection (WDNR, 2016)
- Streambank erosion due to infrastructure, bridge crossings, culverts, etc. (e.g. Riedel, et. al., 2007; Riedel, 2006).
 - Note: maintenance of storm water conveyance is required under MS4 permits and not eligible for generating pollutant trading credits.
 - Natural channel design/streambank stabilization following NRCS streambank stabilization standards (NRCS, 2010)
 - Integrated Streambank Protection (WDNR, 2016)

Criteria for “Integrated Bank Stabilization” category:

- The water quality trading plan identifies a local cause of erosion
- The water quality trading plan demonstrates that proposed measures will address the cause of erosion
- The linear footage thresholds of 500’ and 1000’ as defined in WI NRCS 580 are observed
- DNR will evaluate the linear footage threshold on a case-by-case basis

1.4 Stream Restoration

Uncertainty Factor: 3

With Habitat Adjustment: 2

In contrast to localized streambank stabilization that may be sufficient to address acute/riparian causes of erosion, large-scale spatial (e.g. watershed/basin scale) and temporal spectrum (e.g. 10's to >100's of years) of changes in fluvial driving variables can cause systemic instability as the entire drainage network reworks itself to accommodate the shifting climatic, hydrologic and geologic conditions. Multiple episodes of stream instability can propagate through stream and river systems, with different parts of the same watershed operating under different response conditions. For example, upstream of a knickpoint, a watershed might be relatively stable, while downstream of the knickpoint, the fluvial system may be actively incising and widening. Finally, the mouth/outlet of the system may possibly be experiencing aggradation/sedimentation from the increased sediment load from upstream processes and propagation of the knickpoint up the main river and tributaries (Stone, et. al., 2015; Stone, et. al., 2010b; Riedel, et. al., 2002; Verry, 2000; Fitzpatrick, et. al., 1999; Macklin, 1997; Leopold, et. al., 1995; Frissell, et. al., 1986).

“Knickpoint: In geomorphology, a knickpoint or nickpoint is part of a river or channel where there is a sharp change in channel bed slope, such as a waterfall or lake. Knickpoints reflect different conditions and processes on the river, often caused by previous erosion due to glaciation or variance in lithology.”

In situations such as this, stabilization of an eroding streambank is unlikely to address the underlying causes of bank erosion. In fact, such practices are unlikely to result in reduction of pollutants to the stream and may only serve to shift erosion issues downstream and inadvertently have detrimental impacts on water quality, stream habitat and ecology (Palmer, et. al, 2010; Macklin, 1997).

Anyone considering streambank stabilization or restoration projects for permit compliance via water quality trading or adaptive management is encouraged to reach out to WDNR staff early in the planning process. Local WDNR staff often have locally specific experience and knowledge about streams and rivers in their respective regions and may provide important considerations and guidance to best facilitate design and implementation of successful stream and river restoration projects. When planning streambank stabilization projects for credit generation, the following factors should be considered early in the process:

- **Natural Channel Stability:** A naturally stable stream channel maintains its dimension, pattern and profile such that the stream does not degrade or aggrade. Stable streams migrate across the landscape slowly over geologic time while maintaining their form and function. Naturally stable streams must be able to transport the sediment load supplied by the watershed (Stone, et. al., 2010b; NC State University, 2003; FISRWG, 1998; Macklin, 1997; Leopold, et. al., 1995). Bank erosion is an important process of natural streams and contributes significantly to maintenance of aquatic habitat. “Stabilization” of naturally eroding streambanks can interrupt natural fluvial processes, harm aquatic habitat, destabilize natural streams, and result in excessive erosion downstream.
- **Existing Information:** Have erosion issues already been identified in your area? Consider contacting your County Land and Water Conservation Department. Other organizations or documents such as

watershed plans may have already identified erosion and offer resources or partnership for certain projects.

- Natural Channel Example Sites: Locate and survey stable, “natural channels” in the same region, or even on the same stream. These sites can serve as a “template” to provide important design considerations including (but not limited to) bank full channel dimensions, sinuosity, slope, meander wavelength, riffle-pool spacing, and other important geomorphic and habitat features (e.g. Stream Channel Reference Sites: An Illustrated Guide to Field Techniques, Harrelson, et. al., 1994).
- Hydraulic Design: Natural channel design needs to incorporate and accommodate the hydrologic and hydraulic regimes the stream/river system is subjected to. Streams and rivers modify and maintain their channels to transport the water and sediment loads they are subjected to. Natural channel design and BMPs that do not accommodate these conditions are prone to failure (Simon and Rinaldi, 2006; Macklin, 1997; Frissel, et. al., 1986) and consequently, will not generate pollutant trading credits. Resources that can be beneficial with this approach include:
 - River hydraulic and sediment transport models (e.g. HEC-RAS, SIAM, etc.)
 - Channel restoration/stability models (e.g. Stone, et. al., 2010a; Riedel, et. al., 2006)
 - “WinXSPRO, A Channel Cross Section Analyzer” (Hardy, et. Al., 1994)
- Magnitude of pollutant offset: For compliance-driven projects, the number of credits required may guide the scope of the project.
- General location of the project, relative to the pollutant discharge: Project eligibility, as well as trade ratio, is influenced by location. The most effective locations for pollutant offsets are generally located upstream from the permitted discharge.
- Land access: Landowner support may dictate what areas can be considered. In addition to granting access for preliminary surveying and eventual implementation, the landowner should be willing to enter into a binding agreement to inspect and maintain the practice and/or allow 3rd party inspections and maintenance.

Criteria for “Stream Restoration” category:

- Projects must maintain or restore hydrologic connectivity and access with riparian corridor/floodplain
- Design incorporates hydrologic and hydraulic analyses to appropriately size and design with natural stream pattern, plan and profile as required under WI NRCS 580 and 582 technical standards
- When requesting the habitat adjustment, the design maintains or improves natural fluvial processes to sustain/improve critical aquatic habitat elements (e.g. riffle/pool sequencing, drop pools, sediment transport, bedload)
- When requesting the habitat adjustment, design has been coordinated with DNR fisheries staff to include native/natural habitat elements consistent with the applicable fisheries classification and restoration of native/endemic aquatic ecosystem

Examples of stream restoration and natural channel design:

Streambank stabilization as part of overall stream restoration, in which the stream is being returned to its original channel consistent with natural/historical stream alignment (e.g. Stone, et. al., 2010a; Stone, et. al., 2010b).

- The historical/natural channel should be documented via historical data/imagery, mapping, etc.
- Stream was straightened/alterd to accommodate agricultural drainage ditches, sluiceways, or other engineered waterway that is being decommissioned/removed to restore natural stream functions, fish passage, conveyance, etc.
- Natural channel design features and engineering principles are returning stream to original alignment and will restore habitat, fish passage, natural function, etc.
- Work should be done in consultation with WDNR fish biologists/restoration team.

For example, Mason Creek in Waukesha County, WI, despite having an endemic cold water brook trout population, had been channelized and agricultural fields were tile-drained and regularly tilled up to the stream banks. As part of the project, the tiles were removed, land purchases and easements were used to provide buffers along the entire length of stream, and agricultural best management practices were implemented on remaining fields. The stream was restored to its original channel, with extensive streambank stabilization using natural design principles, and riffle/pool and other important habitat features were recreated to restore natural spawning and refuge habitat for the trout.



FIGURE F5: AERIAL IMAGE OF MASON CREEK RESTORATION MID-CONSTRUCTION. THE CHANNELIZED DITCH IS VISIBLE IN THE LEFT OF THE PHOTO, WHILE THE RESTORED/RECONSTRUCTED CHANNEL IS VISIBLE FOLLOWING THE ORIGINAL COURSE OF THE CREEK, AS IDENTIFIED FROM HISTORIC SURVEYS AND FIELD INVESTIGATION. NATURAL CHANNEL DESIGN FEATURES, FISH HABITAT (ENGINEERED RIFFLES, POOLS, ETC.), AND NATURAL DESIGN ELEMENTS WERE USED IN THIS PROJECT TO FULLY RESTORE MASON CREEK TO A NATURAL CONDITION AS A COLD-WATER TROUT STREAM (PHOTO CREDIT: TALL PINES CONSERVANCY)



FIGURE F6: CLOSE-UP IMAGE OF MASON CREEK RESTORATION PROJECT, SHOWING AN ENGINEERED RIFFLE-POOL SEQUENCE WITH NATURAL STREAM MEANDERS AND CHANNEL METRICS FOLLOWING THE ORIGINAL CHANNEL. NATIVE VEGETATION AND BIOENGINEERING PRINCIPLES WERE USED TO STABILIZE STREAMBANKS, PROVIDE SHADING, AND COMPLETE THE RIPARIAN RESTORATION COMPONENT OF THIS NATURAL STREAM RESTORATION PROJECT.

Another example: Pleasant Valley Branch is a tributary to Kittleson Valley Creek and is in the Gordon Creek watershed. Excess sedimentation from agricultural sources degraded water quality and habitat in Pleasant Valley Branch. As a result, the entire creek was added to Wisconsin's 1998 Clean Water Act (CWA) section 303(d) impaired waters list for degraded habitat. The Pleasant Valley Branch subwatershed was part of a multifaceted effort to improve the riparian corridor and habitat of the stream, while also addressing nonpoint source issues in the watershed as a whole. From 1998 to 2014, the Dane County LWRD worked with landowners to implement practices along the riparian corridor. Concurrently, a consortium of public and private partners worked with landowners in the watershed to improve barnyards and to reduce the amount of sediment and nutrient runoff from agricultural lands and pastures. Between 1998 and 2014, landowners in the subwatershed installed three grade stabilization structures and eight water/sediment control basins, restored 27,556 feet of streambank and 11 acres of wetlands, and implemented numerous agricultural BMPs. Natural channel design concepts were used to address excessive sediment deposition in the stream, restore pool habitat, and stabilize streambanks using natural design elements, riparian vegetation/bioengineering, and livestock exclusion.



FIGURE F7: PHOTOS SHOWING A GRAZED SECTION OF PLEASANT VALLEY BRANCH CREEK BEFORE AND AFTER RESTORATION. LIVESTOCK EXCLUSION, REGRADING, AND EXTENSIVE SEDIMENT REMOVAL, BANK TREATMENTS, AND INSTREAM HABITAT STRUCTURES WERE USED TO RESTORE THIS STREAM AND ULTIMATELY, REMOVE IT FROM THE 303(D) LIST OF IMPAIRED WATERS ([SECTION 319 NONPOINT SOURCE SUCCESS STORY: RESTORATION OF PLEASANT VALLEY BRANCH THROUGH STREAM CORRIDOR REHABILITATION](#)).

Numerous techniques exist for stabilizing eroding streambanks. A common approach is to regrade a steep bank to a more gradual slope, thereby providing stability and dispersing the energy of high flows. However, regrading alone will leave soil particles exposed and vulnerable to erosion. Additional practices should be implemented to avoid erosion of the disturbed area, such as:

- Immediate seeding with a native seed mix suitable to the conditions of the site
- Plantings of native riparian vegetation
- Use of erosion breaks and or structures such as coir (coconut fiber) logs
- Erosion matting or webbing
- Surface hardening, such as rock rip rap

Unnatural quantities of rock in riparian areas may impede vegetation growth and decrease the aesthetic and habitat values of a stream corridor. Projects that employ excessive hardening may need to be modified prior to approval. The criteria outlined in WI NRCS Code 580: Streambank and Shoreline Protection should be adhered to.

1.5 Measuring the Current Pollutant Load

By implementing a project that stabilizes an eroding streambank, soil particles that would have entered the waterway now remain on land. A series of measurements and calculations can quantify the mass of pollutants kept out of the waterway. Values are often reported in pounds per year. These reductions equate to pollutant credits, generated annually for the life of the practice.

Several key steps are needed to properly quantify pollutant reductions:

- Delineation of erosion areas
- Measurement of individual erosion sites (length, height, recession rate)
- Soil sampling and lab analysis
- Calculations, using the above information

1.6 Identifying Erosion Areas

Erosion sites are most commonly identified by a lack of vegetation. This condition indicates that erosion is likely occurring. However, streambanks lacking vegetation may not be eroding, or may be eroding very slowly. Other observations can help verify the presence of erosion.

Other symptoms of erosion include:

- Banks with steep or vertical slopes, often with loose soil
- Overhanging vegetation or recently fallen trees
- Deformations in the shape of the bank, relative to other banks
- Soil fracture lines, slumping, or sliding
- Exposed plant roots
- Buried cultural features are now exposed (fence posts, footings, foundations, etc.)

A comprehensive erosion survey will provide the baseline data needed to plan a project. Walking a section of stream and completing a standardized streambank erosion survey form can provide a structured approach. Beyond site-specific measurements (discussed next), data collected should include: a unique site ID, center point GPS coordinates, bank designation (right or left, facing downstream), apparent cause of erosion, and vegetative condition on and above the bank. Obtaining comprehensive photographic documentation of all erosion areas is strongly recommended. This is best accomplished outside of the growing season when vegetation is down.

Site Delineation

On certain streams, erosion may be concentrated in localized “pockets”, with stable bank conditions found between sites. Other streams may exhibit a continual stretch of eroding bank. A degree of variability along an eroding bank is expected, which should be addressed by averaging all measurements for a site. However, large scale averaging across a highly variable bank does not properly quantify the site’s baseline. When deciding

where to “split or lump”, consider bank height, recession rate, soil texture, and cause of erosion. If any of these observations substantially change, it is best to split the bank into two or more individual sites, with specific measurements for each site. Photographs of the site should be taken. Photographic coverage of the entire site should be included in the project plan to support measurements and calculations. Include an object of known length such as a survey rod in each photograph to provide a relative means of height evaluation.



FIGURE F8: EXAMPLE STREAMBANK EROSION DELINEATION

Measuring Bank Height and Length

Basic measurements required for quantifying pollutant reductions include bank height and length. As discussed previously, reasonable averaging across a site can occur, but large-scale averaging should be avoided, as it does not properly quantify pollutant reductions. The height of a bank should include the entire eroding slope. Length measurements are dictated by the linear distance downstream where erosion is shown. Detailed survey measurements may satisfy documentation requirements in lieu of comprehensive photographic coverage.

Bank Height:



Bank Length:



FIGURE F9: EXAMPLE BANK HEIGHT AND LENGTH MEASUREMENTS

Measuring Lateral Recession Rate

Lateral recession rate, or depth of bank loss, has a large influence on the amount of soil estimated to be entering the stream from a given site. Lateral recession rate is most commonly measured in feet per year, and ranges

from 0 ft/year (no erosion occurring) to 1+ ft/year (very severe erosion). This value should be a long-term average, since high-water events will intermittently cause greater amounts of erosion, with less erosion occurring during low flows. Various methods exist for measuring recession rate. These involve taking a baseline reading with survey equipment at two points in time and calculating bank surface differences between before and after surveys. Bank pins or stakes (multiple, arranged to represent the entire bank) may also be used as a benchmark for comparison of current and future conditions. Due to the episodic nature of erosion, long-term measurements (10–20-year periods) are typically needed to arrive at a representative annual average. Highly episodic erosion that occurs on less than an annual basis may not be appropriate for water quality trading. Measured lateral recession rates are typically capped at 1.0 ft/yr because credits are generated and used on an annual basis, rather than during flood events which cause erosion.



FIGURE F10: EXAMPLE LATERAL RESSION DIRECTION AND SURVEY EQUIPMENT

If it is not feasible to measure lateral recession rate, it may be estimated through qualitative observations. Vegetative indicators are moderately useful. A lack of vegetation does not guarantee that erosion is occurring, so additional methods should be used to quantify recession rate. WDNR does not typically accept estimated values beyond 0.5 ft/year when using this type of qualitative lateral recession rate estimation. The following points should be observed and compared to the NRCS erosion severity chart below:

- Exposed Roots
- Physical deformation of the bank surface including gullies, rills, or slumping
- Bank grade steeper than what is sustainable
- Channel shape indicates active cutting

Lateral Recession Rate (ft/yr)	Category	Description
0.01-0.05	Slight	Some bare bank but active erosion not readily apparent. Some rills but no vegetative overhang. No exposed tree roots.

Lateral Recession Rate (ft/yr)	Category	Description
0.06-0.2	Moderate	Bank is predominately bare with some rills and vegetative overhang. Some exposed tree roots but no slumps or slips.
0.3-0.5	Severe	Bank is bare with rills and severe vegetative overhang. Many exposed tree roots and some falls trees and slumps or slips. Some changes in cultural features such as fence corners missing and realignment of roads or trails. Channel cross section becomes U-shaped as opposed to V-shaped.
0.5+	Very Severe	Bank is bare with gullies and severe vegetative overhang. Many fallen trees, drains and culverts eroding out and changes in cultural features as above. Massive slips or washouts common. Channel cross section is U-shaped and stream course may be meandering.

To estimate recession rate using qualitative observation, comprehensive photographic coverage of the entire project area is needed. To provide comprehensive photographic coverage, the water quality trading plan must contain photographs clearly showing the entire eroding bank area that is proposed for stabilization to generate credits.

With the growing availability of spatial data, remote measurements of lateral recession rate may be possible at many sites. Remote measurement involves using aerial photography or LiDAR elevation data to compare bank position between two points in time. This approach generally involves making a measurement of bank movement over time and dividing the total measured migration by the number of years between datasets.

Remote measurements should observe the following:

- Define the points between which measurements are made; include these measurements on maps in the WQT plan.
- Ensure water surface elevation is similar between datasets. For example, comparing low-flow to flood conditions may cause misinterpretation of bank heights or stream widths.
- Measurements involving fixed objects are needed when comparing aerial photos. Stream features or certain cultural features (trails, field edges) may change position in some instances.
- For topographic data, providing multiple control points can demonstrate data alignment.

1.7 Soil Sampling Protocol

By measuring length, width, and lateral recession rate of an erosion site, the amount of soil entering a stream can be determined. Once the phosphorus concentration of the soil is known, the amount of phosphorus entering a stream can be calculated.

Composite soil samples must be taken to represent an average phosphorus concentration for each site. Sub-samples should be taken from each soil horizon, ensuring that variability in soil texture is captured, then combined into one composite sample per site. Mix, bag, and transport samples in accordance with lab procedures. Samples must be analyzed for total phosphorus. This is also known as total leachable P or P₂O₅. The

Bray-1 soil or other soil phosphorus tests are inappropriate for this purpose and will underestimate total phosphorus contributions resulting from erosion. Samples should be analyzed at a certified laboratory.

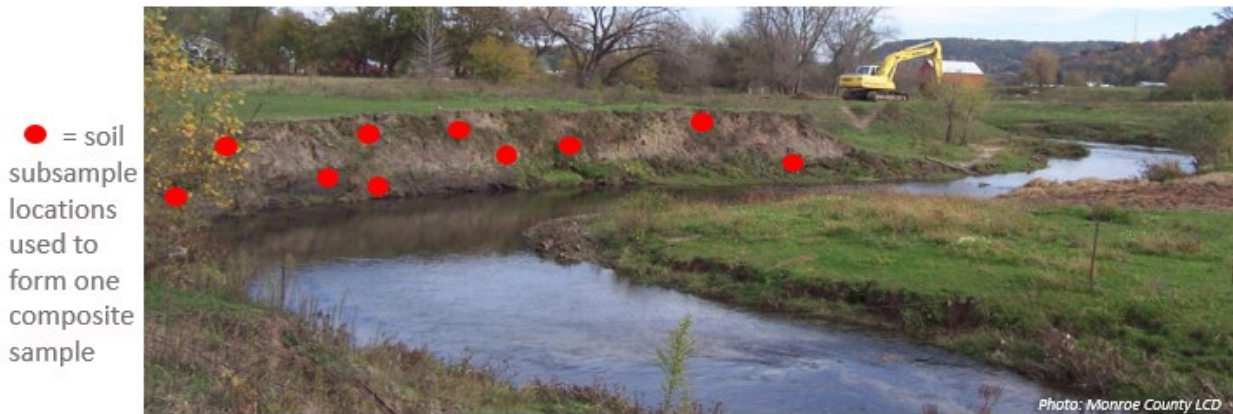


FIGURE F11: EXAMPLE SOIL COMPOSITE SUBSAMPLE LOCATIONS

A simple, mass-based equation is used to calculate phosphorus reductions from streambank stabilization:

$$P \text{ Yield } \left(\frac{\text{lbs}}{\text{year}} \right) = L \times H \times R \times bD \times (\%P \div 100)$$

Where:

L = Bank Length (ft)

H = Bank Height (ft)

R = Lateral Recession Rate (ft/year)

bD= Soil Bulk Density (lbs./ft³)

%P = Total Phosphorus Concentration (%)

1.7 NRCS Erosion Tool

The Natural Resources Conservation Service (NRCS) has created a spreadsheet that estimates soil loss at an erosion site using all components of the phosphorus yield equation, with the exception of soil total phosphorus (%). Standardized soil bulk densities are pre-programmed into the spreadsheet, and are applied once a site soil texture is selected. The NRCS spreadsheet can be found here: [NRCS Spreadsheet \(https://dnr.wi.gov/topic/surfacewater/documents/ModelingTools/gully-ephemeral_-streambank_-irrig_ditch_erosion.xlsm\)](https://dnr.wi.gov/topic/surfacewater/documents/ModelingTools/gully-ephemeral_-streambank_-irrig_ditch_erosion.xlsm)

Field Number	Eroding Strmbnk Reach #; or Ditch Side/Bottom	Eroding Bank or Ditch Length (Feet)	Eroding Bank Height; or Ditch Bottom Width* (Feet)	Area of Eroding Strmbank or Ditch (FT ²)	Lateral or Ditch Bottom Recession Rate (Estimated) (FT / Year)	Estimated Volume (FT ³) Eroded Annually	Soil Texture	Approximate Pounds of Soil per FT ²	Estimated Soil Loss (Tons/Year)
N/A	Site 1A	50.0	2.0	100	0.05	5.0	Organic	22	0.1
	Site 1B	85.0	2.5	213	0.10	21.3	Loamy Sand	100	1.1
	Site 1C	20.0	5.0	100	0.50	50.0	Fine Sandy Loam	100	2.5
Total Estimated Annual Streambank or Ditch Erosion Soil Loss (Tons):									3.6

FIGURE F12: EXAMPLE NRCS EROSION ESTIMATOR SPREADSHEET

Once soil loss is calculated in the spreadsheet, it can be multiplied by soil total phosphorus (%) results from the lab. This final result represents the pounds per year of phosphorus reduction. Reductions are subject to trade ratios and TMDL credit threshold when calculating credits generated.

1.8 Habitat Adjustment to the Uncertainty Factor

Many of Wisconsin’s waters are impaired due to a combination of chemical, biological, and aquatic habitat impairments. In many cases, habitat restoration may be necessary for the listed surface water to achieve its full designated use. Therefore, eligible streambank stabilization projects that include habitat restoration features may qualify for an aquatic habitat adjustment to the uncertainty factor (reduced from 3 to 2).

- To qualify, the stream in which the habitat is placed must exceed the applicable criterion for the traded pollutant.
- The habitat feature(s) must help alleviate the impacts of the traded pollutant.
- The habitat features(s) must provide substantial gains in aquatic habitat, appropriate for the stream in which they are installed.
- Follow criteria outlined in WI NRCS 395 Technical Standard

A chapter 30, Wis. Stats., waterways permit may be needed to conduct in-stream work.

Refer to [Waterway Protection - Fish and Wildlife Habitat Structures](https://dnr.wisconsin.gov/topic/Waterways/Permits/PermitProcess.html)

(<https://dnr.wisconsin.gov/topic/Waterways/Permits/PermitProcess.html>) for more information. It is recommended that this permitting process be initiated as soon as possible. Habitat structure types must fall under the stream habitat general permit or an individual permit to be eligible for the habitat adjustment.

The following should occur to verify that proposed habitat features are appropriate and substantial:

- Consult with your regional WDNR fisheries biologist when planning habitat projects. The biologist may provide recommendations on appropriate habitat types and quantities. Your county LCD or other professional experienced with stream habitat work may facilitate this conversation.

- Submit habitat installment details as part of the water quality trade plan. This includes proposed structure types, quantities, and locations relative to bank stabilization sites. This may be accompanied by a completed stream assessment outlined in WI NRCS 395 Technical Standard. Elements 12 and 13 of the [Stream Visual Assessment Protocol Version 2 \(https://www.nrcs.usda.gov/conservation-basics/conservation-by-state/north-dakota/stream-visual-assessment-protocol-svap\)](https://www.nrcs.usda.gov/conservation-basics/conservation-by-state/north-dakota/stream-visual-assessment-protocol-svap) will be suitable for qualified projects.

1.9 Operation and Maintenance (O & M) Plans

As a component of the trade plan, an O&M plan should be developed to outline necessary actions that ensure adequate performance and long life of the practice. An O&M plan should be developed for each set of similar features. The plan should be consistent with WI NRCS code 580.

Consider the following content for O&M plans:

- Define who is responsible for implementing the O&M plan.
- The practice(s) should be inspected at set intervals, and after every flood event.
- Remove debris that are channeling flow towards the banks, threatening damage.
- Establish and maintain vegetative cover, control invasive species as needed.
- Repair any damage or further erosion and revegetate as soon as possible. Define a timeline for responding to damages.

Depending on stream characteristics and the types of bank or channel modifications employed, reach-scale maintenance may be required.

1.10 Waterways Permit and Written Agreements

- A Chapter 30, Wis. Stats., Waterways permit may be required for streambank stabilization projects. Refer to [Waterway Protection – Stream Bank Erosion Control \(https://dnr.wisconsin.gov/topic/Waterways/Permits/PermitProcess.html\)](https://dnr.wisconsin.gov/topic/Waterways/Permits/PermitProcess.html) for more information. This permitting process should be started as soon as possible to ensure permits are in place prior to the desired project start date.
- Pursuant to s. 283.84 (1), Wis. Stats., a trade agreement is required between two parties engaging in a water quality trade. A common approach is to establish the agreement between the landowner and permittee, with the O&M plan requirements included in the agreement as a responsibility of the landowner. If the permittee directly implements measures on its own land, then the agreement will be between the WDNR and permittee. Refer to WQT Guidance (section 3.6) for general agreement information.
- Streambank stabilization has the potential to be a component of many WQT, AM, or MDV plans. Permittees and consultants are encouraged to seek site-specific advice by contacting WDNR when considering this option.

References

- Baedke, S.J., Thompson, T.A., Jpohnston, J.W., & Wilcox, D.A. 2004. Reconstructing Paleo Lake Levels from Relict Shorelines Along the Upper Great Lakes. *Aquatic Ecosystems and Management*. October, 7(4)435-449.
- Bloom, A., Viparelli, E., & Chavarrias, V. 2016. "The Graded Alluvial River: Profile Concavity and Downstream Fining." *American Geophysical Union, Geophysical Research Letters*, June, 43(12): 6285-6293.
- Cendrero, A., Remondo, J., Beylich, A.A., Cienciala, P., Forte, L.M., Golosov, V.N., Gusarov, A.V., Kijowska-Strugała, M., Laute, K., Li, D., Navas, A., Soldati, M., Vergari, F., Zwoliński, Z., Dixon, J.C., Knight, J., Nadal-Romero, E., & Płaczkowska, E. 2022. Denudation and Geomorphic Change in the Anthropocene; a Global Overview.. *Earth-Science Reviews* 233(2022):104186.
- Dahl, T., Stone, A.G., and Riedel, M.S. 2009. "Development of a Channel Stability Tool for the Great Lakes Region". *J. of The American Military Engineer, American Society of Military Engineers*, May-June: 61-62.
- Dunne, T., & Leopold, L.B. 1995. River Channels. Chpt 16. In *Water in Environmental Planning*. W.H. Freeman and Co., NY. Pp 590-660.
- Fitzpatrick, F.A., Knox, J.C., and Schubauer-Berigan, J.P., 2009, Channel, floodplain, and Wetland Responses to Floods and Overbank Sedimentation, 1846–2006, Halfway Creek Marsh, Upper Mississippi Valley, Wisconsin, in James, L.A., Rathburn, S.L., and Whittecar, G.R., eds., *Management and Restoration of Fluvial Systems with Broad Historical Changes and Human Impacts: Geological Society of America Special Paper 451*, p. 23–42.
- Fitzpatrick, F.A., Knox, J.C., & Whitman, H.E. 1999. Effects of Historical Land-cover Changes on Flooding and Sedimentation, North Fish Creek, Wisconsin. U.S. Geological Survey Water-Resources Investigations Report 99-4083. 12p.
- FISRWG 1998. *Stream Corridor Restoration: Principles, Processes, and Practices*. By The Federal Interagency Stream Restoration Working Group (FISRWG)(15 Federal Agencies of the U.S. Govt.). GPO Item 0120-A: SuDocs No. A 57.6/2:EN3/PT.653.
- Frissell, C.A., Liss, W.J., Warren, C.E., & Hurley, M.D. 1986. A Hierarchical Framework for Stream Habitat Classification: Viewing Streams in a Watershed Context. *Environmental Management*. 10(2)199-214.
- Hardy, T., Panja, P., & Mathias, D. 2005. "WinXSPRO, [A Channel Cross Section Analyzer, User's Manual, Version 3.0](#)." Gen. Tech. Report RMRS-GTR-147. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. January. 95pp.
- Harrelson, C.C; Rawlins, C. L.; Potyondy, J.P. 1994. [Stream channel reference sites: an illustrated guide to field technique](#). Gen. Tech. Rep. RM-245. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 61 p.
- Lane, E.W. 1955. The importance of fluvial morphology in hydraulic engineering. *Proceedings from the American Society of Civil Engineers*. 81(745): 1-17.
- Leopold, L.B., Wolman, M.G., & Miller, J.P. 1995. Channel Changes with Time. Chpt 11 in *Fluvial Processes in Geomorphology*., Dover Publications, Inc., NY. Pp 433-474.

- Lundberg, E., Druschke, C.G., & Booth, E.G. 2021. A Q-method Survey of Stream Restoration Practitioners in the Driftless Area, USA. *River Res. Applications* 38:1090-1100.
- Macklin, M.G. 1997. Natural Channel Stability and Time Perspectives. Section II in *Applied Fluvial Geomorphology for River Engineering and Management*. By Thorne, C.T., Hey, R.D., & Newson, M.D. John Wiley and Sons, Inc. NY:13-66.
- NC State University. 2003. *Stream Restoration: A Natural Channel Design Handbook*. North Carolina Stream Restoration Institute and North Carolina Sea Grant. 82pp.
- NRCS 2010. *Stream Corridor Restoration: Principles, Processes, and Practices*. Natural Resources Conservation Service National Engineering Handbook Part 653A.
- Palmer, M.A., Menninger, H.L., & Bernhardt, E. 2010. River Restoration, Habitat Heterogeneity and Biodiversity: a Failure of Theory or Practice? *Freshwater Biology* 55(s1)205-222.
- Riedel, M.S. 2006. "Quantifying Trail Erosion and Stream Sedimentation with Sediment Tracers", Proc. Second Federal Interagency Conference on Research in the Watersheds, USDA Forest Service Southern Research Station, Coweeta Hydrologic Laboratory, Otto, NC, May 16-18.
- Riedel, M.S., Swift Jr., L.W., Vose, J.M. & Clinton, B.D. 2007. "Forest road erosion research at Coweeta Hydrologic Laboratory". In: M Furniss, C Clifton, and K Ronnenberg, eds., *Advancing the Fundamental Sciences: Proceedings of the Forest Service National Earth Sciences Conference*, San Diego, CA, 18-22 October 2004, PNW-GTR-689, Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station:187-194.
- Riedel, M.S., Brooks, K.N., and Verry, E.S. 2006. "Stream Bank Stability Assessment in Grazed Riparian Areas", Proc. Joint 8th Federal Interagency Sedimentation and 3rd Hydrologic Modeling Conferences, Reno, NV, April 2-6.
- Riedel, M.S., Verry, E.S., & Brooks, K.N. 2005. Impacts of Land Use Conversion on Bankfull Discharge and Mass Wasting. *J. Environmental Management*. 76 (2005) 326–337.
- Riedel, M.S., Verry, E.S. & Brooks, K.N. 2002. Land Use Impacts on Fluvial Processes in the Nemadji River Watershed. *Hydrological Science and Technology*, 18 (1-4): 197-205.
- Rosgen, D.L. 1997. A Classification of Natural Rivers. *Catena*. 22(3)169-199.
- Simon, A. & Rinaldi, M. 2006. "Disturbance, Stream Incision, and Channel Evolution: The Roles of Excess Transport Capacity and Boundary Materials in Controlling Channel Response. *Geomorphology*. Sept. 79(3-4):361-383.
- Stone, A.S., Selegean, J., Dahl, T., Riedel, M.S., & Brunton, A. 2015. "Understanding Drivers of Sediment Loads in a Morphologically Active Watershed: A Multidisciplinary Approach to Watershed Management". Proc. of the 2015 Interagency Sediment Transport and Hydrologic Modeling Conference, U.S. Advisory Council on Water Information, Reno, NV.
- Stone, A.G., Riedel, M.S., Dahl, T., & Selegean, J. 2010a. Application and Validation of a GIS-based Stream Bank Stability Tool for the Great Lakes Region. *J. Soil and Water Conservation*. July 2010, 65 (4) 92A-98A.

Stone, A.G., Selegan, J.P., Dahl, T., and Riedel, M.S. 2010b. "Boardman River Existing-Conditions SIAM Model for Dam Removal". Proc. Joint Federal Interagency Conference on Sedimentation and Hydrologic Modeling, Las Vegas, NV, June 27 – July 1.

Verry, E.S. 2000. Water Flow in Soils and Streams: Sustaining Hydrologic Function. Chpt 6 in Verry, E. S., J.W. Hornbeck, C.A. Dolloff. Riparian Management in Forests of the Continental Eastern United States. Lewis Publishers, NY, NY.

WDNR. 2016. Streambank Erosion Control – Integrated Bank Treatment General Permit Application Checklist. Wisconsin Department of Natural Resources.

WGNHS. 2011. Glaciation of Wisconsin. Wisconsin Geological and Natural History Survey. Educational Series 36, 4th ed. 4p.