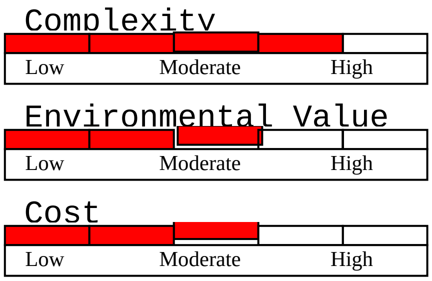
Low Head Stone Weirs

By: Jon Fripp[1],
Dr. Craig Fischenich[2],
and Dr. David Biedenharn[2]



OVERVIEW

Establishing a stable grade in an eroding stream is a critical first step in any stream stabilization or restoration effort. Grade control structures have long been used by engineers to stabilize streams. However, many traditional grade control structures are incompatible with stream restoration objectives. They can adversely impact fish passage, substrate composition, recreation, and other environmental functions. Low-head stone weirs (LHSW) can not only provide the same stabilization benefits of traditional grade control structures, but can also provide riffle and pool habitat, reoxygenate water, establish desired substrate characteristics, improve local bank stability, and enhance diversity and visual appeal.

Channel incision, or entrenchment, is a form of degradation that significantly changes the form and function of a stream. Channel incision is the enlargement of a channel from erosion processes, first by degradation of the channel bed and subsequently through the accompanying widening of the channel as stream banks fail. The most common causes of channel incision include increased discharge, decreased sediment load, channel constriction, and lowered base levels. All four causes are common in locations where stream restoration projects are implemented - particularly in urban and suburban environments. LHSW can be used to arrest this incision by providing a stable hard point in the bed. The shape of LHSW can also divert intermediate level flows from the banks and provide some energy dissipation.

The riffle and pool habitat that is created by LHSW is also significant and can be the sole justification for their use in a stream restoration project. Scour holes adjacent to stabilization structures in unstable, incised channels have been found to support diverse and stable populations of fish than the surrounding channel habitats without structures. Furthermore, fish populations in incised channels have been shown to respond quickly (about one year) to the restoration of pool habitats (Sheilds ET al., 1995).

Figure 1: Stone Weir, Montgomery County, Maryland.

PLANNING

[1]USAE, Baltimore District, P.O. Box 1715, Baltimore, MD 21203
[2] USAE, Waterways Experiment Station, 3909 Halls Ferry Rd., Vicksburg, MS 39180

The first step in the planning process is to determine that an LHSW is an appropriate measure to address the habitat and stability objectives for the study reach. LHSW are best suited for use in streams of a type where naturally occurring riffles and boulder outcrops provide stability and habitat. Stable and unimpacted reaches in the same general geographic area can be examined to ascertain if the use of LHSW is appropriate. An interdisciplinary team should be used in the planning and design of LHSW. Team members should include hydraulic engineers, civil engineers, and others who have an understanding of stream mechanics, restoration and habitat requirements. The team should also include a fisheries biologist who is knowledgeable about the local stream conditions and habitat requirements for the targeted species. Questions that should be addressed include the following:

1) Is the stream in need of grade stabilization and/or instream habitat enhancement?
2) Are the geomorphic and geological characteristics of the stream suitable for the use of a LHSW?
3) Is the size of the stream appropriate for the use of LHSW?
4) If a LHSW is to be used to reduce the amount of incision by building up the level of the bed, then careful consideration should be made to possible adverse affects on flood profiles.
5) If habitat improvement is the primary goal of the structures then it should be determined that neither water quality nor nutrient availability are limiting factors.
6) Will the placement adversely affect fish migration or recreational navigation?
7) Will instream and riparian site conditions permit construction?
8) Are the costs acceptable?

Costs for LFSW are dependent upon the size of the stream. Permitting and construction costs can vary significantly with site conditions and the regulatory environment.

SITE CONSIDERATIONS

LSW are primarily intended for use in lower order perennial streams for bed stability and habitat improvement. The subject reach should not be subject to braiding or aggradation. Caution should be exercised in reaches with a high debris load since the material may build up on the weir stones. LHSW should be located to correspond, as much as possible, to existing riffles and shallow areas. Deep pools and deep water will limit their effectiveness. Eventually, these weirs will become the riffles of this reach. As possible, changes to the existing profile should be minimized. The grade at the lower end of a series of LHSW should be stable or should be stabilized.

DESIGN

The primary design considerations for LFSW are a) configuration, b) stone sizing, and c) spacing.

Configuration

The design of the weirs typically consists of a double row of stones angled in a v shape with the vortex of the v pointed upstream. A recommended interior angle is approximately 120 degrees but there can be significant variability to this estimate. A wide stream (> 50 feet) may necessitate a w shape or flattened u shape to the weir in order to minimize the channel length of the structure. A narrow stream (<6 feet) may prohibit any shape other than a line of weir stones perpendicular to the channel. The angle of the stones will deflect flows from the banks and thus provide some measure of local bank protection. It can not be assured that bank protection will be provided for flows that have depths that are significantly (> 5 times) the size of the stones. The weir does not necessarily need to be symmetrical and may be shaped to align the flow through a bend or for aesthetic reasons. However, skewing the weir or placing it near a bend may exacerbate flanking of the weir.

The crest of the stones of the up stream end of the weir should be lower than the stones that are keyed into the bank so that the structure slopes down from the bank. In a typical placement on a 20-foot wide stream, the stones on the upstream portion of the vortex would be 0.5 feet above the existing stream grade and stones at the end of the v would be one foot above the existing grade. Modifications can include a notch at the vortex of the v. To reduce the possibility of flanking, the entire structure should be keyed into the banks. Consideration should be given to providing bank protection upstream, at, and below the structure. This may be especially appropriate if the structure results in a significant drop or if the structure is located near a migrating bend.

A scour pool will form within the vortex of the LHSW. To control the development of this scour hole so that it does not undermine the stones of the weir, a blanket of riprap or graded stone should be provided as bedding and backfill under and around the weir stones. The bedding should extend several feet beyond the boulders. It can be expected that the water will initially flow freely through the bedding and stones but these voids will eventually become filled if there is a sufficient supply of gravels being transported through the reach. A profile is shown in Figure 2.

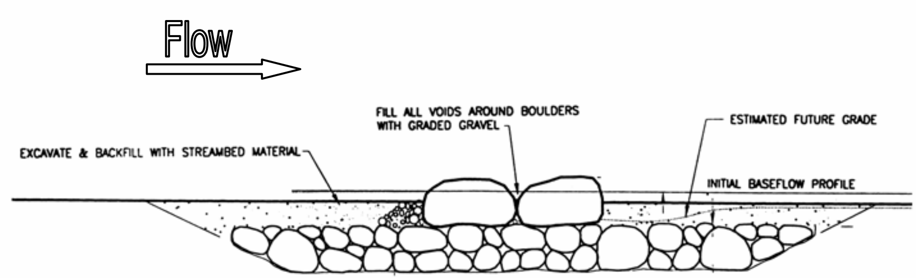


Figure 2: Profile of a LHSW.

If LHSW are placed in a fine grained, highly mobile and/or rapidly degrading stream reach, an impervious barrier is recommended between the boulders. This barrier can consist of clay, concrete, or sheet pile and is to prevent the loss of material through the voids between the boulders. The barrier will also reduce the likelihood of boulder displacement due to erosion caused by seepage flow in and around the boulders for aesthetic purposes (WES Stream Investigation and Streambank Stabilization Handbook, 1997; Laiho and Fitzgerald, 1998). This impervious barrier should be placed to its minimize visibility.

Variants on the configuration of the LHSW include the chevron weir (shown in Figure 4) and the step pool weir (shown in Figure 5). The chevron weir is particularly applicable to large, sand bed channels. The step pool weir applicable to small streams for the creation of instream pool habitat and as an aesthetic measure.

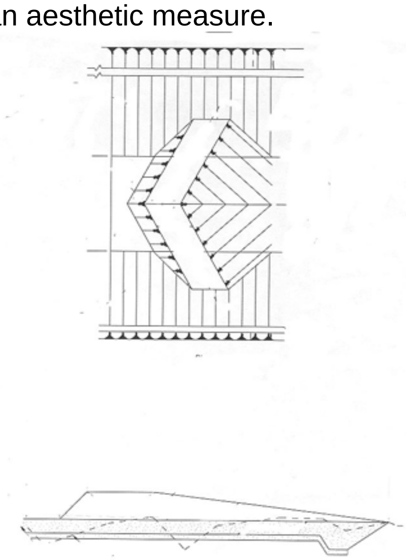


Figure 4: Chevron Weir

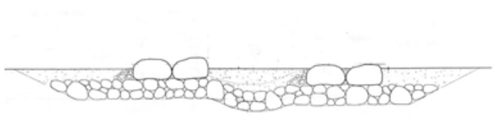


Figure 5: Step Pool

Stone Sizing

The stones for the weir should be sized using conventional riprap design guidance such as provided in EM 1110-2-1601. This guidance provides a modification to the Maynord equation as follows:

$$d_{30} = C \times \left[\left(\frac{\Gamma_W}{\Gamma_S - \Gamma_W} \right)^{0.5} \times \frac{V}{\sqrt{K_1 \times g \times d}} \right]^{2.5}$$

Where:

$$C = SF \times C_S \times C_V \times C_T \times d$$

d_m = Stone size; m percent finer by weight

SF = factor of safety

C_s = Stability coefficient

C_v = Velocity distribution coefficient

C_T = Thickness coefficient

d = depth

Γ_x = Specific weight; stone or water

V = local velocity

K_1 = side slope correction

The outside bend velocity coefficient is computed as follows:

$$C_v = 1.283 - \log(R/W)$$

Where:

R= center-line bend radius

W = water surface width

Adjustments should be made to the coefficients for impinging flow. Guidance in EM 1110-2-1601 recommends a velocity coefficient of 1.25 and a local velocity equal to 160% of the channel velocity. Since the stones are placed on the bed, the side slope correction factor can be assumed to be unity.

Confirmation of the stone size can be made using Federal Highway Administration guidance (FHWA-IP-79-3). Angular rocks, which reduce the likelihood of rolling, should be chosen and the long axis of the boulders should be placed parallel to the stream bank. For aesthetics, larger stones/boulders may be used. Stones on the banks should be sized similarly but with coefficients that reflect the nature of their placement.

Spacing

If the grade of the reach is stable and the purpose of the LHSW is to provide riffle and pool habitat in areas where shallow run habitat is abundant, then the LHSW should be placed in existing shallow areas to maximize the habitat for the target species and as aesthetics dictate. However, if the purpose of the LHSW is to provide grade stability, then spacing should be calculated. It is recommended that limiting slope criteria be used to estimate the minimum spacing in gravel bed streams.

There are a variety of limiting slope criteria available for different stream types and conditions. An example of one is the Meyer-Peter and Muller bed load equation described by Yang (1996). This relation is appropriate for many types of gravel bed streams and is as follows:

$$S_L = \frac{K_1 \times d_{50} \times (n / d_{90}^{1/6})^{3/2}}{Depth}$$

Where:

S_L = limiting slope

n = Manning's n

K_1 = conversion constant

d_s = particle size

The relation used to compute the maximum distance between stone weirs as provided in the WES Stream Investigation and Streambank Stabilization Handbook (1997) is as follows:

$$x = \frac{H}{S_o - S_L}$$

Where:

x = length between LFSW

H = amount of drop removed in reach between the weirs

S_o = original bed slope

S_L = limiting slope

The maximum total drop across the length of riffle that a stone weir can maintain is based upon the size of the stones in the weir but is typically 1.0 foot. A schematic profile is illustrated in Figure 6.

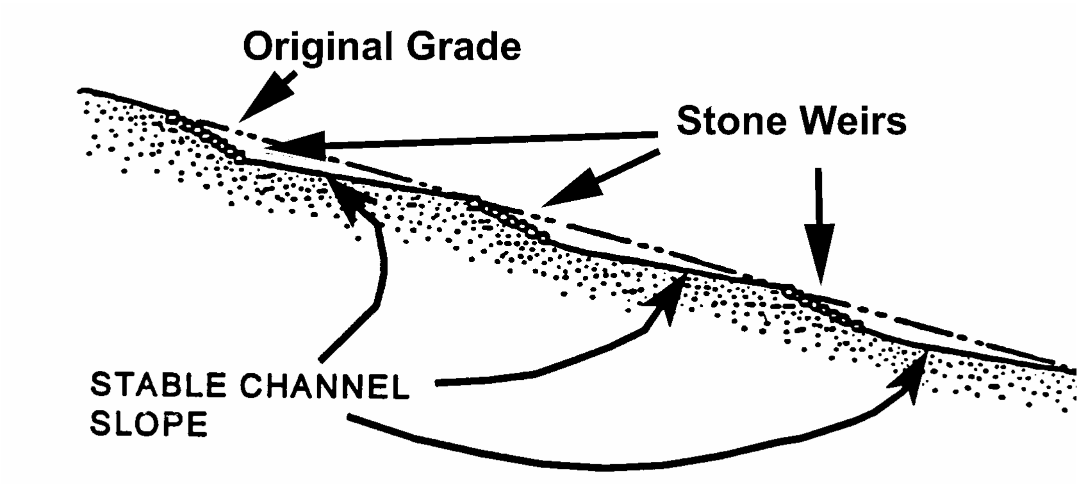


Figure 6: Channel stabilized with a series of LHSW (adapted from WES Stream Investigation and Streambank Stabilization Handbook, 1997

The weirs can be spaced closer and in a non-uniform manner for aesthetic or habitat purposes. Consideration should be given to natural or manmade grade control that exists in the subject reach. If several weirs are to be placed in a stream, the end of the series should tie into a stable grade. An advancing head cut can cause a series of LHSW to fail if the cut is significant. A bedrock outcrop, a bridge sill, a stable channel reach, or the confluence with a larger stable channel can provide this end stability. If there is some uncertainty in the stability of the end of the protected reach, then it is recommended that the final weir should be designed with a significantly larger volume of stone and a deeper bedding.

Backwater Considerations

A typical rule of thumb is that the structure will not have backwater affects to flows with depths that are greater than five times the height of the structure. Therefore, if the height of the structure is less than twenty percent of the height of the bank, then the structure will not result in any increase in out of bank flow. However, possible affects of increased water surface elevations should also be considered on a case by case basis.

CONSTRUCTION

Construction of the LHSW will involve excavation of the stream bank and bed. Construction issues as well as regulatory restrictions often prohibit excavation in an unprotected area. Typically, either a diversion dike or a flow bypass is used to protect the work areas from stream flows. A diversion dike can be used to neck down the stream width to allow work on one streambank at a time. If the stream is small, a diversion dike may not be feasible and a bypass may be more appropriate. A diversion channel or pipe is typically used in conjunction with the diversion dam to bypass baseflow and storm flow around the work area. It is important to note that a diversion channel may involve substantial disturbance to the riparian corridor. To minimize this disturbance, a diversion dam and a pump can be used to divert baseflow. However, such a diversion system may need to be removed to pass storm flows unrestricted. These methods will need to be discussed with appropriate regulatory agencies during the permitting phase of the project.

OPERATION AND MAINTENANCE

Operation and maintenance of stone weirs should be minimal. However, an inspection should be conducted early in the project life after a significant flood event. The inspection should look for evidence of undercutting and flanking. Small movement of the stones is acceptable but significant movement is probably indicative of design deficiencies.

APPLICABILITY AND LIMITATIONS

The techniques described in this Technical Note are generally applicable to projects where the primary objectives include the enhancement of instream habitat, grade stabilization, erosion control, and aesthetic improvements. Since there is no outlet below the crest of the weir, a LHSW can not be considered to provide any flow retention or detention. The use of stone weirs is limited to moderate to steep gradient, gravel bed streams.

Mobile sand bed streams may necessitate a significant foundation less the large stones may literally sink into the bed. In addition, sediment transport capacity should be considered when determining the spacing of weirs in sand bed streams.

If a LHSW are placed in flat gradients, the structure may not form a desired riffle habitat. The reach should not be aggrading nor carrying a large bedload. In either case, the LHSW could become buried. LHSW are is most appropriate in streams where the normal water depth is of the same order of magnitude as the size of stones that make up the weir.

The boulders at in the crest or sill of the LHSW can present a hazard to recreational navigation. If the stream is used extensively by recreational boaters, signal boulders can be incorporated into the design as shown in Figure 7.

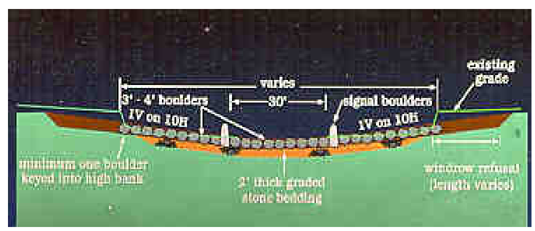


Figure 7: Stone Weir with signal boulders

Caution should be exercised when using low head weirs in streams that are actively meandering or braided. If this treatment is used in streams of these types without other restoration measures, there is possibility that the structure might be flanked. Flanking should also be considered in the design of key-in and bank protection measures adjacent to the LHSW weirs. If large stones are needed for stability and/or an impermeable barrier is necessary, there is a potential for the LHSW to become a barrier to fish migration during low water conditions. Potential adverse impacts to fish passage should be considered in the design and placement of LHSW.

ACKNOWLEDGEMENTS

Research presented in this Technical Note was developed under the U.S. Army Corps of Engineers Ecosystem Management and Restoration Research Program. Technical reviews and comments were provided by Leslie Flanagan, Mike Martyn, and Chris Spaur of the Baltimore District COE.

SUGGESTED REFERENCES

EM 1110-2-1601 (1994). Hydraulic Design of Flood Control Channels. U.S. Army Corps of Engineers.

EL 97-8 (1997). Bioengineering for Streambank Erosion Control. U.S. Army Corps of Engineers.

EM 1110-2-1418 (1994). Channel Stability Assessment for Flood Control Projects. U.S. Army Corps of Engineers.

EM 1110-2-4000 (1989). Sediment Investigations of Rivers and Reservoirs. U.S. Army Corps of Engineers.

FHWA-IP-79-3 (1979), Restoration of Fish Habitat in Relocated Streams. Federal Highway Administration, U.S. Department of Transportation.

Laiho, D. and Fitzgerald, P.A. (1998), Rock Dam Revitalization, Civil Engineering, July 1998.

Shields, F. D., Knight, S. S., and Cooper, C. M. (1995), Incised Stream Physical Habitat Restoration with Stone Weirs. U.S. Department of Agriculture, Regulated Rivers: Research and Management Vol. 10, 181-198.

Spaur, C; Fripp, J.B., Bistany, M; and Flanagan, L; "*Watershed Restoration: Setting Objectives With a Consideration of Restoration 'Need' - an Essay of Modest Proportions";* Presented at the ASCE Water Resources Engineering Division Conference, August 1999, Seattle Washington.

US Department Of Transportation (1979), "Restoration of Fish Habitat in Relocated Streams", FHWA-IP-79-3, December 1979, Washington, DC

WES Stream Investigation and Streambank Stabilization Handbook (1997). Joint WES and EPA streambank protection manual. U.S. Army Corps of Engineers.

Yang, C. T. (1996). Sediment Transport Theory and Practice. McGraw-Hill series in Water Resources and Environmental Engineering. USA