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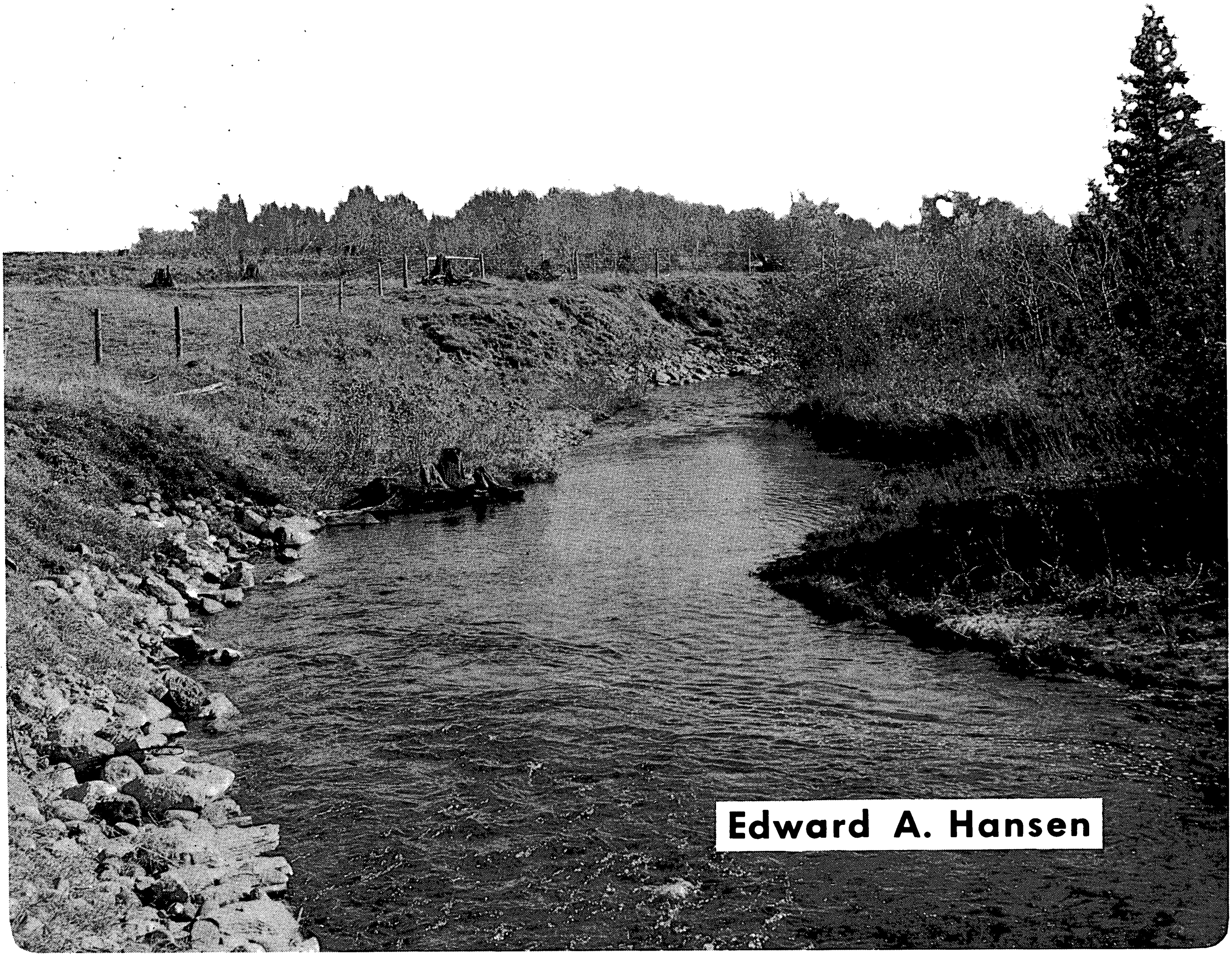
Stabilizing Eroding Streambanks

IN SAND DRIFT AREAS OF THE LAKE STATES



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Cover photo: Bank stabilized by rock rip-rap.

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Stabilizing Eroding Streambanks In Sand Drift Areas of the Lake States

Edward A. Hansen

Streambank erosion has long been a subject of concern to land managers. Some work in this field has been published — much has not. Consequently, much eroding bank stabilization is planned and carried out without benefit of previous experience.

This paper summarizes the present state of knowledge of eroding-bank stabilization on small streams in the sand glacial drift areas in the three Lake States: Minnesota, Wisconsin, and Michigan (Fig. 1). "Small streams" are those that can be waded or used only by small pleasure boats. Some information on lakeshore stabilization in the Lake States is also included.

The recommendations given in this paper are a summary of published information (see Literature Cited, p. 11) supplemented by the experience of many individuals throughout the Lake States who have worked on bank stabilization.

REASONS FOR STABILIZING BANKS

Protect Streamside Values

Streamside values sometimes endangered by bank erosion include buildings, campgrounds, stream access points, and roads (Fig. 2). For these it is easy to determine whether the cost of stabilizing the bank will be less than the anticipated future loss to the streamside value. Although the alternative of moving the item that is being threatened by bank erosion should be considered, it is usually most economical to stabilize the bank.

Most Lake States streams are being used increasingly for canoeing, fishing, and other recreational purposes. It is not presently known whether revegetation of all eroding banks will increase or decrease the scenic value that recreationists place on the stream (Fig. 3). As soon as sufficient information on this aspect becomes available, the role of the eroding bank in the total aesthetic picture of the stream should be considered.

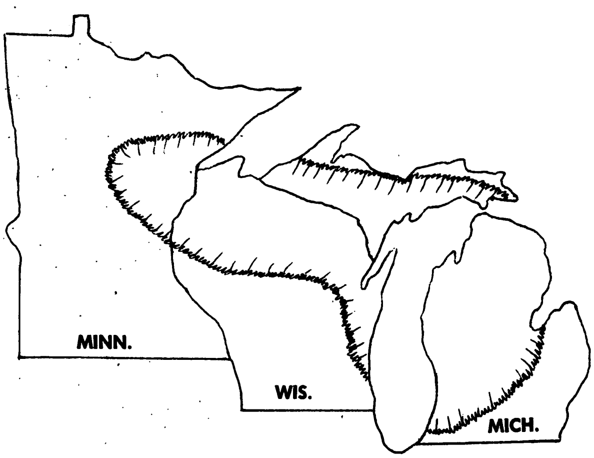

FIGURE 1. — Area of sand glacial drift in the Lake States.

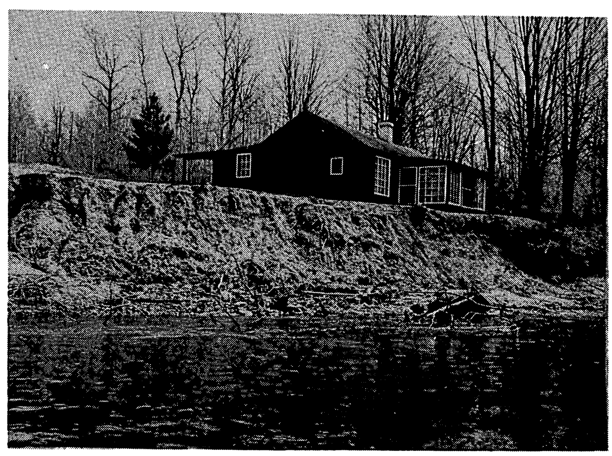

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FIGURE 2. — Eroding bank endangering a cabin. Cost of bank stabilization is minor compared to such an on-site value.

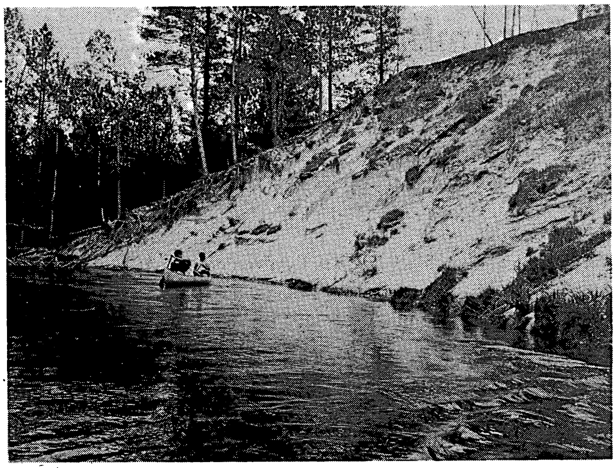

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FIGURE 3. — Would stabilization of this bank change the wilderness setting of this stream?

Reduce Sediment Load

The more comprehensive bank stabilization projects on small streams usually are intended to reduce the sediment load of the stream. This may be done to slow down sedimentation in downstream reservoirs or lakes, or to reduce sedimentation in the stream channel and thereby minimize flood damage, or, more commonly, in the sand drift area of the Lake States to improve the stream habitat for fish (primarily trout).

Again, it is relatively easy to assess the effect of floods or sedimentation on property values and reservoir storage capacity. However, the effect of sediment on stream habitat and on the fish population is much more complex (Fig. 4). Sediment is only one of many factors that may limit the fish population in a particular stream. Suspended sediment concentration in the streams of the Lake States glacial drift area is generally low except during floods. These low concentrations probably do not limit the trout population in most instances. However, the larger sand-size material moving along the bed of the stream may be much more damaging. This coarse material covers spawning beds, fills holes used for cover, and scours food organisms off the bottom of the stream (Cordone and Kelley 1961). However, it is not known to what extent these limit the trout population in any particular stream. Studies have shown that bank stabilization will only partially reduce a stream's sediment load (Parsons, Apmann, and Decker 1964; Striffler 1964, 1965) probably less than 50 percent in most streams. But it is not known whether such a partial reduction in coarse sediment will result in increased trout population.

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FIGURE 4. — One of many eroding banks on this stream. Is the effect of bank stabilization on the fish population worth the cost of control?

TREATMENT PLANNING

Stabilizing an entire section of a stream is costly. There are several ways to reduce this cost or to increase the effectiveness of the treatment with the same amount of money.

One way is to begin bank stabilization at the head of the stream and work downstream. This permits the treated section of stream to attain the maximum benefits of bank stabilization before the entire stream is finished. Thus, if work is halted for any reason before the whole job is done, at least a section of the stream has been completed.

Eroding-bank treatment usually consists of stabilizing the waterline with rock or other heavy material and then sloping the upper bank and seeding. A way to save money, however, when the major objective of the stabilization program is to reduce sediment, is to forego upper bank sloping and seeding. Experience throughout the Lake States has shown that once the toe of a bank is stabilized, the bank will revegetate naturally (Red Clay Interagency Committee 1964; Urie 1967) (Fig. 5). Thus upper bank treatment is not mandatory in stabilizing eroding banks.

Human traffic is becoming increasingly important in bank erosion and hence bank stabilization planning. When the bank is used heavily by people it is usually sloped and seeded. In addition, other things may be necessary to insure successful stabilization: fences or thorny bushes may be used to exclude people, or signs and footpaths used to direct people across or around the bank. Rock rip-rap should be large enough so that it is not easily moved by hand on those banks readily accessible to people.

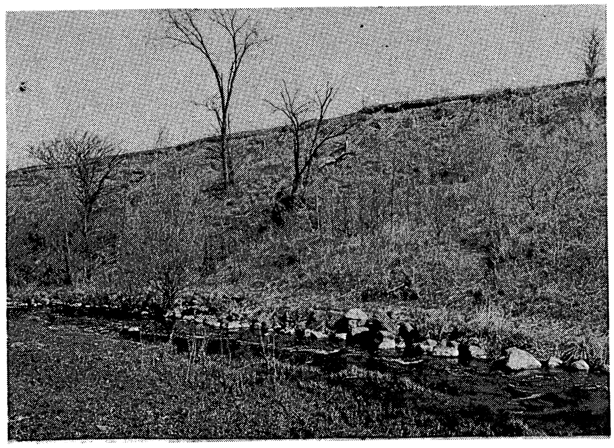

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FIGURE 5. — A bank that revegetated naturally following rock rip-rapping below the waterline 6 years previously. Note natural appearance of bank.

BANK STABILIZATION TECHNIQUES

In this discussion the "lower bank" is that portion frequently covered by flood water. Much effort is usually required to stabilize this part of the bank which comes in periodic contact with high velocity streamflow. This is in contrast with the "upper bank" which is seldom, if ever, exposed to direct erosive action of the stream and for which vegetaton alone usually provides adequate stabilization.

The eroding bank usually has to be sloped to a suitable angle before any structural work can be done. In general, gently sloping banks are more stable for rip-rap or any other material and hence have fewer failures. The following length-to-height ratios for streambank slopes can guide first attempts at bank stabilization in unfamiliar areas:

Soil texture	*Maximum slope*
Clay	1-1¼:1
Loam	1½-2:1
Sand or gravel	2-4:1

Low banks should be completely sloped. Only the lower portion of high banks needs to be sloped, however, leaving the upper bank to revegetate naturally.

One of the techniques used in sloping the lower portion of high banks is to construct a bench along the bank with fill material obtained from across the channel (Fig. 6a). The bench provides working space for men and equipment and should be at least as high as the high water mark of the normal annual

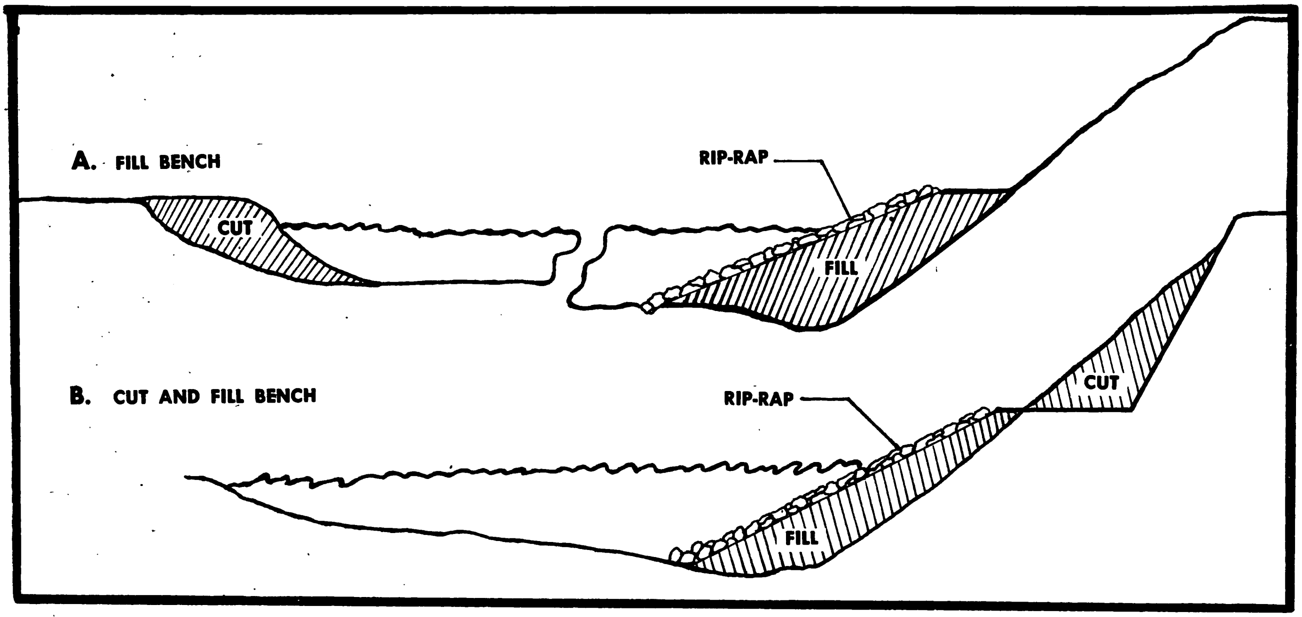

FIGURE 6. — Bench construction on high banks.

flood. The material excavated from the streambed and bank opposite the eroding bank compensates for the reduction in channel cross section due to the bench fill.

An alternative method is to cut the bench into the eroding bank, removing the cut material altogether (Silberberger 1959) or using it to construct the bench and slope the lower bank (Fig. 6b). This latter method causes a narrowing of the stream channel and should only be attempted when the streambed and bank opposite the eroding bank are composed of easily erodible alluvial deposits. In such instances, the narrowed channel cross section will readjust itself during the next flood. After construction of the bench, the lower bank must be stabilized with rock rip-rap or some other material.

Lower Bank

A wide selection of material and techniques is available to use for bank stabilization. Of these, rock rip-rap has been, by far, the most commonly used in the Lake States. Less common are gabions, stumps, and cut-tree revetments. These types of structures are most popular because the materials are available locally, the cost is low compared with other types of structures, the stabilized bank blends in well with the surroundings (Fig. 5), and failure of the structure usually does not immediately endanger life or property. Since these structures are used for most bank stabilization on small streams, this section will be limited to them. For information on more durable and expensive structures using concrete, steel, or asphalt, refer to the following publications:

1. Bank and Shore Protection in California Highway Practice. State of California, Department of Public Works, Division of Highways, Nov. 1960.
2. Watershed Structural Measures Handbook Chapter 2534, USDA Forest Service, Feb. 1959.

Rock Rip-Rap

Rock rip-rap is used most in bank stabilization when the material is readily available; it is easily placed and durable. Several factors need to be considered in order for the rip-rap to adequately protect the bank.

The required thickness of the rip-rap blanket depends on bank slope, stream velocity, and the size, shape, and specific gravity of the rock used. An indication of the size of rock required can be obtained from a graph published by the California State Division of Highways (California Highway Division 1960) (Fig. 7). However, this graph should

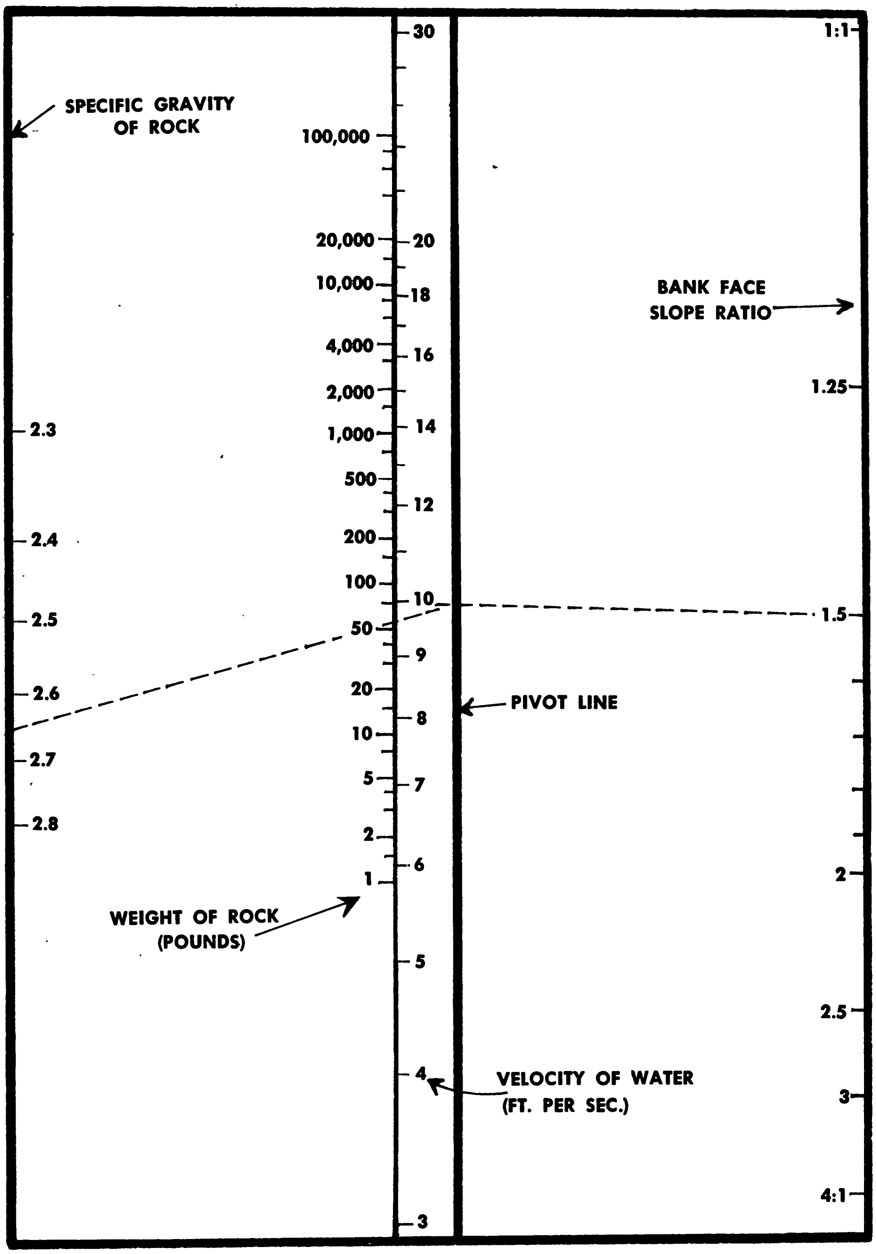

FIGURE 7. — Alignment chart for determining weight of stone to be used for rip-rap.

Example: Find bank slope ratio (1.5:1) on righthand scale. Extend line to appropriate water velocity (10 feet per second) on right side of center scale. Find specific gravity of rock (2.65) on lefthand scale. Extend line to intersect first line at "Pivot line." Read weight of rock (57 pounds) where second line crosses center scale.

be considered only as a point of departure on which to base rip-rap design in the Lake States. The graph shows the minimum weight of the rock that will not be moved by the stream under the design conditions. Two-thirds of the rock should be heavier than the minimum.

The thickness of the rip-rap blanket should be 1.5 times the diameter of the smallest "immovable" rock if the rip-rap is hand-laid and 1.9 times the diameter if rip-rap is dumped and spread with a bulldozer (Fig. 8) (California Highway Division 1960). Minimum recommended thickness of rip-rap is about 12 inches (Silberberger 1959; U.S. Forest Service 1958). In general, the largest rock and the thickest portion of the rip-rap should be at the toe of the slope and where the stream's curve is sharpest. Also, larger rocks should be placed on the face of the rip-rap with the smaller rocks laid underneath and used for chinking.

Provisions must be made to insure that the toe is tied in well to the streambed. A trench should be excavated so that the toe of the rip-rap extends below the scour level of the streambed (Fig. 8). When it is impractical to excavate a trench, enough rock must be dumped at the toe to provide a firm foundation, even following scour and consequent moving and settling of rock that will take place during future floods.

Erosion usually occurs at the outside bank of a stream bend where the water flows fastest. Rip-rap should be extended completely around the bend to protect the bank from the increased velocity. Also, the surface of the rip-rap should be as rough as possible to help counteract this acceleration. However, the downstream end of the rip-rap should be smoothly tied into the natural bank with smaller size rock so as not to create turbulence and eddies that might start a new point of erosion. Failure to do this may result in washouts and higher maintenance costs.

A "backing" or "filter" material is often needed to prevent erosion and loss of bank material between the larger rocks when there is much water turbulence. A 4- to 6-inch layer of gravel underneath the rip-rap will keep the finer textured bank material from washing through the rip-rap (U.S. Forest Service 1958). Durable fine-mesh cloth can also be used as a filter. A filter layer is not needed when the water velocity and turbulence are low or when there is a wide distribution of rock sizes in the rip-rap.

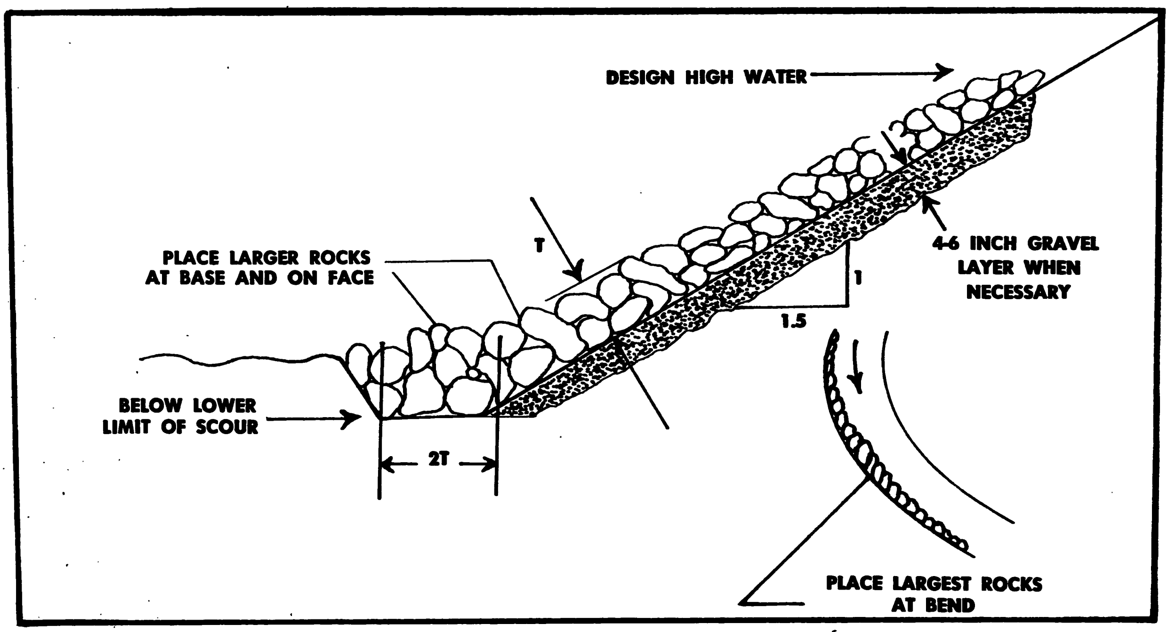

FIGURE 8. — Dimensions of typical rock rip-rap blanket. T is equal to or greater than 1.5 D where "D" is diameter of average size rock. When rock is spherical cobbles, or when machine-placed, T = 1.9 D.

Grouted Rock Rip-Rap

When large rocks are not available, smaller size rocks bonded together by grouting (cementing) may be used to prevent movement. Grouted rip-rap need not be as thick as loose rip-rap and the bank can be steeper. Disadvantages are increased cost and "unnatural" appearing banks.

Grout can only be applied out of the water. This limits its use to the portion of the bank above the low-water level. The part of the bank under the water would have to be stabilized with either larger rock or with a combination of rock and wire mesh.

Grout should penetrate from 6 inches for cobble-size material to 18 inches for rock of ½-ton size (California Highway Division 1960). The rocks to be grouted should be clean and moist. It is usually desirable to decrease stream velocity adjacent to the bank. Therefore, grout should be made with a fairly coarse aggregate (up to three-fourths inch) to increase the surface roughness of the bank. The surface rocks can project one-fourth to one-third of their diameter from the grout as an additional aid in decreasing the adjacent stream velocity.

Rock Rip-Rap and Wire Mesh

Wire mesh may be laid over a rip-rapped slope where the stone is too small to provide adequate protection by itself. This technique is generally better than grouting when very fine stone is used or when the bank is composed of easily erodible material. The simplest technique is to lay wire mesh over the loose stone and pin the wire in place with reinforcing rods (Fig. 9a) (California Highway Division 1960). A concrete-filled pipe or similar weight can be used to hold down the lower edge of the wire wesh. Some vegetation usually becomes established which aids in stabilization and provides a more natural appearance.

More stability may be obtained by placing a sheet of wire mesh underneath the rip-rap with a second sheet on top. The two pieces of wire mesh can then be fastened together into a "mattress" with the rock held in between (fig. 9b). This permits some shifting of the entire structure without undue loss of stone. Mattresses can be used along the toe of a bank to provide flexible protection where scour occurs. As scour proceeds along the lower edge of the mattress, the mattress settles until it reaches the lowest level at which scour takes place. Mattresses have not been successful on bends of streams because scouring lengthens the outer bank and causes the settling mattresses to pull away from each other (California Highway Division 1960). But they have performed satisfactorily along relatively straight reaches of stream.

The wire mesh can be formed into baskets first and then filled with rock. The baskets or "gabions" can be used to cover the bank in a fashion similar to the mattresses, or they can be stacked vertically to form walls (Tobiaski and Tripp 1961). A disadvantage of gabions is their unnatural appearance (Fig. 10). The wire mesh should be small enough so that most of the rock cannot pass through. The strength and durability of the wire are largely a matter of judgment and will depend on the importance of the structure and its desired life.

Tree and Stump Revetments

Whole trees can be place along the edge of the bank and cabled together (Fig. 11). This type of structure needs continual maintenance as individual trees rot and require replacement. However, it may be a desirable technique to use in situations where rock is not available.

Stumps cabled to the bank or fastened to piling, provide a moderate amount of bank protection on some slow-moving streams and, in addition, provide cover for fish. This is likewise a relatively temporary stabilization measure compared to using rock rip-rap. However, data are not yet available on the expected life of these structures.

Upper Bank

Revegetation of the upper bank may be left to natural processes or it can be accelerated with combinations of sloping, seeding, fertilizing, mulching, sodding, planting trees and shrubs, terracing, and fencing. The par-

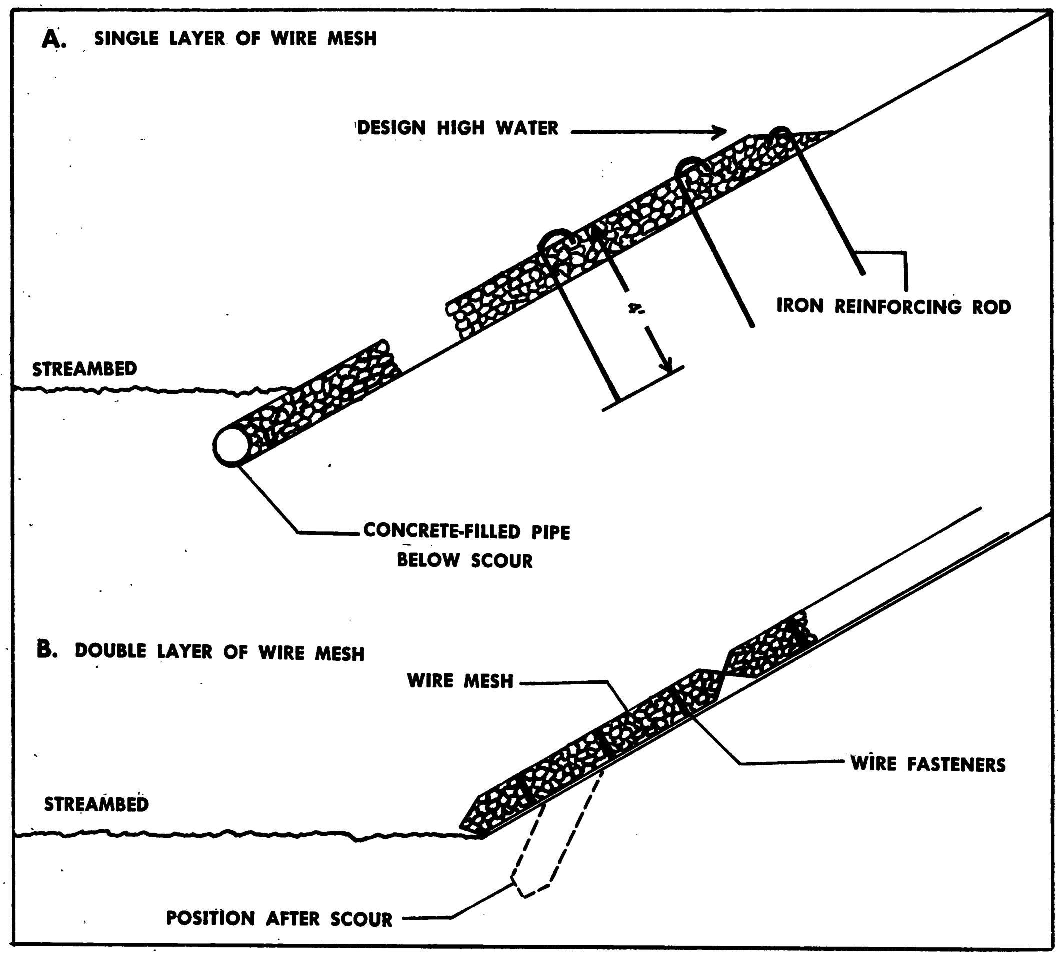

FIGURE 9. — Use of wire mesh to stabilize small rock rip-rap.

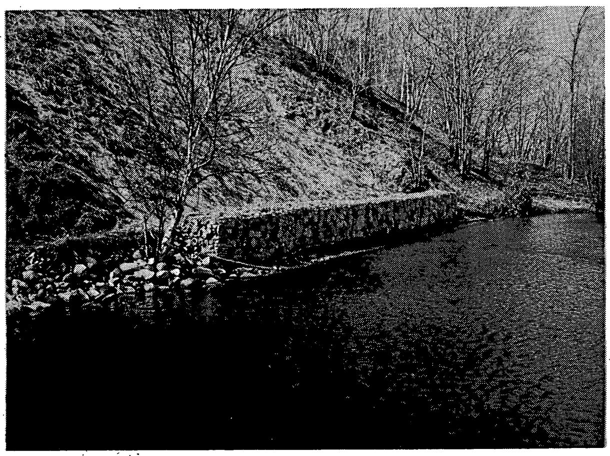

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FIGURE 10. — A gabion structure for controlling waterline erosion. The unnatural appearance may be undesirable in some situations.

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FIGURE 11. — A bank stabilized with whole trees. This structure will need continual maintenance.

ticular combination used depends on the rapidity with which it is desired to revegetate the bank and the anticipated difficulty in establishing vegetation. Three of the most common practices, mulching, seeding, and fertilizing will be discussed in more detail.

Mulching

Mulches are used to stabilize the surface soil, prevent loss of seed, reduce evaporation of water from the soil, and in some cases to increase infiltration of water. Generally, mulches are used above the normal high-water level and are not exposed to stream erosion. However, in some cases vegetation is relied on to stabilize the bank below the high-water level. In those instances, the mulch must provide protection from floods between the time of bank sloping and the establishment of vegetation.

A layer of brush 12 to 18 inches thick can be used when occasional protection is needed from moderately fast water or ice flows (Edminster *et al.* 1949). The brush should be held down with rope tied to stakes driven into the bank, so that floods during the first year or two do not carry the brush away. As the vegetation becomes established, it will provide protection for the bank and help retain the remaining brush. Willows or other water-tolerant shrubs can be planted near the waterline for continued protection from ice following deterioration of the brush mulch. Native species usually give the best results.

Straw is probably the most commonly used mulch due to its availability and low cost. Application rate varies from 1½ to 2 tons per acre (Red Clay Interagency Committee 1964). A straw-asphalt mixture has proved successful on roadbanks. Water-emulsifiable asphalt applied at a rate of 150 gallons per acre acts as a binder and prevents the straw from blowing or washing away.

A fiberglass product called "glassroot,"[1] gave excellent erosion protection when applied to a drainage ditch on heavy clay near Ashland, Wis., (Red Clay Interagency Committee 1964). It forms a tight bond with the surface of the clay yet is easily penetrated by vegetation. The material is fairly expensive but might be feasible on areas exposed to severe water erosion (Ree 1960).

Many other products have been used for mulching banks. Troy Turf is a jute mat that can be used as a substitute for sod (Allen 1962). Included in the mat are the seed, fertilizer, and a growing medium. The mat is transported in rolls that can be unrolled and fastened to a steep bank. Soil Saver is a heavy jute mesh that can be laid on a newly seeded bank to prevent erosion (Broach and Terrio 1960; Ree 1960). A woodfiber cellulose mulch product (Turfiber) can be sprayed on the bank as a slurry (Harper 1961). Seed and fertilizer can also be mixed in the slurry. These products have been used by highway departments of many States.

Many chemical products have been tested as mulches with widely varied results. Most of these are applied in liquid form and have the object of binding the soil particles together. None has had widespread use on streambanks in the Lake States. Tests conducted with these liquid mulches have had only limited success (Urie 1967).

Seeding

Many different mixtures of grasses and legumes have also been tried. The best seed mixture tested for clay banks near Ashland, Wis., was 50 percent smooth bromegrass (Canadian or variety Sac.), 25 percent Empire birdsfoot trefoil, and 25 percent tall fescue (Alta or Kentucky 31) (Red Clay Interagency Committee 1964). Crown vetch also provided good cover although it took several years for a good stand to become established. Good results have been obtained on glacial till soils with mixtures of tall fescue and crown vetch, red fescue and birdsfoot trefoil, or tall fescue and birdsfoot trefoil (Porter and Silberberger 1960). Reed's canary grass is recommended for use at the waterline of eroding banks.

Seeding rates are generally 20 to 30 pounds per acre. Experience indicates that the banks should be seeded as early in the year as is practical.

[1] *Products named are examples only: their mention does not imply endorsement by the U.S. Department of Agriculture.*

Fertilizing

Fertilization usually increases establishment success. Typical application rates are 500 pounds per acre of 10-10-10 or 5-10-5 (Porter and Silberberger 1960; Red Clay Interagency Committee 1964). However, in one instance at Ashland, Wis., an application rate of 2,400 pounds per acre on exposed clay subsoils resulted in additional improvement in the vegetation. An additional monthly application of ammonium nitrate at a rate of 50 pounds per acre was found necessary on sterile glacial till subsoils until the vegetation was well established (Porter and Silberberger 1960).

CAUSES OF FAILURE

It has been said that "bank protection never has been and never will be an exact science" (Rowe 1953). Due to the complex and often unique characteristics of each bank and the consequent large amount of judgment involved in planning bank stabilization structures, there will always be a certain amount of failure. Some of the more common causes of failure are listed below.

Bank stabilization measures using "temporary" materials may fail when the "temporary" materials begin to disintegrate. In some cases, vegetation which has become established at the waterline in the interim may adequately replace the "temporary" material. However, it is not possible, at present, to predict under what conditions vegetation alone will provide adequate protection.

A bank-stabilization structure may be underdesigned, and "normal" stream discharges cause it to fail. One common cause of failure is due to a rough transition between the downstream end of the rip-rap and the natural bank. The rapidly accelerating stream adjacent to the rip-rapped bank is slowed when it reaches the unrip-rapped rough-walled bank just downstream. This change in stream velocity often produces an eddy which initiates a new point of bank erosion (Fig. 12) (California Highway Division 1960).

Finally, regardless of the effort and expense put into bank stabilization, it should be expected that occasional rare flood events of large magnitude will destroy some of the work. Bank stabilization measures usually are not, and probably should not be, designed to withstand these extreme flood events. A planned maintenance program should be a part of any bank stabilization program.

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FIGURE 12. — Bank failure due to a rough transition between rip-rap and natural bank. The rough transition resulted in the eddy indicated by arrows.

SUMMARY

Bank protection planning balances the immediate real cost of stabilization against a probable future benefit. The immediate cost of stabilization can be estimated fairly accurately and can be improved upon with the experience gained from treating the first few banks. Future benefits, such as protection of on-site values or reduction in reservoir or lake sedimentation rates, can be estimated and expressed in economic terms. However, the possible future benefit from attempting to increase fish population through bank stabilization is obscure. Consequently, present justification of such an objective will have to be stated in qualitative terms such as reduced sediment load or possibly improved fish habitat.

There is a wide variety of stabilization techniques that can be used for bank protection. Rock rip-rap is probably the best material to use for stabilizing the lower bank, since there is little that can deteriorate with time. However, rock of sufficient size and quantity is often difficult to obtain in the Lake States. In such cases, alternative methods employing wire, wood, or live vegetation must be used.

The upper bank will revegetate naturally. However, sloping and application of seed, fertilizer, and mulch will accelerate the revegetation process.

Maintenance should be a planned part of a bank-stabilization program because of the possibility of some structural failure in the future and the start of new points of erosion from normal stream meandering.

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