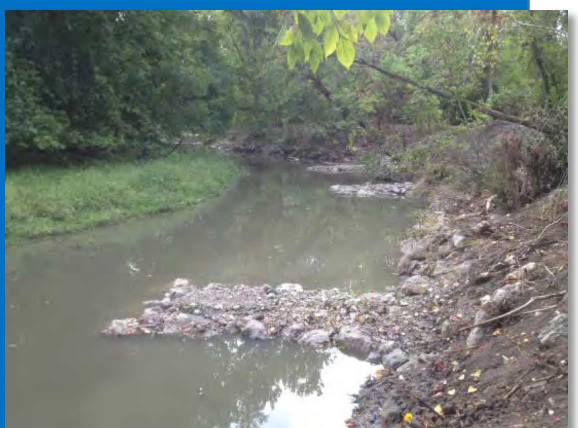

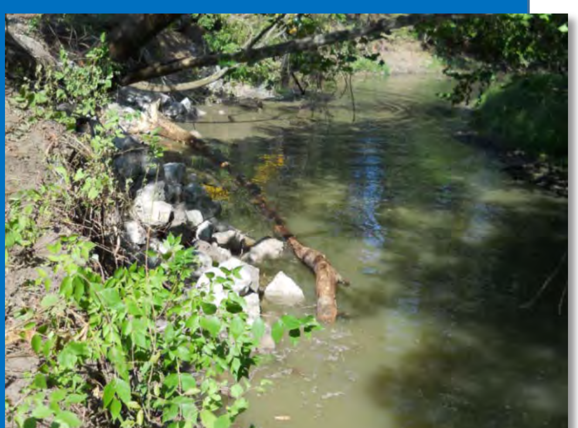

Stream and Habitat Restoration Methodologies and Techniques

A Guidebook

Prepared by Partners for Clean Streams, Inc.

In partnership with River Research and Design, Inc.

Funded by

Great Lakes RESTORATION

December 2014

Using this Guidebook

This guidebook is meant to assist stream restoration practitioners, watershed planners, environmental engineers, and others in considering the restoration options available for use in their own streams and geography and to give "lessons learned" from decades of using these practices in the field. Many of these methods have not been previously published but are well documented by David Derrick in a variety of settings over decades of work with the U.S. Army Corp of Engineers and are often used when other methods are not suitable or fail. The guidebook is not meant to be a holistic guide of all stream restoration techniques. The guidebook highlights an assortment of general practices and then provides more in depth engineering concepts on specific techniques within those suite of practices. Each suite of practices has a fact sheet and then a companion in depth engineering methods sheet, including examples in the field. The selected methods are as follows with each section identified by color for ease of use:

Longitudinal Peaked Stone Toe Protection

Grade Control Structures

Bendway Weirs

Keys

Bioengineering

Locked Logs

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Definition and Purpose

Longitudinal Peaked Stone Toe Protection (LPSTP) is a continuous stone dike placed longitudinally at, or slightly stream-ward of the toe of an eroding stream bank. The cross-section of the LPSTP is triangular, which results in the ability to self-adjust into scour holes created by flowing water. The LPSTP does not necessarily follow the toe exactly, but can be placed to form a "smoothed" alignment through the bend. Smoothed alignment might not be desirable from the environmental or energy dissipation points of view, however. This method does not have a formulaic method for installation or creation, yet some typical practices are included in this document.

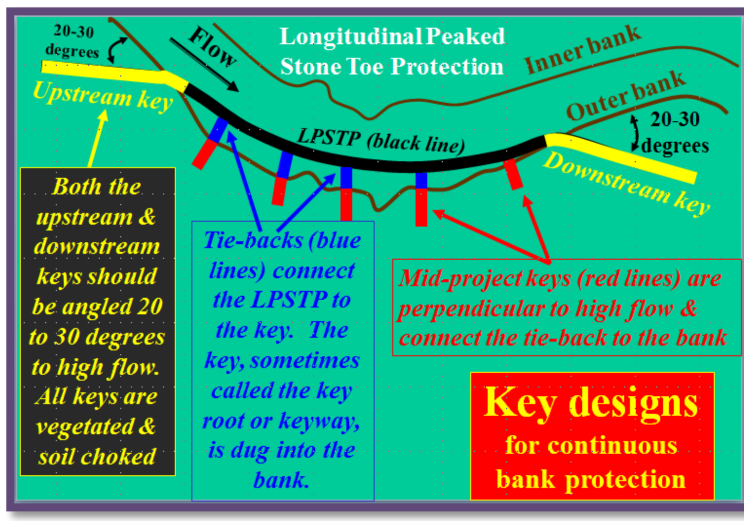

Image 1: Example Longitudinal Peaked Stone Toe Protection placement and associated supporting structures. Dave Derrick.

Longitudinal Fill Stone Toe Protection (LFSTP) is exactly the same as LPSTP except that the crest has a width. All stone for the width of the crest can launch into the scour hole, but the crest height is unchanged from the constructed height. Cross-section is a trapezoid. LFSTP can be located, and is applicable to the same sites as LPSTP, but it has the advantage of more stone volume available to adjust into the calculated scour hole.

Success of this method depends on the ability of stone to self-adjust, or "launch," into the scour hole formed on the stream side of the LPSTP/LFSTP. The stone must be well graded so as to launch properly. The weight of the stone also resists geotechnical bank failure and mass wasting.

Methods typically combined with, or connected to, LPSTP/LFSTP:

- Tie-backs
- Keys
- Locked Logs
- Bendway Weirs

Practice Applicability

Image 2: LPSTP along the Ottawa River, Camp Miakonda, Sylvania, OH. Kyle Spicer

- With the proper sized stone, LPSTP/LFSTP resists the erosive flow of the stream and stabilizes the toe, but does not provide direct protection to mid and upper bank areas.
- This method is not foundation dependent.
- Success depends on the ability of stone to launch into any scour holes formed on the river side of the LPSTP. A well-graded stone that will launch, or self-adjust (self-heal) must be used in LPSTP construction.
- "Smoothed" longitudinal alignment results in improved flow alignment near the bank.
- Weight of stone in the LPSTP (loading of toe) might resist some shallow geotechnical bank failures.
- LPSTP captures alluvium and upslope failed material (colluvium) on the bank side of structure, thus providing a foundation for vegetation to become established, or these areas could be re-vegetated with selected species.
- Provides solid substrate for benthic macro invertebrates.
- Voids between individual stones provide some refugia and cover for fishes.
- Tie-Backs block flow that has jumped landward of the LPSTP.
- Vegetation in keys, or within or above the LPSTP can slow flood flow waters and deposit sediment, organics, nutrients and seed. Deposited seed could be problematic if invasive and noxious weeds are growing upstream.

By definition LPSTP only provides toe protection and does not protect mid and upper bank areas. LPSTP does however work extremely well in zoned and blended configurations with bank paving or bio-engineering in mid to upper bank areas, or Bendway Weirs streamward of the LPSTP.

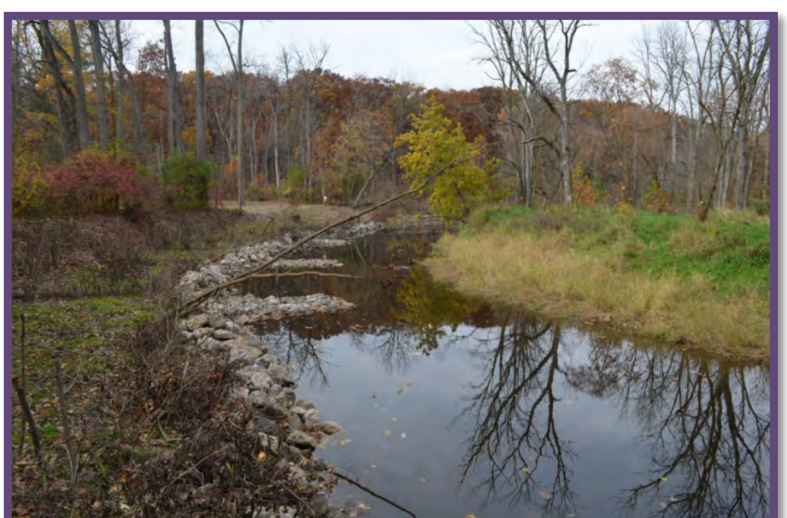

Image 3: LPSTP and Bendway Weirs at Camp Miakonda in Sylvania, OH. Kyle Spicer

Variations on LPSTP/LFSTP have been successfully used with several restoration projects within the Maumee Area of Concern. The Ottawa River bordering Camp Miakonda in Sylvania, Ohio, has over 650 feet of Longitudinal Peaked Stone Toe Protection helping reduce its erosional impact along the banks it shares with Lake Sawyer. Bank protection was also utilized in stabilizing two other local tributaries on camp property using similar methods as LPSTP, but on a smaller scale. LPSTP allows for stream bank stabilization without detrimentally impacting the rest of the surrounding ecosystem. Other local restoration projects include the Secor Dam removal project and at Hill Ditch at Toledo Botanical Gardens.

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Preparing for Longitudinal Peaked Stone Toe Protection

LPSTP acts as an armoring technique, resisting erosional forces of water. This continuous bank protection technique resists the erosive flow of the stream, thereby stabilizing the toe of the bank. The "smoothed" longitudinal alignment results in improved stream flow near the toe of the eroding bank. The LPSTP captures alluvium and upslope failed material (colluvium) on the bank side of the structure, thus providing a foundation for vegetation to become established. If the mid-to-upper bank is left untreated, these areas will fall to a stable slope (at the angle of repose of the bank material), and usually within a short period of time become invaded and naturally re-vegetated by native, or possibly invasive, plants.

Maximum stone size and correct gradation can be generated using any of many available riprap sizing design programs ("ChanlPro", WEST Consultants "RIPRAP", etc.)

Image 4: Ottawa River at Camp Miakonda, Sylvania, OH. Kyle Spicer

- Consideration #1: The minimum amount of stone that would have a launch-able component to any degree would be ½ to ¾ of a ton of stone per ft. The ½ ton/ft. amount would provide a triangular section of stone approximately 2 ft. tall.
- Consideration #2: Maximum scour depth in the bend should be numerically calculated, or estimated from field investigations (depths might be underestimated due to in-filling of scour holes during the falling side of the high-water hydrograph). Typically 1 ton of stone will protect against every 3 ft. of scour. Amount of stone required to armor the estimated maximum scour depth should be calculated, and a factor of safety added.
- Consideration #3: If there is a vegetation line, the mature well-established section of the vegetation line should be analyzed, and if Considerations #1 and 2 are met, then the vegetation line elevation would be the absolute minimum crest elevation. But, since plants immediately above the vegetation line are typically not very robust, and there is no factor of safety included, this minimum crest height should be increased at least 2 to 4 ft. or more, dependent on the situation.
- Consideration #4: The height of the bend's opposite bank point bar bench should be analyzed. If the point bar bench height is taller than the crest of the designed LPSTP, then consideration should be addressed as to whether the LPSTP height should be raised to a height equal to, or taller than, the point bar bench elevation.

Limitations

- With the proper sized stone, LPSTP/LFSTP resists the erosive flow of the stream and stabilizes the toe, but does not provide direct protection to mid and upper bank areas.
- This method is not foundation dependent.
- Success depends on the ability of stone to launch into any scour holes formed on the river side of the LPSTP. A well-graded stone that will launch, or self-adjust (self-heal) must be used in LPSTP construction.
- Weight of stone in the LPSTP (loading of toe) might resist some shallow-fault geotechnical bank failures.

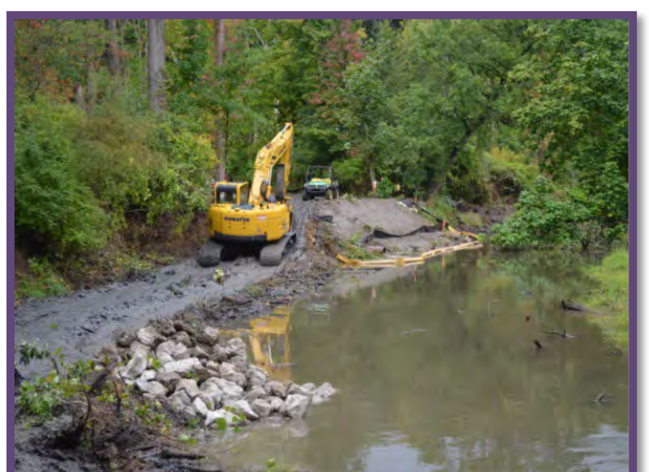
Guidelines and Tips for Construction

If there is the opportunity to build a demonstration project do so. Either test different heights of LPSTP in a number of similar bends, or for testing in a single bend start at the upstream end with a reasonably tall 50 ft. long section of LPSTP (take the amount of stone calculated from consideration #2 and add 4 ft. to the height). Continue in the downstream direction reducing height in 1 ft. increments until an unusually small amount of stone is used (3 ft. below low-flow water surface elevation for example, or below the vegetation line if one exists). After a reasonable time and at least two flood or long-duration high-flow events the sections that failed will provide some guidance for the minimum effective crest height.

- At this time, no specific design criteria exists that relates the crest elevation of LPSTP to the channel forming discharge, effective discharge, or dominant discharge.
    - One ton of LPSTP per lineal ft. is approx. 3 ft. tall (using well-graded limestone @110lbs/cu ft.)
    - Two tons per lineal ft. is approx. 5 ft. tall
    - Three tons per lineal ft. is approx. 6 ft. tall; 7.5 tons is 9.5 ft. tall
    - Four tons per lineal ft. is approx. 7 ft. tall; 10 tons is 11 ft. tall
    - Six tons per lineal ft. is approx. 8.5 ft. tall; 14 tons is 13 ft. tall

- LPSTP must be deeply keyed into the bank at both the upstream and downstream ends and at regular intervals along its entire length. Charlie Elliott's spacing rules-of-thumb for keys in flat-sloped sand bed water bodies: 50 to 100 ft. intervals on smaller streams, 1 to 2 bank-full widths on larger waterways.
- Keys at the upstream and downstream ends of LPSTP should not be at a 90 degree angle to the LPSTP structure, but at 20 to 30 degrees to HIGH FLOW.
- Keys should go far enough back into the river bank, and tied into the existing stable bank so river erosion and migration will not flank the key and the LPSTP.
- Keys should be vegetated if possible. Key length can be extended with vegetation alone in some cases.
- Volume of material per ft. of key should equal or exceed the volume of material per ft. in the LPSTP. Stone max size and gradation should be the same as the stone used in the LPSTP and Tie-Backs.
- Minimum key width should be three times the D-100 of the stone used.

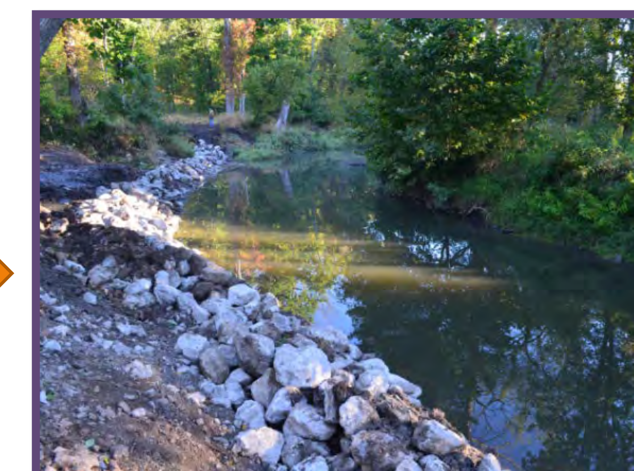
Example Construction Sequence



Construction begins by moving the stream bank material to position the LPSTP into a smoothed alignment.

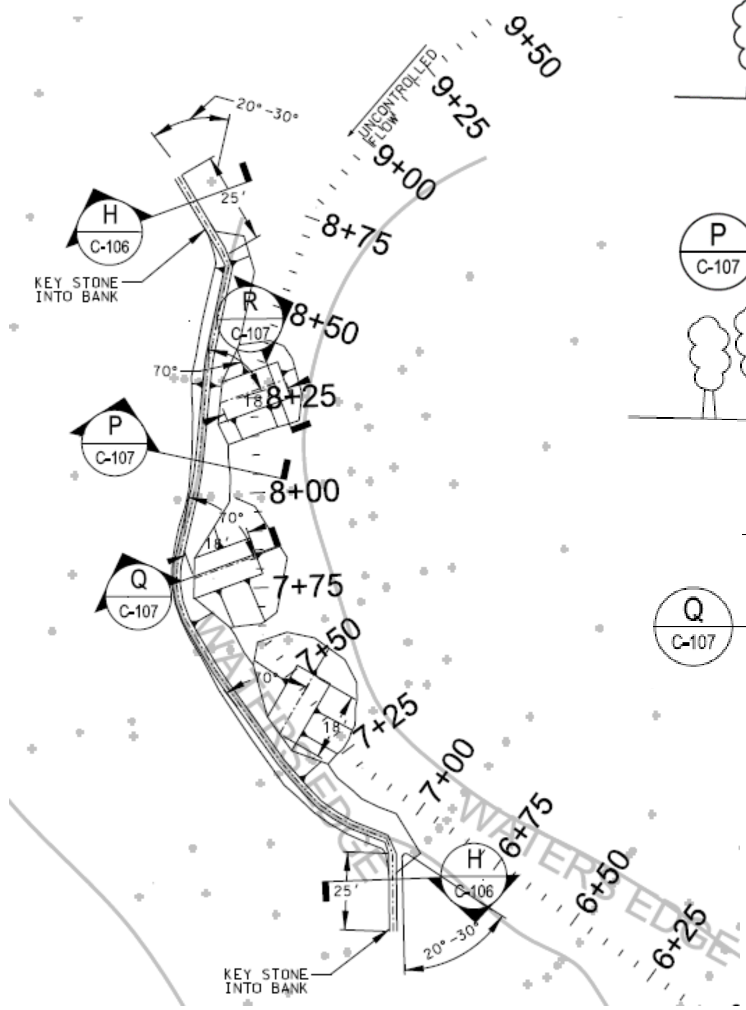
Stone is then deposited, depending on the size of the stream, over the bank with a skid loader or dump truck.

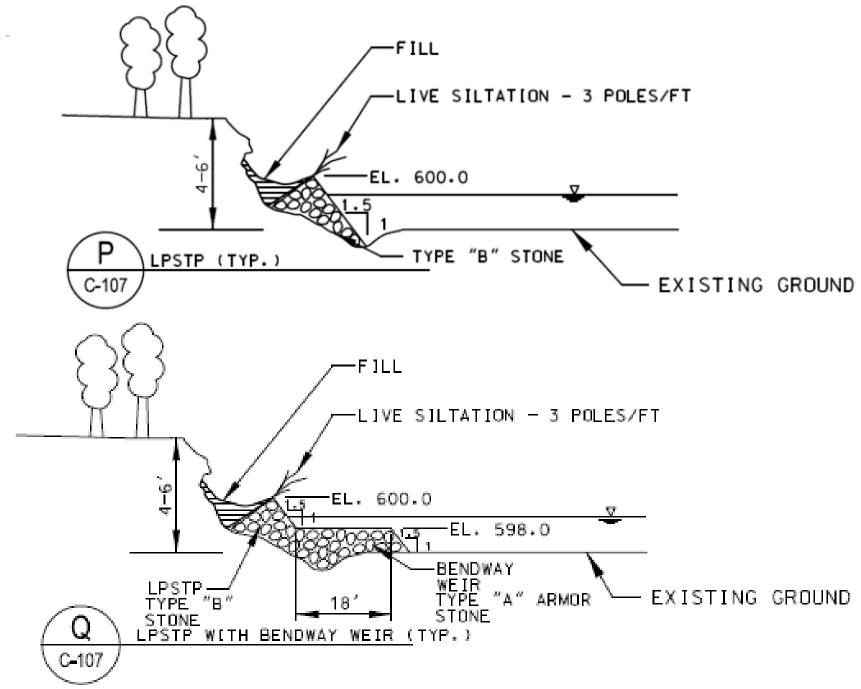
Excavator then positions the stone into the triangular shape, or otherwise if installing LFSTP. Behind the excavator's work, Live Siltation is installed against the stone.



The area behind is then backfilled to create a contoured bank. The stone will self-adjust over times, further stabilizing the bank and looking more evenly contoured.

Example Plan Drawings





Estimating Time and Materials

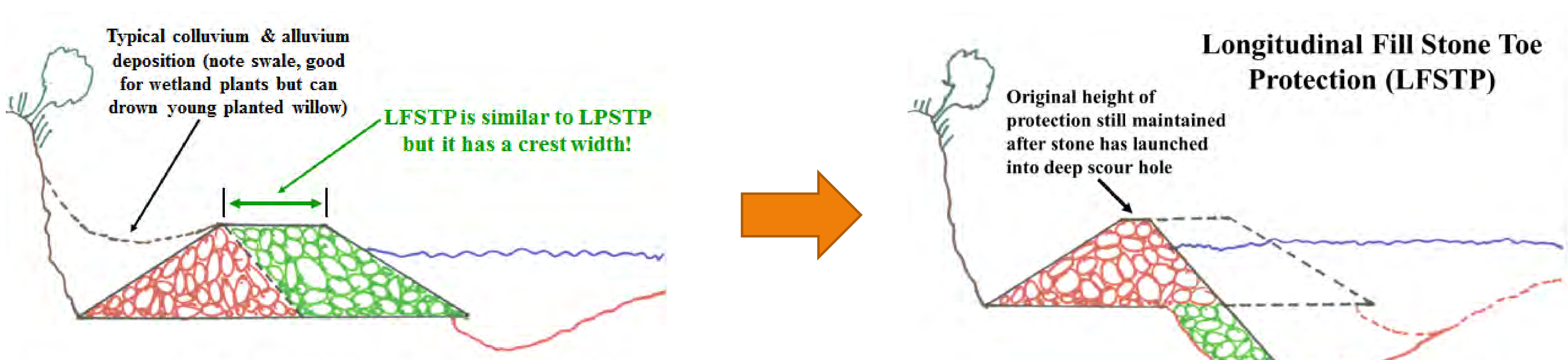
LPSTP has a relatively low cost in terms of volume of material and installation. The design, construction, inspection, and monitoring are quick and straight forward. These attributes make this a method widely applicable in a wide range of settings from small to medium-large streams, and many bends. LPSTP is useful in most bends, but a vector analysis should be undertaken to determine attack angles and associated scour. Enough stone must be placed to mitigate the anticipated scour and possible super elevation of water in small radius bends.

Monitoring and Maintenance

Monitor overall condition (especially height), any scour on the bank immediately above the crest, scour at the connection to the key, and location of thalweg. Do the BW's need modification to increase functionality?

Monitor for excessive scour on the river side. Analyze and measure the river side slope of the LPSTP/LFSTP. It should range from 1 on 1.25, to 1 on 1.5. If steeper, then stone has launched as designed. Is more stone needed for launching, or to build height back up to As-Built specs?

Monitor any Large Woody Debris captured. Will it impact the design or function of the structures? Does it need removed?



Longitudinal Fill Stone Toe Protection (LFSTP)

Definition and Purpose

Grade Control Structures (GCS) are typically placed across a stream channel and keyed into both banks, oriented approximately perpendicular to flow for the purpose of controlling, or raising, the bed of the stream and preventing streambed degradation on-site and upstream. Stream discharge flows over the GCS from a higher to lower elevation in a controlled fashion. There are literally hundreds of GCS designs. Many of the rigid (non-adjusting) designs have fallen out of fashion, and many vertical or steep-sloped designs are a barrier to fish passage and are difficult to permit. Typically GCS will form an energy dissipating pool at their downstream ends. Many grade control designs will incorporate a pre-dug and overdug pool at the downstream end to help dissipate this energy.

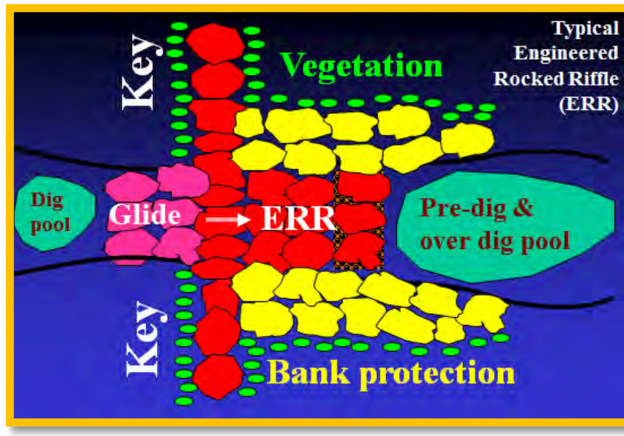


Figure 1: Typical Engineered Rocked Riffle (ERR) diagram. Dave Derrick.

There are dozens of different types of GCS, including “At-Grade,” “Hinged,” and “Underground.” At-Grade GCS are used to hold the bed of the stream at its current elevation (not allowed to degrade) by having the crest of the structure’s stone equal to the bed of the stream. At-Grade GCS is also designed to arrest advancing headcuts by building it with a sufficient calculated volume of stone at the downstream end, so once the headcut reaches the structure, this stone at the downstream end is undercut and adjusts into a rock ramp from the GCS to the headcut. Hinged GCS are typically built of Articulating Concrete Mattress that adjusts and self-heals to undercutting foundation failure due to headcutting at the downstream end of the structure. Underground GCS are a typical ERR built completely under the bed of the stream to stop a known height of headcut(s) from moving past the structure, but the stone is not required to self-adjust, or launch. The headcut simply uncovers the buried ERR. The required stream, and possibly watershed-wide functions needed, will dictate the type of GCS installed.

Image 1: ERR has a 20 to 1 slope on the downstream face for stability, to entrain air, for fish passage, and to dissipate energy. Camp Miakonda. Kyle Spicer.

Engineered Rock Riffles will become the steepest section of the stream once installed. Several low GCS are better than one large GCS, resulting in cheaper overall costs and better fish passage.

Grade Control

Methods Sheet

Practice Applicability

Image 2: Typical ERR. Designed to raise the bed of the stream up approximately one ft. Camp Miakonda in Sylvania, OH. Kyle Spicer

Typically, grade control is needed in response to overall bed lowering of several interconnected rivers, streams, and tributaries over a fairly large area, and in many cases a watershed-wide area. Usually, a series of structures are designed and installed as a system, sometimes with each performing different, but compatible and complimentary functions.

Straightened streams typically have enough energy to degrade (lower) the bed, in some cases up to several feet or more. This systematic instability can result in millions of dollars in damage to infrastructure (bridges, low water road crossings, undermined culverts, pipelines, other exposed utilities), and can result in significant land loss due to stream widening. A patchwork of bank protection works for this threatened infrastructure can cost millions over the years, without addressing the main cause of the instability! Understand the system before setting the path forward can result in a fully functioning system.

Engineered Rock Riffles (ERR) are a type of Grade Control Structure (GCS). The successful GCS built within the greater Toledo Area projects have all been stone ERRs since they mimic the natural riffles found in these pool-riffle-pool regime streams.

Image 3: Using a log to raise grade on Hartman Ditch. Rigid object (log was the only material on hand) was later undercut and failed, Camp Miakonda. Kristina Patterson.

Grade Control Structures have been implemented all over the U.S.A. Several restoration projects in the Maumee Area of Concern (AOC) are among those success stories. Camp Miakonda in Sylvania, Ohio, has several different types of Grade Control, including At-Grade ERR to stabilize the overflow channel of a restored lake, one typical ERR on Cunningham Ditch to stop a headcut from forming; five on Hartman Ditch: one providing fish passage on an existing vertical concrete headwall, one to raise the bed of the stream to lower bank heights and reconnect the stream with its historic floodplain; one to raise the bed up to the pre-headcut elevation; and two to raise the bed to prevent undercutting a large road culvert. Preventing and protecting against bed lowering (head cut migration) proved successful while also reducing the potential sediment load into local tributaries, rivers, and a restored historic WPA hand-dug lake. Other local restoration projects with Grade Control include Highland Dam (two ERR in series to drown out a dam for public safety and fish passage), three at Toledo Botanical Gardens to maintain grade after two vertical concrete dames were removed, and Secor Dam (At-Grade) to maintain the bed elevation after a concrete dam was removed. All ERR mimicked natural riffles in these pool-riffle-pool type regime streams and rivers.

Methods typically combined with Grade Control:

- Longitudinal Peaked Stone Toe Protection (LPSTP) or other bank protection attached to the GCS both upstream and downstream
- Bioengineering
- Pre-dug and Overdug energy dissipation pools

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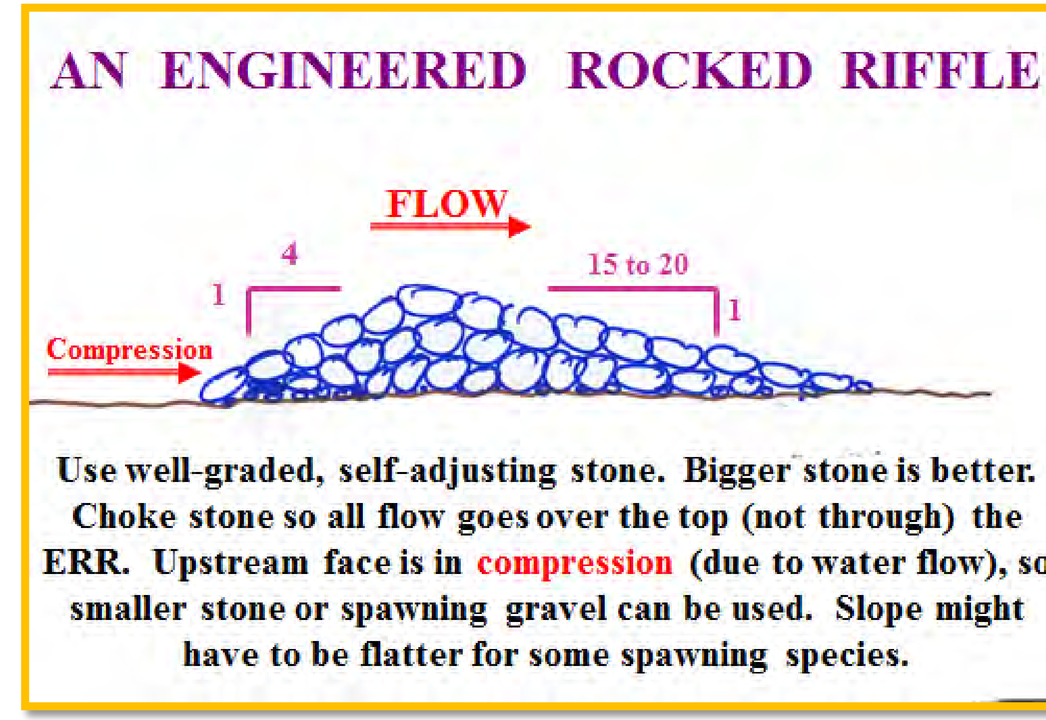
Preparing for Grade Control

Conceptually, stabilize headcuts first, and then worry about bank instability second. Key all grade control structures into both banks. All GCS will require bank protection on both banks. Considering Grade Control Structures brings in a host of options to analyze before design is initiated. A reach wide, or watershed wide analysis needs to be undertaken to understand the area where Grade Control is needed. How will GCS affect the local hydrology, water table, flooding, tribs, and drainage, including effects on existing surrounding bodies of water? Will the water level rise affect geotechnical instability (saturate sand lenses)? Will increases in flood elevations affect infrastructure? Will bridge abutments and piers be more stable? Will sediment storage upstream of GCS starve the downstream reach? Will bank stability be increased due to shorter bank heights? How much bank instability will not occur due to the elimination of headcut migration? How much wetland can be created? How many overbank areas can be hydraulically reconnected to the stream?



Limitations

- If the stream or river is FEMA flood mapped, the "no net rise" rule will be in effect, i.e., the 100 year flood elevation of the stream cannot be raised more than 1/100 of a ft., unless the increased flood elevation area is contained within the borders of the builders land.
- GCS are like small, low-elevation dams, and conceptually must be thought of as such.
- Stable tall banks must be available for the GCS to be keyed into.
- Never build a GCS under another structure (bridge) where repairs are impossible to implement.

General Guidelines for Construction

- Hydraulic Consideration: What maximum flow must be passed?
- Geotechnical Consideration: Is there a narrow area with stable banks? Danger of piping under the GCS?
- Flood Control Impacts: Can flood storage be integrated into the project?
- Tributary Impacts: Typically GCS are located downstream of the confluence of the rib and main stream, to stabilize both water bodies.
- Infrastructure Impacts: Underground utilities protected? Infrastructure flooded?
- Environmental Impacts: Fish passage maintained or enhanced? Sediment storage could change.
- Geologic Controls: Are there stable bed and banks to tie GCS into?
- Local Drainage: Needs to be controlled so GCS is not flanked.
- Channel Alignment: Locate GCS in straight crossing area of stream so flow does not impinge into bends.
- Grade Control structures are typically built where riffles or drops in bed elevation naturally occur, in the straight sections of stream between bends. Spacing between riffles should be 5 to 7 channel widths apart (measured at bankfull stage), and ideally have a bend in-between

.

Example Construction Sequence

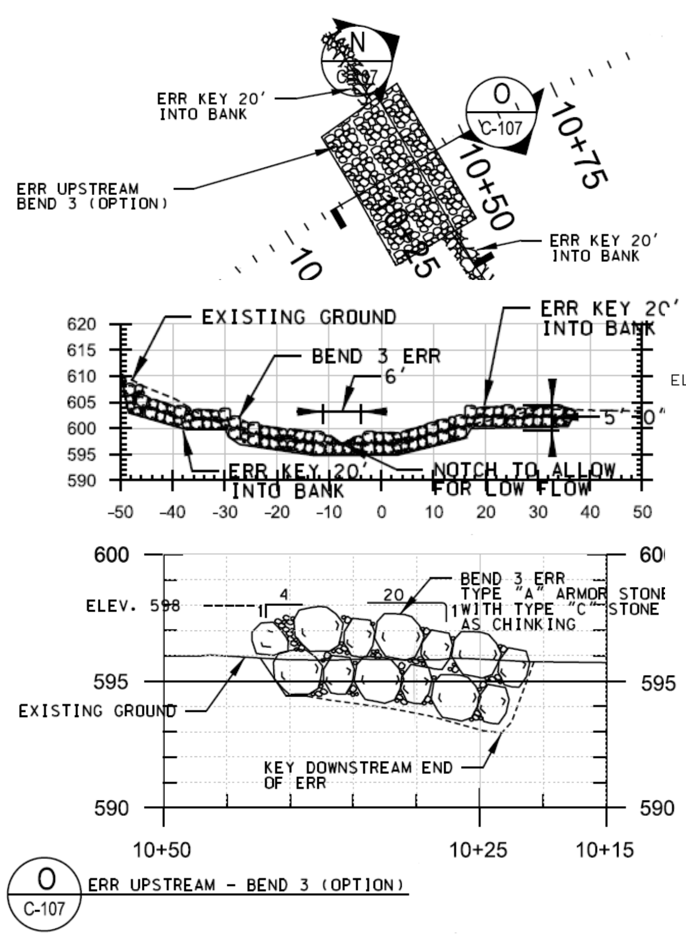
Dirt work “roughing in” location for ERR for lake overflow from historic hand-dug lake at Camp Miakonda.

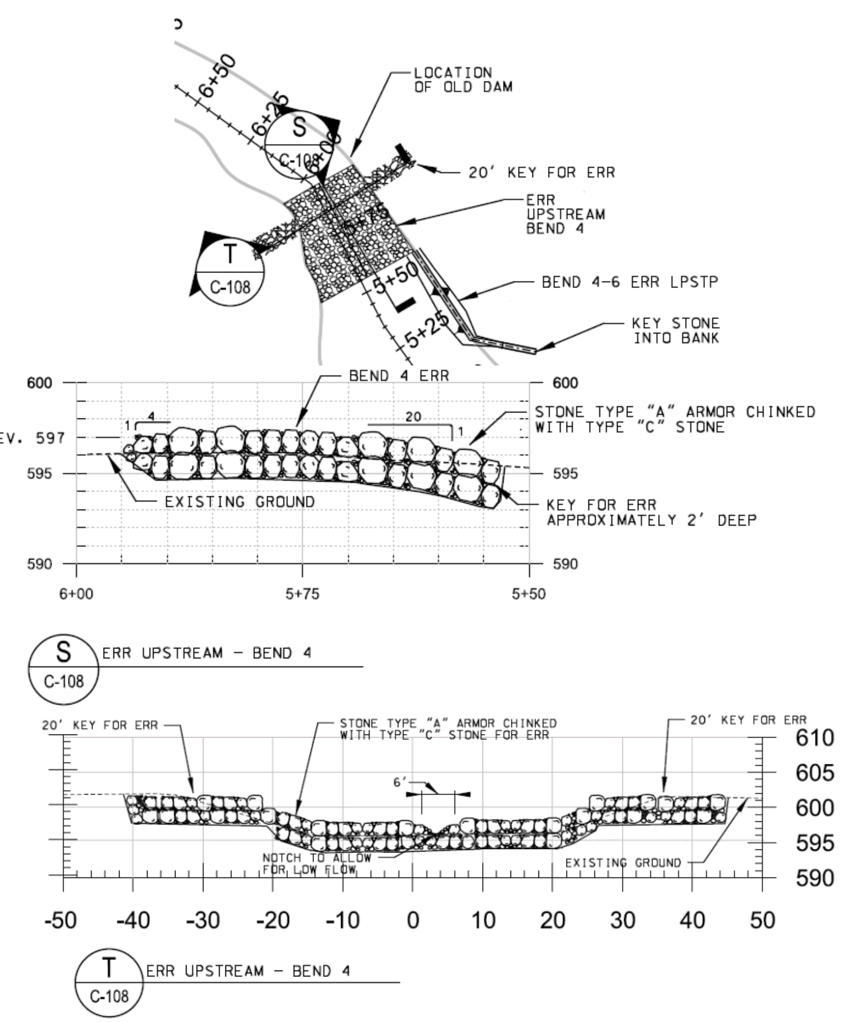
Bank protection starts with plugs and/or poles before it receives soil to cover base ends of poles, then stone will be placed.

Bed protection of pool begins first, roughing in stone based on project needs (elevation control, fish passage [slope], and energy dissipation).

Finished ERR is sloped at 20 to 1, built of a well-graded, self-adjusting, self-filtering stone that was well-choked with smaller stone and gravel-cobble to fill in voids.

Example Plans and Drawings





Estimating Your Time and Materials

Grade Control is never cheap, but a systematic, well-designed comprehensive project in most cases will save money in the long run (project life cycle) compared to a Band-Aid helter-skelter approach. As the project increases in scope, and the need for GCS expands to a longer stretch of river or stream, keep in mind a series of smaller structures will typically cost less than one larger one.

Maintenance and Monitoring

Due to their complexity, all Grade Control projects should have an As-Built Survey performed immediately after construction to accurately measure exactly what was built. This provides base-line data for monitoring comparisons. With any structure, flanking is of utmost concern. Robust, well-constructed keys up both banks, that go “up the hill into roughness” should reduce those concerns, but bank stability and channel meandering upstream of the GCS should be closely monitored. As with any stone structure, subsidence can be a concern, although effective filters, or the use of self-filtering stone, can possibly mitigate this concern. Scour or deposition patterns within the scour hole should be closely monitored, especially at the downstream end of the GCS. Monitoring condition of vegetation should be watched and underperforming sections of plants analyzed, and either replaced or augmented. Possibly the initial plant species used was inappropriate and needs to be changed.

Definition and Purpose

Usually installed as a series or as a cohesive system, a Bendway Weir (BW) is a low-elevation stone structure that extends from the streambank, angled into flow (upstream) 70 degrees from a line tangent to the intersection of the BW to the bank. BW are level-crested (flat), at a height one ft above the base flow water surface elevation. Water flowing over the BW is redirected at an angle perpendicular to the longitudinal axis of the weir. Since the BW is angled upstream, this redirects the erosive energy (flow) away from the outer bank of the stream and reduces velocities within the weir field by approximately 50 percent, even when the weir is overtopped by several ft of flow. Erosive helical flow, created as the stream travels through a bend, is broken up. This reduced flow velocity creates a resting area (within channel refugia) and increased diversity and complexity of depth, velocity, and substrate for fish.

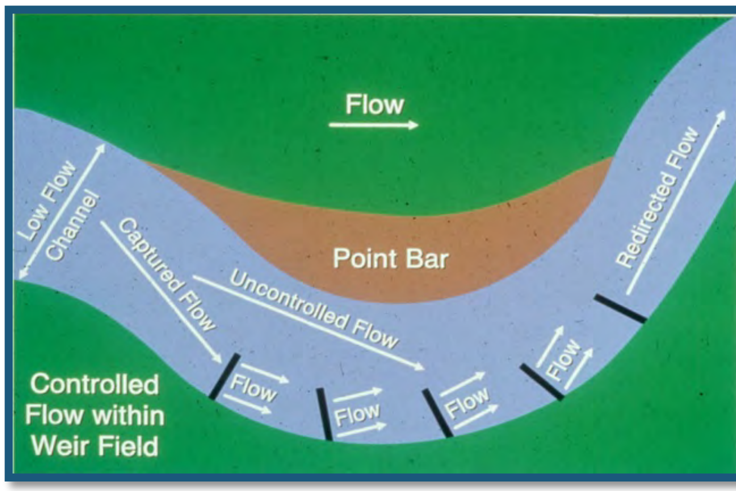


Image 1: Example Bendway Weir placement and resulting flow indicated by lines. Dave Derrick.

> ***Bendway Weir design generally affects channel alignment, flow distribution and velocities across the entire channel, and at times, a great distance downstream of the last weir. There is no "cook book" solution, and each case must be evaluated and examined for unique characteristics and circumstances to create a design that will prevent the generation of problems elsewhere in the channel system.***

A study on the Little Blue River, KS, showed that installing BW, sloping the bank to 4 on 1, and installing multi-species riparian plantings in a long eroding bend (14.9 acres lost in 23 years) increased species richness of fishes by up to 260% and individual numbers over 24,000% (7 individuals to 1,704 fishes after 5 years). Slower near-bank stream velocities in over-widened rivers can allow for deposition and plant colonization within the BW field. In addition, the deepest and highest velocity section of the river (thalweg) is moved from the toe of the eroding outer bank of the bend to a smoothed alignment off the stream end of the weirs.

Methods typically combined with, or connected to, Bendway Weirs:

- Longitudinal Peaked Stone Toe Protection (LPSTP)
- Longitudinal Fill Stone Toe Protection (LFSTP)
- Vegetated Keys
- Locked Logs

Practice Applicability

The following are a list of possible applications and outcomes from installing Bendway Weirs:

Image 2: Bendway Weir and thalweg (bubble line) at Camp Miakonda in Sylvania, OH. Kyle Spicer

- BWs have been successfully built using single 5 ft long stones in small streams and can be up to 1,400 ft long in the Mississippi River
- One of the few bank erosion reduction methods that changes direction of flow and that flow redirection can be predicted (even downstream of the project)
- The reduction in stream forces within the weir field can result in some sediment deposition between weirs and on the outer bank
- The reduction in stream forces immediately adjacent to the bank, combined with sediment deposited on the outer bank (seeds, nutrients), can benefit volunteer or planted vegetation
- Aquatic diversity and complexity is increased (depths, substrate material, velocities), and edge length is increased
- Loose large woody debris can be naturally recruited (or placed) between Bendways, and especially immediately DS of the last Bendway Weir in a series. Locked Logs can also be installed under the BW during construction
- Costs are competitive or lower than many traditional methods
- Bendway Weirs blend well with many other bank protection methods
- Bendway Weirs can at times be retrofitted to existing projects to reduce concentrated flow

> ***Bendway Weirs, like all redirective methods, will usually reduce, but does not eliminate bank erosion because the primary function is thalweg management and energy dissipation.***

Image 3: Bendway Weirs at Camp Miakonda in Sylvania, OH. Kyle Spicer

Bendway Weirs have been implemented all over the world. Several restoration projects in the Maumee Area Of Concern (AOC) are among those success stories. The Ottawa River bordering Camp Miakonda in Sylvania, Ohio, has two separate sets of three Bendway Weirs each, helping to reduce the scouring impact of the river on its eroding outer banks. One set of BW were top choked with smaller stone, resulting in a walkable BW that can be utilized as a fishing platform (pier) for Scouts. Several Single Stone Bendway Weirs (SSBW) were also installed in Hartman Ditch. By utilizing this redirective method, the quality and amount of in-stream habitat has increased, erosion to the bank was minimized, and the stream thalweg has been realigned just riverward of the ends of the weirs. Other local restoration projects with BW include the Ottawa River on University of Toledo campus, Hill Ditch at The Toledo Botanical Gardens, and the Secor Dam removal project.

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Preparing for Bendway Weirs

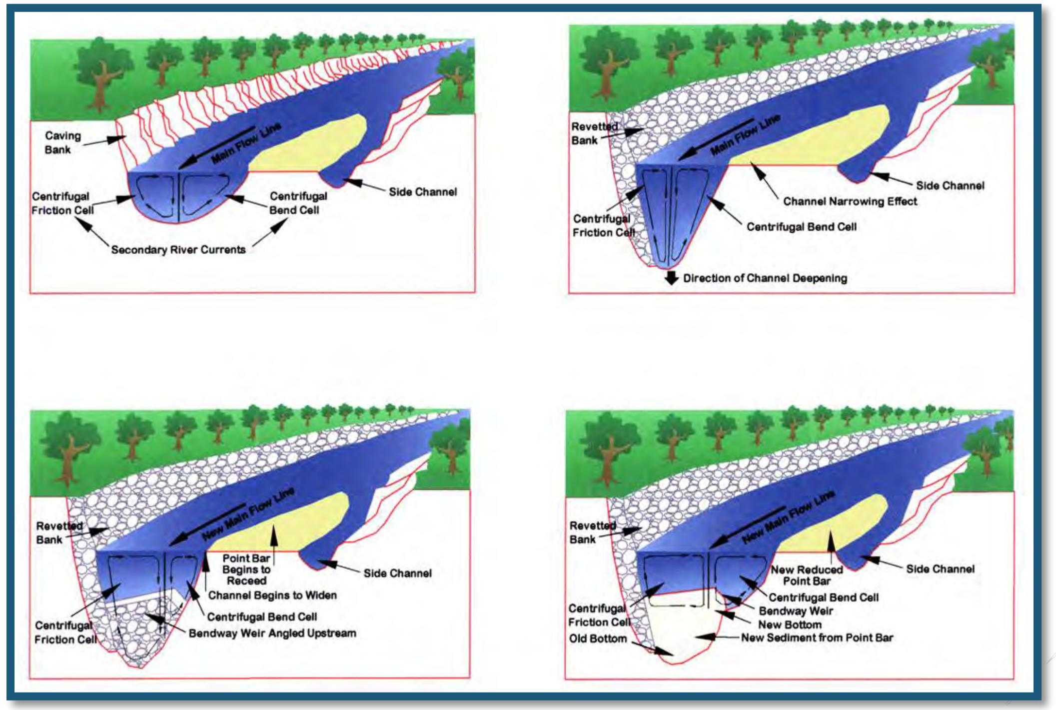


Figure 1: From Rob Davinroy, St. Louis Corps

Constructing Bendway Weirs usually falls between two categories, depending on the size of the body of water. The general concept of construction can be described as below:

On larger rivers:

- From barges: Use bulldozers or dragline to push rock off barge and into river
- End dump method (build key, then dump rock off key into river forming a wide "road like" weir)
- After working to the river end, track hoe can work backwards toward shore building a taller, narrower weir

On streams and smaller rivers:

- Machine-built (2 methods)
- Build “road-like” key from top bank, then working from key, construct remainder of weir
- Working from point bar, dig key, construct key, then weir

Limitations

- Suitable for large rivers to medium-sized streams. A section of erodible un-vegetated point bar will allow the BW field to shift the entire river and erode the riverward part of the point bar formation.
- In narrow streams (base-flow water width is less than 20 feet) Single Stone Bendway Weirs might be applicable, but caution is advised as over-constricting the stream will result in erosion on the unprotected (opposite) bank.
- Larger equipment will be needed for construction.
- Can be expensive if large graded stone is not locally available.
- Design considerations must include effects of altered flow pattern at site and immediately downstream and upstream
- In cobble or gravel bed streams the redirective effects of Bendway Weirs are limited in the downstream direction due to the resistance of the bed materials not allowing the channel thalweg to be relocated by stream energy redirected by the weirs (which is a main objective of BW use). A pilot channel for the relocated thalweg can be dug in tougher bed material.
- In tight radius bends, caution is advised when bend radius to channel width at bank-full (R/W) is less than 4 to 1.
- In bends with an arc angle greater than 60 degrees LPSTP might have to be placed between BW toward the downstream end where high flow over the point bar will imping on the outer bank between BW.
- If point bars are tall and built of cobble or gravel, increased velocities in that area might not be able to erode the point bar.
- Very few Bendway Weir projects have been built in high velocity, supercritical flow, or steep-sloped stream systems.

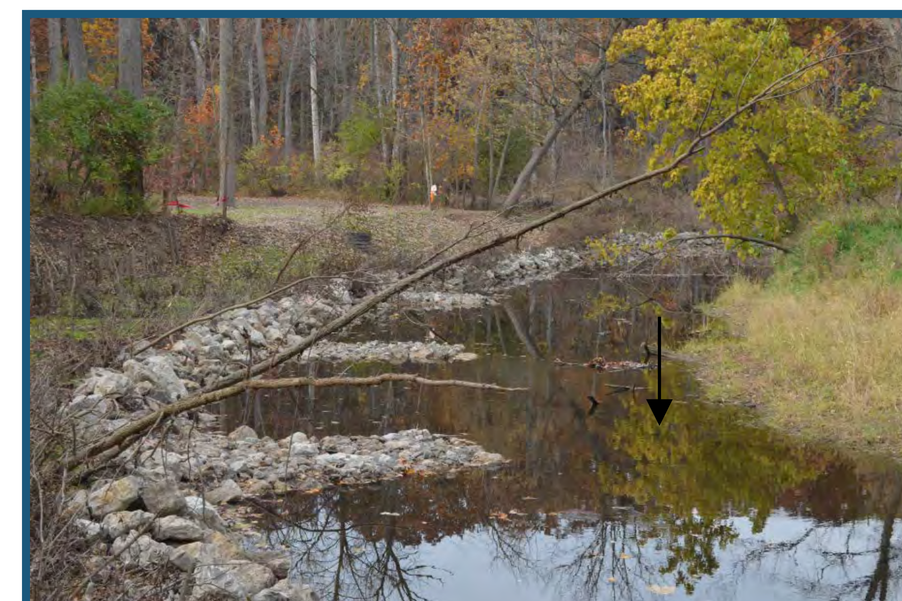


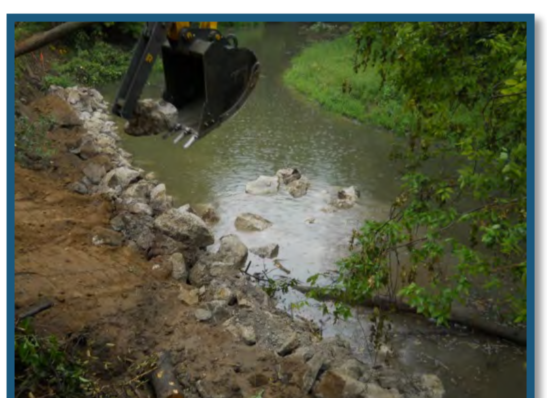
Image 5: Bendway Weirs, Ottawa River, Camp Miakonda. Kyle Spicer

Guidelines and Tips for Construction

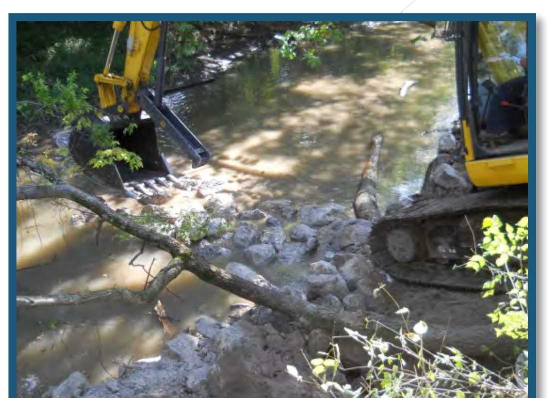
Based on project goals, the required new location of the thalweg of the stream should be mapped out (upstream, through the project, and downstream). The upstream Bendway Weir (BW) should be positioned at a point in the bend where the bank is stable, and angled 70 degrees from a line perpendicular to a tangent line where the BW intersects the bank. The high flow attack angle into this BW should be less than 30 degrees from perpendicular into the BW. Flow over the bank-end of the most upstream BW at an angle perpendicular to the longitudinal axis of the BW, should intersect the downstream (DS) BW at a point 1/3 of the length of the BW from the bank. This spacing should continue until the perpendicular line from the bank end of a BW does not intersect the outer bank of the bend DS of that BW. The lengths of all BW should be built just short of the anticipated thalweg location, considering river end slope of the BW and drag from the BW. High flow attack angles into the BW field should then be studied. Any attacking flows hitting the outer bank of the bend without intersecting a BW will typically require some type of bank protection from weir to weir in that area. The amount of river that needs to be controlled and redirected (flowing over the weirs in the BW field) should be studied. The shift of the active channel toward the point bar should be analyzed to make sure the river can erode the section of point bar that needs to disappear.

- The stream should have a stable bed.
- Stream width at base flow is at least 20 feet.
- The height of a BW is usually one foot above the base flow water surface elevation (typical low flow or 80 percent exceedance). Every Bendway Weir needs to be keyed into the bank.
- The crest elevation of the weir needs to be lower than any flow that can erode the bank.
- Weirs can be used as a single practice or in combination with other toe protection, large wood placement, and/or bio-engineering practices. See: Longitudinal Peaked Stone Toe Protection (LPSTP), Keys, and Living Vegetation for examples. The crest of the BW should always be lower than the crest of the bank protection used.
- Entrance and exit conditions to the bend should be stable and accessible by heavy equipment. High flow attack angles into the weir field should not change over time. If they do, then bank protection might be needed between all BW.
- Minimal disturbance to the upper bank is desired if vegetated, or bank should be sloped to a geotechnically stable angle and vegetated, usually planted on a grid (with dense rows of adventitious poles to slow on-bank currents)
- Available sunlight may preclude use of vegetative practices, or requires shade-tolerant species.
- Some "bank scalloping" between weirs is acceptable when used as a single practice. Keys should be long (deep into the bank) and robust.
- Deeper pools formed at the stream end of the weirs will improve aquatic habitat and help to relocate the thalweg in both sand and gravel-cobble-boulder bed streams.
- Stream reach has a radius of curvature to stream width ratio greater than 6 (i.e. 40 foot wide stream must have at least 240 foot radius).

Example Construction Sequence

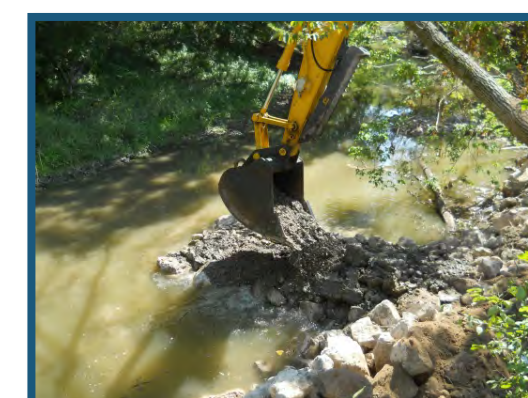


Construction begins by placing smaller stone as a filter, then buckets of well-graded stone. BW must be well-connected with the key stone.



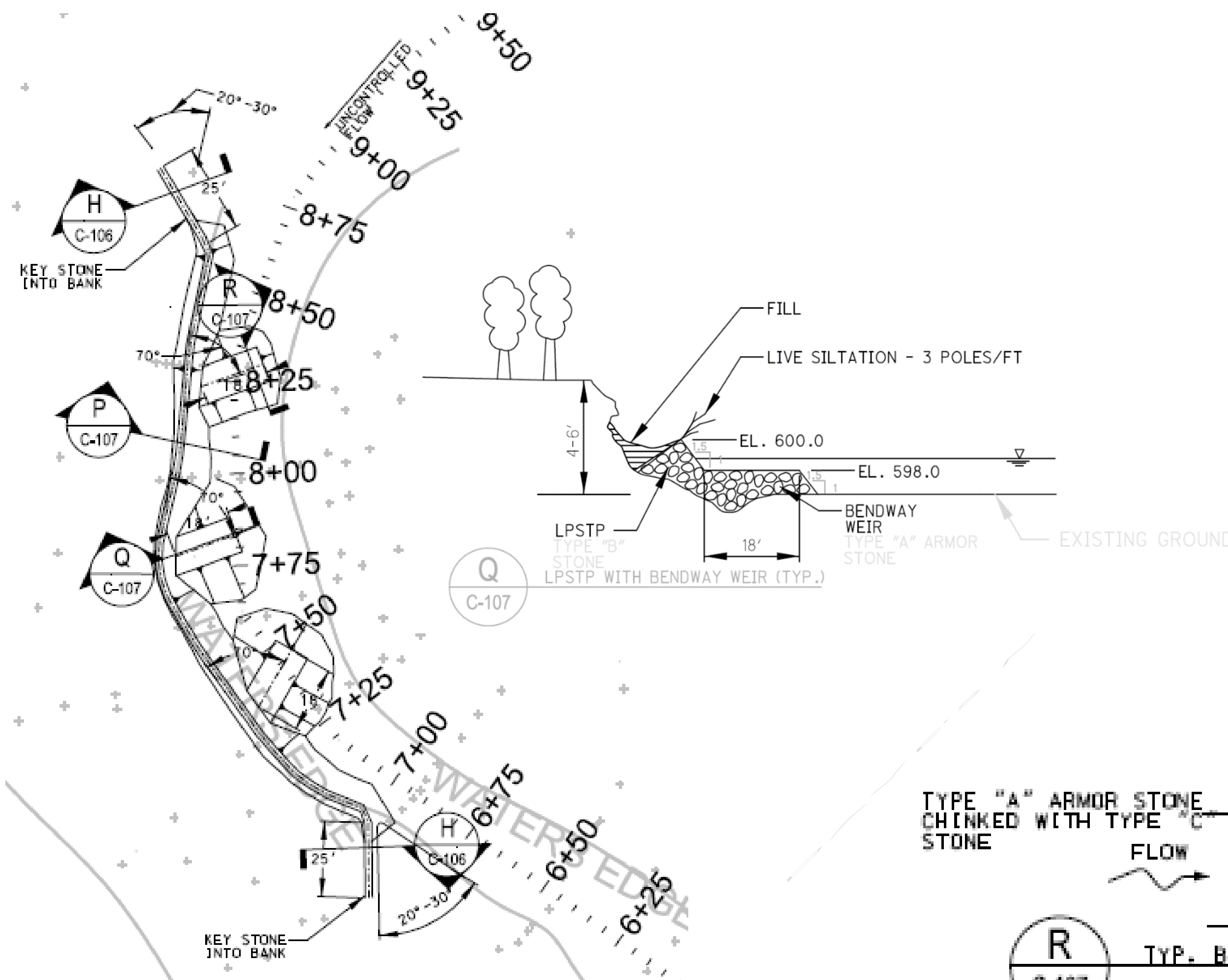
The BW is shaped as additional stone is placed on top. For medium – large streams, a majority of the stone is placed one bucket of well-graded stone at a time.

The typical BW has now taken shape. If fishing access is desired the BW can be top-choked with smaller stones and gravel.



These BW in particular were heavily choked, to create a smoother surface for people to walk on and gain access to the river.

Example Plan Drawings

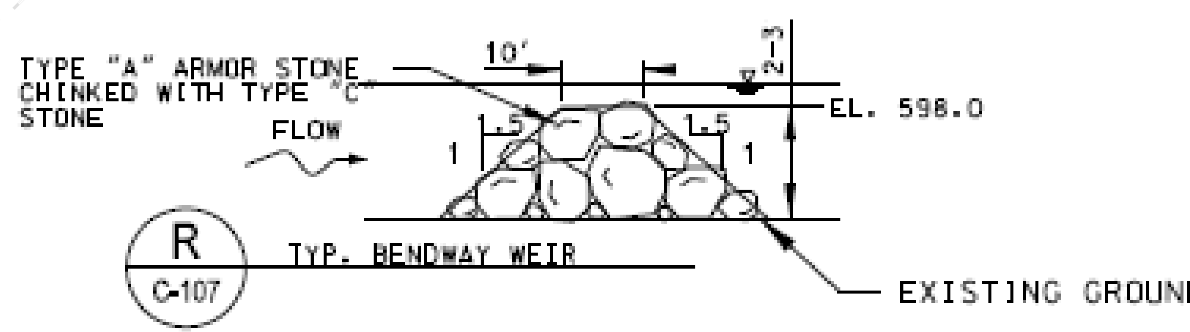


Estimating Time and Materials

Typical BW installations have been significantly less expensive that traditional direct, continuous bank stabilization methods. Direct comparisons of redirective methods on similar bends between Bendway Weirs and Rock Vanes (RV) or Bank Barbs (BB); have shown that BW are 1/3 the cost, 1/3 the material, and 1/3 the machine time of RV or BB.

Maintenance and Monitoring

Due to their complexity, all BW projects (every project actually) should have an As-Built Survey performed immediately after construction to accurately measure exactly what was built. This provides baseline data for monitoring comparisons. With any structure flanking is of utmost concern. A robust, well-constructed key that goes "up the hill into roughness" should reduce those concerns, but bank stability upstream of the BW should be closely monitored. As with any stone structure, subsidence or can be a concern, although effective filters, or the use of self-filtering stone, can possibly mitigate this concern. Due to their location within the highest velocity portion of the stream or river, BW are susceptible to undersized stone being mobilized during high velocity flow events. Since BW are relatively low elevation structures, and take up a small cross-sectional area, shortening of the BW (reduction in length due to excessive scour at the river end of the BW) has been very minor in dozens of projects studied. Launching due to excessive scour on either the upstream or downstream sides of a BW has never been encountered, but should be monitored, especially when using large blocky stone, or with Single Stone Bendway Weirs. Leaching or piping of material from underneath a BW with a top width of 4 times the D100 dimension of the stone used in construction has never been observed, but should be monitored, especially with SSBW.



Definition and Purpose

A Key is a structure made of stone, wood, plants, or a combination of such material that connects bank stabilization works, or a river training structure, to the riverbank, reducing the chance of the stream to bypass, or "flank" the project works. A trench is dug into the bank of a river or stream (potentially up to top bank and into the overbank), with adventitious live poles placed on one or both sides of the trench. Soil is placed to cover the basal ends of the poles, and the trench is then filled to within 1 foot of the surrounding soil with a well-graded, self-adjusting, self-filtering stone. The stone is then choked with a cobble-gravel-sand mix (possibly obtained from the stream bed), backfilled with soil, and overfilled with 1.5 feet of additional soil for settling.

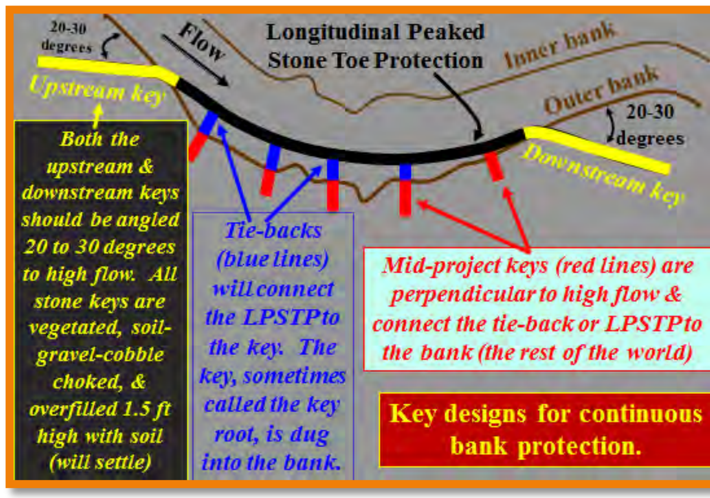


Figure 1: Key installation connected to Longitudinal Peaked Stone Toe Protection (LPSTP). Derrick.

Keys are cheap and easy insurance for any stream or river project. They serve to connect a project's structures to the river bank, reducing the chance of the river flanking the project.

Image 1: A flanked grade control structure. Derrick

The biggest key to stability in a stream project is the Key! A Key needs to go up the bank and tie into roughness. If roughness is not available, it should be planted. The picture on the left is what happens to a project with either short or improperly installed Keys. If they are built of large blocky stone, water tends to flow through the voids between stones. When stream forces interact with the Key, the stone will not self-adjust. It's important when using stone that it has the ability to "launch," or self-adjust, when the Key is undercut. Because of this, Keys are the cheapest and easiest project insurance to include in development and planning. Keys can be used to protect bank protection, grade control, river training structures, plants, and more.

Practice Applicability

Image 2: Locked Log selection at Camp Miakonda in Sylvania, OH. Kyle Spicer

The Key itself should be heavily vegetated so as to slow flow velocities over it. Slower water on the bank and overbank means less chance of flanking. Vegetation is designed to act like a Living Dike (closely spaced adventitious rooting poles, and/or rooted stock plants, and/or container plants). In some cases the length of the Key can be extended with vegetation alone, or other materials like buried anchored logs (with vegetation), or a poorer quality stone with vegetation installed.

Willow and dogwood poles are the easiest and most successful plants to use for this purpose. The poles can be harvested with long-handled loppers, or a small chainsaw, and then stripped of excess leaves or extraneous branches (leaving some is appropriate). The poles can be bundled and then soaked up to two weeks before their installation. Studies have shown that Black Willow soaked for 10 days can put out up to 2,600% more roots!

If funding is scarce, put money into the upstream Key (extend and reinforce it). If the upstream Key gets flanked, the entire project will be compromised.

Image 3: Thalweg displacement by Locked Log in Ottawa River at Camp Miakonda, Sylvania, OH. Kyle Spicer

Keys have been implemented all over the U.S.A. Several restoration projects in the Maumee Area of Concern (AOC) are among those success stories. The Ottawa River bordering Camp Miakonda in Sylvania, Ohio, has multiple Keys securing LPSTP, Bendway Weirs, Single Stone Bendway Weirs, Bioengineering, and Grade Control. By protecting the investment in project structures, the quality and amount of in-stream habitat has increased, erosion to the bank was minimized, and the stream thalweg has been realigned, all while being safely insured that the river and surrounding tributaries do not bypass the projects. Other local restoration projects with Keys include the Ottawa River on the University of Toledo campus, Secor Dam decommissioning, and Hill Ditch within Toledo Botanical Gardens.

Methods typically combined with, or connected to, Keys:

- Longitudinal Peaked Stone Toe Protection (LPSTP)
- Bendway Weirs
- Grade Control
- Project Vegetation

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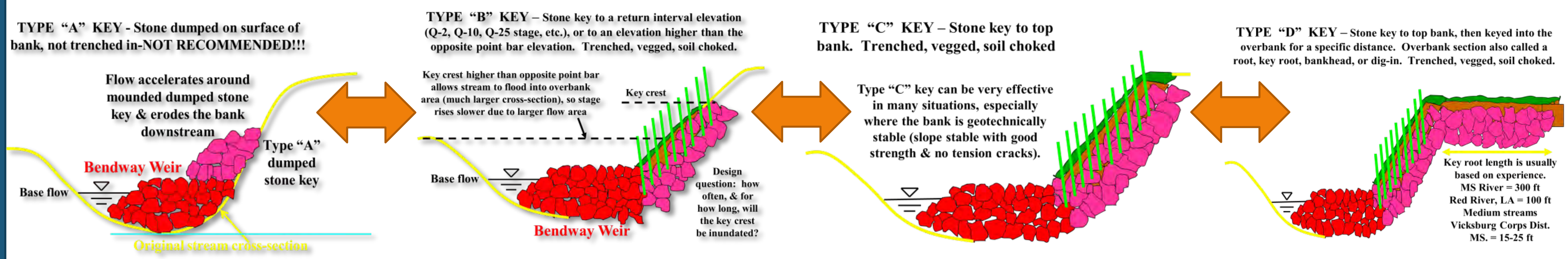
Preparing for Keys

Keys are best built of self-adjusting (well-graded), preferably self-filtering stone. If you cannot locate self-filtering stone, a granular filter might be needed. Stone used in the Key can be the same used as bank paving, Bendway Weirs, or Longitudinal Peaked Stone Toe Protection (LPSTP).The amount of stone in a Key should equal or exceed the amount of stone used per lineal foot in the bank protection or river training structure. The design for Keys must factor in soil type, bank competence (tension cracks or visible failure planes), active failure areas, vegetation (or lack thereof), and height of bank. Stream or river size, flow velocities, flood crests, durations, and recurrence intervals must be factored in as well. There are no rules of thumb for all of this.

There are four different Key Variations:



Limitations

- If a Key cannot be dug into the bank, i.e. bank is too tall to excavate, there exist environmental or land ownership issues, or an archeological site is present, etc., then a portion of the bank will have to be paved to provide protection from flanking.
    - Rule-of-thumb for downstream paved distance from a dike is three times the sum of the maximum bank height and maximum scour depth. Upstream paving from dike equals the sum of the maximum bank height and maximum scour depth.
- Bendway Weir (BW) Keys are the most difficult to build. Since the crest (top) of the BW is only 1 ft above the water, the location where the BW ties into the river end of the Key (toe of the bank) is mostly underwater. It's hard to dig out and maintain the required continuous section (thickness) of the Key in non-cohesive bank materials.
    - In this case, it might be wise to double the volume of the Key in this critical area to over-compensate for the possibility that the original Key cross-section was not completely excavated.

General Guidelines for Construction

- Keys should go up bank and far enough back into the overbank so river migration will not flank the Key. Analyze the meander belt width of the stream or river to determine if the Key can get flanked.
- Minimum Key width should be two times the D-100 of the stone used.
- Any continuous bank protection method, (LPSTP, bank paving, LFSTP) must be deeply keyed into the bank at both the upstream and downstream ends, as well as at regular intervals along its entire length. A spacing rule-of-thumb for Keys in flat-sloped sand bed water bodies:
    - 50 to 100 foot intervals on smaller streams, one to two bank-full channel widths on larger waterways.
- Keys at the upstream and downstream ends of LPSTP should not be at a 90 degree angle to the LPSTP structure, but at 20 to 30 degrees to high flow (or the bank), then curved away from the stream (greater angle) further from the stream (see Figure 1).
- Volume of material per foot of Key should equal or exceed the volume of material per foot in the LPSTP or river training structure.
- Keys should be vegetated to slow flow velocities over the Key. Slower water on the bank and overbank means less chance of flanking. Key length can be extended with vegetation alone in some cases.

Example Construction Sequence

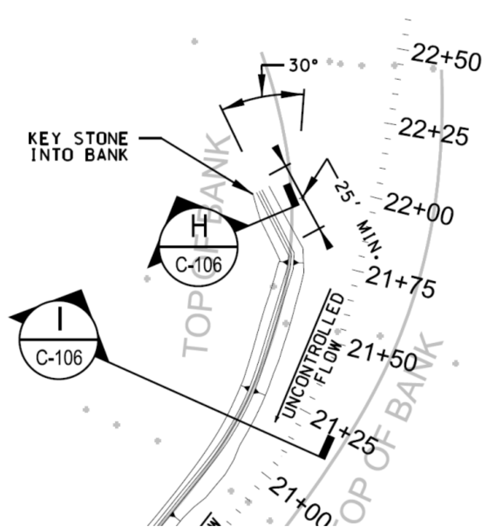
After calculating the appropriate size and direction, and before the LPSTP installation, a trench is dug for the Key.

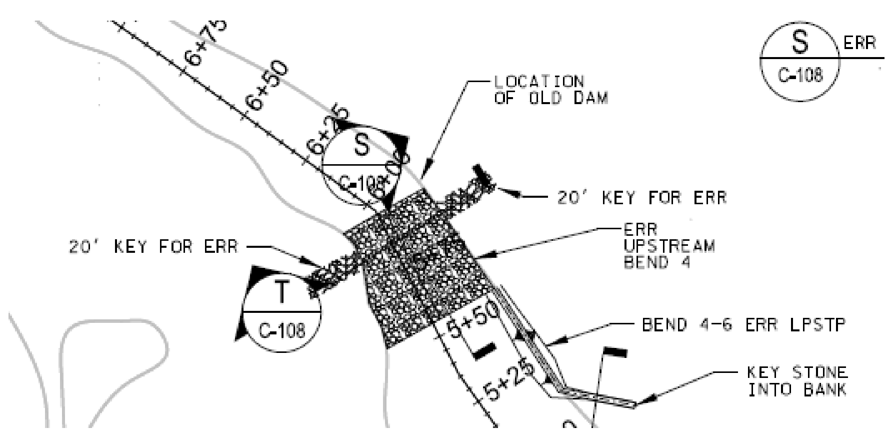
Willow and/or dogwood poles are then placed within the trench, against one or both sides. Make sure the ends of the poles are in the water table, or the capillary zone.

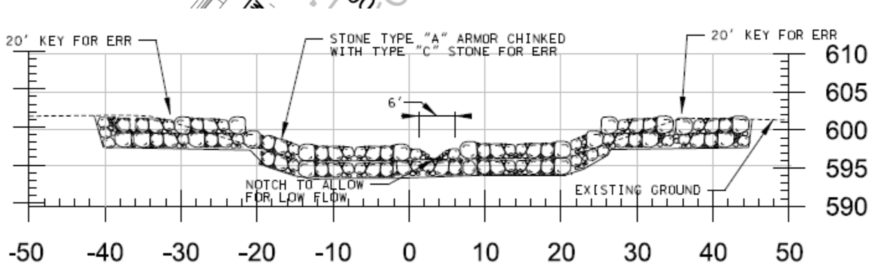
Self-filtering stone is then placed within the trench, taking care to not disturb the recently installed poles. If not able to use self-filtering stone, a granular filter is put down first.

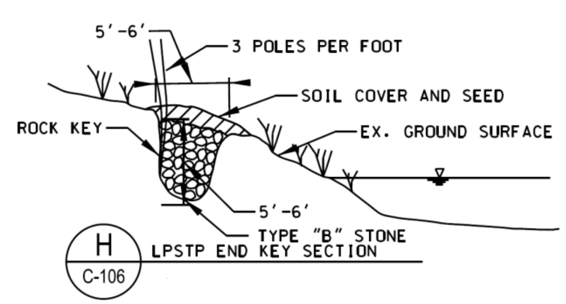
The stone is then backfilled and overfilled with native soils to compensate for any potential settling. The soil is not compacted. Seed heartily and generously!

Example Plan Drawings









Estimating Time and Materials

Incorporating Keys and understanding their necessity when it comes to river and stream projects is important, as catastrophic failure can occur, rendering the project useless! When viewed as "extensions" for structures like Bendway Weirs (BW) and Longitudinal Peaked Stone Toe Protection (LPSTP), it's easier to understand the amount and size of stone required to secure your initial investment. Keys also take little time to complete, depending on the recommended type for your project. In many cases stone for the key can be dumped directly into the key trench from an articulating front end loader, not bucket-at-a-time from the track hoe.

Maintenance and Monitoring

Keys require little maintenance; however it is important to monitor their condition within a year after implementation, especially during and after high flow events. Monitor vegetation in Key for condition, growth, and debris accumulation. If the vegetation is laid over, in what direction (upstream or downstream) is it pointed? When possible, if there is any damaged or missing vegetation, replant it. Dead vegetation still fulfills the need for roughness, and oftentimes creates more roughness than living plants, however if the project is in its early stages of recovery, it's recommended that replanting occurs when possible. Deposition or local scour on the bank or overbank may occur, while in-channel scour or deposition near the toe of the Key and area where the Key connects to the structure can also be of concern.

Bioengineering

Living Dikes - Camp Miakonda, Sylvania, Ohio - Looking downstream

Definition and Purpose

Bioengineering is the use of living plants to stabilize streambanks, wetlands, floodplains, and other near-stream areas. Bioengineering typically uses an assemblage of species to "jumpstart" what nature would do over time. It is essential in these disturbed areas to install dense rows of native plants parallel and perpendicular to flow to capture floating debris, increase roughness, and help shape the project's success by decreasing near-bank and overbank velocities. Several methods for incorporating native plants will quicken post-project recovery and enhance overall long-term project performance. Planting near streams not only protects a project's monetary investment, but enhances the ecological benefits. Rows of adventitious rooting poles (willow, dogwood, sycamore), in addition to rooted stock plants, can be installed perpendicular, parallel to, or in both directions to high flow. These "Living Dikes" create roughness, slow water and encourage nutrients, seed, and sediment to drop out, strengthening the project area.

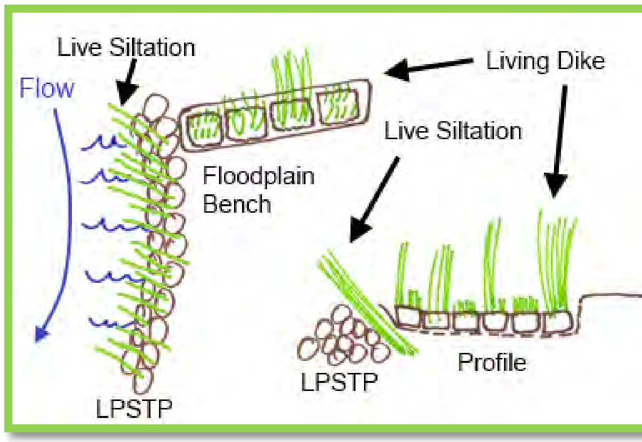


Figure 1: Profile and Plan views of Live Siltation and Living Dikes. Drawing by Dave Derrick

> ***Adventitious rooting plants, in which new plants can grow from an un-rooted cutting, are best harvested and planted when dormant (after the leaves have dropped and before the leaf buds appear in the spring).***

Image 1: Vegetated Key on Ottawa River. Camp Miakonda, Sylvania, OH. Kyle Spicer

Bioengineering can be used to augment existing stone structures like Longitudinal Peaked Stone Toe Protection (LPSTP), Bendway Weirs (BW), and Keys. These structures can benefit from "Live Siltation" and "Vegetated Keys". Both of these methods differentiate themselves from Living Dikes by being integrated with the stone, yet provide similar benefits. A Vegetated Key is a row of native live poles planted deeply in the Key trench before the stone is installed, while Live Siltation is live poles placed on the bank side of the LPSTP before the area is backfilled, resulting in a parallel row of vegetation adjacent to, and hanging over the stream. All of the aforementioned methods for installing native vegetation result in improved performance for any restoration project, assist in stabilizing stone structures, bank and overbank soils, and creating roughness during high water.

Practice Applicability

Image 2: Live Siltation installed along an Engineered Rock Riffle and Keys. Camp Miakonda, Sylvania, OH. Kyle Spicer

Willows, dogwoods, Sycamore, and Cottonwood, in many areas of the USA, typically grow on the lower third of a stream bank, which makes utilizing them for bioengineering purposes ideal since their installation mimics their natural tendencies. If these live poles are planted deep in a trench, the poles will grow slightly further up the bank than would otherwise be found in nature. Other species of adventitious plants (River Birch, Ninebark, Brookside Alder) can be planted further up the bank. Combined with various species of rooted stock and container plants results in dense foliage and robust root systems that can hold the bank together until other slower growing species, or the seed bank establishes. Until then, these species provide shade, cover, vertical and horizontal structure, stabilize and/or lower water and air temperatures (microclimates), help maintain dissolved oxygen levels, and supply carbon to the stream. Essentially, installing these initial pioneer species plants helps to establish positive riparian buffer zone features while preparing a project for its long-term existence.

Willows and dogwood will not be long-term dominant species. They are short-term aggressors that will stabilize the bank quickly post-construction until other more slowly growing species can be established.

Image 1: Live Siltation installed over Longitudinal Peaked Stone Toe Protection at Camp Miakonda, Ottawa River. Kyle Spicer

Although Bioengineering is a broad category that includes the aforementioned specific examples for implementation, utilizing these methods has resulted in countless numbers of successfully grown plants in several restoration projects in the Maumee River Area of Concern (AOC). Ottawa River at Secor Dam Decommissioning Site, The University of Toledo sites, as well as the wetlands, floodplain, and surrounding upland habitat within Camp Miakonda have thousands of native plants installed. Hundreds of willow and dogwood were used as Living Dikes, Live Siltation, and Vegetated Keys. Other local restoration projects with these types of Bioengineering include Swan Creek at Highland Park, and Hill Ditch at The Toledo Botanical Gardens.

Methods Occasionally Combined with Bioengineering:

- Keys
- LPSTP and LFSTP
- Engineered Rocked Riffles
- Floodplain Benches
- Bendway Weirs and Single Stone Bendway Weirs

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Preparing for Bioengineering

The single most important feature of the described bioengineering practices is the use of the appropriate plant species. Take careful consideration of plant requirements (soil type, elevation above the stream, water table fluctuation, sun, shade, aspect, etc.), but specifically, what local plants would thrive in the environment they're needed to be installed in. Willow, dogwood, and several other species are adventitious rooting plants, meaning that a new plant can grow from an un-rooted cutting. These species require a lot of water, prefer a dynamic landscape (disturbance and stress are handled well) are fast growing, short lived (40-80 yrs), early pioneering species, and therefore will not become the long-term dominant climax community species that will remain for decades. Over the years these plants will be shaded by slower growing, longer lived, later successional species.

Image 2: Crews install Live Siltation at Camp Miakonda, Hartman Ditch, Sylvania, OH. Kyle Spicer.

A list of known, successfully implemented, adventitious rooting plants follows:

Banker's Willow	*Salix x cottetii*
Streamco Willow	*Salix purpurea*
Black Willow	*Salix nigra*
Pussy Willow	*Salix discolor*
Red Osier Dogwood	*Cornus stolonifera*
Silky Dogwood	*Cornus amomum*
Buttonbush	*Cephalanthus occidentalis*
Sycamore	*Platanus occidentalis*
Cottonwood	*Populus deltoids*
Box Elder	*Acer negundo*
Speckled Elder	*Alnus rugosa*
Elderberry	*Sambucus Canadensis*
Elm	*Ulmus Americana*
Bow Wood, Hedge Apple, Horse Apple, Osage Orange	*Maclura pomifera*
River Birch	*Betula nigra*
Black Locust	*Robinia psedoacacia*
Northern Catalpa	*Catalpa speciosa*
Mulefat	*Baccharis salicifolia*

Limitations

- Plantings need to be closely monitored for insect infestation and mortality; some spot replanting can be expected during the second growing season. If all plants in an area are dead, a more thorough investigation needs to be undertaken.
- Although willow and dogwood can sustain themselves in wetter conditions, too much water can cause the plants to not take root. Adaptive management is always encouraged when dealing with plantings.
- Is irrigation needed? Weed control? Fencing for browsing control and buck rub?
- Soil needs to be geotechnically stable.

General Guidelines for Construction

- First look up to analyze for amount of light and overhead power lines, then look down for suitable soil and pipeline right-of-ways, then look around for exotic plant competition, and where/if the plants of choice are growing naturally. Plants on opposite banks might grow in different elevation bands. If plants are not found naturally, why aren't they? What historic plants typically found in these settings are missing? Why?
- Plant materials can be obtained through commercial growers, NRCS plant material centers, grown in-house, or harvested from the wild.
- Harden off-rooted-stock plants (place outside greenhouse) before planting.
- Harvested cuttings should be kept moist and out of direct sunlight.
- Some cuttings benefit from soaking. Black Willow demonstrated 2,600% more roots when soaked for 10 days in one experiment. Water that plants are soaked in should be fresh and oxygenated.
- It's important to have good soil-to-stem contact, this must be carefully specified in contracts

Example Construction Sequence

Plants are harvested, bundled, tied together, placed in the shade, and then soaked until installation.

Live Siltation

Living Dikes

Vegetated Keys

After LPSTP is placed, some soil is added to cover the LPSTP, and then live poles are installed over the LPSTP (parallel to the body of water).

Living Dikes can be straight or curved (Smiles), to capture and slow water flow. They must be keyed into the bank using additional vegetation.

Live Siltation

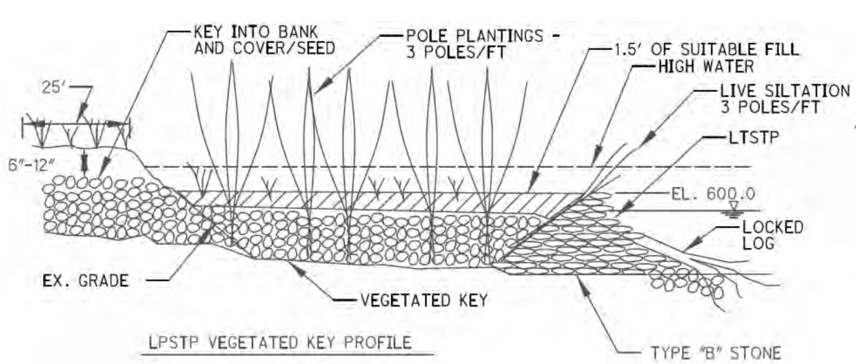
Living Dikes

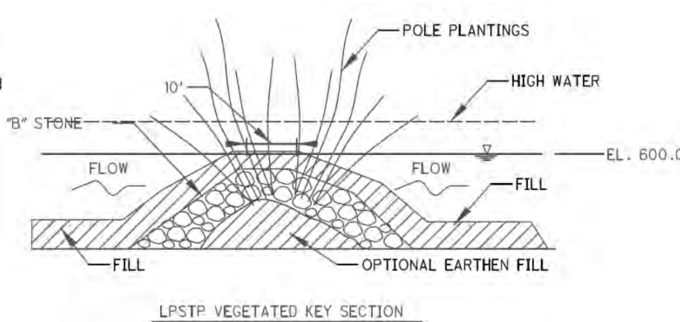
Vegetated Keys

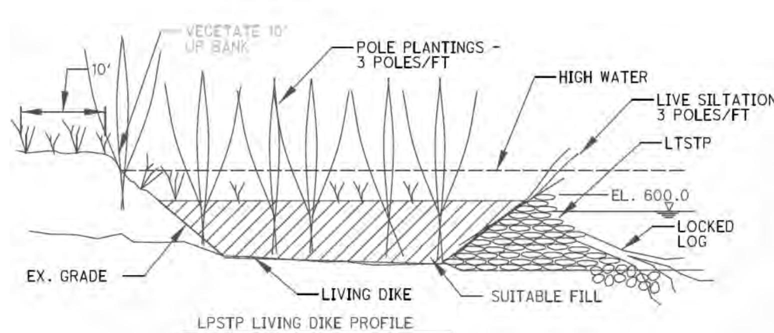
Plants are installed by hand after Keys are dug and before rock is installed.

Vegetation is backfilled and secured; typically overfilled to accommodate settling soil. Now just add time!

Example Plans Drawings







Estimating Time and Materials

If obtained commercially, the nursery might need some lead time. Instead of purchasing the hundreds to thousands of plants needed to support many stream restoration projects, consider reaching out to local agencies, park districts, and/or consultant groups that could potentially supply your project. Many local park districts have the ability to reserve maintained tracts of land containing dogwood and willow for any organization needing vegetation (especially if you contact them before their prescribed burn season). Take into account contractors or consultants who also have access to local greenhouses, and could help supply your project cheaper than if you were to buy the plants retail. Consider hosting a hands-on workshop to allow attendees to harvest and installed the needed bioengineering. Living Dikes, Live Siltation, and Vegetated Keys can be done while the structures they're associated with are also being built, so additional time during on-the-ground implementation is minimal.

Maintenance and Monitoring

Unlike stone structures, bioengineering practices can be detrimentally affected by a number of different factors. Weather, wildlife, and people all play a factor in whether or not you'll need to replant or otherwise repair any of these bioengineering practices. Low lying and near shore plants could be subject to inundation or flooding, deer and other wildlife might negatively affect your work through grazing or antler rub. Finally, depending on the location of your project, the human element might be cause for alarm too. Close monitoring of the project within the first few years will help to gauge the need for additional work. If visible growth or sprouting doesn't occur after the first growing season, understand why plants are not growing, redesign as needed, then replant.

Definition and Purpose

Locked Logs are entire trees, large or small, with root wads attached, anchored under, or within, in-stream structures such as Bendway Weirs, Longitudinal Peaked Stone Toe Protection (LPSTP), or Longitudinal Fill Stone Toe Protection (LFSTP). The Locked Log is place on the bed and the structure stone is placed on the locked Log, holding (or locking) it in place. The Locked Logs should be underwater at all times (if possible), angled downstream relative to the bank, and angled downhill while also protruding into deeper scoured areas. Locked Logs provide horizontal and vertical structure, hydraulic roughness, and areas of refugia for fish.

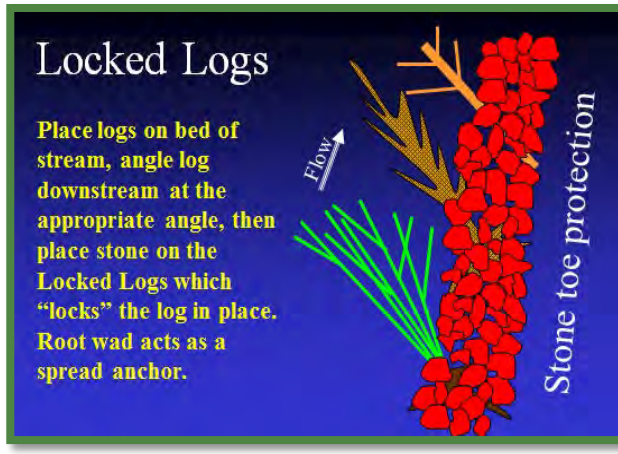


Figure 1: Locked Log Installation. Drawing by Dave Derrick.

Locked logs can be placed with staggered heights to better slow water down at various flood stages. Proper hydrologic studies during planning are important in determining these levels.


Image 1: Ice buildup around Locked Logs in Missouri River. Dave Derrick

These structures serve to partially realign the thalweg away from the eroding bank, reducing pressure from the stream's flow. This ultimately helps reduce bank erosion. An example of thalweg realignment can be seen during initial ice formation in some stabilization and/or restoration projects. Ice will form first in slower water and will become thicker than other areas. The thick ice near the bank will stay put after the "ice out" and will melt in place so that the plants are not sheared and smaller stones are not removed (plucked).

Locked Logs

Methods Sheet

Practice Applicability

The following are functions of Locked Logs/Locked Limbs:

- Provide turbulence, return currents, eddy fences, internal distortion, pressure zones, and flow complexity.
- Establishes diversity and complexity of velocities.
- Creates within channel refugia during high flow events.
- Provides in-stream overhead cover, and horizontal and vertical structure for fish.
- Creates feeding lanes for fish
- Provides solid substrate for benthics.
- Hydraulic roughness dissipates stream energy.

Image 2: Locked Log selection at Camp Miakonda in Sylvania, OH. Kyle Spicer

Locked Logs, like all redirective methods, will usually reduce, but do not eliminate, bank erosion because the primary function is thalweg management and energy dissipation.

Image 3: Thalweg realignment Locked Log in Ottawa River at Camp Miakonda, Sylvania, OH. Kyle Spicer

Locked Logs have been implemented all over the U.S.A. Several restoration projects in the Maumee River Area of Concern (AOC) are among those success stories. The Ottawa River bordering Camp Miakonda in Sylvania, Ohio, has multiple locked logs positioned within LPSTP and under Bendway Weirs, helping to reduce the scouring impact of the river on its eroding outer banks. By utilizing this redirective method, the quality and amount of in-stream habitat has increased, erosion to the bank was minimized, and the stream thalweg has been realigned. Other local restoration projects with LL include the Ottawa River on the University of Toledo campus and at Hill Ditch within The Toledo Botanical Gardens.

Methods typically combined with, or connected to, Locked Logs:

- Longitudinal Peaked Stone Toe Protection (LPSTP)
- Longitudinal Fill Stone Toe Protection (LFSTP)
- Bendway Weirs
- Project Bioengineering

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Preparing for Locked Logs

Three questions should be deliberated in the preparation of or consideration in deciding to use Locked Logs or other wood structures in any configuration.

1. *If it stays, what will happen?*

Like any in-stream structure, keep in mind the structures can capture more debris than anyone might think. It's almost impossible to plan for everything that could flow through and potentially impact your structure, but you can identify the necessary precautions depending on your stream size and/or bend radii. Objects angled downstream and downhill typically collect very little debris.

2. *If it gets loose, or removed by the flow, what happens?*

No matter how much we plan, sometimes nature decides to have a little too much fun. It's important to consider where wood structures might end up and what infrastructure could be impacted.

3. *If it works, how long will it last?*

Keep in mind the project life expectancy. Locked Logs will last longer if they are completely submerged at all times. Slow growing hardwoods, or species of trees that farmers use for fence posts last the longest!

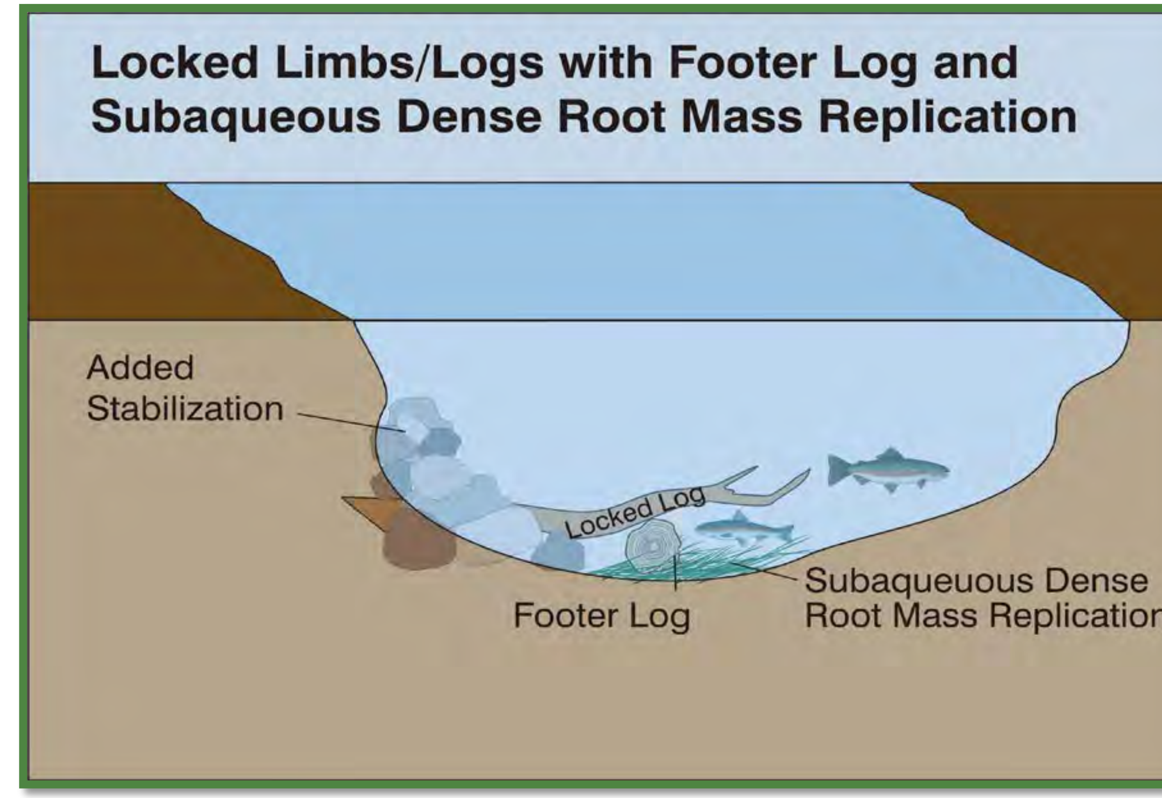


Figure 2: Locked Log design. Courtesy of Ecology and Environment, Inc.

Limitations

- Sufficient depth is needed so that the Locked Logs are mostly underwater, even during base flow.
- Locked Logs are best used in medium to large streams, and up to the largest of rivers.
- Locked Logs can be used in medium to large radius bends, gentle curves, or straight stretches.
- Narrow, tight bends should be avoided.
- Locked Logs should not block more than 15-20% of the width of the stream or 15-20% of the channel cross-sectional area.
- In narrow stream applications, Locked Logs should not aim flow into the opposite bank (small angle relative to the bank).

General Guidelines for Construction

- Locked Logs should always be angled downstream relative to the bank. To determine this range of angles, study patterns of downed trees moved by flow prevalent in local streams should be undertaken.
- Typical angles observed for medium-sized streams are 10 to 35 degrees downstream, relative to the bank. On the Missouri River near Vermillion, S.D., angles varied from 30 to 70 degrees downstream, so do your homework!!
- The spacing of Locked Logs is not critical, can vary, be random, follow observed spacing patterns, replicate natural wood deposition areas, or they can be placed in groups with "bare" areas in between.
- Denser placement will better realign the thalweg, further reduce near-bank velocities, and reduce damage from collisions between Locked Logs and floating Large Woody Debris.

Example Construction Sequence

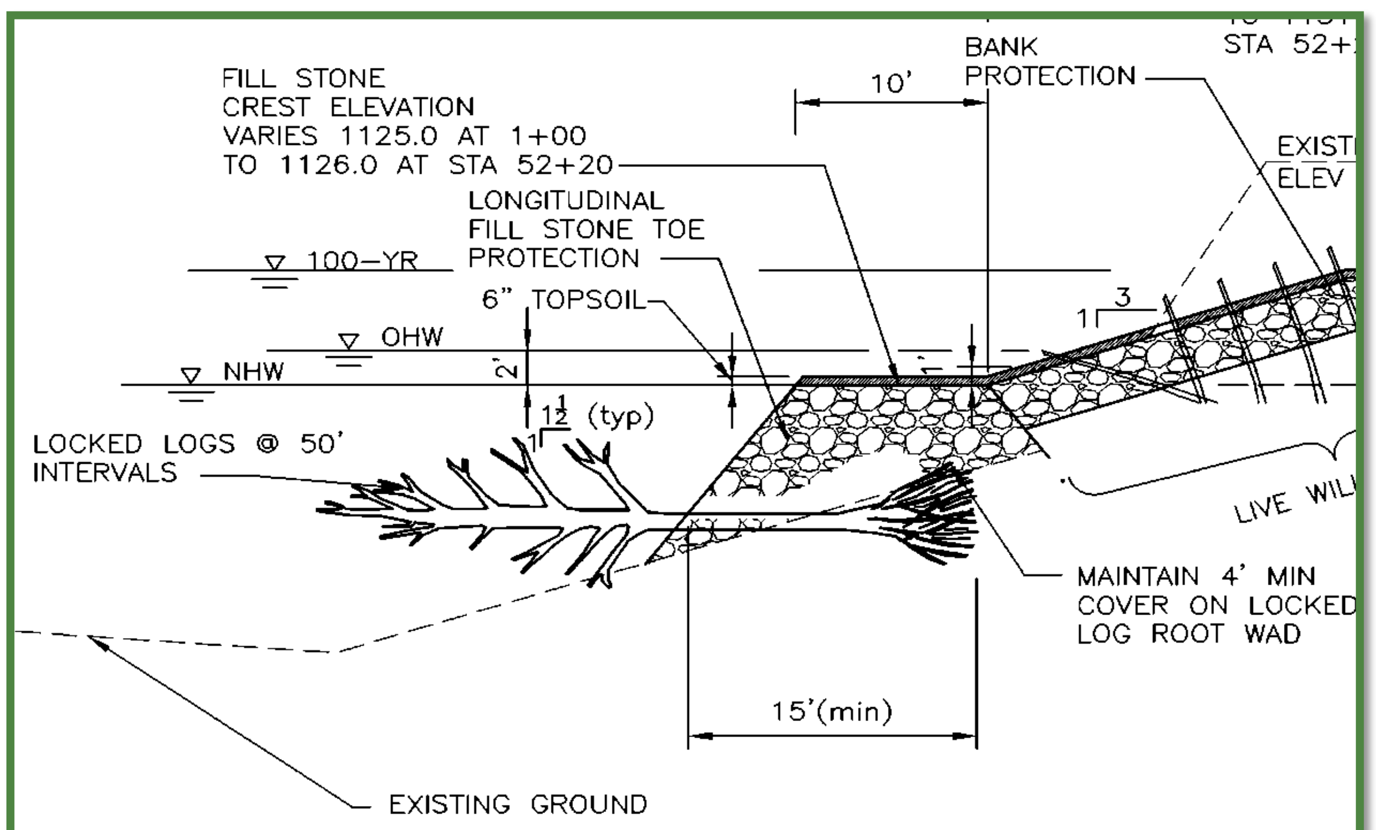
After securing the appropriate log (note branches and root wad intact), the contractor uses an excavator to position the Locked Log.

The Locked Log is placed root wad towards bank, with trunk into the stream and angled downstream. The LPSTP will cover and "lock" the root wad in place.

After the root wad is locked into place within the LPSTP, 3-4 ft of stone is placed over the root wad and lower tree trunk for further stabilization.

The completed structure. Upstream logs are actually naturally eroded trees that fell into the river, angled downstream by flow. Appear strikingly similar to the downstream placed Locked Logs!

Example Plan Drawing



Estimating Time and Materials

Typical locked log installations can benefit from usable materials existing within the project's proposed boundaries. Otherwise, obtaining entire hardwood trees (including root wad) can be somewhat difficult. Contacting local landowners, tree removal services, state departments of transportation, or environmental organizations might be necessary. Many times local landowners will be willing to work with you, especially if a tree presents itself as a current or future hazard.

Maintenance and Monitoring

Locked Logs require little maintenance; however it is important to monitor their condition within a year after implementation, especially during and after high flow events. Due to the nature of the structure, debris could be caught by the Locked Logs. It may become a concern over time, and action should be taken to remove any excess buildup. Like any wood structure, Locked Logs could become dislodged, and impact downstream. These should be removed immediately and work should likely be done to repair and/or replace the Locked Log.

In partnership with River Research and Design, Inc., The Stream and Habitat Restoration Methodology and Techniques Guidebook is meant to serve as a reference for any organization planning, or otherwise implementing, riverine and/or riparian restoration efforts throughout the Great Lakes Region. The associated Methods and Technical Sheets accompanied within this guidebook are prepared in a manner in which any professional could, at a glance, incorporate the ideas and methods presented into their own engineering and design plans.

Dave Derrick, a practiced hydrologic engineer since 1978 with the U.S. Army Corps of Engineers, and now with River Research and Design, Inc., has assisted Partners for Clean Streams with publishing his knowledge of stream restoration, including the work done through the Great Lakes Restoration Initiative. Specific examples given in this guidebook come from the Restoring Ottawa River Wetlands and Habitat at Camp Miakonda Project in Sylvania, Ohio. Other mentioned projects include The University of Toledo's Ottawa River Habitat Restoration Project, Highland Park Dam Mitigation Project, and the Toledo Botanical Gardens' Lake and Stream Restoration Project.

Without the help of our numerous partners throughout the Maumee Area of Concern, projects like these could not be accomplished and become the successful examples they are within the Great Lakes Region. Thank you to the Boy Scouts of America for their cooperation, U.S. Army Corps of Engineers for their tireless assistance in planning and design, and the U.S. EPA for the funding opportunity through the Great Lakes Restoration Initiative. We hope this guidebook is as invaluable as we think it will be to you, as well as all of our future partners, and that more projects using these techniques are implemented through the Great Lakes Region.

Great Lakes RESTORATION

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IMPROVING THE PLANET...ONE STREAM AT A TIME

R2D, Inc.