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Technical Supplement 14H

Flow Changing Techniques

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Cover photo: Weirs, barbs, spurs, and dikes can be used to focus high stream velocities away from the banks, resulting in bank stability.

Advisory Note

Techniques and approaches contained in this handbook are not all-inclusive, nor universally applicable. Designing stream restorations requires appropriate training and experience, especially to identify conditions where various approaches, tools, and techniques are most applicable, as well as their limitations for design. Note also that product names are included only to show type and availability and do not constitute endorsement for their specific use.

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Flow Changing Techniques

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Purpose

Flow changing devices are a broad category of structures that can be used to divert flows away from eroding banks. They are often used to shield banks from eroding flows, build up the toe of the bank, and direct flows to create a stable alignment. While this technical supplement provides descriptions of a variety of techniques, the primary focus is on the analysis, design, and installation of stream barbs. This supplement draws on recent field evaluations that focused both on projects where these structures have performed satisfactory, as well as areas where the performance has been less than satisfactory. A design description includes cautions and warnings related to specific design features. Finally, a step-by-step design procedure for stream barbs is also provided.

Introduction

The U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) has installed numerous flow-changing techniques in support of both streambank stabilization and stream restoration practices. This supplement primarily addresses stream stabilization techniques that work to decrease flow stresses on an eroding streambank through redirection of flow. While a variety of techniques are described, the primary focus of this supplement is on stream barbs. This supplement also provides current NRCS design recommendations for stream barb design.

Flow-changing techniques

The structures used for stream and bank restoration in NRCS projects can be categorized into one of three general classes. The terms used to identify structure classes are somewhat descriptive of the structure function.

- deflector
- redirective
- retard

A deflector type structure forms a physical barrier that protects the bank and forces the flow to change direction either by direct impact or deflection. These structures tend to be massive and often continuous along the protected reach. When properly designed, deflector structures are stable over a wide range of flow conditions.

Rock riprap, grouted rock, concrete lining, rock jetties, gabions, and spur dikes are examples of deflector structures that have historically been used in streambank protection work. Except for rock jetties and spur dikes, these structures harden the bank and reduce roughness, thereby increasing flow velocity. Common building materials for these structures are graded rock, concrete, earthfill, or combinations of these materials. Some of these techniques are addressed in more detail in NEH654.14.

A redirective type structure is designed to be placed in the stream to minimize direct impact and rely more on the characteristics of fluid mechanics to modify the streamflow direction. These structures tend to be less massive and are submerged at higher stages of flow. Redirective structures are usually discontinuous, independent structures. In many cases, they are more likely to be damaged during major events.

Spurs, rock veins/weirs, stream barbs, and bendway weirs fall into the category of redirective structures. Redirective structures can be contrasted with deflector techniques, such as riprap and gabions, which are more static and harden the bank. Common building materials for these structures typically include large rock, graded rock, and earthfill.

A retard structure increases flow resistance by increasing drag, thereby slowing the velocity in the vicinity of the structure. These structures are more porous with a high percentage of open area. Retard structures are generally used where the channel carries a high sediment load and reducing the velocity will result in sediment deposition. Common building material for these structures can include wood, steel, rock, and live plantings. Fence jetties, Killner jacks, timber piling, live poles, and most bioengineered structures are examples of retard structures. Some of these structures are addressed in more detail in NEH654.14.

It is not uncommon to use all three types on projects initiating and terminating protected reaches with deflector type structures and using redirective and retard structures between the hard points. All of the methods mentioned can be combined with bioengineering measures to improve stream function and bank stability. A general outline of the different techniques is provided in table TS14H–1. Some of these techniques are addressed in further detail in this technical supplement, as well as in NEH654.14.

Table TS14H–1 Common flow-changing techniques, brief description, structure class, and function

Practice	Description	Structure class	Function
Concrete bank lining	Hard, smooth surface of concrete, gravity, or structural support	Deflector	Flow is physically deflected or trained by physical barrier
Rock masonry bank lining or wall	Hard, semismooth of rock and mortar, gravity support	Deflector	Flow is physically deflected or trained by physical barrier
Geocell slope/bank protection	Fine or granular fill retained in cells, semismooth to rough, vegetated option	Deflector	Flow is physically deflected or trained by physical barrier
Rock riprap	Loose rock on slope, semismooth to rough, full or partial bank	Deflector	Flow is physically deflected or trained by physical barrier
Groins	Rock dike projecting into stream in downstream direction	Deflector	Full range of flows physically deflected away from bank
Dike	Earth or rock full bank height	Deflector	Flow is physically deflected or trained by physical barrier
Stream barbs	Low rock sill projecting into stream	Redirective	Flow direction changed by flow over structure
Bendway weirs	Low rock sill projecting into stream	Redirective	Flow direction changed by flow over structure
Rock vein	Instream rock sill	Redirective	Flow direction changed by flow over structure
Rock “V” weir	Instream rock sill	Redirective	Flow direction changed by flow over structure
Spur dike	Short rock, timber, or earth dike projecting from bank, porous or impermeable	Deflector/retard	Physical barrier, full bank height
Jetties (fence)	Parallel lines of spaced posts, porous	Retard	Velocity of flow through structure is reduced by friction
Live stakes, geogrids, brush layers	Vegetative treatment	Retard/deflector	Velocity of flow through and around vegetation is slowed by friction
Vegetated slope	Vegetative treatment	Retard/deflector	Velocity of flow through and around vegetation is slowed by friction

Spur dikes

Spur dikes are short dikes that extend out perpendicular from the bank into the channel along a reach of eroded bank. Spur dikes can be short or long, but generally with a top elevation above flood stage or equal to the bank elevation. Streamflow impacting spur dikes is retarded and diverted away from the bank. Spacing of the spur dikes is important to prevent formation of strong eddies that can result in erosion between the dikes. Spur dikes are generally constructed using earthfill with rock riprap surface protection. However, soil bioengineering practices can also be used in between spurs.

Groins

Historically, groins have been in widespread use for many years and are the precursors to redirective structures. Much of the guidance for redirective structures is based in part on the experience with groins. However, there are important differences that the designer must keep in mind. Groins typically are higher profile and affect all stages of flow. Their crest is typically above the high-flow water surface elevation, and they are seldom completely submerged. They act to deflect flows away from the bank. They have a significantly higher effect on the shape of the streams cross-sectional shape since they are used to narrow the stream. Since they are rarely overtopped, they can be effective when oriented downstream.

Jetties

Jetties are fence-like structures extending from the bank into the stream. They are often installed in pairs or multiple pairs to train flow towards the center of the channel. They can also be installed on one side of a stream channel to direct flow away from that bank. Jetties can be permeable or impermeable and are usually installed diagonally in a downstream direction along the bank.

Figure TS14H–1 shows an example of permeable fence jetties. Permeable jetties are used for streams with high sediment loads. The flow passing through the jetty is slowed, allowing deposition of material between the jetties. Impermeable jetties are seldom used except where the line of flow must be diverted away from a structure or other feature. Permeable jetties can also be constructed out of woody debris, jacks, or a combination of logs and large boulders. In streams where there is a large amount of woody material and debris, permeable deflectors can collect and retain this material and become less permeable with time. Once they become impermeable, the portions that project from the bank may function more in a redirective capacity.

Figure TS14H–1 (a) Permeable fence jetty, close up; (b) Aerial view (*Photo courtesy of Lamont Robbins, NRCS*)

(a)

(b)

Pin deflectors

A variation of the permeable jetty is the pin or piling deflector. Pin deflectors are generally used in streams where only a small reduction in velocity is needed. Generally, wood pilings are used for their construction. These pilings are driven to a depth where they can resist the forces of the water, as well as any anticipated drift and debris that they may collect. A rule of thumb is a depth that is at least twice that of the projection above the channel bottom, but this is dependent on channel materials. In some applications, it is specified that the piling be driven to refusal. After being driven to the design depth, the pilings can be trimmed with a chain saw to form the design profile. Pilings can be linked with cross pieces or left as individual elements. When connected, they act together. When unconnected, outer wood pilings may fail without putting the rest of the structure in jeopardy.

Bendway weirs

Bendway weirs were developed by the U.S. Army Corps of Engineers (USACE) to reduce erosion along the Mississippi River, and then adapted for smaller streams. As with stream barbs, the premise behind the function of bendway weirs is that flow over the weir is directed perpendicular to the angle of the weir. Bendway weirs are oriented upstream at an angle that is between 50 to 80 degrees to bank tangent. The length of a bendway weir is typically less than a fourth bankfull width. Often, the design is based on baseflow widths. In this case, their length is typically between a fourth to a half of the baseflow width. In all cases, both the length and angle may vary through the bend of the river to better capture, control, and direct the flows. They are typically wide structures with a flat to slight weir slope up toward bank. They should be keyed into the bank at a length equal to the bank height plus anticipated scour depth. More information on the design and application of bendway weirs is provided in the WES Stream Investigation and Streambank Stabilization Handbook (Biedenharn, Elliott, and Watson 1997). While bendway weirs are often used on large streams and rivers (fig. TS14H–2), an example of a bendway weir on a small stream is shown in figure TS14H–3.

Numerous applications have shown that bendway weirs reduce the velocity near the bank. On the little Blue River in Kansas, Balch (2004) observed a 50-percent reduction in stream velocities within the weir field (fig. TS14H–4).

Stream barbs

Stream barbs are low dikes or sill-like structures that extend from the bank towards the stream in an upstream direction. Stream barbs are similar in structure to bendway weirs, perform a similar function, and were developed about the same time by NRCS for

Figure TS14H–2 (a) Bendway weir, under construction; (b) Completed bendway weir (*Photos courtesy of Mark Locke, NRCS*)

(a)

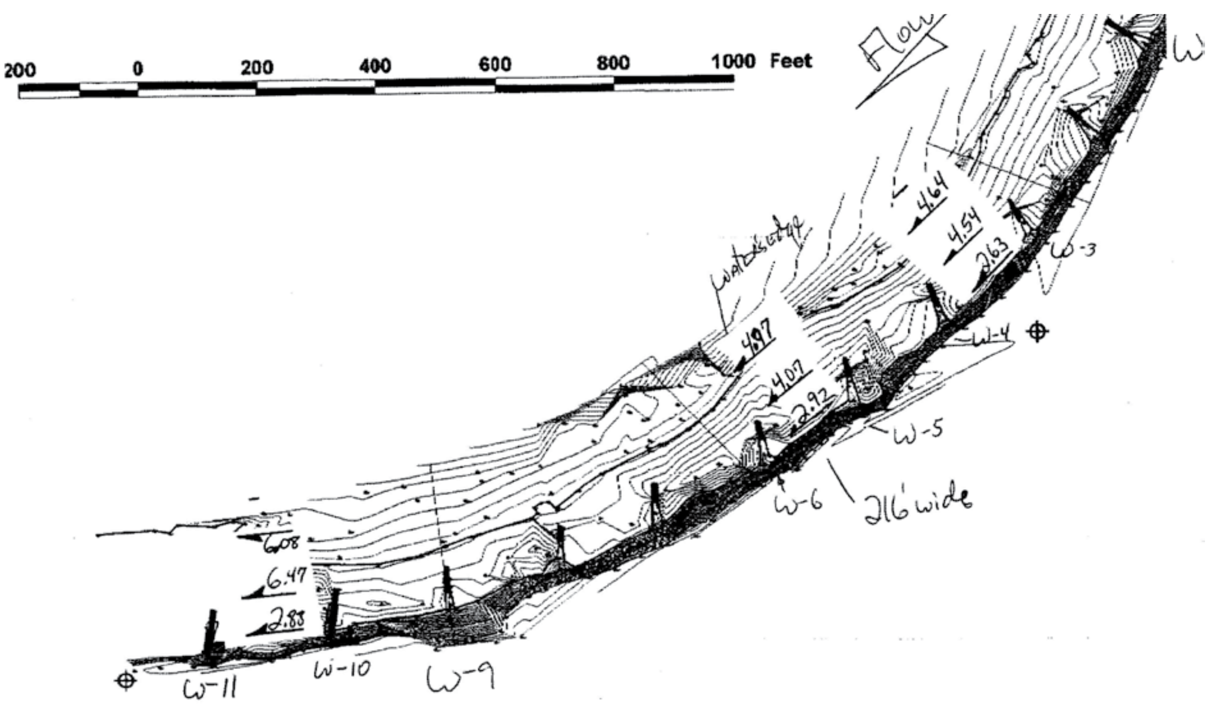
(b)

Figure TS14H–3 Bendway weir (*Photo courtesy of Wayne Kinney, NRCS*)

smaller streams. As flow passes over the sill of the stream barb, it accelerates, similar to flow over the weir of a drop structure, and discharges normal to the face of the weir. Thus, a portion of the streamflow is redirected in a direction perpendicular to the angled downstream edge of the weir. If the weir is too high, flow is deflected instead of being hydraulically redirected, and if too low, the redirected flow is insignificant relative to the mass of the stream.

Performance varies as the streamflow stage varies. At low flows, a stream barb may first deflect flow, and then, as the stage increases, flow passes over the weir and is redirected. At high-flow stage, the weir effect becomes insignificant. The height of the stream barb weir is important, since it will generally function most

Figure TS14H–4 Water velocities on Geffert River Project, Neosho River, Allen County, KS—12 feet of water over weirs. (*Observations and sketch by P. Balch, D. Derrick, and B. Emmert in 2001*)

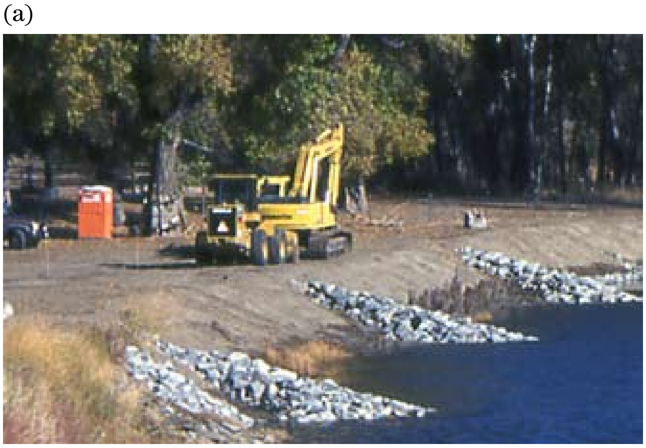


efficiently during bankfull or channel-forming flow events. Welch and Wright (TN–23(2) (USDA NRCS 2000)) have noted that, for purposes of many stream barb designs in the Pacific Northwest, the bankfull stage generally coincides with the regulatory field interpretation of ordinary high water. Stream barbs are typically constructed with rock; however, brush may be used for some applications. Figure TS14H–5 shows both rock and brush barbs. More information on the design of brush barbs is provided in NEH654 TS14I.

Stream barbs are used for bank protection measures to increase scour of point and lateral bars, direct streamflow towards instream diversions, and change bedload transport and deposition patterns. Other benefits of stream barbs include encouraging deposition at the toe of a bank, reducing the width to depth ratio of a stream channel, and providing pool habitat for fish. Trees with rootwads can be added to these structures to improve fish habitat value. The design of stream barbs is addressed in more detail later in this technical supplement.

Figure TS14H–5 (a) Rock barbs; (b) Brush barbs

(a)



(b)

Vanes

Vanes are structures constructed in the stream designed to redirect flow by changing the rotational eddies normally associated with streamflow. They are used extensively as part of natural stream restoration efforts to improve instream habitat. There are quite a few variants on rock vane design. The Rosgen style cross vane and J-hook structures are addressed in NEH654 TS14G and NEH654.11.

Vanes are typically oriented upstream 20 to 30 degrees to the bank tangent. However, the angle may vary as they work around the curve. Design of vanes is based on bankfull depth. The length is typically a third of the bankfull width, and the height at the bank is a third of the bankfull depth. The weir slope is 2 to 7 degrees up towards bank. The required stone size for vanes is often very large. A typical rock vane is shown in figure TS14H–6.

Figure TS14H–6 Rock vane

Stream barbs

The NRCS has installed numerous stream barbs to protect streambanks throughout the country in support of stream restoration practices. The term stream barb refers to a low-sill (typically rock) structure that projects from the streambank into the flow, angled in an upstream direction. These structures typically have geometry developed from site-specific hydrologic and hydraulic characteristics. Their purpose is to decrease flow stresses on an eroding streambank primarily through redirection of flow.

In the early 1990s, NRCS field staff in eastern Oregon began using low rock sills in stream restoration work. These structures were designed to redirect flow away from eroding banks and required much less rock than traditional rock riprapped banks. The structures were referred to as stream barbs. These structures offered an alternative to rock riprap (which had lost favor with state fisheries personnel), and NRCS field staff were enthusiastic because they seemed to work well with other bioengineering bank treatments. However, there were no set design procedures or guidelines for installing them, other than to use the largest rock available. A field evaluation in 1993 by NRCS West National Technical Center personnel resulted in the development of preliminary design guidelines for layout and installation of stream barbs. Since those first guidelines were issued, these structures have been installed at many sites across the country. Field and empirical observations have resulted in changes to the original guidelines and improvements continue. In 2001, the National Design, Construction, and Soil Mechanics Center (NDCSMC), in cooperation with state NRCS personnel, began to conduct a systematic review of stream barb projects at various sites across the country to compile the lessons learned in their successful design and implementation (Saele et al. 2004). This effort included site visits, review of plans, and interviews with designers. This section incorporates current design practices with a step-by-step worksheet to facilitate design and layout of these structures.

Hydraulic function

As noted earlier, a stream barb is a low sill-like structure that projects into the streamflow, oriented in an upstream direction. Stream barbs redirect streamflow with a very low weir and disrupt the velocity gradient in the near-bank region. Stream barbs can provide two hydraulic functions which serve to provide stability to a streambank.

- divert erosive streamflows away from the bank
- encourage deposition at the toe of the bank

The low-weir section is pointed upstream and forces the water flowing over it into a hydraulic jump. Flowing water turns to an angle perpendicular to the downstream weir face causing the flow to be directed away from the streambank. Figure TS14H–7 shows observations of near bank velocity reductions through a series of stream barbs during moderate flows.

The weir effect continues to influence the bottom currents even when the barb is submerged by flows greater than the channel-forming flow. When functioning to divert flows in this manner, the height of the structure in relation to the design storm is more important.

Stream barbs can encourage the creation of a low bench at the toe of an eroding bank. In this case, the height of the structure is not as critical. The disruption of the velocity gradient as the water flows over the weir section reduces channel bed shear stress and slows near bank flows, resulting in sediment deposition adjacent to the barb. The flow separation caused by the hydraulic jump and flow redirection creates an eddy downstream of the barb. This eddy can promote sediment deposition. However, it is important to note that a significant sediment load must exist in the stream at low to moderate events for this deposition to occur. The best sediment deposition performance has been observed where plants were included in the design and when additional plantings were provided after deposition began. Treatments such as tree revetments (see NEH654 TS14I) between the barbs also act to encourage sediment deposition.

Design criteria

The following is a generalized discussion of design criteria specific to stream barb design. Since all designs in a riverine environment are site specific, the user is cautioned that there are certainly variants in many of the recommendations that are provided herein. Refer to figures TS14H–8 and TS14H–12 for clarification and identification of terms.

Figure TS14H–7 Approximate surface velocity measurements at Snake River at Moose, WY. The average of the annual mean annual streamflows from 1996 to 2004 at this site was approximately 3,200 ft^3/s.

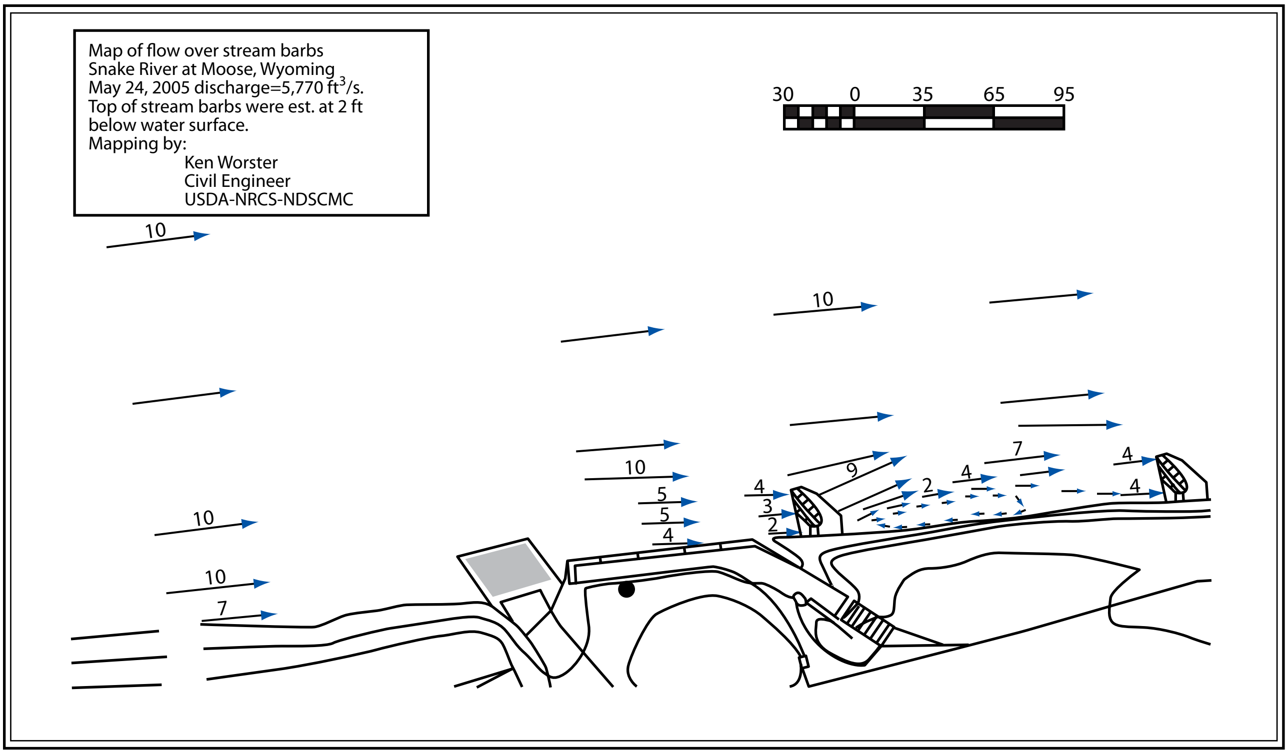
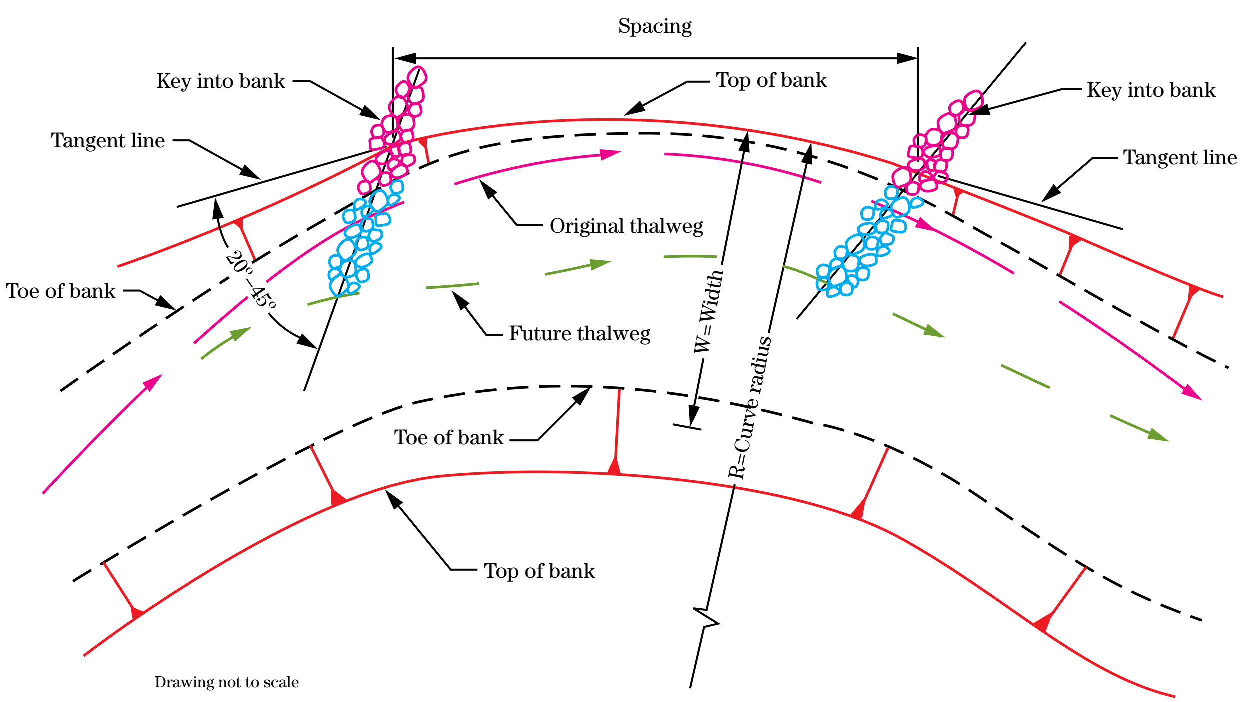


Figure TS14H–8 Typical stream barb design layout



Bank erosion—The cause of bank instability must be carefully assessed by the designer. Stream barbs are appropriate for sites where the mechanism of failure is toe and lower bank erosion. They decrease near-bank velocities and create low-flow eddying adjacent to the toe of the bank which promotes sediment deposition. They are often used in combination with soil bioengineering methods since the sediment deposition and accumulation between the barbs promotes riparian establishment and development. Soil bioengineering techniques may also enhance further deposition between the barbs.

Stream barbs will not protect banks that are eroding due to rapid drawdown or mass slope failure. Problems have been observed where stream barbs have been applied to repair problems that are geotechnical, rather than fluvial in nature.

Channel stability—Stream barbs are not appropriate where the grade of the channel is unstable. In degrading streams, the foundation of the stream barb may be undermined, while in aggrading streams, the stream barb may be buried. In addition, problems have been observed where these techniques have been applied in braided streams or stream systems that are prone to avulsions.

Channel approach—The placement, length, and alignment of barbs are dependent on the approach that the channel makes into the project area. Using stream barbs to make abrupt channel alignment changes should be avoided. The designer should consider the full range of flow behavior at the site as the alignment may change at high flows. For all significant design flow levels, the stream barb should serve to redirect, rather than deflect or split the flow.

Location—Stream barbs are typically placed along the outside of a bend where the thalweg is near the streambank. Generally, these structures are not used when the thalweg is away from the bank, except in situations where the channel is excessively wide or where they are used to induce sediment deposition at the toe of an eroding bank. The stream barb should then be located to capture the flow with a longer weir section, control it through the curve, and direct it downstream towards the center of the channel.

The furthest upstream stream barb should be located in the area that is first impacted by active bank erosion. Research by Matsuura and Townsend (2004) indicates that stream barbs upstream of the active erosion were less effective than those placed at the point that bank erosion starts. Designers should note that since most of the stress is in the lower two-thirds of a bend, protection should extend to the point where the bank is stable and vegetated.

Field assessments documented by Sean Welch and Scott Wright in NRCS TN–23(2) (USDA NRCS 2000) indicate that the placement should be restricted to the outer portions of the current meander belts. This will reduce the possibility of flanking. Figure TS14H–9 illustrates a typical meander belt in a Rosgen C4 class river.

Bend radius—While stream barbs are primarily used to control erosion in bends, their performance may not be satisfactory in sharp bends. When the meander bend radius divided by stream width is much less than three ($R/W<3$), there are often problems with erosion below the stream barb as a result of flow separation. This restriction may be relaxed by protecting the banks between the barbs, increasing the number of barbs and decreasing the angle between the barb and the bank. However, in appearance, this may result in nearly a fully riprapped bank.

Determining a radius is not necessarily a simple exercise. Many bends are, in fact, more of a spiral. In addition, the bend radius and approach angle may change at high flow. The designer must assess affects at low, moderate, and high flows. As with all aspects of stream barb design, experience and judgment play an important role.

Studies are underway to develop design measures that will improve stream barb performance for $R/W<3$ (Matsuura 2004). Also, it should be noted that some sites have been observed with R/W ratios approaching two that seem to be functioning well. However, this may be due to approach and alignment at the erosive flows being such that the radius is in effect increased.

Angle—The structure weir section must be oriented in an upstream direction. The angle (θ) generally varies, from 20 to 45 degrees off a tangent to the bank, depending upon the curvature of the bend and the intended realignment of the thalweg. The tighter the stream bend, the smaller the angle, and for situations where $R/W <3$, it probably should be less than 20 degrees. If the purpose is to maintain a deep thalweg near the streambank, then a tight angle (20°) is desirable. A vector analysis, assuming a perpendicular flow direction from the weir alignment, can be used to estimate the angle required to turn the flow.

Length—There are two important length terms associated with stream barbs: weir length (L_w) and effective length (L_e). Weir length defines the length of the weir section of the stream barb and is relative to how much flow can be redirected and energy dissipated. The longer the weir, the more streamflow affected and energy dissipated. Effective length is a function of the stream width (W) and defines the perpendicular projection of the stream barb from the bank into the stream. Experience has shown that an L_e greater than a third the stream bankfull flow width has been observed to result in unsatisfactory results by causing erosion on the opposite bank.

Maximum effective length: $L_e = \frac{W}{4}$

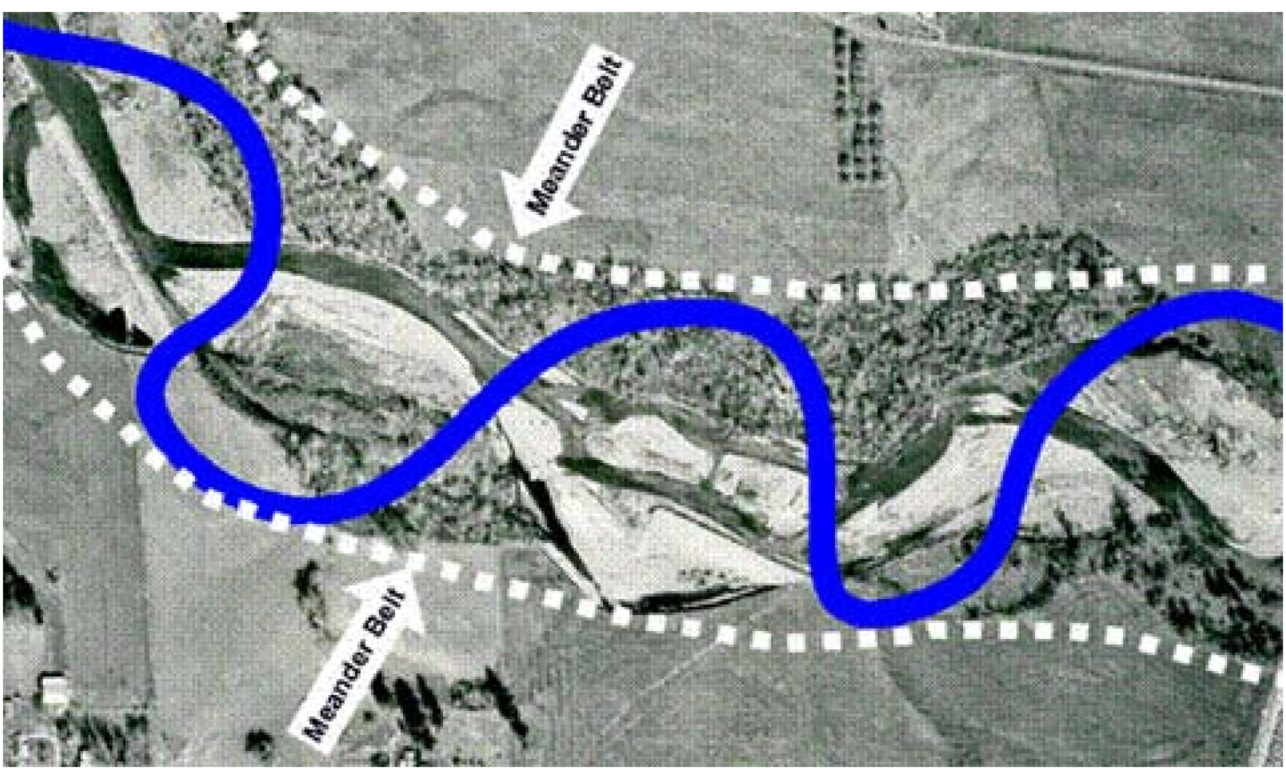
$$L_W = \frac{L_e}{\sin\theta}$$

Suitable range of L_e for effective bank protection:

$$\frac{W}{10} < L_e < \frac{W}{4}$$

For stream barbs to affect the dominant flow pattern, they must cross the thalweg. Shorter stream barbs will affect only secondary, near-bank currents. If the calculated effective length results in barbs that do not influence the dominant flow path, adjustments should be made to the barb length. If this is not feasible, other techniques should be considered. Stream barbs that extend much beyond the effective length tend to alter the meander pattern of the stream and could adversely impact the opposite bank. Stream barbs should not

Figure TS14H–9 Historical meander migration limits



be used to change the meander pattern of an entire stream system or to channelize the streamflow.

Number and spacing—The number of stream barbs required at any given site will be determined by the following:

- spacing
- the length of the eroding meander bend
- channel geometry
- desired effect for treatment of reach

Proper spacing of stream barbs is necessary to prevent the streamflow from cutting between two barbs and eroding the bank. A vector analysis consists of plotting the proposed layout with vectors projecting at right angles to the downstream side of the stream barb. This can provide the designer with an indication of flow lines and flow interception by subsequent stream barbs. Given that the flow will leave the stream barb in a direction perpendicular to the downstream weir face, the subsequent structure should be placed so that the flow will be captured in the center portion of the weir section before the streamflow intersects the bank. Since the flow direction is controlled by the alignment of the stream barb, the downstream side of the stream barb is typically straight, so that this direction can be better estimated. Another method that can be used is shown on the design worksheet.

Although there is much local variation, typically, stream barbs influence the flow patterns for a distance downstream from five to ten times L_e. A limited stream barb spacing of four to five times L_e provides more consistent results.

Height—The height of the stream barb weir section (H_w) is related to the channel-forming or bankfull flow depth. The main portion of the weir should be below the bankfull flow depth, such that significant flow is over the weir. In some situations, a stream barb may be used to protect banks from flows that are considerably larger than bankfull. In these situations, the height may be larger, but generally, should not exceed the bankfull flow level, as this results in a jetty, rather than a barb.

The height of the stream barb weir is generally limited as follows:

$$H_W = \frac{1}{3}D_a \text{ to } \frac{1}{2}D_a \quad \text{(eq. TS14H–1)}$$

D_a = average bankfull flow depth (as defined on design worksheet)

Once flows are more than five times the height of the stream barb, the relative effectiveness of the barb in redirecting flow is significantly reduced. If the height of the design storm is significantly higher than the height of the barb, it may be advisable to increase the height, augment the stream barbs with more bank protection between the barbs, or select another treatment technique.

The relative height between successive stream barbs is important. The difference in height between stream barbs should approximate the energy grade line of the stream regardless of local variations in bed topography.

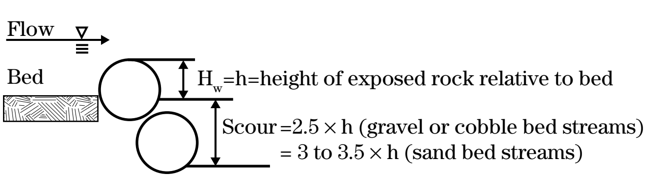
Profile—A stream barb is intended to function as a weir; therefore, the profile is nearly flat with a positive slope towards the bank (slope of 1V:5H is common). Stream barbs constructed with a negative slope or where rocks have been displaced resulting in a negative slope may force water closer to the bank, and thereby increase, rather than decrease erosion. The profile should transition from the weir section to a steeper slope at the bank (1V:1.5H to 1V:2H is common). A typical configuration would be a profile starting at one-third H at the outer end and increasing to one-half to two-thirds H at the bank end of weir section. The top of the key must be high enough to prevent water from flowing around and eroding behind the structure. Banks that are frequently overtopped will require a more extensive key that extends further back into the bank. Bank material will also need to be considered when designing the dimensions of the key.

Width—The width of a stream barb generally ranges from one to three times the design D_{100} rock size. The width does not need to be more than two rock diameters and can even be the width of a single large rock at the tip of the barb. However, stream barbs with a top width of a single stone have been shown to be more susceptible to damage than structures which are multiple stones in width. The stream barb width may also need to be increased (10 to 15 feet total width) to accommodate construction equipment in large rivers or where necessary. Wider structures will result in a more uniform, stronger hydraulic jump. Wider structures should be used if a deep scour hole downstream of the barb is expected.

Length of bank key—The purpose of the bank key is to protect the structure from flanking due to erosion in the near bank region. The bank key length should be at least 8 feet and not be less than one and a half times the bank height. Buried logs with rock ballast can be used in conjunction with the bank key. An inadequate key into the bank has been frequently observed to cause the structure being flanked. Rilling from overbank return flows down the backfilled bank key has also been observed to be a problem. It is also suggested that the key be planted with live poles and/or live clumps. The design can take advantage of the required excavation into the bank to assure adequate moisture is provided to these soil-bioengineering practices. This planting will not only enhance stability but also provide important habitat benefits. More information on soil bioengineering practices is provided in NEH654 TS14I.

Depth of the bed key—The depth of the bed key is determined by calculating the expected scour depth around the tip of the structure. This scour depth will likely exceed the depth of the thalweg. If a bed key is not incorporated, or if the bed key is too shallow, scour may erode the bed material downstream, causing the rock to fall into the scour hole. Higher barbs cause greater flow convergence, and thus greater scour depths. To reduce scour depths, decrease the barb height. The bed key is typically placed at a minimum depth of D_{100}. Scour analysis is addressed in NEH654 TS14B can be used to make these estimates. In lieu of a scour analysis, scour depth can be estimated using the information provided in figure TS14H–10.

Figure TS14H–10 Depth of bed key



If it is not feasible to excavate below the anticipated scour depth, the designer can increase the width of the weir section so that sufficient stone is available to launch into and armor the scour hole.

Scour hole development—Developing a scour hole at the nose or tip of a stream barb may be a project goal as it can provide important benefits to instream habitat. Numerous practitioners have documented the formation of these scour holes. Figure TS14H–11 (TN–23(2) USDA NRCS 2000) illustrates a typical scour hole at the tip of a stream barb in a Rosgen C4 class river.

One of the most frequently observed causes of failure is due to scour undermining the structure. Many practitioners have noted that the ends of stream barbs are often shortened with time as the rock at the nose falls into this hole. Efforts have been made to use larger rock to resist this, but it has been found that the best performance in gravel-bed streams is provided from barbs that are designed with sufficient key in to the invert of the channel.

Scour at the nose of stream barbs in sand-bed streams has been especially difficult to estimate. One approach, used on fine to medium sand rivers, is to construct the weir section of the stream barb and allow the induced scour hole to form overnight. The designer then returns the next day to rebuild the end of the structure using the launched material as a foundation (Balch 2004).

Rock size—Rock for stream barbs shall be durable and of suitable quality to assure permanence in the climate in which it is to be used. Because stream barbs are positioned to redirect fluvial forces at locations where these forces are greatest within stream channels, the rock used to construct them must be larger than the rock that would be required in a riprap revetment along the streambank at the same location. Numerous failures have been attributed to using undersized rock.

Material sizing should follow standard riprap sizing criteria for turbulent flow. One guide is the NRCS Far West States-Lane method, NEH650.16. The rock should be sized for the design flow and then modified in accordance with the following:

D_{50}, stream barb = 2 × D_{50}, as determined for streambank riprap

D_{100}, stream barb = 2 × D_{50}, stream barb

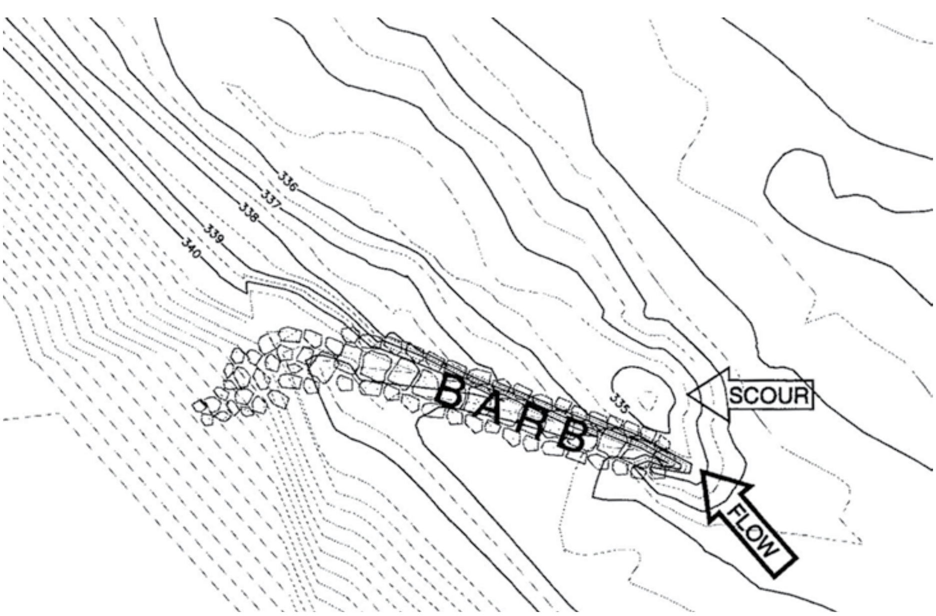
$D_{minimum}$ = 0.75 × D_{50}, as determined for streambank riprap

Note that the Far West States-Lane method gives the riprap D_{75}, and not the D_{50}. A designed gradation is required to obtain the riprap D_{50}. When the ratio of curve radius to channel width is less than six, rock sizes become extremely large and may result in a conservative design.

Rock in the barb should be well graded in the D_{50} to D_{100} range for the weir section; the smaller material may be incorporated into the bank key. The largest rocks should be used in the exposed weir section at the tip and for the bed key (footer rocks) of the barb. The Isbash curve (NEH650.16) is not appropriate for sizing rock for stream barbs, as it results in sizes too small for this application.

In general, structures that are constructed with graded material perform better than ones built out of a few large boulders. This may be due to the fact that a structure built with a larger number of smaller stones can be more easily constructed to a specified grade and can adjust better than one made out of a few larger boulders. However, it should be noted that, depending on availability, large rock (generally greater than 3 feet in diameter) can be less expensive by weight and can take less time to install. More information on stone size is provided in NEH654 TS14C and NEH654 TS14G.

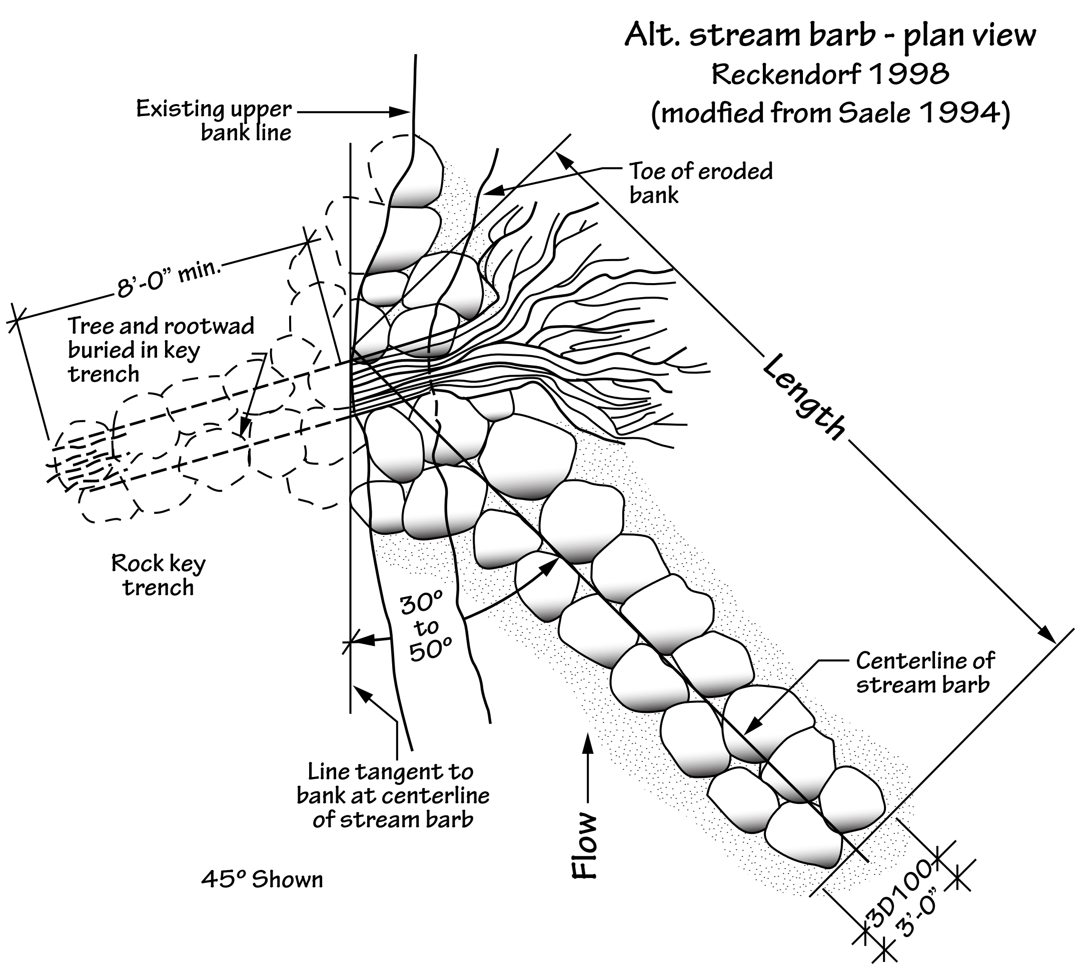
Figure TS14H–11 Scour effects at the barb tip



Woody debris—Rootwads and other woody debris have been incorporated into stream barbs to enhance aesthetics and the habitat benefits of the structure. Details of such structures are provided in figure TS14H–12. Large wood elements have also been incorporated into the weir, as well. Rootwad sections have been incorporated both perpendicular to the weir, as well as longitudinally. In either case, the anchoring requirements of the wood elements must be considered.

If the wood element is not anchored sufficiently, it may break loose, damage the structure, and possibly result in adverse downstream impacts. Anchoring could be accomplished by cabling to rock bolsters, soil anchors, or with the weight of the rocks that make up the barb. Forces of the flows during design conditions, as well as buoyancy should be considered. In addition, the consequences of the woody material catching floating debris should be considered in the design and evaluation of its anchoring requirements. More information related to designing soil anchors is provided in NEH654 TS14E.

Figure TS14H–12 Rootwad used in the key of a stream barb



Finally, the designer should also consider how the placement of woody debris within the structure might also affect its hydraulics. Woody material should not be placed and aligned where it might direct flows into the bank.

Design worksheet

This section provides a generalized worksheet for designing a stream barb. The user is cautioned that, as with all stream projects, the design and placement of stream barbs are site specific. These listed steps will likely need to be modified and adjusted for specific projects. Figures TS14H–8, TS14H–10, and TS14H–12 will facilitate these steps.

Step 1 Investigate site and obtain physical- and geomorphic-based parameters. The designer should determine if site is suitable for stream barbs.

Can *yes* be answered to the following questions::

Is erosion occurring on the outside of a bend?

Is the channel bed stable or quasi stable?

Is the stream thalweg close to the eroding bank toe?

Is this a natural channel (uncontrolled)?

If the answer is *yes* to all of the above questions, proceed.

Step 2 Determine bankfull elevation, radius of outer bank, typical section, and hydraulic gradient. Develop a plan drawing of site from aerial photo or from survey information showing outer bank, bankfull line on opposite bank, on the eroding bank if it is significantly different than top of bank, and the thalweg. Locate beginning and ending points of the eroding bank. Using CAD or other methods, approximate the outer bank radius and bankfull width. If the radius varies significantly through eroded section of bend, determine the radius, width, and area at the beginning of erosion and at one or two other points that typify the stream curve.

From field survey and cross-sectional data, determine widths, radius, and area of bankfull discharge.

Radius of bend (R)R_1 = __________

R_2 = __________

Bankfull width (W) W1 = __________

W_2 = __________

A_1 = __________

Bankfull area (A)A_2 = __________

Determine the average depth

$$D_a = \frac{\frac{A_1}{W_1} + \frac{A_2}{W_2} + \cdots \frac{A_i}{W_i}}{i} \qquad D_a = \_\_\_\_\_\_\_\_\_\_$$

Note: The value of $\frac{A}{W}$ for each section should be somewhat similar. Use extreme outliers with caution.

Calculate the ratio of radius of bend to width (R/W) for each section of the bend, and determine the most favorable angle θ for stream barb alignment. See the description, and use the guide below.

$\frac{R_1}{W_1} \geq 3$

If <3, consider other treatment
If <6, consider reduced angle, $\theta \leq 30°$
If >6, $\theta = 30°$ to $45°$ generally satisfactory
If >9, consider larger angle, $\theta > 45°$

Step 3 Mark the beginning point of bank erosion on the outer bank curve. This determines the location of the first stream barb and marks the point where the downstream face of the weir will intercept the bank line.

Step 4 Draw a tangent to bank curve passing through the point where the weir line intercepts the bank. Refer to design layout (fig. TS14H–13). Note that the circled numbers refer to the step numbers listed herein.

Step 5 Beginning at the tangent point above, draw a line angled upstream, θ degrees (determined in step 2), from the tangent line and extending streamward. This line forms the downstream face of the stream barb. Extend this line out a sufficient distance to cross the thalweg, and measure the length from the bank. This length determines the stream barb weir length.

Step 6 Determine the effective length (L_e) of stream barb:

$$L_e = L \times \sin\theta =$$

$$\text{Check length: } \frac{W}{4} =$$

$$\text{Is } L_e \le \frac{W}{4} \text{ ?}$$

If the answer is *yes*, proceed. If no, consider a reduced weir length or reevaluate the use of stream barbs at this site. Toe erosion may be caused by processes other than direct streamflow.

Step 7 Locate subsequent stream barbs:

From a point on the outer end of the first stream barb, draw a line extending downstream to the point where it intercepts the bank. This projected line (7), should be parallel to the tangent line (4). Determine L_s, the distance from this point back to the point where previous stream barb intercepts the bank. If, L_s is $\le 5 \times L_e$, then this point is a suitable location for the next stream barb. If this point is $>5 \times L_e$, consider limiting the distance to $5 \times L_e$. It is important to note that anecdotal evidence indicates that close spacing may be required in fast, high-energy streams.

Step 8 Repeat steps 4 through 6 for subsequent stream barbs. Typically the last stream barb ends near the end of the eroding section of bank or end of bend.

Step 9 Determine stream barb section properties.

$$H = \frac{1}{3} D_a = \text{ height of weir section, outer end}$$

$$H = \frac{1}{2} D_a = \text{ height of weir section, bank end}$$

$$S = \left(\frac{1}{3} \text{ to } \frac{1}{2}\right) \times 2.5 \times D_a = \text{ depth of bed key}$$

Step 10 Determine rock size per the description on rock size (TS14H–16).

Step 11 Prepare construction drawings. See figure TS14H–14, Typical construction drawing. Figure TS14H–15 shows a detail that illustrates one possibility of incorporating a rootwad into a rock stream barb.

Cost

The cost of rock stream barbs can vary considerably given availability of material, construction access, and permitting requirements. Stream barbs are often used in combination with other treatments. In general, their cost is between $2,000 and $5,000 per individual barb. Maintenance may involve replacement of materials. Monitoring should focus particularly on the area immediately below a series of stream barbs and the bank key.

Construction considerations

Instream devices like stream barbs are best constructed during low flow. Achieving a design key in depth may require dewatering, which may be accomplished with a cofferdam. If the designs include soil bioengineering or planting, either as part of the project or to stabilize the root or bank key, then appropriate planting designs also need to be considered. All stream or river design techniques should consider critical spawning and migration periods, as well as other regulatory concerns.

Conclusion

A variety of flow-changing techniques are applicable for use in stream design projects. They can provide valuable stability and habitat benefits. Stream barbs have been well received, and it is apparent these structures will continue to be a valuable tool for streambank restoration projects in NRCS. However, they do not work in all circumstances and must be designed to fit site-specific conditions.

Figure TS14H–13 Drawing and layout details

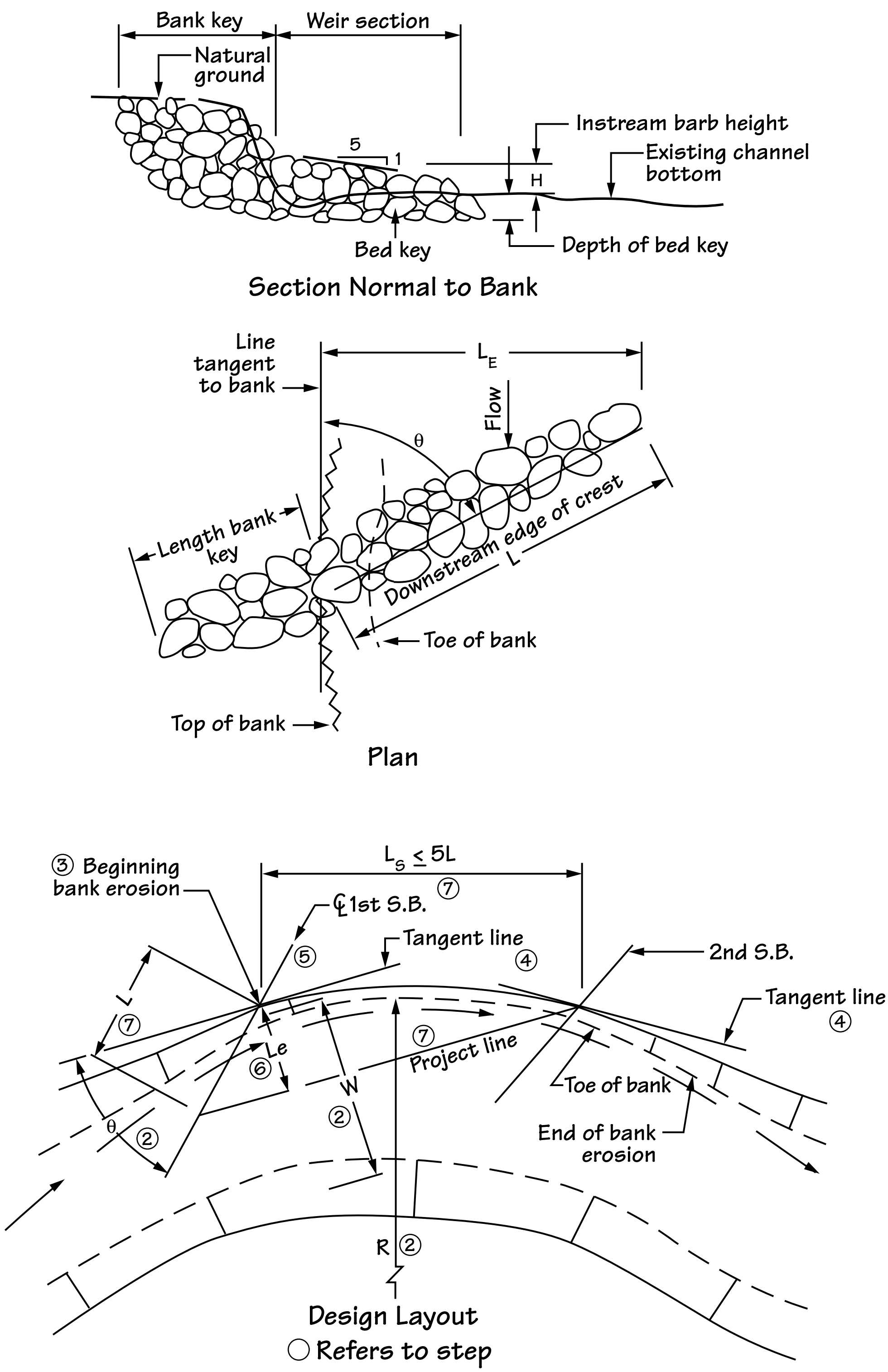


Figure TS14H–14 Typical stream barb construction drawing

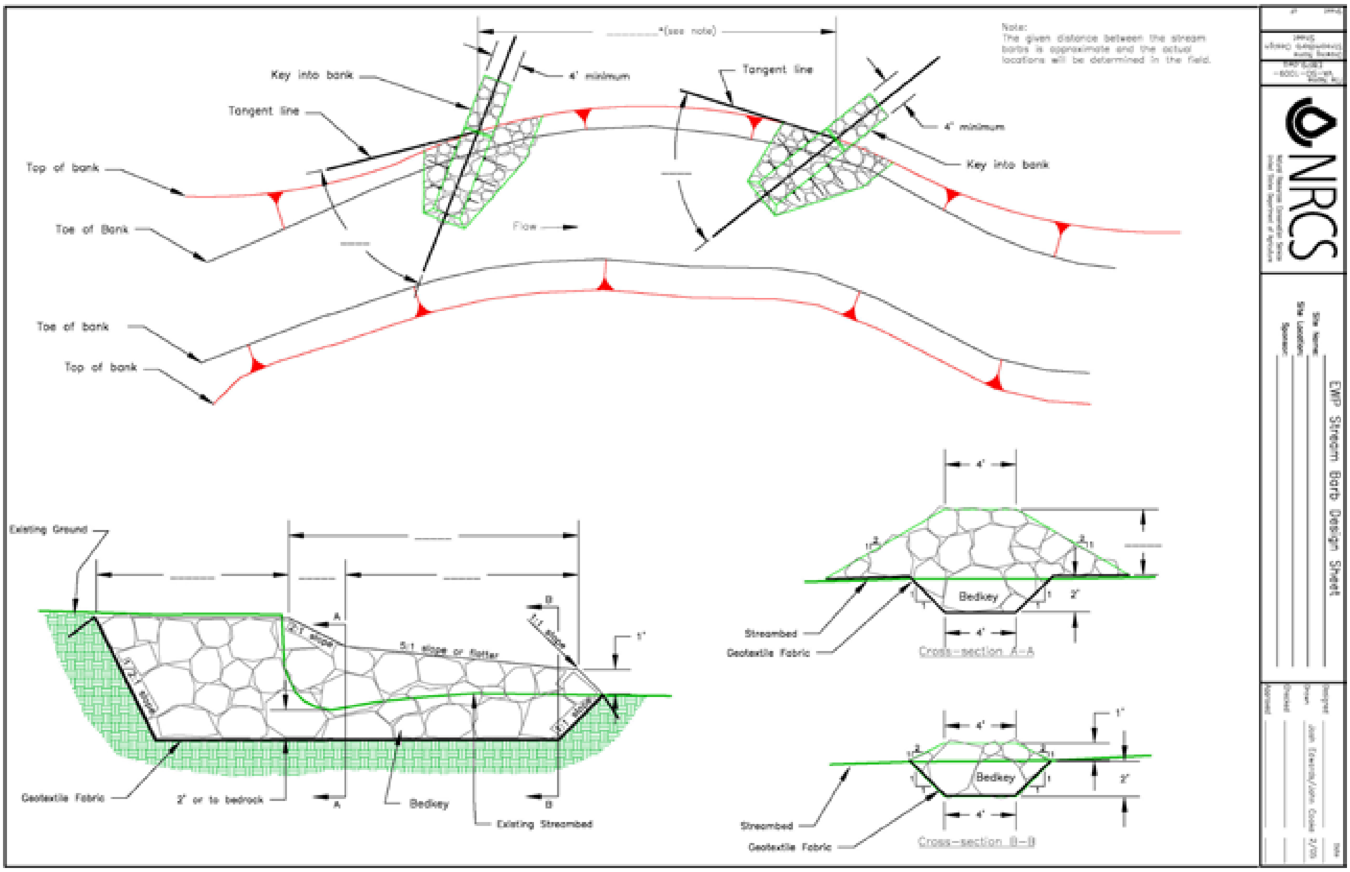


Figure TS14H–15 Detail showing the use of a rootwad incorporated into a stream barb