Definition and Purpose

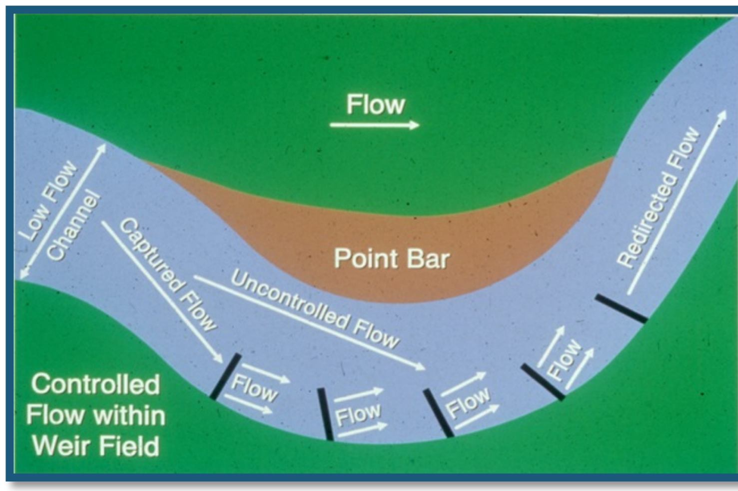

Image 1: Example Bendway Weir placement and resulting flow indicated by lines. Dave Derrick.

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.

> ***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.

IMPROVING THE PLANET...ONE STREAM AT A TIME
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Preparing for Bendway Weirs

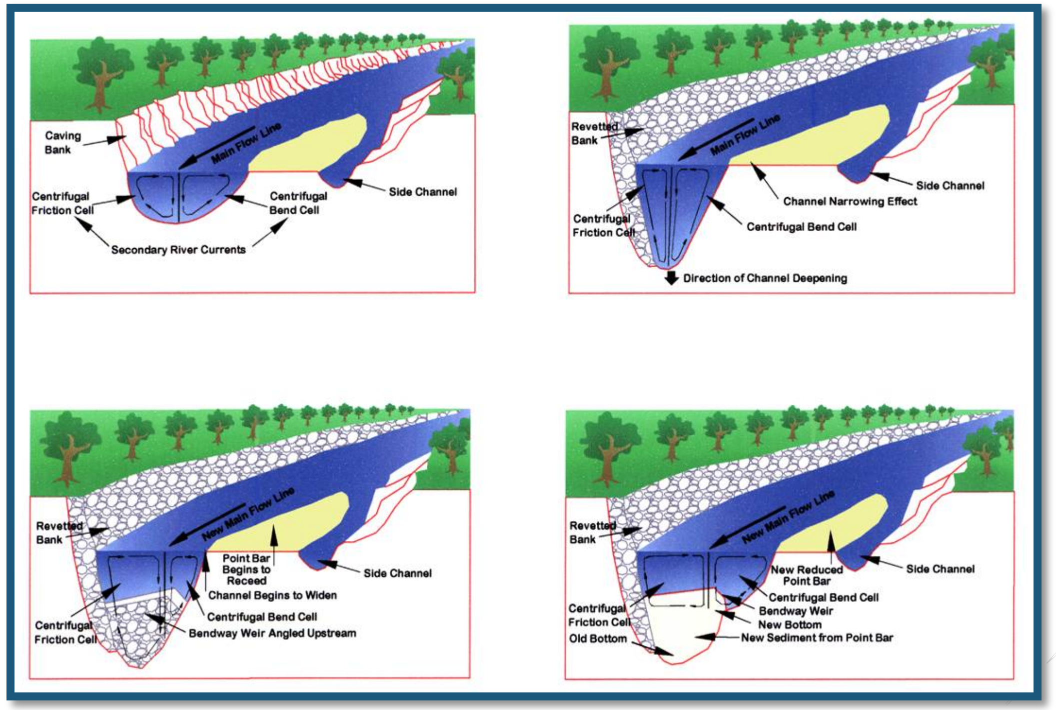


Figure 1: From Rob Davinroy, St. Louis Corps

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.

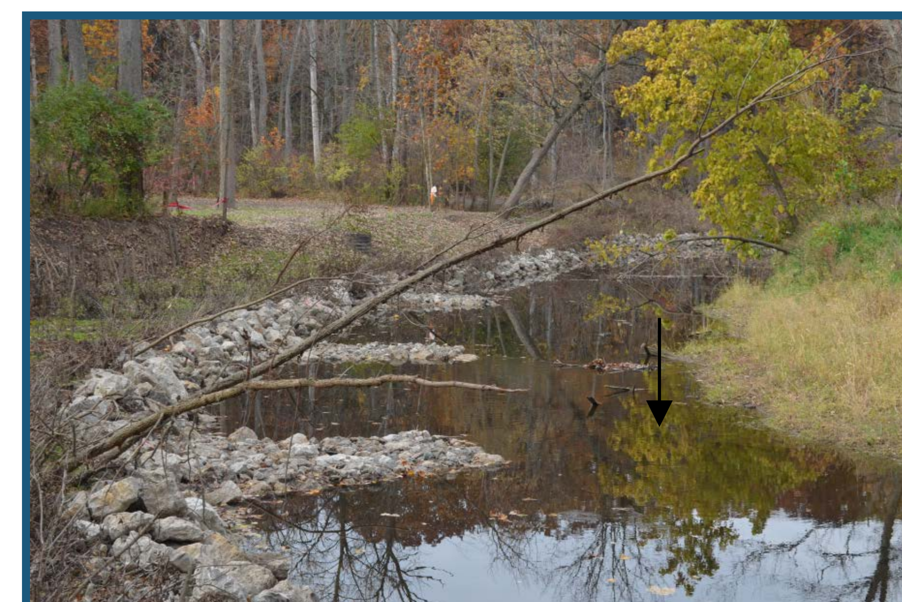


Image 5: Bendway Weirs, Ottawa River, Camp Miakonda. Kyle Spicer

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.

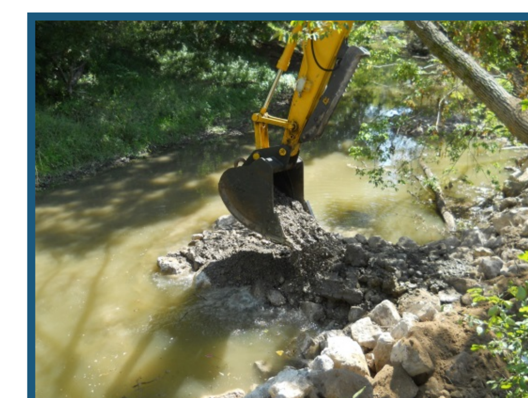
- The stream should have a stable bed.
- Stream width at base flow is at least 20 feet.
- The height of a BW is usually one foot above the base flow water surface elevation (typical low flow or 80 percent exceedance). Every Bendway Weir needs to be keyed into the bank.
- The crest elevation of the weir 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.

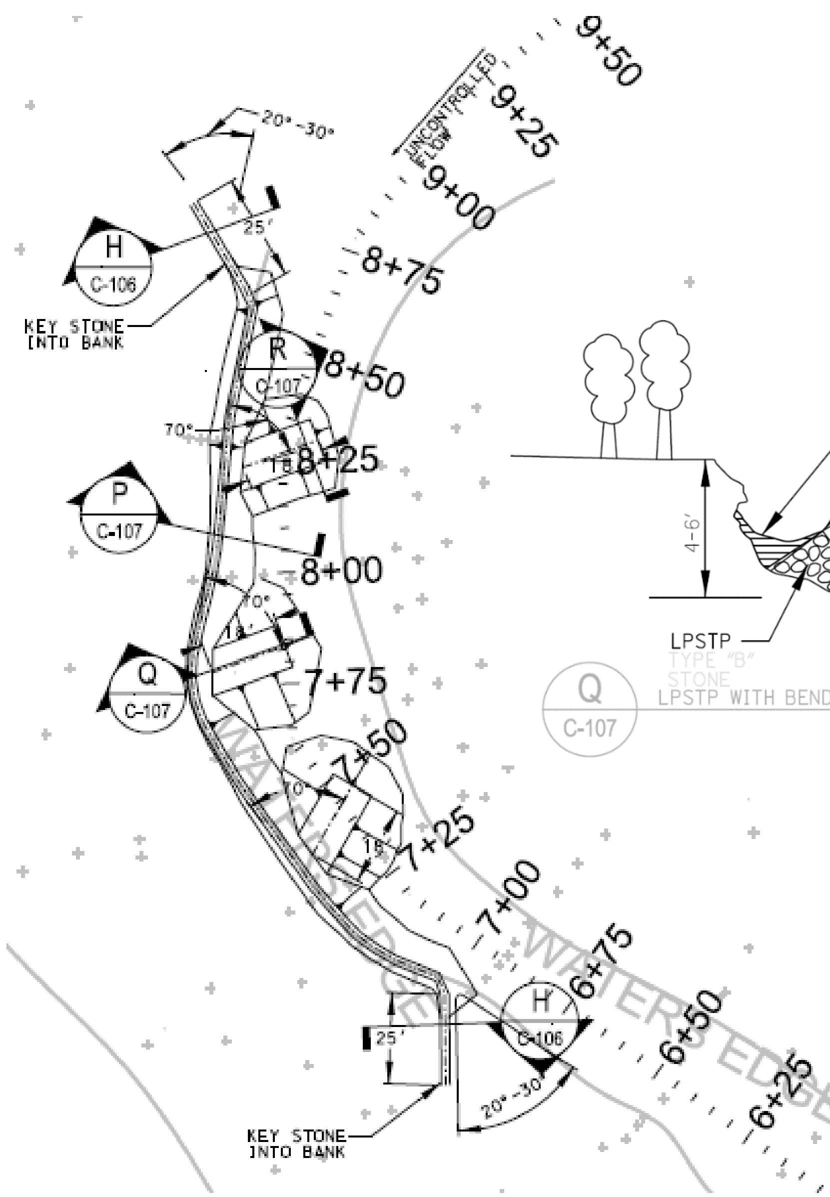
The BW is shaped as additional stone is placed on top. For medium – large streams, a majority of the stone is placed one bucket of well-graded stone at a time.

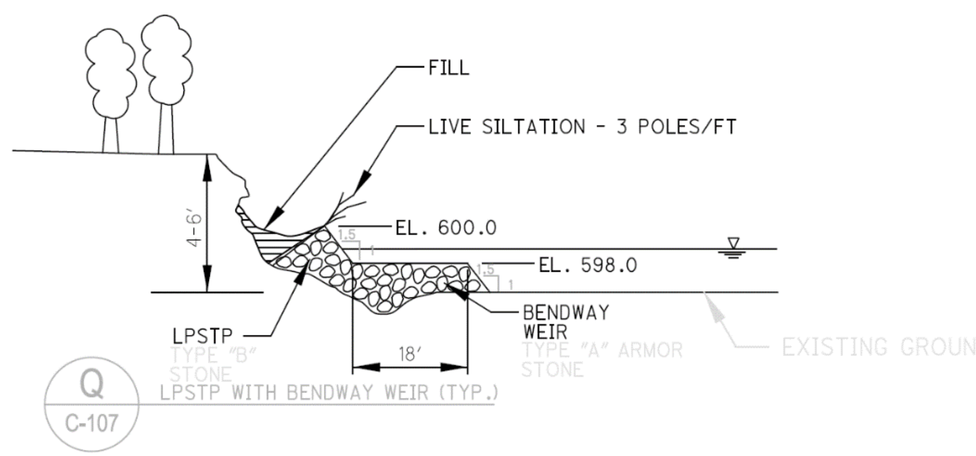
The typical BW has now taken shape. If fishing access is desired the BW can be top-choked with smaller stones and gravel.

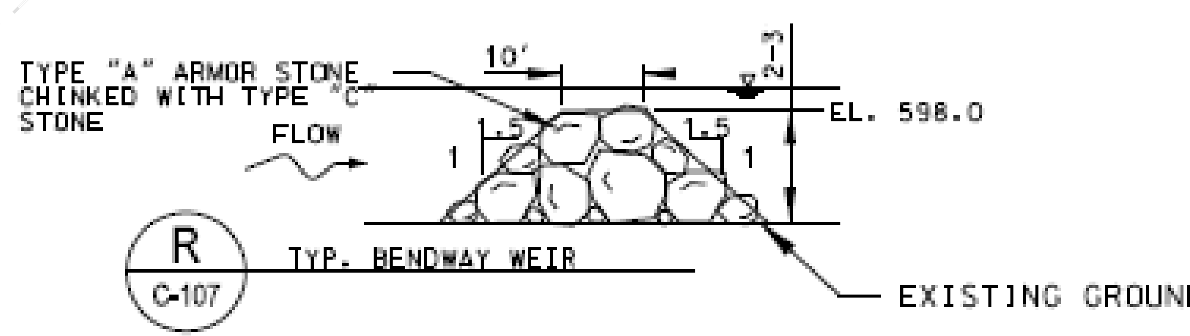


These BW in particular were heavily choked, to create a smoother surface for people to walk on and gain access to the river.

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.