Streambank Protection

There are five general approaches to be considered when dealing with a streambank erosion or failure problem:

—Relocate endangered assets

—Implement effective land use management practices

—Reroute the stream channel away from the problem area

—Remove streamflow obstructions

—Plan, construct, and maintain a project that will provide the needed streambank protection

The decision to deal with the problem or "let nature take its course" is part of the planning process. If the landowner or local government decides to try to alleviate the problem caused by a distressed bank condition, then one or more of the five approaches discussed in this section may be applicable.

RELOCATE ENDANGERED ASSETS

For problem areas where streambank erosion or failure must be halted, relocation may not be a practical consideration. However, if the bank can be allowed to erode or fail without any serious consequences other than loss of a structure, road, or utility line, then relocation of these assets away from the problem area may be a viable solution. If relocation is feasible, the key factors that must be considered are the bank recession rate and the available relocation distance. If a bank has receded at an average rate of 10 feet per year for the past 5 years and a road can only be moved 20 feet, relocation is not a logical consideration; however if the bank has receded at an average rate of 3 inches per year for the past 50 years, then relocation would be a much more attractive solution to the distressed bank problem. Recession rates can often be determined from dated photographs, surveys, or plat maps. Also, information can be obtained from county land records, local public and historical libraries, national and state archives (contact National Archives and Records Service, General Services Administration, Washington, DC 20408, phone 202-523-3236), the ASCS (contact ASCS Aerial Photography Field Office, P. O. Box 30010, Salt Lake City, UT 84130, phone 801-524-5856), and the U.S. Geological Survey (see address on page 21). Relocation without the benefit of any recession rate information is risky at best.

IMPLEMENT EFFECTIVE LAND USE MANAGEMENT PRACTICES

Landowners and local governments can reduce the probability of streambank erosion or failure by maintaining or implementing effective land use management practices. These practices include:

—Protection of existing vegetation along streambanks

—Regulation of irrigation near streambanks

—Rerouting overbank drainage

—Control of rainfall runoff

—Minimizing load on top of streambanks

Relocation of this home may be more cost-effective than protecting the bank.

Clearing of a greenbelt adjacent to the top of a streambank often leads to severe erosion. Note natural greenbelt in background.

The protection provided by existing vegetation on streambank slopes and in greenbelts adjacent to streambanks is often the key factor that prevents development of a distressed bank condition. Several basic land use management practices should be observed to protect the vegetation:

RIGHT: Selective tree removal can eliminate problems caused by large trees toppling into a stream. The chain around the trunk of the tree is tied off to another tree further up the bank slope. After the tree has been cut down, the chain can be used to drag the tree out of the floodplain so it will not become floating debris or contribute to a log jam during the next floodflow.

BELOW: Animals should not be allowed to strip and trample protective vegetation on streambanks.

a. Greenbelts should not be clearcut to top bank to provide more land for cultivation or to provide a better view. The greenbelt prevents overuse of the top bank area by man, animals, and machinery. The belt also retards rainfall runoff down the bank slope and provides a root system that binds soil particles together.

b. In contrast to clearcutting a greenbelt, trees may need to be selectively removed or trimmed to promote grass and brush growth on top bank and on the streambank slope.

c. Many distressed streambank problems are caused by trees that are gradually undermined by flowing water and topple into the stream. Fallen trees can cause two problems: they may divert the streamflow into a bank or their root mass may leave a large, exposed hole susceptible to erosion. This problem can be minimized by removal of those trees that are likely to fall into the stream.

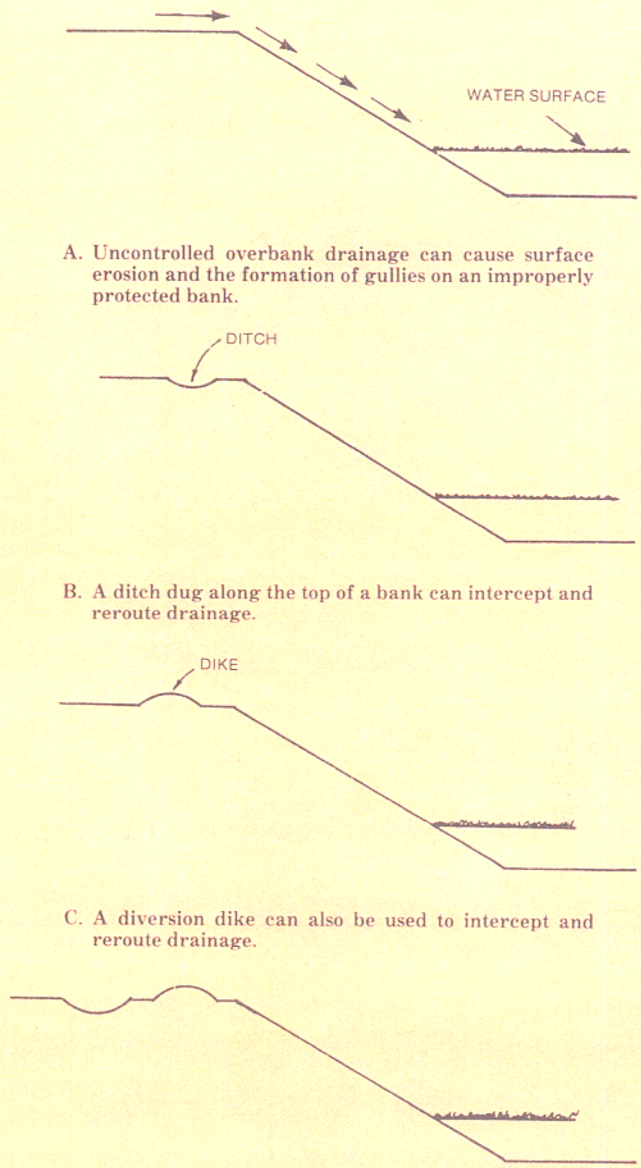
d. People, vehicles, and grazing animals should be kept off of streambank slopes to prevent vegetation from being stripped or trampled. If access between the top and toe of the bank is needed, steps or a ramp should be constructed. fencing can be erected along the top of the bank to keep vehicles and grazing animals back from the bank.

Irrigation near a streambank should be regulated such that protective vegetation and cultivated plants receive their needed amounts of water. On the other hand, irrigation should not be so excessive that the bank becomes saturated. This condition may lead to swelling of clay or increased groundwater pressure from within the bank, both of which may lead to bank failure. Another type of irrigation problem can develop during the summer months when stream levels are low. Because crop irrigation is most intensive during this period, seepage can develop on the bank face. As seepage occurs, soil particles on the bank surface may be forced loose. The resulting downslope movement of seepage water and loosened soil particles can further erode the bank.

Unless effectively controlled, overbank drainage can cause sheet and rill erosion on streambank slopes. Overbank flow can be intercepted and rerouted away from the top of a bank by ditching or a diversion dike. The ditch or dike should be laid out along top bank to a location where the water can be safely discharged into the stream without causing soil erosion (such as through a lined ditch or pipe). Runoff should not be allowed to pond behind a dike and drain through the bank face as groundwater seepage because the bank may become saturated and fail.

Good soil conservation practices such as contour farming, terracing, strip cropping, controlled grazing, and construction of farm ponds can play a major role in controlling local rainfall runoff. When such conservation practices are widely and intensively used, they can change flow conditions so that more of the runoff is held in fields and ponds or at least delayed such that peak flood flows passing a streambank are reduced. With flood peaks reduced, the potential for bank erosion and failure is decreased. Urban development can also change rainfall runoff conditions but not in the beneficial manner of effective soil conservation practices. Buildings, highways, and parking lots cover large areas that were once available for rainfall infiltration before urbanization. The reduction of natural surface area and the construction of efficient stormwater sewer systems in upstream urbanized areas can accelerate rainfall runoff and result in greater-than-normal downstream flood flows. Zoning ordinances to manage urban growth and regulations to control runoff rates can help to alleviate downstream flood problems.

Excessive load on the top of some banks may lead to failure. Since a detailed analysis by an engineer is required to determine how much load can be safely placed on top of a bank, the best policy is not to construct buildings near the top of a bank and to keep heavy vehicles away from the bank.



A. Uncontrolled overbank drainage can cause surface erosion and the formation of gullies on an improperly protected bank.

B. A ditch dug along the top of a bank can intercept and reroute drainage.

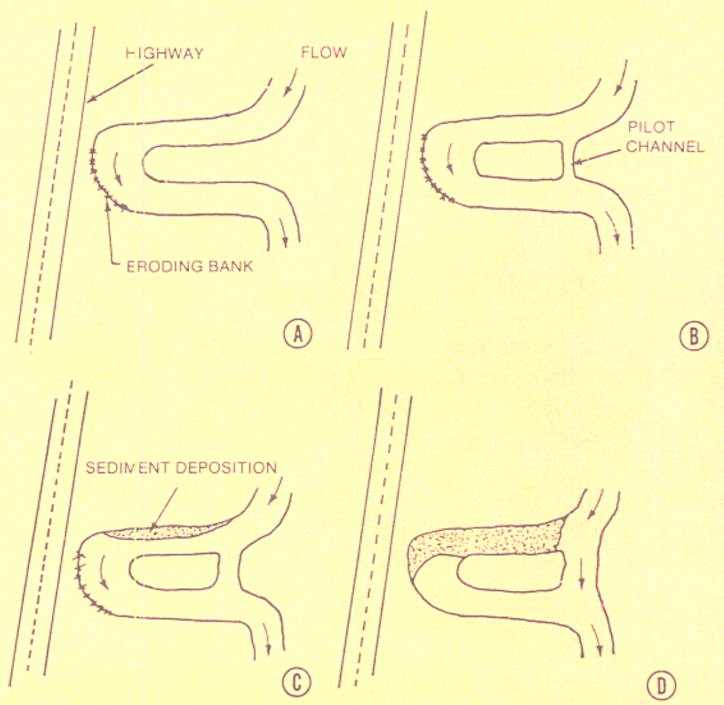
C. A diversion dike can also be used to intercept and reroute drainage.

D. Combination ditch and dike (constructed from material excavated from ditch).

Methods to control overbank drainage.

REROUTE THE STREAM

If streamflow along the outside bank of a bend (the cut bank) is the principal reason that a landowner or local government finds a bank in a distressed condition, then relocation of the channel can be an economical alternative to more costly approaches to protect the bank. Channel relocation is usually accomplished by cutting a pilot channel from a point upstream of the distressed bank to a point downstream from the bank. Because the slope of the pilot channel is steeper than the natural channel, the stream will start to flow through the pilot channel. This flow will erode soil from the banks and bed of the pilot channel, thus increasing the water carrying capacity of the new channel. Eventually the pilot channel will capture the



Protection of eroding bank by rerouting the stream. A. Eroding bank threatens highway. B. Pilot channel is excavated. C. Pilot channel begins to capture streamflow; some sediment deposition occurs in the natural channel. D. Pilot channel has captured the streamflow; water movement through the natural channel is now blocked by sediment deposition and bank erosion is stopped. See "Caution" in text.

Trees undermined by passing streamflow can deflect current against opposite bank. Arrow indicates direction of deflected streamflow.

streamflow as the channel enlarges and as the slower water movement through the natural channel is blocked by sediment deposition. Although excavating a pilot channel with heavy equipment or explosives may provide a quick and relatively economical method for keeping streamflow away from an eroding bank, this action may cause serious future problems. Shortening the length of a channel can upset the natural balance of a stream. As a consequence, bank erosion may result upstream from the pilot channel and flooding downstream. *CAUTION: prior to developing a plan to protect a streambank by excavation of a pilot channel, the Corps of Engineers or the SCS should be contacted for professional guidance.*

REMOVE STREAMFLOW OBSTRUCTIONS

Obstructions in a stream channel can alter the flow characteristics of the stream in a manner such that bank erosion and failure may occur. Typical problems are:

a. A tree undermined by passing flow can fall into the stream and deflect the current against a bank.

b. Log jams can develop at constrictions such as a bridge or a narrow reach of the stream or where one or more trees have fallen into the stream and block the travel of logs and debris floating downstream.

c. Midchannel sand and gravel bars form when the stream velocity decreases to a point where sediments can no longer be carried by the water. As a bar forms the current may be shifted against a bank causing erosion.

d. As water passing through the inside of a bend slows down, the sediments moving with the current flow settle out and start building up a point bar. As the bar builds up it can deflect the stream current against the bank across from the point bar.

Solutions for these problems are discussed below; however, landowners and local governments should be aware that implementing these solutions may provide only

Bank erosion may occur as a stream attempts to flank a log jam.

Formation of a midchannel sand and gravel bar forces current against the far bank. Tilt of tree stems indicates that severe erosion is occurring around the roots.

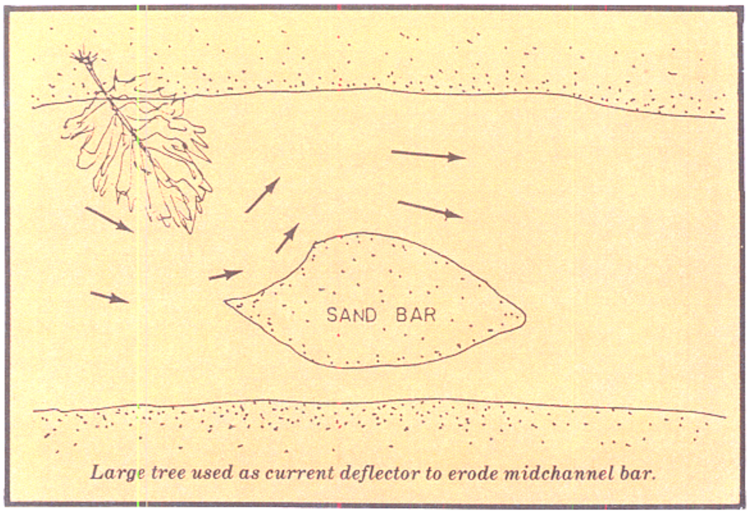
temporary relief unless used in conjunction with permanent bank protection works. For instance, removal of a point bar may move erosive currents away from the cut bank, however the point bar will probably build up again. When this occurs the cut bank will again come under attack and suffer erosion unless measures have been implemented to protect the bank with a revetment or dikes.

The remedy for fallen trees and log jams is twofold: saws and safety. Due to the unstable nature of fallen trees and log jams in a stream and the potential danger of injury when using high speed chain saws, rigid safety practices must be enforced while clearing a channel. Once a log is free, it should be removed far enough from the channel such that it cannot be refloated during high water and contribute to another log jam.

Because of the large volume of sand and gravel involved, the landowner or local government probably cannot remove a mid-channel bar or point bar. The alternative is to let the stream do the work by using the following procedures. If there are tall trees growing on the bar, they should be removed with a tractor and a block and tackle, if necessary. Always remove as much of each tree's root mass as possible. The extensive root system of large trees hold the sand and gravel in place on the bar. If the tree is too large to pull out, cut it down at ground level. Smaller shrubs need not be removed at first since their root systems are usually shallow.

Point bar deflects stream current against cut bank.

Log being removed from channel.



Large tree used as current deflector to erode midchannel bar.

If later observations indicate that the shrubs are preventing the bar from eroding, then they will have to be removed. Next, dig one or more pilot channels through the bar. The pilot channels can be dug with hand tools if trenching equipment is not available or if the bar is not accessible to machinery. Locate the channels at such an angle that a rapid current is diverted into the trench. This rapid current is needed to erode the bar. If the bar is large, several pilot channels may have to be dug. Any large stones or leaf debris should be raked off the sides of the bar. This will increase the current flow along the edges of the bar and promote erosion. If the bar is not removed by flow through the pilot channels, a current deflector can be used. The deflector consists of a brush pile or fallen tree secured at a point upstream from the bar. The current deflector should be positioned to divert the stream current against the bar. If the bar is large, several current deflectors may be needed to divert the current into the bar at several points.

STREAMBANK PROTECTION METHODS

Many streambank protection methods have been tried over past years, some being very successful and some not so successful. Several of these methods are not suitable for landowners and local governments because of heavy equipment requirements, costly construction materials, and the need for extensive financial and professional assistance. Further, some approaches to streambank protection may significantly alter the channel such as the formation of a scour hole adjacent to a project; thus, allowances must be made in project design plans to accomodate anticipated channel modifications. In spite of these constraints, several approaches to bank protection, *(both singularly and in combination)*, are realistically within the resources of local interests. Some of the more feasible methods are: (1) bed scour control, (2) vegetation, (3) bank shaping, (4) surface soil stabilizers, (5) riprap, (6) rubble, (7) gabions and wire mattresses, (8) sacks, (9) blocks, (10) used-tires, (11) fences, (12) Kellner jacks, (13) bulkheads, and (14) dikes.

BED SCOUR CONTROL. The streambed

Pilot channel eroding point bar (left). Concrete check dam (right).

acts as a foundation for its banks. If streamflow scours out the bed and in the process erodes the bank toe, then the upper bank may no longer have sufficient support; bank failure can follow. Streams experiencing active bed scour can be identified by the presence of small waterfalls or a short reach of rough water in an otherwise tranquil stream (often called headcutting). Two methods are commonly used to control bed scour: check dams and lining the channel with erosion resistant materials.

A check dam should be placed bank to bank across the scouring channel bed and located downstream from the rough water or waterfall. (NOTE: Check dams can also be placed upstream from the waterfall or rough water to intercept the headcut; however, this solution should not be considered without the benefit of professional assistance.) The net effect will be to reduce the stream velocity and to encourage sediment deposition which will build up the scoured bed. Check dams can be constructed from stone, concrete, sand-cement bags, treated timber, metal, etc. The toe of the check dam should be well protected to prevent the structure from being undermined. Further, the ends of the dam should be rooted into the banks so the structure cannot be flanked. Streambanks immediately downstream from a check dam sometimes show a tendency to erode. These banks should be watched after the dam is completed. Check dam construction can be very expensive; thus, in most cases this constraint will limit landowners and local governments to work on small streams. Further, these dams can affect the overall balance of a stream and its tributaries. Professional assistance should be sought before one or a series of dams are placed in a stream.

Another approach to controlling channel bed scour is lining the bed and lower bank with erosion resistant materials. Suitable materials are stone, rubble, sand-cement bags, blocks, or establishing a healthy stand of grass tolerant to inundation. Also, a filter may be required (see Glossary). The cost for constructing a lined channel can be prohibitive if the reach of a stream that is experiencing bed scour is long or the bed is wide.

VEGETATION. Of all the approaches available to landowners and local governments for protecting a streambank, vegetation is probably the most commonly used method because it is relatively easy to establish and maintain, is visually attractive, and is the only streambank protection method that can repair itself when damaged. Below a stream's waterline, vegetation can effectively protect a bank in two ways. First, the root system helps to hold the soil together and increases overall bank stability by forming a binding network. Second, the exposed stalks, stems, branches and foliage provide resistance to the streamflow, causing the flow to lose energy by deforming the plants rather than by removing soil particles. Above the waterline, vegetation

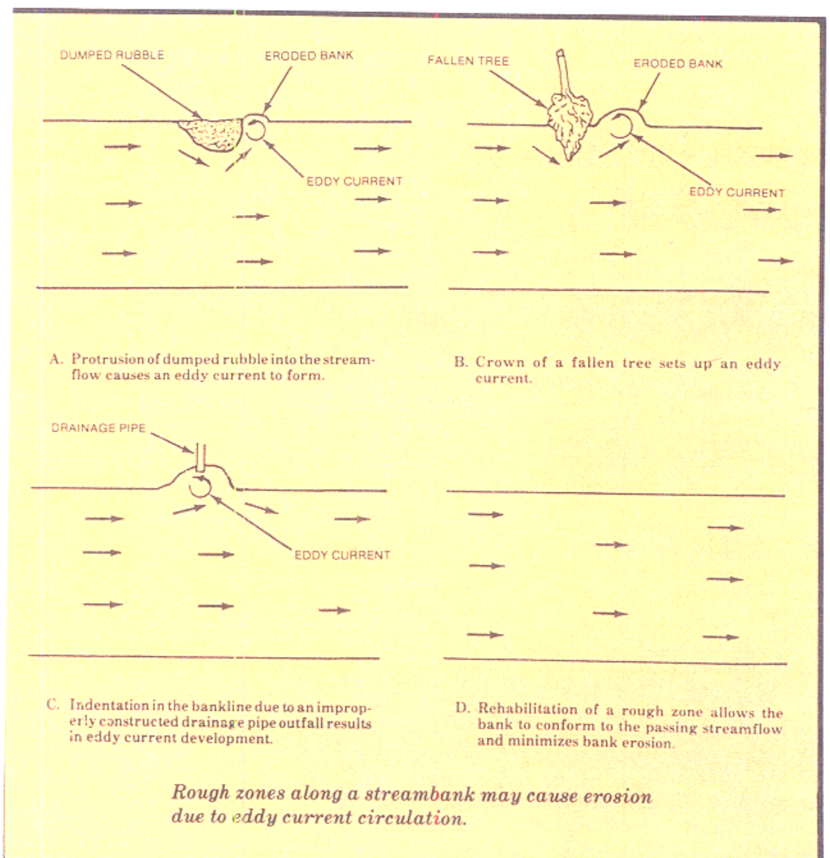
The bed and lower bank of this channel were lined with manufactured precast concrete blocks to retard active bed scour. Openings in the blocks allow grass to grow through (left). Properly selected grass species can provide effective streambank protection (right).

prevents surface erosion by absorbing the impact of falling raindrops and reducing the velocity of overbank drainage flow and rainfall runoff. Further, vegetation takes water from the soil providing additional capacity for infiltration and may improve bank stability by water withdrawal.

Vegetation is generally divided into two broad categories: grasses and woody plants (trees and shrubs). The grasses are less costly to plant on an eroding bank above the toe and require a shorter period of time to become established. Woody plants offer greater protection against erosion because of their more extensive root systems; however, under some conditions the weight of the plant will offset the advantage of the root system. On very high banks, tree root systems do not always penetrate to the toe of the bank. If the toe becomes eroded, the weight of the tree and its root mass may cause a bank failure.

The major factor affecting species selection is the length of time required for the plants to become established on the slope. Species selection should also be based on compatibility with the soil, air temperature ranges, total rainfall, distribution of rainfall, bank slope, and the ability of the soil to store water for plant growth during dry periods. For sections of a streambank where scour is a problem, woody plants established at the toe of the slope and grass above the toe have proven to be good protection. For assistance with species selection, landowners and local governments should contact the USDA Soil Conservation Service, USDA Forest Service, county agricultural extension services, soil and water conservation districts, as well as other experts. Information needed to contact the SCS Plant Materials Centers is provided on pages 53-54.

Grass can be planted by hand seeding, sodding, sprigging, or by mechanical broadcasting of mulches consisting of seed, fertilizer, and other organic mixtures. Several commercial manufacturers now market economical erosion control matting that will hold the seed and soil in place until new vegetation can become established. The matting is generally installed by hand and secured to the bank with stakes or staples. If livestock graze near a bank where plantings have been made to prevent erosion, then a fence should be placed along top bank. If the livestock require access to the stream for watering or crossing, gates should be placed in the fence at locations where the cattle will do the least amount of damage to the planted bank; additionally, crossings should be fenced.



A. Protrusion of dumped rubble into the streamflow causes an eddy current to form.

B. Crown of a fallen tree sets up an eddy current.

C. Indentation in the bankline due to an improperly constructed drainage pipe outfall results in eddy current development.

D. Rehabilitation of a rough zone allows the bank to conform to the passing streamflow and minimizes bank erosion.

Rough zones along a streambank may cause erosion due to eddy current circulation.

BANK SHAPING. A properly shaped streambank should be smooth enough to prevent *rough zones* along the bankline from setting up eddy currents that may severely erode the bank. These zones are caused by protrusions or indentations in the bank line. Such irregularities should be removed by smoothing the bank surface. All areas that are exposed or stripped of vegetation during rehabilitation of a rough zone should be protected with vegetation or some other type of streambank protection. The reader should note that a series of protrusions (or dikes) may sometimes be successfully used for streambank protection; however, unless properly designed, there is a danger of creating the undesirable rough zones just discussed. A later section in this pamphlet describes the proper placement of dikes.

Another method that can be used to stabilize a bank is shaping the bank (more commonly called laying the bank back) to a slope less than the maximum slope at which the bank can stand without any danger of failing. Determination of how far a bank must be laid back to satisfy this requirement is a very complex problem. The tradeoff is to ensure that the bank is laid back far enough to minimize the chances of failure, but on the other hand not so far that unnecessary earthwork is done. If this method appears to be a feasible approach, then professional assistance should be sought to develop a sound estimate for an acceptable slope steepness.

SURFACE SOIL STABILIZERS. Three surface soil stabilization methods have been successfully used for streambank protection: (1) sand-cement blankets, (2) clay-lime-cement blankets, and (3) mulches.

A sand-cement blanket with 8 to 15 percent cement is an economical and effective streambank protection method for use in areas where vegetation is difficult to establish and the bank material is predominately sand. The sand can be mixed with cement by hand or mechanically to a depth of at least 4 inches. The mixture should then be wet down and allowed to set up. This method has the advantage of low cost. However, there are three major disadvantages: impermeability, low strength, and susceptibility to temperature variations. If the bank behind the blanket becomes saturated and cannot drain, failure may occur. Also, because a sand-cement blanket is relatively brittle, very little if any traffic (vehicular, pedestrian, or livestock) can be sustained without cracking the thin protective veneer. In northern climates the blanket can break up during freeze-thaw cycles.

If the streambank soil is mostly clay, lime must first be mixed with the soil to make the tiny clay particles form *clods*. After a suitable curing period, cement is then mixed with the soil and wet down. The bank is then compacted by rolling a rubber-tired vehicle over the surface. This operation strengthens the soil against erosion. There are no firm guidelines on the percentage of lime to be mixed with the clay, the curing time, the percentage of cement to be mixed with the clay-lime clods, or the number of times the rubber-tired vehicle must pass over the bank surface to bring it to a condition of maximum erosion resistance. Professional assistance should be sought if this type of bank protection is considered.

Mulches composed of straw, hay, and wood chips are commonly used to stabilize exposed soils prior to seeding for long term vegetation growth. In addition to functioning as an intermediate stabilization measure, mulches, when applied during permanent seeding, also aid in the germination process by conserving moisture and absorbing the impact of falling raindrops.

RIPRAP. Stone riprap is natural rock dumped or hand placed on a streambank to prevent erosion. Three general approaches are used:

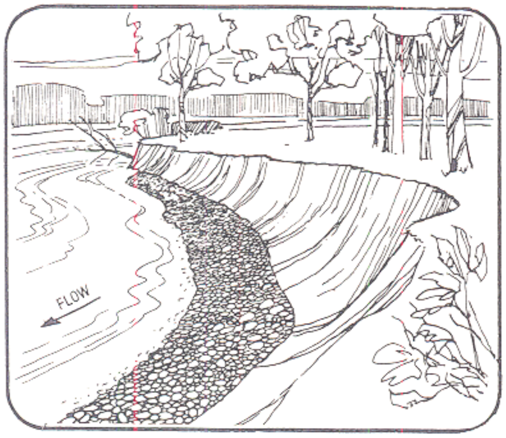
- Riprap placed along the toe of a bank to minimize scour
- A riprap blanket laid over a bank slope to prevent erosion
- A windrow of riprap stockpiled on top of or buried in an eroding bank to stop advancing erosion

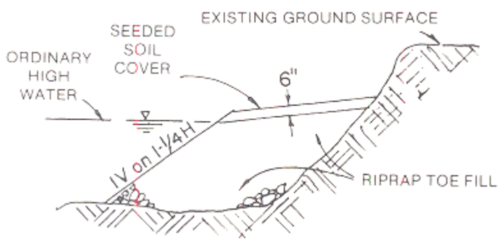
These three approaches are discussed below.

When the toe of a bank is scoured out, support for the upper bank is lost. As a result, the upper bank may fail. Stabilization of a bank toe with riprap in conjunction

Soil-cement blanket.

(Photo courtesy of Portland Cement Association)





Riprap is an effective method to control toe scour. A drawing of a typical toe is shown in the lower view.

with some other form of protection on the upper bank such as vegetation offers an effective approach to bank protection if toe scour is the major problem.

Riprap blankets can be used to protect streambanks in areas where quality stone is economically available. A blanket is relatively flexible and can conform to minor changes in bank shape due to settlement or scour. In addition, construction of a riprap blanket is not complicated, no special equipment is necessary, and minor damages can be repaired by placement of more stone. For these reasons, riprap blankets are widely used as protection for an entire bank face or in some cases the portion of the bank below the high water mark. Several factors should be considered in properly designing a riprap blanket:

- □ What shape and weight of stones will be stable in the streamflow?
- □ What blanket thickness is required?
- □ Is a filter (see Glossary) needed between the bank and the blanket to allow seepage but to prevent erosion of bank soil through the blanket?
- □ How will the blanket be stabilized at the toe of the bank?
- □ How will the blanket be tied into the bank at its upstream and downstream ends?

Block-type riprap is preferred over elongated stone for construction of a blanket because the stones fit together better. Large protruding stones should be removed from the blanket or broken up because accelerated water flow around a large stone can cause scour as well as removal of small stones adjacent to the large one. A well distributed mix of stones weighing from 20 to 200 pounds will be suitable for applications where the maximum stream velocity is less than 10 feet per second.* With this range of weights, the openings formed by the larger stones will be filled with the smaller stones in an interlocking fashion. The stone should be hard and dense and free from cracks and other defects that would tend to increase deterioration due to weathering. Professional guidance should be sought if there is any question about the quality or size of the stone.

For banks where the primary soils are silt and fine sand, a filter can be placed between

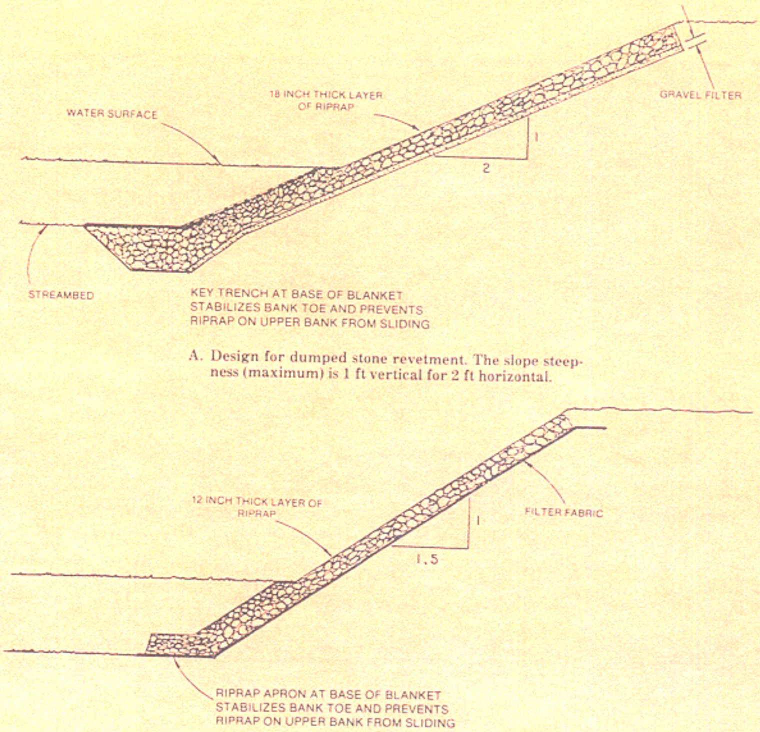
A completed stone riprap blanket.

* The stream velocity can be estimated by tossing a wood chip into the flow near the bank where the riprap is to be placed and then measuring the time required for the chip to travel over a known distance. For instance, if the chip floats 100 feet downstream in 11 seconds, its velocity is 9 feet/second. The greatest velocities generally occur during flood flow, therefore, the best estimate for the maximum stream velocity would probably result from measurements made during high water periods.

the riprap blanket and the bank to prevent the loss of fine materials through the blanket but to still allow seepage. A layer of gravel and/or sand or a properly selected filter fabric is suitable as a filter. If a filter is used, technical assistance should be obtained to ensure that the filter will be properly matched with the riprap blanket and the soil.

The thickness of a riprap blanket should be at least 1 to 1.5 times the maximum diameter of the largest stones used in the blanket or twice the average diameter of the stones used. For most applications, a 12- to 18-inch-thick blanket is acceptable. The thickness of the blanket should be increased 50% for portions of the revetment that will be underwater at the time of placement. The recommended maximum slope steepness for dumped stone is 1 foot vertical for 2 feet horizontal. The maximum slope can be increased to 1 foot vertical for 1.5 feet horizontal for hand-placed stone. The blanket should be stabilized at its base with a key trench or apron to prevent the stone from sliding down the bank. The upstream and downstream ends of the blanket should be tied into the bank to prevent stream currents from *unravelling* the blanket. The most common method to tie into the bank is to dig a trench at the ends of the blanket. The depth of a trench should be twice the blanket thickness and the bottom width of the trench three times the thickness. Once the final plans for a riprap blanket are completed, they should be submitted for technical review to an engineer experienced in stone riprap blanket design.

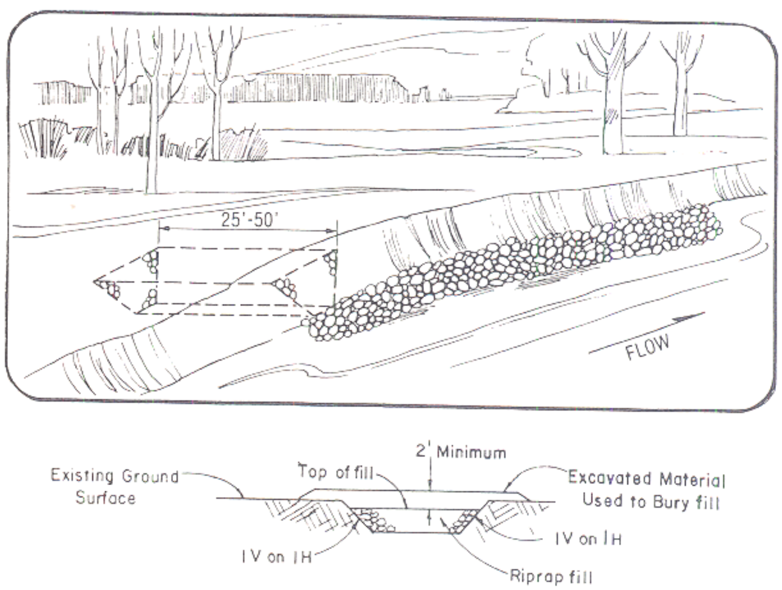
In addition to using stone riprap for toe protection and for construction of a blanket, riprap can be stockpiled or buried along the top of an eroding bank as a windrow revetment. As the windrow is undercut, riprap will slide down the bank and armor the eroding area which will help to prevent further undercutting. Once the erosion is stopped, any stone that is not undercut can be salvaged and relocated on the top of another eroding bank. Care should be taken not to overload the top bank such that a failure occurs due to the weight of the riprap (see next page).



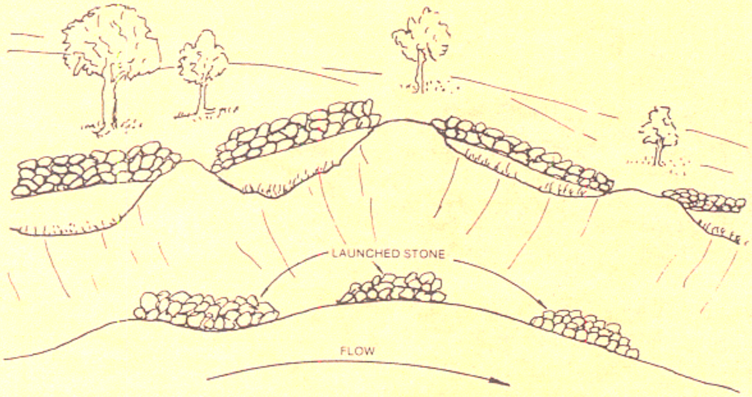
A. Design for dumped stone revetment. The slope steepness (maximum) is 1 ft vertical for 2 ft horizontal.

B. Design for hand-placed stone revetment. The slope steepness (maximum) is 1 ft vertical for 1.5 ft horizontal.

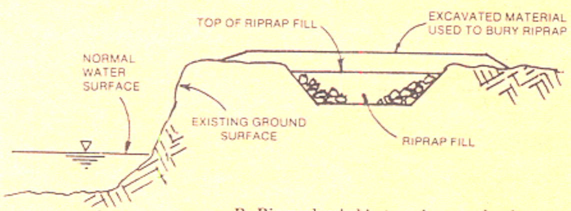
Typical stone riprap blanket designs.



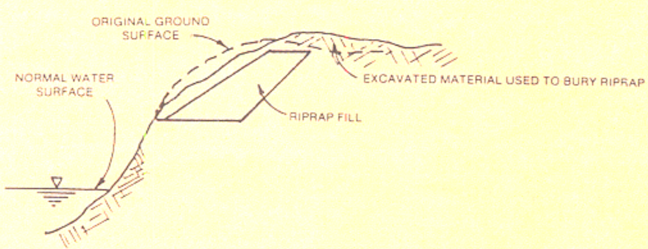
A tie-in trench should be dug into the bank at the ends of the riprap blanket to prevent the revetment from unravelling. In the example shown, the trench has been dug to the top elevation of the upstream end of the revetment; as unravelling occurs the stone slides into the eroded revetment to prevent flow behind the blanket. Under optimum construction conditions, heavy excavating equipment is available so that the trench can be dug to the elevation of he waterline or lower.



A. Riprap stockpiled on top bank. Note that some stone has been undercut and launched down the slope to protect the toe.



B. Riprap buried in trench on top bank



C. Riprap buried in notch on top bank

Windrow revetment. Caution should be exercised in working near top bank with heavy equipment.

RUBBLE. Urban renewal projects and other redevelopment efforts have made large quantities of rubble available. Although sometimes unsightly, rubble can provide an effective alternative approach to bank protection when minimal funds are available. The major problem associated with using rubble is that there is often no control over the type and size of materials dumped on an eroding bank. As a result, the rubble may offer little protection because of insufficient weight to stay in place during floodflows and in addition may pollute the stream if the dumped material is soluble in water or will rust. Some of the types of rubble suitable for dumping on an eroding bank include broken pavement, bricks, building blocks, slag, and quarry waste. Large flat slabs should be broken up into smaller pieces. Garbage, vegetation, scrap lumber, gypsum board, roofing, metal refuse, etc., should not be used under any circumstances.

GABIONS AND WIRE MATTRESSES. If available stone is not of sufficient size to stay in place during floodflow or if the bank to be protected is steep, then rock and wire in combination can provide several alternatives to stone used by itself. The more commonly used combinations are:

—Gabions

—Rock and wire mattress

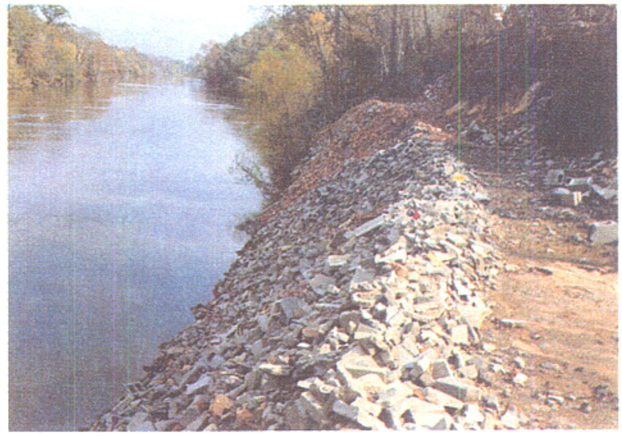
—Wire mesh over stone

Commercially prefabricated gabions have been marketed in Europe for many years; however, this type of gabion has only been available in the United States during the past 20 years. The basic element of the gabion revetment is the cage or basket. The basket is a rectangular wire-mesh structure divided into cells. The mesh is generally galvanized steel wire.

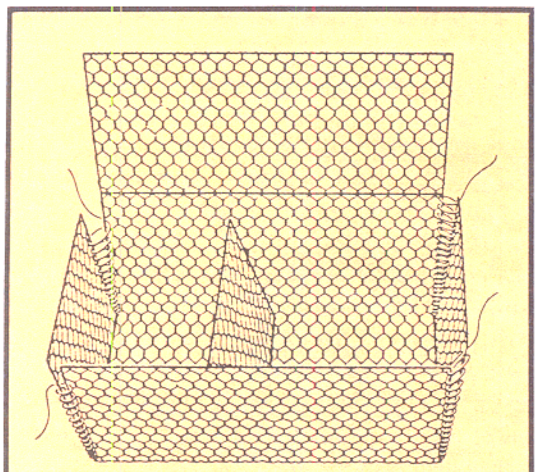
Prior to placement of the baskets, a support apron should be laid on the bank toe extending past the foot of the gabion revetment (the apron can also be constructed out of gabion baskets). Each basket should be placed and securely wired to the apron or its neighbors and then filled with stone which should be larger than the wire mesh openings. Tie wires are often connected between opposite walls inside the cells prior to filling with stone to avoid bulging on the sides of the basket. Although gabion baskets are commercially available, they can be constructed using a wooden or metal frame.

The rock and wire mattress is closely akin to the gabion approach except that the basket is much thinner. Prefabricated baskets are commercially available; however, they can be made from locally available materials. Although the rock and wire

Rubble revetment constructed from broken pavement, concrete blocks, and house brick.



Junk dumped on an eroding bank is not only unsightly but will not provide any long-term protection.



Prefabricated commercial gabion basket.

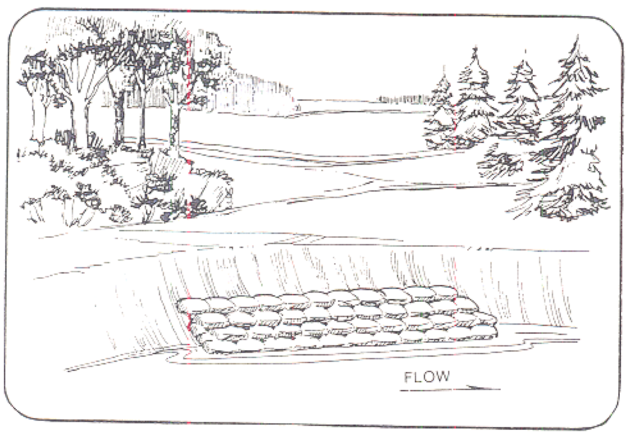
Completed gabion revetment made from prefabricated baskets. Note support apron (arrow) extending from toe of structure.

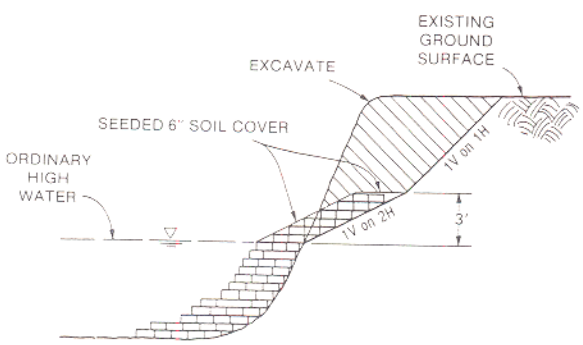
mattress is generally used as a substitute for a riprap blanket when stones of sufficient size are not available, the mattress has the added benefit of generally requiring a lesser thickness of stone than the blanket to achieve the same degree of protection. The major drawback is that a rock and wire mattress generally costs more to place than a comparable riprap blanket.

The most economical combination of rock and wire for streambank protection is simply laying wire mesh over stone. The major problem with this approach is keeping the mesh in place. One successful solution has been to bend pipe or rebar into the shape of a staple and then drive it through the mesh into the bank (see photo next page).

Rock and wire mattress made from prefabricated baskets.

Wire mesh over stone. Note "rebar staple" driven through mesh into the bank





Typical sand-cement bag revetment.

SACKS. Burlap sacks filled with soil or sand-cement mixtures have long been used for emergency work along levees and streambanks during floods. In recent years commercially manufactured sacks (burlap, paper, plastics, etc.) have been used to protect streambanks in areas where riprap of suitable size and quality is not available at a reasonable cost. Although most types of sacks are easily damaged and will eventually deteriorate, those sacks filled with sand-cement mixtures can provide long-term protection if the mixture has set up properly. Sand-cement sack revetment construction is not economically competitive in areas where good stone is available. However, if quality riprap must be transported over long distances, this type of sack revetment can often be placed on an eroding streambank at a lesser cost than riprap.

If a permanent revetment is to be constructed, the sacks should be filled with a mixture of 15 percent cement (minimum) and 85 percent dry sand (by weight). The filled sacks should be placed in horizontal rows like common house brick beginning at an elevation below any toe scour (alternatively, riprap can be placed at the toe to prevent undermining of the bank slope). The successive rows should be stepped back approximately 1/2-bag width to a height on the bank above which no protection is needed. The slope steepness of the completed revetment should be no more than 1 foot vertical for 1 foot horizontal. After the sacks have been placed on the bank, they can be hosed down for a quick set or the sand-cement mixture can be allowed to set up naturally through rainfall, seepage or condensation. If cement leaches through the sack material, a bond will form between the sacks and prevent free drainage. For this reason weepholes should be included in the revetment design. The installation of weepholes will allow drainage of groundwater from behind the revetment thus helping to prevent pressure buildup that could cause revetment failure.

BLOCKS. Precast cellular blocks can be manufactured using locally available sand, cement, and aggregate or can be obtained from commercial sources. Cellular blocks are cast with openings to provide for drainage and to allow vegetation to grow through the blocks thus permitting the root structure to strengthen the bank. Fabric or a gravel blanket can be used as a filter under the blocks if there is any danger that the bank soil will be eroded through the block openings by streamflow or seepage. If a filter is used, technical assistance should be obtained to properly match the filter with the soil. Although specialized equipment can be used to install large sections of blocks, hand placement is frequently used when mechanized apparatus is not available, access to the bank is limited, or costs need to be minimized. After the blocks have been placed, the revetment has sufficient flexibility to conform to minor changes in bank shape. Solid blocks should not be used because the bank may not be able to drain freely and failure could occur.

Commercially manufactured cellular concrete blocks.

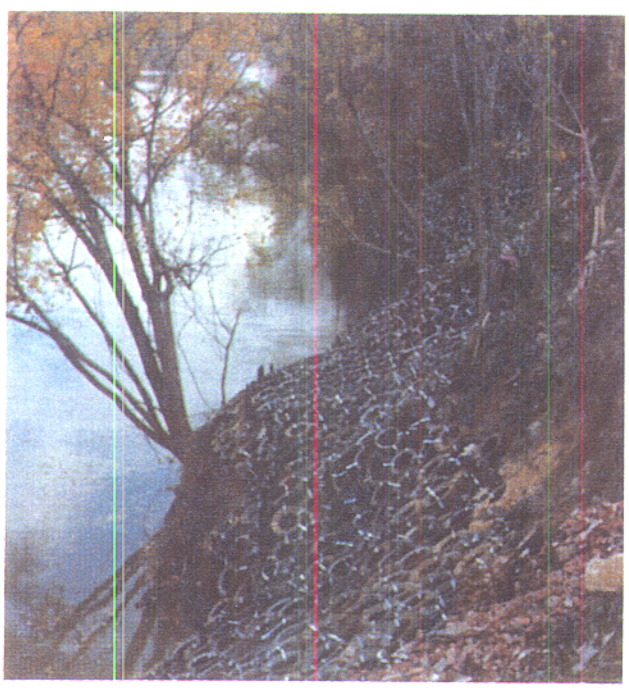
USED TIRES. Used tires can often be found in large quantities around car service centers and junk yards. Because uses for old tires are limited, most of these tires eventually end up in a scrap pile or buried in a landfill. During the past 15 years, landowners and local governments have reported successful use of old tires for streambank protection. Tires have been placed both as a mattress and stacked back against the bank. Both methods appear to have good potential as an economical approach to protect a streambank.

During construction of a tire mattress on an eroding bank, two precautions should be considered to ensure that the mattress will stay in place.

- The tires must be banded together; alternatively, cables running the length and width of the mattress can be woven through the tires.
- The top, toe, and the upstream and downstream ends of the mattress must be tied in to the bank (see diagram next page). If scour is anticipated, riprap should be placed at the toe of the mattress for additional protection.

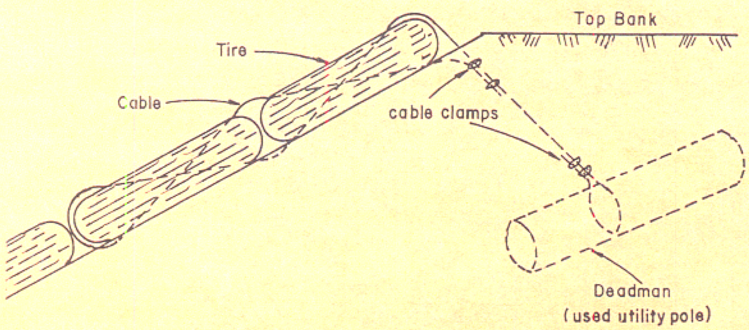
While the precautions listed above are essential for successful construction of a stable mattress, other considerations can further improve the chances that the revetment will provide long-term bank protection.

- Holes can be cut, drilled, or burned in the tire sidewalls to prevent flotation.



LEFT: Used-tire mattress with tires banded together.

BELOW: Stacked-tire revetment.



Deadman and cable used to tie in top of mattress to bank. Piles, posts, or screw-type anchors are other types of materials that can be used as deadmen.

Stacked tires should be packed with stone or rubble.

- Presorting the tires by size may help to fit them together.
- Earth screw anchors (or some other type of anchor) fastened to the mattress can be placed in the bank at various points on the face of the revetment.
- The tires can be packed with stone or rubble.
- Willows can be planted inside the tires preferably at the beginning of the growing season. Once established the root system will further strengthen the bank and obscure the somewhat unsightly mattress. If willows are not readily available, another species should be planted. Assistance with species selection is discussed under vegetation.

If the mattress effectively controls the streambank erosion and remains intact, sediment may gradually cover the revetment. If willows have not been planted, volunteer vegetation will probably become established in areas with a temperate climate.

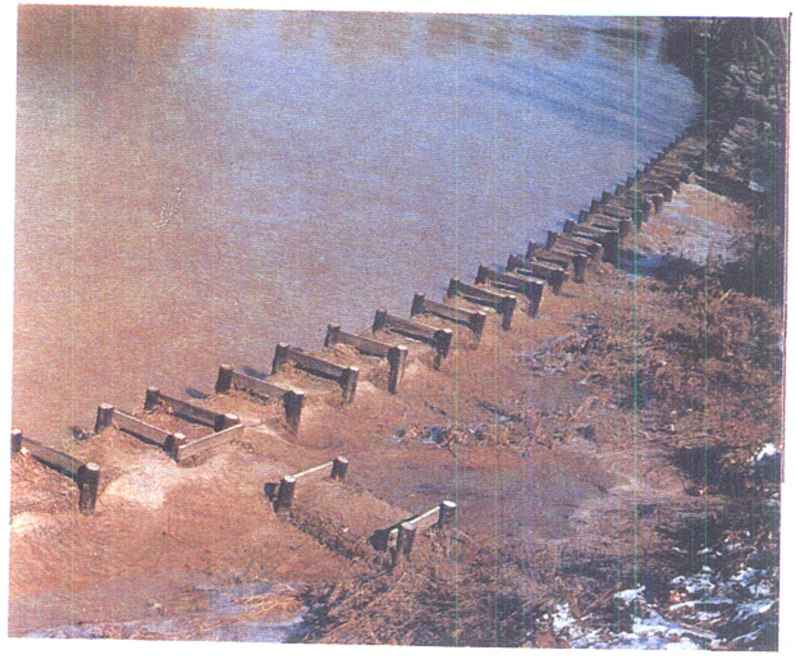
Prior to constructing a stacked-tire revetment, the bank face should be shaped so that the tires can be laid in horizontal rows. The revetment should be started at the toe of the bank and stepped back 6 to 12 inches per row. Each tire should overlap the two tires under it. The stacked tires should be packed tightly with stone or rubble. Any space behind the tires should be filled with free-draining soil so that the soil mass will not become saturated and cause the revetment to fail. In addition, the upstream and downstream ends of the revetment should be tied into the bank so that there is no flow behind the revetment.

FENCES. Fence construction parallel to a bankline can serve three purposes:

- To reduce the velocity of the stream near the bank so that erosion will be minimal.
- To encourage sediment deposition (as a result of the lower stream velocity) which will build up the bank.
- To develop a new bank alignment or to maintain the existing bank alignment; that is to keep the same channel shape along the eroding bankline so that additional land will not be lost.

Many types of local materials have been used for fence construction. Wood, used rails, pipe, steel beams, etc., are suitable as fence posts. The same materials can be used to back brace the fence. Wood and wire are generally used for the fencing material. If wire is used it should be strong enough to withstand the expected current load of water and debris. Field fencing and welded-wire fencing are effective against heavy and medium current loads, while chicken wire is suitable for lighter loads. Double row fences are sometimes constructed to provide additional resistance to stream attack with the gap between the fences filled with brush, hay, stone, or used tires.

Fences offer a good approach to landowners and local governments for protecting a streambank because no equipment is needed for construction other than machinery commonly found around farms or in



local government maintenance barns; in addition, the materials needed to construct fences are widely available. A few important points should be considered during the design and construction of a fence:

a. If the stream carries extremely heavy debris during floods, the elevation of the fence top should be well below the high-water level so that debris such as heavy logs will pass over the fence.

b. The ends of the fence should be tied into the bank at the upstream and downstream ends of the fenceline to minimize flow between the fenceline and the bank that could cause erosion. If the fence is long, tiebacks are needed at regular intervals between the fenceline and bank.

c. Fencing should be fastened to the channel side of the fence post so that the force of the water and impact of debris will not be entirely on nails, staples, or bolts.

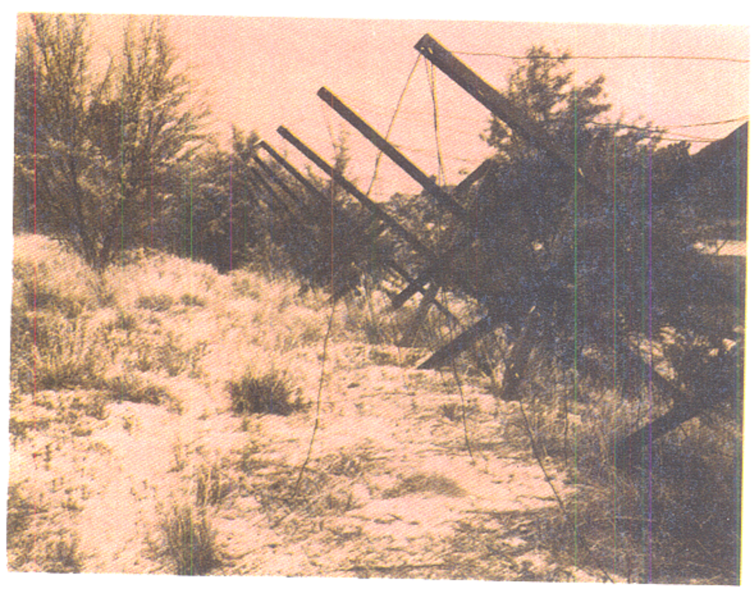
d. Wire fencing and hardware should be galvanized.

e. Fence posts should be placed to a depth equal to 1/2 to 2/3 of their total length. If stream velocities of 10 to 15 feet per second are expected during flood flow and the stream has a sandy bed, posts should be set to a depth of at least 15 feet (see footnote, page 38).

f. The toe of the fence must be protected with riprap or rubble if bed scour is anticipated, or if the fence is located on the cutbank of a bend.

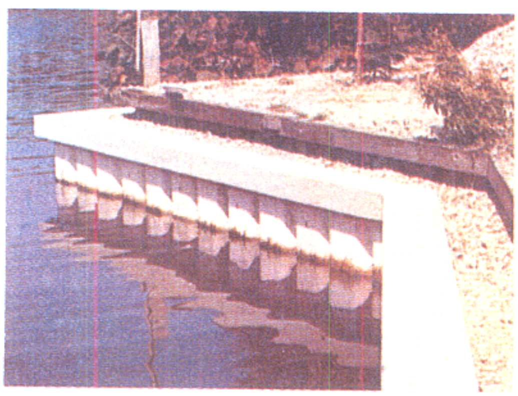
KELLNER JACKS. A string of Kellner jacks can be placed along a bankline to prevent erosion in the same manner as a fence. Jacks can be assembled from angle iron, timber, pipe, rails, rebar, precast concrete, etc. Each jack consists of three members bolted or welded together at their midpoint such that each member is at right angles to the other two (similar to the shape of a toy jack). The members are then laced together with cable. Finally, the jacks are cabled together to form a string along the bankline. Additional strings can be placed perpendicular to the bankline to tie the main string in with the bank and to reduce the stream velocity against the bank.

Wooden fence constructed along eroding streambanks. Note sediment deposition behind the fenceline and the tie-back fences between the fence and bank. If the fence is long, tie backs are needed to minimize flow between the fenceline and bank (left). Double row fence (right). Fences are most successful as a bank protection method on streams with heavy sediment loads.



Kellner jacks assembled from angle iron.

BULKHEADS. Bulkheads can be used to prevent streambank erosion or failure. As an additional benefit, a bulkhead may provide a substantial increase in waterfront area and an improvement in water/land access. Concrete, steel, timber, and more recently, aluminum, corrugated asbestos, and used tires have been used to construct bulkheads. Concrete and steel bulkheads generally cost at least four times as much as a comparable bulkhead of another material; however, the service life is longer and less maintenance is required. Timber and used tires are the most commonly available materials for economical bulkhead construction and have been used by many landowners and local governments to protect streambanks.



ABOVE: Timber bulkhead.

RIGHT: Asbestos fiber bulkhead with a concrete cap serves as a boat dock and stabilizes the bank.

BELOW: Used-tire bulkhead.

Timber bulkhead construction is similar to common fence construction except that a few precautions should be observed:

a. All wood should be treated with preservative to minimize deterioration due to repetitive wetting and drying or insect activity.

b. The toe of the bulkhead should always be protected with riprap or rubble. The most common cause of bulkhead failure is scour around the pilings, followed by the structure tipping over due to the pressure of the bank behind the bulkhead.

c. Piles should be anchored to deadmen buried in the bank.

d. Fill material placed between the bulkhead and natural bank should be free draining so that the soil behind the bulkhead will not become saturated and push the structure over.

e. If there are no cracks between the planks, weepholes should be drilled in the fence at regular intervals to allow the bank to drain. Filter fabric or gravel can be placed as a filter behind openings in the fence to prevent fine soils from leaching through. If a filter is used, technical assistance should be obtained to properly match the filter with the soil.

f. The bulkhead should be tied into the bank at the upstream and downstream end of the structure to prevent flow behind the bulkhead.

If used tires are readily available, an economical bulkhead can be constructed provided the completed structure is less than 4 feet high. The tires should be laid out in horizontal rows with each tire being tightly packed with stone or rubble. Further, the tires should be stacked so that all tires overlap the two tires under them. Any space between the bulkhead and the natural bank should be filled with free-draining soil. In addition, the upstream and downstream ends of the bulkhead should be tied into the bank to prevent flow behind the structure. This type of bulkhead can provide protection against erosion by stream currents and wave attack, but no protection against bank failure unless the tires are banded together and anchored to deadmen buried in the bank. If the tires are properly banded together and anchored into the bank, the bulkhead can be constructed to heights greater than 4 feet.

DIKES. Dikes can protect a streambank in two ways:

- By reducing the stream velocity as the current passes through the dike so that sediment deposition occurs instead of erosion (permeable dike).
- By deflecting the current away from the bank (impermeable dike).

While a structure that reduces the stream velocity or diverts currents is called a dike in many areas, several other terms are also used to describe the same type of structure, such as groin, spur, jetty, deflector, etc.

A permeable dike is most effective on streams carrying heavy sediment loads. As sediment-laden flow moves through the dike the sediment will be deposited on the streambed and bank if there is a sufficient reduction in water velocity. Deposited soil particles will build up the eroded bank and possibly lead to volunteer vegetation growth. A series of permeable dikes placed along an eroding bank (often called a dike field) can be constructed using several approaches; among the most common are board and wire fences. Materials to construct fences are readily available; however, these materials should be chosen with care to withstand anticipated piling scour, debris impact, and stream currents.

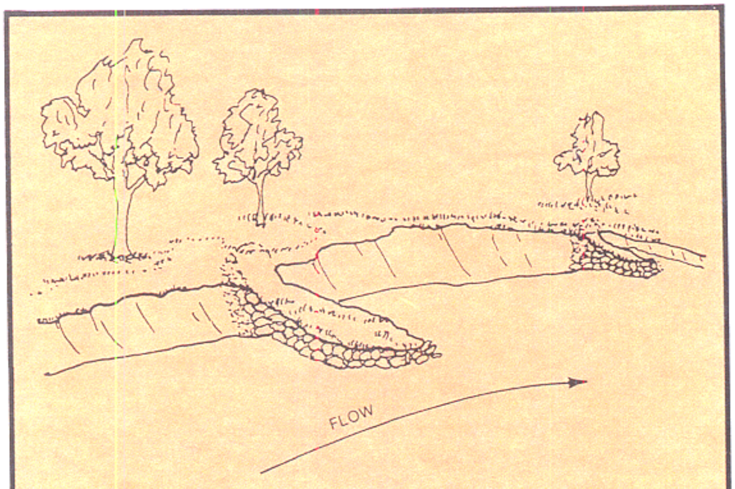
Although some types of impermeable dikes pass a small amount of flow, their major function is to divert eroding currents away from a bank. Impermeable dikes can be made from brush, logs, stone, or rubble. The first dike along an eroding bank should be constructed immediately upstream from the location on the bank where erosion is initially apparent. After this dike is completed, the current will be deflected toward

ABOVE: Board fence dike field.

LEFT: Brush dike.

LEFT: Brush dike tied into bank with cable.

BELOW: Wire fence dike field. Note that the top of each fence post is guyed to the bottom of the fence post immediately upstream and that each fence line is tied into the bank.



Impermeable dike constructed out of stone with earth fill.

the center of the channel and then may stay in midstream, return to the bank, or touch the opposite bank. The path of the current should be followed by throwing a float into the current upstream from the first dike. If the float does not return to the bank, one dike may be sufficient to arrest the erosion* (this procedure should be repeated to see if identical results are obtained). If the float does touch the bank on the same or opposite side, another dike should be constructed at the point of contact to deflect the current back toward midstream. The procedure should be continued until the float remains in midstream and does not touch either bank. The flow characteristics of the stream may change as the stream moves from a low water to flood condition, thus, the path of a float could change depending on the depth of the stream. Generally, dike locations should be determined when the stream is at a depth where the most erosion occurs. Professional guidance may need to be sought in order to determine the length, height, and geometry of a dike and its angle with respect to the streamflow.

Materials used to construct an impermeable dike ought to be heavy enough to stay in place and not be carried away by stream currents. If light materials must be used, such as brush, they should be well secured by weighting the material down and the dike should be tied into the bank with cable or chain.

*Corps of Engineers experience has shown that one dike is usually not sufficient to eliminate a streambank protection problem; in fact, one dike usually causes more problems than it cures.