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Use of Vegetation To Stabilize Eroding Streambanks

Abstract

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Streambank erosion is very costly and is a major problem throughout the United States. If left unchecked, this erosion can become acute and result in astronomical losses of land and other physical property. Studies were done on stream channels in northern Mississippi to determine the feasibility of using vegetation to stabilize eroding streambanks. This use of vegetative materials was developed from the concept that vegetation, properly established and managed, will provide satisfactory and economical protection and help to supplement and reduce the use of expensive structural materials. Studies were conducted on 1,536 m (5,040 linear ft) of formed channel banks with 29 treatment areas 15.2–182.9 m (50–600 ft) long. The treatment areas were composed of 19 species of vegetative plantings with various combinations of six different structural materials. The studies were continued for 10 growing seasons to allow proper evaluation of the plant materials. To be effective in protecting streambanks, plant materials must survive the cycles of extreme meteorological conditions of a given area. Results showed that vegetative materials can be successfully used in a streambank-protection program and should be considered an integral part of the engineering design.

Keywords: vegetation, stabilize, streambanks, channel bed, erosion, bank shaping, structural materials, maintenance

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Streambank erosion is a common occurrence along many miles of streams and rivers throughout the United States and is considered a national problem. Barnes (1968) estimated that 480,000 km (300,000 mi) of eroding streambanks in the United States produce approximately 450 billion kg (500 million tons) of sediment each year, or approximately 1,670 tons/mi per year. Research by the U.S. Department of Agriculture (USDA) National Sedimentation Laboratory has helped to establish the quantity of erosion that may occur in unstable channels (Bowie 1987). Channel erosion contributed up to 55 percent of the total sediment yield measured from a 117-mi^2 complex watershed in northern Mississippi. The computed yield from channel bank erosion was as much as 1,050,000 kg/km (1,860 tons/mi) per year. On another Mississippi watershed, Grissinger et al. (1991) estimated that about 85 percent of the total sediment yield from Goodwin Creek originated from the channel banks and bed.

If left unchecked, streambank erosion can become acute, resulting in astronomical losses of land and other property. In many sections of the United States, this loss is valued at millions of dollars annually. In addition, sediment from eroded streambanks fills streams, waterways, and reservoirs; increases the potential for flooding; and spoils the habitat for fish and wildlife. The removal of sediment each year from choked stream channels and reservoirs in this country is estimated to cost more than $250 million (Barnes 1968).

Effective streambank-protection measures have been costly to install and to maintain. It was estimated by the Chief of Engineers (1969) in a report to the Secretary of the Army that the annual cost of preventive treatment for 238,000 km (148,000 mi) of known severely eroding streambanks was approximately $420 million. This report indicated that the treatment of many of the damaged areas could not be justified, because the treatment at that time consisted primarily of costly structural materials. This report also indicated that research programs were needed to develop cheaper and more effective methods of treatment. In cooperation with the U.S. Army Corps of Engineers and the Soil Conservation Service, the USDA National Sedimentation Laboratory initiated studies on stream channels in Panola County, Mississippi, to determine the feasibility of using vegetation to help stabilize eroding streambanks (Bowie 1981, 1982). Two upland channels, located in northern Mississippi, near the eastern bluff line of the Mississippi River alluvial plain, were selected for study because they had bank-erosion problems that were considered representative of other channels throughout the Southeast and other sections of the United States.

For vegetation used in this study, the time required to reach maturity or the stage of maximum production varies greatly, depending on the species and the growth environment. To establish good ground cover, at least two growing seasons are required for many of the grasses, in a good environment with the proper balance of soil moisture and plant nutrients. Porter and Silberberger (1960), in their vegetative work along Buffalo Creek in northwestern New York State, found that woody shrub species required 4–7 yr before giving effective cover. It was determined at the beginning of the vegetative studies on Johnson and Goodwin Creeks that 8–10 growing seasons would be required before a complete evaluation of material performance could be obtained. This decision was contingent on the need for recurring cycles of meteorological conditions to fully test the survival and protective characteristics of the various vegetative and structural materials. Construction was completed in late 1979 and in 1981. This report gives the results of those studies.

Description of Study Areas

Two channels, Johnson Creek and Goodwin Creek, in Panola County near Batesville, Mississippi, were selected for study (fig. 1). Generally those channel banks are composed of alluvial soils; that is, they contain clay, silt, sand, gravel, or similar material deposited by flowing water. In most reaches (the length of a stream referenced to definable objects or fixed points), the channel bottom or bed is a mixture of sand and gravel (Grissinger and Bowie 1984). Along the reaches where the bed instability is most pronounced, the channel banks are vertical and quite deep (fig. 2). Bank instability is due primarily to a high bank, erosion of the bank toe, and internal bank pressure created by the lateral movement of groundwater. Figure 3 illustrates the channel bank failure that is prevalent throughout the study area.

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Two locations were selected on Johnson Creek for studies using vegetation in conjunction with (1) bank shaping and structural materials and also (2) bank shaping without structural materials. As shown in figure 1, the two study reaches are separated by a highway bridge. The upstream study reach no. 1 is 183 m (600 ft) long and is curved. It has several combinations of treatments along the concave (outside) bank and a continuous single treatment along the convex (inside) bank. The downstream study reach no. 2 is 496 m (1,627 ft) long and is straight. It has several combinations of treatments along both banks. The banks along both study reaches averaged 4.5 m (15 ft) high, and the channel bottom width was 6–11 m (20–35 ft). Before treatment, the bed gradient averaged 3.5 m/km (18.5 ft/mi). Later construction of a grade-control structure 60 m (200 ft) downstream from study reach no. 2 reduced the bed gradient to 1.5 m/km (7.9 ft/mi). The catchment area above the two reaches is 16 km^2 (6.2 mi^2).

The Goodwin Creek location (fig. 1) was also selected for studies of vegetation in conjunction with bank shaping with and without structural materials. The study is located in a 139-m (456-ft) channel reach with alternating bends. Several combinations of treatment were included along the concave and convex banks. The banks averaged 3.2 m (10.6 ft) high, and channel bottom widths were 9–12 m (30–40 ft). The bed gradient was approximately 4.9 m/km (26 ft/mi). The catchment area above the study reach is 14 km^2 (5.4 mi^2).

Hypotheses and Research Objectives

Studies by the USDA National Sedimentation Laboratory on the use of vegetation to stabilize eroding streambanks were based on the following hypotheses: (1) Vegetation is the most readily available material and can be used successfully in stabilizing streambanks; (2) both woody plants and herbaceous vegetation (having little or no woody tissue), properly established and managed, are the cheapest source of protection and play an important role in bank protection; (3) vegetation greatly reduces the water velocity and tractive forces on the bank to values below those required to initiate erosion; (4) vegetation properly established and managed provides esthetic benefits, enhances the environment for fish and other wildlife, and does not excessively reduce the carrying capacity of streams; (5) the effectiveness of expensive structural material that is required for stabilizing severely eroding channel banks can be greatly enhanced by the proper combination with vegetation.

Objectives of the studies were as follows: To evaluate the effectiveness of various species of grassy and woody plants for stabilizing streambanks and floodways; to determine the proper combination of structural materials and vegetation for the most effective and economical control of streambank erosion; and to determine the type and scope of maintenance required to sustain, improve, and extend the life cycle of vegetative material.

Selection of Control Measures

A variety of control measures for stabilizing eroding streambanks are available. The type of protection needed for a specific case is largely determined by the characteristics of that channel. Factors to be considered in selecting the control measures include the height of bank, stability of bank material, stability of channel bottom, channel width, curvature of stream, bed gradient, availability of protective materials, use of property adjacent to the channel, and allotted resources and cost of their implementation.

Water Velocity

The potential of a stream to erode its banks varies from one section to another and is persistently high in some locations (Parsons 1960, Edminster et al. 1949). The type of protection needed for banks along straight alignment differs from that required for banks at curves and in reaches where the higher water velocities come close to or strike the bank. In straight channels, the higher velocities are usually near the center of the channel and close to the water surface, so a wider array of protective materials is permitted. In channel bends, the highest velocity is close to the concave bend and near the center of water depth. Because excessive erosive forces are exerted on the concave bank, more substantial protection in the form of structural materials is needed there. But as a general rule, deposition of sediments occurs along the convex bank, so much less or even no bank protection is needed in that area.

Stability of Streambed

The effectiveness of any streambank-protection work is directly proportional to the stability of the streambed. If the potential for bed degradation exists or if the bed is actively degrading, then corrective actions are required before bank protection is initiated. Without the corrective actions, most bank-protection techniques become ineffective or fail completely. One technique for stabilizing degrading channels is the use of grade-control structures constructed laterally (from one bank to the other) across the channel at strategic locations. Several types of structures have been used for gradient control with varying degrees of success. Research at the USDA National Sedimentation Laboratory led to the design and development of a low-drop grade-control structure that has many distinct advantages over previously used conventional structures (Little and Daniel 1982). That structure is now commonly used.

If it is uncertain that the bed will degrade and if a decision has been made to proceed with bank-protection work, then extra protection in the form of structural materials should be provided along the bank toe. These materials should be placed deeper than the existing streambed, to exceed any expected channel degradation. Under all circumstances, the most economical structural material that is suitable for the job should be used.

Vegetation

Because structural treatment is expensive, vegetation should be used to the fullest extent possible. The purpose of the vegetation is to provide a permanent dense cover that will prevent erosion of the channel banks but not overly restrict the channel capacity. Maximum use should be made of native vegetation. Suitable vegetative materials must withstand any expected flooding, provide year-round protection, become well established under adverse climatic and soil conditions, be long lived, develop a root system that will withstand the drag force of streamflow on the plant tops, have branch characteristics with many stems emerging from the boundary surface, have tough resilient stems and branches, and require only minimum maintenance.

Preparation of Banks

Since most unstable channel banks have been eroded and undercut to a very steep unplantable slope, bank shaping is required for the satisfactory establishment of grassy species and many shrub-type woody species. Under most conditions, the requirements of vegetation, soil stability, and maintenance dictate that bank slopes be not steeper than 2:1 (that is, 2 m horizontal and 1 m vertical). Site preparation for shaping, planting, and vegetation management becomes too difficult on steeper slopes. A slope of 2.5:1 to 4:1 should be used when possible. A slope of 2:1 on the lower bank adjacent to the channel toe is acceptable for the placement of flexible-type structural materials such as riprap and concrete-type blocks.

The grading and other bank preparation should be done during periods of low precipitation and the work scheduled to minimize the time of soil exposure. The ideal time for completion is during the planting season. Stockpiling and respreading the topsoil to a depth of 0.2–0.25 m (8–10 inches) on the sloped bank may be required if the channel-slope material, after excavation, is not adequate for establishing herbaceous vegetation. The need for fertilizer and lime should be determined by a soil test; when required, they should be applied before seeding and be worked into the seedbed to a depth of 0.15–0.2 m (6–8 inches). Most herbaceous vegetation grows best in soils with a pH level of 6.5–7. An adequate mulch cover, properly anchored, should be applied during or immediately after seeding to conserve moisture, increase infiltration, and prevent erosion from rainfall. The spoil and all areas along the top of finished banks should be graded landward with sufficient slope to prevent drainage of surface water over the face of the bank into the stream. The entire vegetative area should be protected from livestock and other traffic by permanent fencing.

Construction of Study Reaches

The criteria discussed above were used to the fullest extent possible in the design and construction of the Goodwin and Johnson Creeks study reaches. Because the unstable channel banks in the study areas had eroded and undercut to a very steep and unplantable slope (figs. 2 and 3), bank shaping was required.

Johnson Creek Study Reach No. 1

A site plan of the Johnson Creek study reach no. 1 is shown in figure 4. Nine treatment sites, 15.2–30.5 m (50–100 ft) long, were established on the shaped concave bank of the bend. In addition, the entire length of the convex bank was considered one treatment site. The materials used for treatment are listed in table 1. The finished concave bank consisted of fill material excavated from the opposite (convex) bank. The convex bank was shaped to a 2:1 slope without structural materials, except for a hard point constructed at the upstream end (fig. 4). The concave bank was shaped to 2:1, 2.5:1, and 3:1 slopes, and structural materials were used as shown in figure 4. Sloping the banks in this study reach increased the channel cross-section area by about 45 percent. This increased area more than offset the retarding effect of vegetative and structural materials on the capacity of the channel to transport flood flows. The streambed was relocated toward the convex bank in order to decrease and smooth the curvature of the bend, to flatten the bank slope for the concave bank without infringing on adjacent farmland, to establish a more uniform bottom width, and to provide the needed fill material.

For Johnson Creek study reach no. 1, a trench 1.5 m (5 ft) wide by 0.9 m (3 ft) deep was excavated at the toe line of the finished bank along the concave bank. Creosote-pressure-treated pilings with a minimum tip diameter of 0.2 m (8 inches) and 4.9 m (16 ft) were driven on 2.4-m (8-ft) centers in the excavated toe trench and adjacent to the channel bottom. Each piling was driven to a depth of 4.3 m (14 ft), and 0.6 m (2 ft) remained above the finished grade of the streambed. A chain link fence of 9-gauge galvanized steel fabric, 1.5 m (5 ft) high, was attached to the bank side of the pilings and even with the top of the pilings. The toe trench was backfilled with stone riprap to the top of the fence (fig. 5). The gradation or rock size for the riprap was determined from the USDA Soil Conservation Service design criteria, which required 50–75 percent of the stones to weigh more than 34 kg

(75 lb) each. The lower bank was protected with concrete cap blocks 0.1 X 0.2 X 0.41 m (4 X 8 X 16 inches) placed between and anchored by two layers of 11-gauge galvanized wire netting, which in effect formed articulated matting. The design height of 1.8 m (6 ft) of structural revetment on the lower bank (shown in fig. 5) was equal to the maximum depth of flow expected for 90–95 percent of annual storm events and the additional erosive force expected on the concave bend. The upper bank was planted with herbaceous and woody vegetation.

All bank seedbeds for Johnson Creek study reach no. 1 were treated with 0.09 kg/m^2 (800 lb/acre) of 13–13–13 commercial fertilizer and limed at the rate of 0.45 kg/m^2 (4,000 lb/acre). The fertilizer and lime were incorporated into the top 0.2 m (8 inches) of soil, and the banks were seeded and covered with mulch for erosion control. The top of the finished bank was sloped away from the channel to prevent drainage of surface water over the face of the bank into the stream (fig. 5). Figure 6 is an upstream view of the study reach before construction. The same location after completion of construction is shown in figure 7 and after six growing seasons in figure 8.

Johnson Creek Study Reach No. 2

A site plan for Johnson Creek study reach no. 2 is shown in figure 9. Nine treatment sites 62–143 m (200–470 ft) long were included in the study. The materials used for treatment are listed in table 1. The top 0.6 m (2 ft) of soil along both sides of the channel was stockpiled during bank shaping and later used on the prepared seedbeds.

The excavated-bench method, with the lower bank and toe protected by structural revetment (concrete blocks and rock riprap), was used for bank sloping on five of the nine treatment sites (fig. 10). The purpose of the excavated bench is to provide a better environment for establishing woody vegetation. The toe of the lower bank along three of those five sites was provided with extra protection consisting of rock riprap placed in a trench excavated to at least 0.76 m (2.5 ft) below the existing channel bottom (fig. 10). The alignment of the channel bottom was not altered during construction.

In Johnson Creek study reach no. 2, the lower bank was protected with riprap, or cellular concrete blocks, or concrete cap blocks. Plastic filter cloth of woven polypropylene fabric was installed between the revetment and the subgrade. The design height of 1.2 m (4 ft) of structural revetment on the lower bank was equal to the maximum depth of flow expected for 90–95 percent of annual storm events. The lower bank was constructed to a 2:1 slope, the bench (2.1 m or 7.0 ft wide) to a 5:1 slope, and the upper bank to a 2.5:1 slope. The bench was planted with woody species and the upper bank with herbaceous species. Four sites were constructed to a continuous 2.5:1 slope without structural materials (fig. 11). After treatment with fertilizer and lime, the entire bank was planted with various species of herbaceous vegetation. Figure 12 is a downstream view of the study reach before construction. The same location after completion of construction is shown in figure 13 and after nine growing seasons in figure 14. Sloping the banks in this study reach increased the channel cross-section area by about 35 percent.

Goodwin Creek Study Reach

A site plan for the Goodwin Creek study reach is shown in figure 15. Ten treatment sites 16.8–30.5 m (55–100 ft) long were included in the study. Seven of those sites, 16.8–30.5 m (55–100 ft) long, were on the concave banks. Three sites, each 30.5 m (100 ft) long, were on the convex bank. The materials used for treatment are listed in table 1. Soil excavated from the convex bank was used for fill material along most of the concave bank. The concave bank was shaped to 2.5:1, 3:1, and 4:1 slopes, and structural materials were used as shown in figure 15. The convex bank was shaped to 3:1, 4:1, and 5:1 slopes without structural materials. Sloping the banks in this study reach increased the channel cross-section area by about 25 percent. The streambed was relocated toward the convex bank for the same purpose stated for Johnson Creek study reach 1. Also, the same specifications and method of construction for the concave bends were used (fig. 16), except as follows: The lower bank was protected with cellular concrete blocks 0.11 X 0.41 X 0.61 m (4.5 X 16 X 24 inches) weighing 41 kg (90 lbs) each. The design height of 1.5 m (5 ft) of structural revetment on the lower bank was equal to the maximum depth of flow expected for 90–95 percent of annual storm events and the additional erosive force expected on the concave bends. The upper banks were planted with herbaceous and woody vegetation.

In the Goodwin Creek study reach, the bank area along the convex bank was planted with herbaceous vegetation. All of the bank's seedbeds were treated with a 13–13–13 commercial fertilizer at 0.09 kg/m^2 (800 lb/acre); treated with lime at 0.45 kg/m^2 (4,000 lb/acre) incorporated into the top 0.2 m (8 inches) of soil; seeded; planted; and covered with emulsified asphalt-treated mulch for erosion control. The tops of the finished banks were sloped away from the channel to prevent drainage of surface water over the face of the slope into the stream (fig. 16). Figure 17 is a downstream view of the Goodwin Creek study reach before construction. The same location after completion of construction is shown in figure 18 and after six growing seasons in figure 19.

Results and Discussion

The construction of Johnson Creek study reach no. 2 was completed in 1979, and vegetative plantings were completed in 1980. In April and May 1981, the construction of Johnson Creek study reach no. 1 and Goodwin Creek study reach was completed, and they were planted with vegetation. During the 10 yr of record, meteorological events fully tested the survival and protective characteristics of the various vegetative and structural materials. The meteorological influence is reflected in the overall evaluation of materials for streambank stabilization. Surveys were made at the end of the 1982 growing season to determine the stand survival and growth conditions for plants in each study reach. Boston ivy (*Parthenocissus tricuspidata*) and buffalograss (*Buchloë dactyloides*) did not establish sufficiently the first growing season due to very poor stand and seed germination, and they were replaced with other plants. Evaluation of information from the surveys is shown in table 2.

Meteorological Conditions

All study reaches were subjected to severe flooding and other plant-growth stresses at various times during the period of record, 1980–90. Normal annual precipitation, based on a 48-yr record for the general geographical area, is about 137 cm (54 inches). During the period of record, precipitation averaged 120 percent of normal for 5 yr and 80 percent of normal for 4 yr. Large-storm runoff events produced velocities of over 3.7 m/sec (12 ft/sec) at the center of the streams and 0.76–0.92 m/sec (2.5–3 ft/sec) near the bank surface of the channels. A record runoff event occurred in 1982 and 1983 and produced peak stages that equaled the full channel capacity for the two Johnson Creek study reaches and that exceeded the full channel capacity for the Goodwin Creek study reach. No appreciable damage to any of the treatment sites was observed.

In this region, the normal annual rainfall during the growing season May through August averages 41 cm (16 inches). During this study, the rainfall for four very dry growing seasons ranged, for 30 consecutive days, from no rainfall to an average 43 percent of normal. The dry periods were accompanied by above-normal high temperatures. Temperatures of 37–40 °C (98–104 °F) were recorded for each dry period for several successive days; as many as 9 consecutive days were above 37 °C (98 °F). An average high temperature of 33 °C (91 °F) during the growing season is usually recorded in July and August.

Record low winter temperatures occurred during 3 consecutive years. Temperatures below -2 °C (28 °F) were recorded for 37 successive days in December 1983 and January 1984; the lowest minimum temperature was -18 °C (0 °F). Temperatures below -5 °C (23 °F) were recorded for 28 successive days in January and February 1985; minimum temperature was -23 °C (-9 °F). The ground remained frozen at 10–15 cm (4–6 inches) deep for approximately 15 days. Average low temperatures in winter, based on historical records for the region, are 0 °C (32 °F) for December, -2 °C (28 °F) for January, and 1 °C (34 °F) for February.

Evaluation of Materials

The effects of the adverse meteorological conditions are reflected to some extent in the lower ratings for some of the vegetative materials shown in table 3. The ratings in table 3 are established on a scale of 1 to 9 (9 for best and 1 for worst). Evaluation ratings for herbaceous plants were determined from stand density, growth vigor, resistance to diseases and insects, and tolerance of inundation and adverse weather. The rating factors for woody plants included stand, growth vigor, abundance of stem and foliage, resistance to diseases and insects, and tolerance of inundation and adverse weather. The rating factors for structural materials included cost and requirements for installation, degree of stability and protection provided, compatibility with vegetation, durability, and maintenance requirements. Mulch materials were rated primarily on the degree to which they prevented erosion.

Herbaceous vegetation

The best overall rating for herbaceous plants was given to Alamo switchgrass (*Panicum virgatum*) and Sericea lespedeza (*Lespedeza cuneata*). Both plants responded well during each year of the study period, forming dense ground cover for excellent bank protection. Alamo switchgrass grew equally well over the entire bank area to the toe of the channel and survived extended periods of inundation with no appreciable damage. The plant grows erect, is about 150 cm (60 inches) tall, and has numerous flexible stems in each bunch. During storm flow along the bank area, the stems form a dense protective matting on the bank surface and then return to an upright position after the flow recedes. Deposition occurred, up to 0.15 cm (6 inches) deep, along the concave (outside) bank in the channel bends that were protected with cellular concrete blocks and had been overseeded with Alamo switchgrass. Sericea lespedeza provided not only bank protection but also good habitat for wildlife and added greatly to the esthetic value of the area. Sericea was easily propagated from seed, recurred each year, and provided excellent protection for the upper bank, including the landward area beyond the bank top.

Other herbaceous plants that were rated average include Pensacola bahiagrass, common bermudagrass, and Penngift crownvetch. Bahiagrass provided fairly good cover and protection on the upper sections of banks having a southern exposure. Pensacola bahiagrass is not tolerant to extreme freezing temperatures for prolonged periods, so this plant is best used on the northern side of east-west-oriented channels. Common bermudagrass is similar in nature to bahiagrass but is less shade tolerant. Bermudagrass requires considerable sunlight for sustained growth, is not compatible with tall plants, and is also nontolerant to prolonged extreme freezing temperatures. The plant will survive longer periods of drought than will some other grasses. Bermudagrass cultured under the right environment will provide good protection on the upper and top sections of most channel banks. Propagation of Penngift crownvetch was more successful by sprigging than by seeding. A good stand of Penngift crownvetch, giving fair ground cover, was established during the second growing season. In succeeding years, the ground cover improved, but growth was affected by drought and high temperatures. Crownvetch performed very poorly on the Goodwin Creek study reach, due primarily to the extended periods of drought and high temperatures. That study site was later overrun by native vegetation. The overall rating for crownvetch for channel bank protection is average.

False anil indigo (*Indigofera pseudotinctoria*) and common reedgrass (*Phragmites communis*) were rated as fair for channel bank protection. False anil indigo continued to recur with a fair stand each year but failed to compete sufficiently with native vegetation to produce the best cover for bank protection. This plant can possibly be upgraded to an average or better rating if the various species of native vegetation are controlled. Common reedgrass was planted on the lower bank along the toe of the inside bend of Goodwin Creek treatment site no. 1 (fig. 15). A fair stand with good-vigor growth was maintained throughout most of the study period. Attempts to propagate reedgrass on the upper bank area above the toe line were not successful.

Poor performances were seen from appalow sericea, Halifax maidencane, and Reed canarygrass. Appalow sericea produced a fair stand and growth during the early growing seasons but was eventually overrun and crowded out by taller native vegetation. Maidencane was planted along the toe of the inside bend of Goodwin Creek treatment site no. 3 (fig. 15). The initial live stand rate was approximately 50 percent, but the recurring deposition of sand severely restricted the stand's further growth and development. Attempts to establish maidencane along the toe of channels unprotected from rapidly flowing water have not been successful. Reed canarygrass originally established with a fair stand and growth; however, the plants failed to fully develop and eventually succumbed to succession, leaving only a few scattered plants that provided little or no bank protection.

Attempts to establish stands of buffalograss and subterranean clover were complete failures. As noted in Results and Discussion, buffalograss did not establish sufficiently due to poor seed germination and was replaced with other plants. The return stand of subterranean clover became less each year, until it was completely dominated and replaced by native vegetation.

Woody vegetation

Native black willow (*Salix nigra*) and multiflora rose (*Rosa multiflora*) were rated above average overall. Black willow was superior to the hybrid varieties of willow and other native trees in both survival and growth. Stock cuttings from native willows, about 30 cm (12 inches) in length, were planted along the toe of the channel bank at approximately 0.75-m (2.5-ft) intervals. [These can be thinned to 1.5-m (5-ft) intervals at the beginning of the second growing season to permit faster growth.] Two-year-old black willow trees, spaced about 1.5 m (5 ft) apart, had an average crown height of 244 cm (96 inches) and average canopy cover of 215 cm (85 inches). At the end of the third year, the average crown height had increased to 310 cm (122 inches) and the average canopy cover to 275 cm (108 inches). Native black willow, if left unattended, matures into a rather large tree, thereby losing much of its effectiveness as a channel bank protector and possibly compromising the integrity of nearby structural materials. One technique for controlling the tree's height is to cut about 25 percent of its total height from its crown. This should be done during the dormant period following the third growing season. A tree-pruning tool with an extension pole can be used for this task.

Multiflora rose, a thorny shrub, was propagated by sprigging and after two growing seasons produced dense cover with good bank protection. The plant survived periods of inundation with no apparent damage and was very tolerant of adverse weather. It provides a good habitat for wildlife and discourages penetration by domestic animals. There were no problems in preventing the plant from spreading to nondesignated areas. Multiflora rose has been recommended for use as a living fence along streambanks to control and exclude livestock and other undesirable traffic from vegetative bank areas (Edminster 1949).

Indigo bush (*Amorpha fruticosa*) and bristly locust (*Robinia fertilis arnot*) were planted along the bank bench area and lower berm of several treatment sites on each of the three study reaches. Good stands and growth were recorded for both shrub types on the Johnson Creek study reaches following the second growing season. A fair stand with poor growth was recorded for indigo bush on the Goodwin Creek study reach; bristly locust did not survive there past the first growing season. The poor response and failure in the Goodwin Creek studies are attributed to the soil type (excessive sand and gravel) and the low levels of moisture. At the end of the 10-yr study, the stand rate for both plants was less than 50 percent of the original plantings. As shown in table 3, these plants are rated fair (overall rating) for bank protection.

The same techniques used for planting native black willow were used for streamco willow (*Salix purpurea streamco*). The stand rate at the end of the second growing season was 20 percent of the original plantings. The surviving plants had an average height and also average canopy cover of approximately 120 cm (48 inches). This plant proved to be nontolerant to blight diseases. None of the plants survived through the third growing season. It is questionable whether streamco willow will adapt to conditions outside its natural environment.

Attempts to establish stands of the ivy plants were unsuccessful. Boston ivy (*Parthenocissus tricuspidata*) did not survive past the first growing season. English ivy (*Hedera helix*) is nontolerant to prolonged extreme freezing temperatures and did not survive the winter of 1983.

Structural materials

Primary factors in the selection of a structural material for channel bank protection are the material's proposed use, effectiveness, durability, availability, and cost of placement and delivery to the construction site. All structural materials used as a part of the streambank vegetative studies are considered satisfactory for channel bank protection, with the exception of the sand-clay-gravel mix.

The sloped-bank area of one treatment site was overlaid with 0.15 m (6 inches) of a compacted ***sand-clay-gravel*** mix and then overseeded with common bermudagrass. The early armoring effect of the sand-clay-gravel prevented the establishment of suitable ground cover by the bermudagrass. Accumulated rainfall on the bank surface gradually eroded the sand-clay-gravel to the extent that little bank protection was left. A good stand of native vegetation later stabilized the bank surface.

The highest rating was given to ***cellular concrete block*** (grid), primarily for its protection features and its compatibility with herbaceous vegetation and some woody-type vegetation. This product is also known as monoslab and grass paver. The grid is constructed with three parallel slots with 75-percent openings and recesses below the upper surface to allow the growth of vegetative cover, and a minimum of 15-percent openings at the base surface for root development. It is recommended that the grids be laid in a smooth uniform plane, be firmly bedded on the bank slope, and be placed in courses with their length parallel to streamflow. After installation is complete, the voids can be filled level with topsoil and planted with herbaceous or small shrub-type vegetation.

Stone riprap proved to be a very good material for protecting the toe of the channel bank, using the "trench-fill" technique (figs. 5, 10, and 16). Riprap was also effectively used in constructing the hardpoint protective areas at the upstream and downstream ends of the study reaches (figs. 4 and 15). Properly constructed hardpoints will help prevent the erosion and undermining of open-ended areas and the consequent failure of structural materials and other channel bank-protection materials. It is generally advisable to limit the use of riprap on channel banks to those areas not planned for vegetation.

Concrete cap blocks are satisfactory for use in channel bank-protection work. Because of their relatively small size and weight, it is advisable to install the blocks as articulated matting. Compared to the cost of cellular concrete blocks and riprap, there is no substantial cost saving in using cap blocks because of the requirements for individual block placement and construction of wire-tie-reinforced matting. However, the local availability of precast concrete cap blocks may be an asset, because often cellular blocks and stone riprap must be transported long distances to a construction site.

As previously stated, more substantial protection is needed on concave banks in channel bends because of the excessive erosive forces exerted on the bank by high-velocity flows. The technique used for these studies consists of a ***revetment fence*** constructed of heavy-gauge wire fabric attached to creosote-pressure-treated pilings and backfilled with riprap. This technique was very successful. Details of installation are discussed under Construction of Study Reaches.

The question often arises as to the need for a ***filter blanket*** in conjunction with the use of structural materials for stabilizing streambanks. A filter blanket is a permeable layer between the bank and the structural material (such as riprap or concrete blocks) and is graded in texture so that the waterflow from the bank to the outer face of the blanket will not carry any of the material. Opinions and practices on the use of a filter blanket vary even within federal agencies. Sloping the top of finished banks landward and controlling the drainage of overland flow into the channel, as part of the design and construction criteria, will help minimize the need for filter blankets. Techniques such as divergence and drop inlet structures have proven to satisfactorily control the drainage of overland flow into channels. The Goodwin and Johnson Creeks studies show that where herbaceous vegetation is established on cellular concrete blocks, filter cloth serves no purpose and can actually restrict root development. Good root development of vegetation on a channel bank provides excellent filter action. Reducing the use of riprap on the bank slope, to the extent possible, will also help reduce the need for a filter blanket. The longer the area of riprap up and down the slope, and the greater the quantity of surface-water damage over the face of the slope, the greater is the need for the blanket. A commercial filter cloth of woven polypropylene fabric was installed between the revetment and the subgrade on three treatment sites in Johnson Creek study reach no. 2. This was done primarily for evaluation and comparison with other treatment sites.

Mulch materials

When sloped channel banks are newly prepared and bare, they are subject to severe erosion, so it is critical at that time to seed or sprig the banks with herbaceous vegetation. Until the vegetation becomes established, a mulch or matting material is needed to protect the bank surface. A satisfactory mulch or matting material does the following: protects the soil surface from the erosive action of raindrops, decreases runoff, increases infiltration, retains moisture, and enhances the seedbed for vegetative growth.

Three types of mulch material were selected for use with the Johnson and Goodwin Creeks vegetative studies: paper netting, wood excelsior blanket, and asphalt-emulsified wheat straw. The ***excelsior blanket*** was given the highest rating. This material contained most of the desirable features for protecting the channel bank until vegetation was firmly established: It is easy to apply and to secure by hand, and it comes in rolls to provide uniform coverage of the bank surface. The ***asphalt-emulsified wheat straw*** also performed satisfactorily. This requires the use of a mechanical blower-type applicator to mix the asphalt tacking agent with the mulch during application. A skilled operator is required to achieve the proper mix, depth, and uniform coverage of the bank surface. Improper application will cause drifting of the material during rainfall runoff, leaving the exposed bank areas vulnerable to erosion and loss of potential vegetative cover. ***Paper netting*** was the least satisfactory of the mulch materials. The application and securing of the paper netting to the bank surface was very difficult during windy weather. As a result, large sections of the bank area became exposed before seed germination, leading to some erosion problems that required refinishing the bank surface and replanting.

Conclusions and Recommendations

These studies showed that vegetation can be successfully used in a streambank-protection program and should be considered an integral part of the engineering design. Certain channel physical factors must also be considered and included in the design. Primary among these factors is stability of the channel bottom, which is usually a prerequisite for streambank stabilization. But before vegetation can stabilize bank erosion, it is necessary to check or eliminate scouring forces that degrade the channel bed. Often the failure of bank-protection work can be attributed to failure of the bank toe from scour, which in turn creates undercutting and sloughing of the upper bank. If it is possible that the bed may degrade, extra bank-toe protection should be included in the design criteria. This includes (1) excavating the channel bottom along the toe, deeper than any expected bed degradation, and (2) backfilling with stone riprap.

If unstable channel banks have become severely eroded and undercut to very steep and unplantable slopes, bank shaping is required before vegetative materials can be planted. After shaping, the sloped channel banks should be treated with commercial fertilizer and lime, incorporated into the top 0.2 m (8 inches) of soil. The banks may then be planted with vegetative materials and covered with mulch to control erosion until vegetation establishes and develops. Maximum use of suitable native plants promotes better overall adaptation of vegetation. A mix of woody and herbaceous plants should be used to protect the soil surface, either by a very dense stand of shrubs or by shade-tolerant grass and legumes in a less dense stand of woody growth. Except for hardpoint areas, the use of structural materials on sloped banks may be required on only the lower section of the banks. The construction criterion for the height of structural revetment on a lower bank may be determined from the maximum depth of streamflow expected for 90–95 percent of annual storm events.

To remain effective, every streambank-protection project requires some maintenance after the installation of structural materials and vegetation, as follows:

- Special attention and followup are recommended during the first 2 yr to assure the establishment of vegetation. Undesirable and unwanted plants should be eliminated. Once the desired vegetation is fully established, inspections are usually concerned with assuring continued protection.

- Control measures, once installed, are not automatically permanent. Structures installed along with vegetative plantings may deteriorate or become ineffective due to changes in the channel's hydrologic or physical characteristics. Such structures need to be maintained or replaced.

- Plant cover may change through plant succession or from destructive physical forces. As a result, vegetation may require replanting or even replacement by another kind.

- Excessive plant growth of woody species along narrow channels can reduce the channel flow capacity, thus increasing the potential for undesirable bank overflow. In such a case, the excessive growth must be trimmed or the plant removed altogether. Excessive growth of trees, especially native black willow, can be partly controlled by cutting a portion of the crown height during the early stage of growth.

- Some of the herbaceous vegetation (such as Alamo switchgrass) produces a very heavy, thick thatch that may restrict or prevent the appearance of new growth. Controlled burning every 3 or 4 yr during dormancy (late winter or early spring) will help correct this problem.

Common maintenance operations for vegetative streambanks include mowing, fertilizing, liming, control of undesirable weeds and plants, and control of domestic livestock. Periodic fertilizing at optimum rates will help sustain the desired stands of vegetation that are needed for continuous bank protection. Soil tests should be made and lime applied as needed. Selective herbicides may be used for the control of undesirable weeds and other plants, but precautions must be taken to ensure their proper use. It is important that domestic livestock be excluded from vegetative streambanks. Fences should be constructed as needed to exclude grazing animals, traffic, and people.

Because the physical characteristics of a stream channel may fluctuate from one extreme to another, it is impossible to predict how long any streambank-protection measure will effectively function without maintenance. Only by continuous vigilance can the best practices be maintained. So the success of any streambank-maintenance program, after completion of construction, depends largely on the interest, initiative, and action of the local landowners.

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Table 1.—Materials used for stabilizing eroding streambanks

Materials	Creek study reach		
	Johnson no. 1	Johnson no. 2	Goodwin
Vegetative materials			
Alamo switchgrass (*Panicum virgatum*)		X	X
Appalow sericea (*Lespedeza cuneata Appalow*)			X
Bahiagrass (*Paspalum notatum Pensacola*)	X	X	X
Bermudagrass (*Cynodon dactylon*)	X	X	X
Black willow (*Salix nigra*)	X		X
Bristly locus (*Robinia fertilis arnot*)	X	X	X
Boston ivy (*Parthenocissus tricuspidata*)	X		X
Buffalograss (*Buchloë dactyloides*)	X		X
Crownvetch (*Coronilla varia Penngift*)	X	X	X
English ivy (*Hedera helix*)	X		X
Indigo bush (*Amorpha fruticosa*)	X	X	X
False anil indigo (*Indigofera pseudotinctoria*)			X
Halifax maidencane (*Panicum hemitomon*)			X
Multiflora rose (*Rosa multiflora*)	X		X
Reed canarygrass (*Phalaris arundinacea*)		X	
Reedgrass, common (*Phragmites communis*)			X
Sericea lespedeza (*Lespedeza cuneata*)	X	X	
Streamco willow (*Salix purpurea streamco*)		X	
Subterranean clover (*Trifolium subterraneum* L.)			X
Structural materials			
Stone riprap	X	X	X
Cellular concrete block		X	X
Concrete cap block	X	X	
Creosote piling	X		X
Chain link fence	X		X
Sand clay gravel		X	
Mulch material			
Paper netting		X	
Wood excelsior blanket	X	X	X
Asphalt-emulsified wheat straw	X		X

Table 2.—Vegetative response after second growing season

Plant material	Bendway studies: Johnson Creek no. 1 — Stand*	Bendway studies: Johnson Creek no. 1 — Growth†	Bendway studies: Goodwin Creek — Stand*	Bendway studies: Goodwin Creek — Growth†
Bermudagrass	Poor	Poor	Good	Good
Crownvetch	Good	Fair	Good	Fair
English ivy	Fair	Poor	Fair	Poor
Bahiagrass	Good	Fair	Fair	Good
Serecia lespedeza	Good	Good	—	—
Appalow serecia	—	—	Fair	Fair
Multiflora rose	Good	Fair	Good	Fair
False anil indigo	—	—	Fair	Fair
Alamo switchgrass	—	—	Good	Excellent
Subterranean clover	—	—	Good	Excellent
Black willow	Good	Good	Good	Good
Bristly locust	Good	Fair	None	—
Indigo bush	Good	Fair	Fair	Poor
Common reedgrass	—	—	Fair	Fair
Halifax maidencane	—	—	Poor	Poor

Plant material	Johnson Creek no. 2, Straight channel reach — Stand*	Johnson Creek no. 2, Straight channel reach — Growth†
Alamo switchgrass	Excellent	Excellent
Bahiagrass	Good	Good
Bermudagrass	Fair-Good	Fair-Good
Crownvetch	Fair	Good
Reed canarygrass	Fair	Good
Sericea lespedeza	Excellent	Excellent
Bristly locust	Good	Good
Indigo bush	Excellent	Excellent
Streamco willow	Poor	Poor

*For seeded herbaceous species, stand refers to number (percent) of plants/ft from seeding rate used (adjusted for germination test); for transplanted species, it refers to percentage of survival. For woody species, stand refers to percentage of live plants. Excellent = 80-100%, good = 60-79%, fair = 30-59%, poor = <30%.

†For nonseeded herbaceous species, growth is evaluated as approximate percent of ground cover. For woody species, average growth is evaluated as height of plants and density of foliage expected for each variety. Excellent = 90-100%, good = 70-89%, fair = 40-69%, poor = <40%.

Table 3. Evaluation* of materials for stabilizing eroding streambanks

Materials	Creek study reach: Johnson 1 rating	Johnson 2 rating	Goodwin rating	Overall rating
Vegetative materials				
Herbaceous				
Alamo switchgrass		7	9	9
Appalow serecia			1	1
Pensacola bahiagrass	3	5	5	5
Common bermudagrass	7	3	3	5
Buffalograss	0		0	0
Crownvetch	5	5	1	5
False anil indigo			3	3
Halifax maidencane			1	1
Reed canarygrass		1		1
Reedgrass, common			3	3
Sericea lespedeza	9	9		9
Subterranean clover			0	0
Woody				
Black willow	7		7	7
Boston ivy	0		0	0
Bristly locust	3	3	0	3
English ivy	0		0	0
Indigo bush	3	5	1	3
Multiflora rose	7		7	7
Streamco willow		0		0
Structural material				
Stone riprap	7	7	7	7
Cellular concrete block		7	9	9
Concrete cap block	7	7		7
Creosote piling	7		7	7
Chain link fence	7		7	7
Sand-clay-gravel mix		1		1
Mulch materials				
Paper netting		1		1
Wood excelsior blanket	9	7	9	9
Asphalt-emulsified wheat straw	7		7	7

* 9 = Excellent, 7 = good, 5 = average, 3 = fair, 1 = poor, 0 = failure (or none).

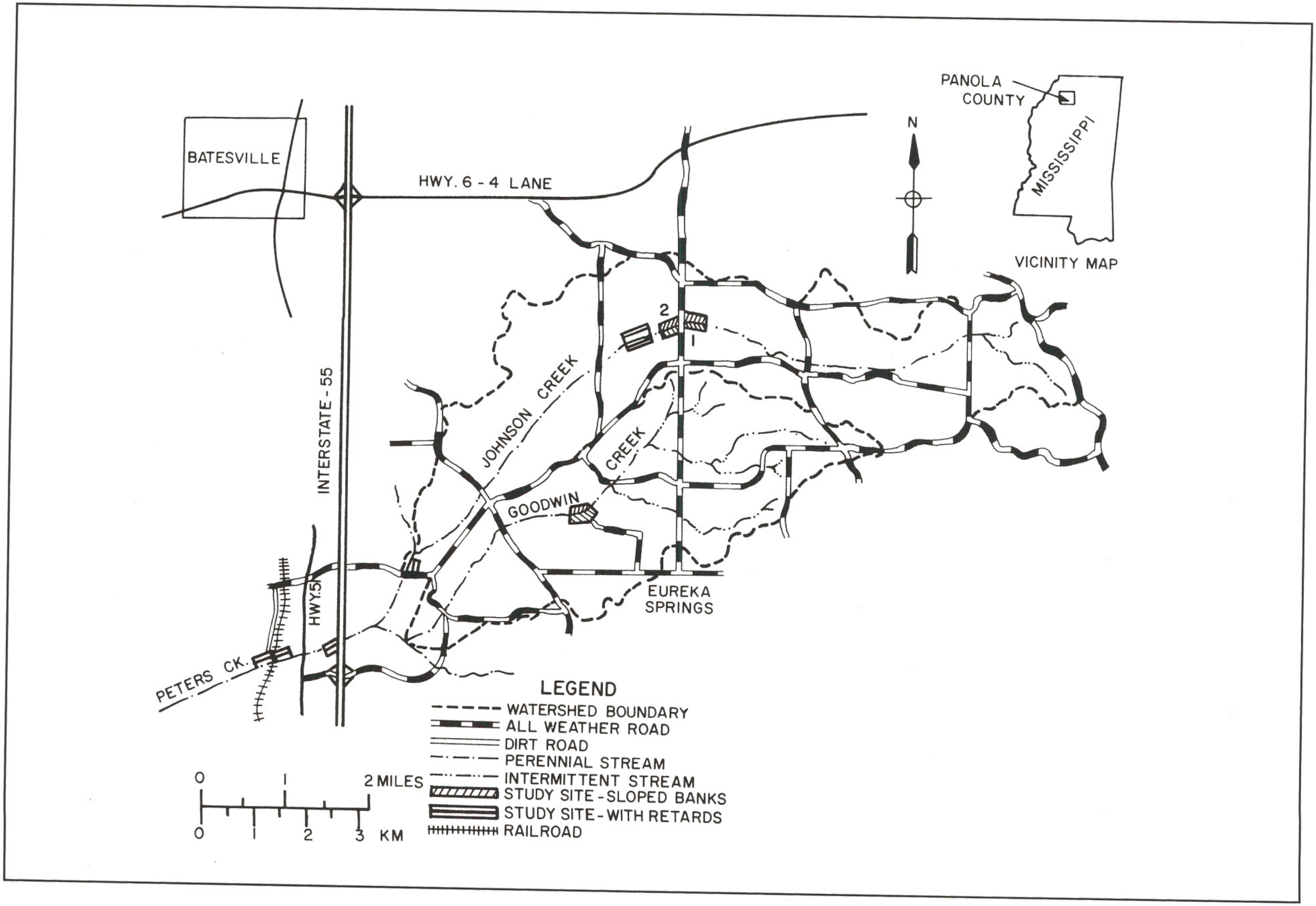

Figure 1. Location map of streambank vegetative study area

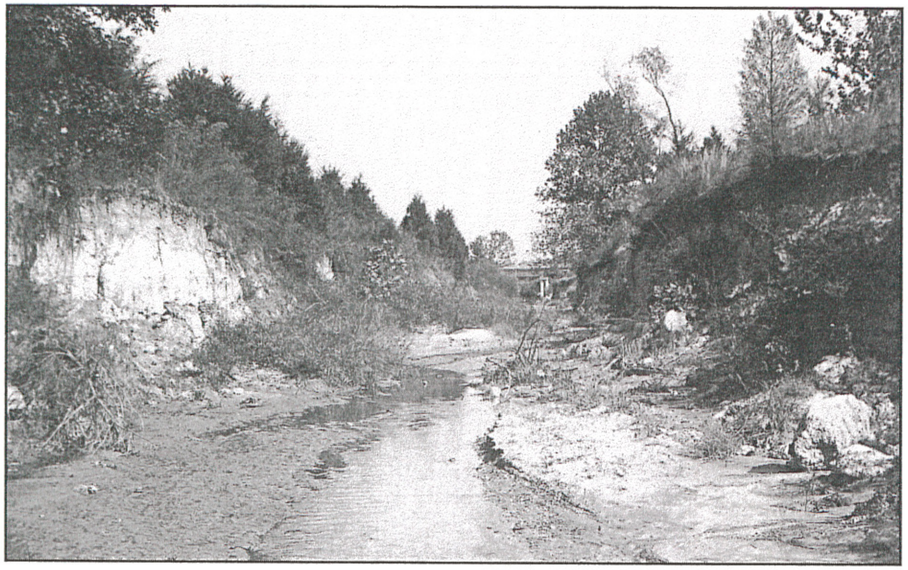

Figure 2. Typical channel cross section of Johnson Creek

Figure 3. Johnson Creek bank failure due to undermining

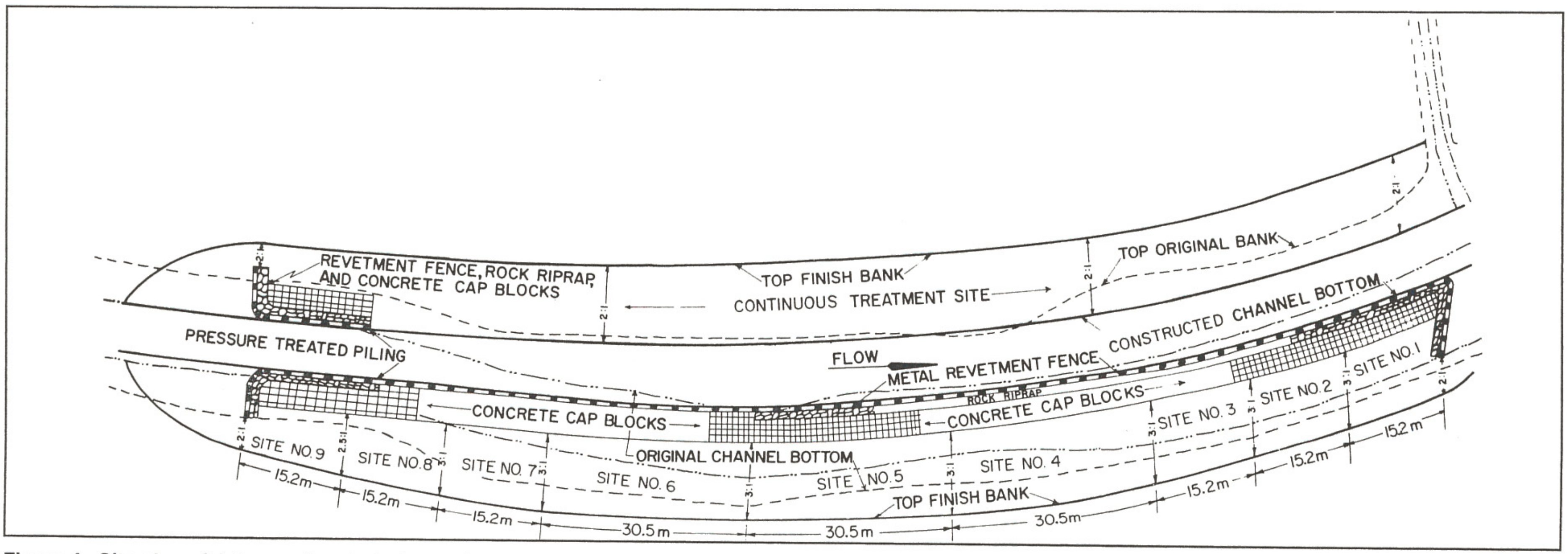

Figure 4. Site plan of Johnson Creek study reach no. 1

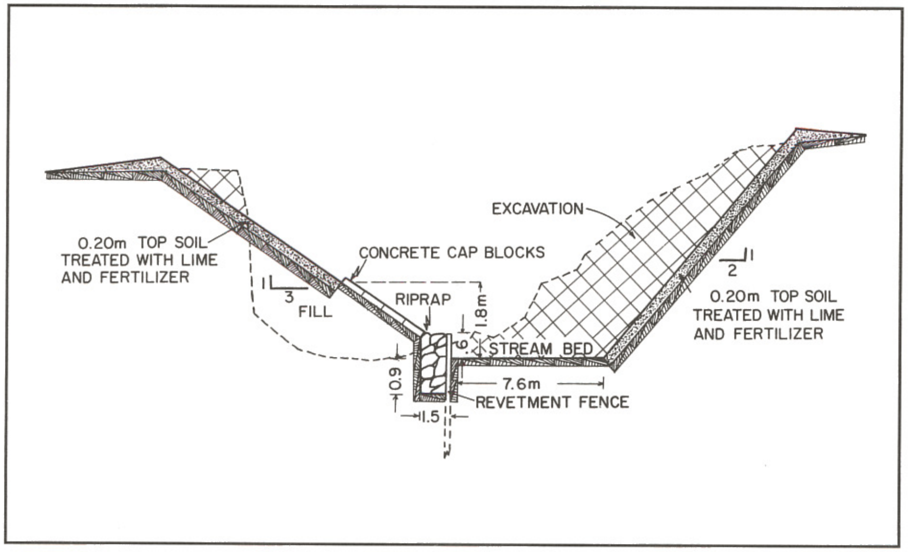

Figure 5. Cross section of typical treatment of Johnson Creek study reach no. 1

Figure 6. Upstream view of Johnson Creek study reach no. 1 before construction

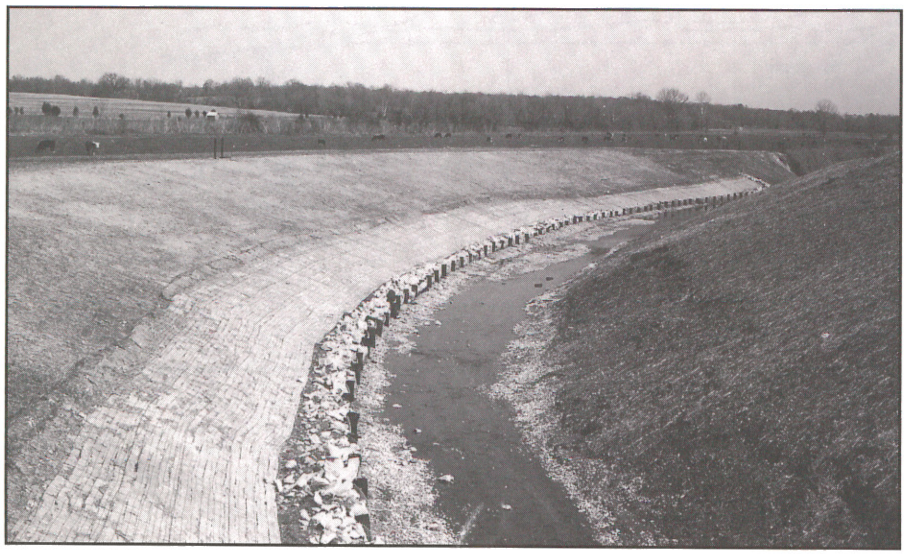

Figure 7. Upstream view of Johnson Creek study reach no. 1 after construction

Figure 8. Upstream view of Johnson Creek study reach no. 1 after six growing seasons

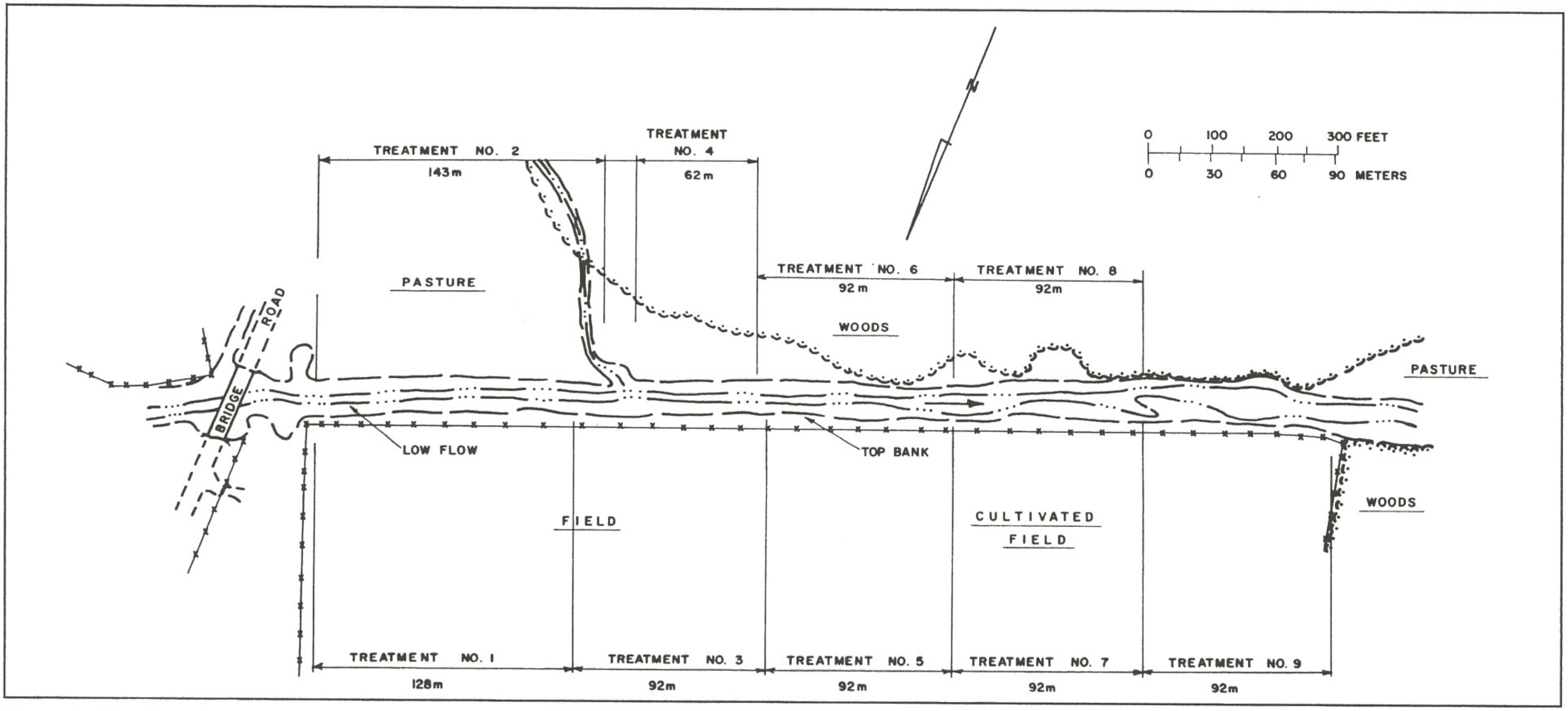

Figure 9. Site plan of Johnson Creek study reach no. 2

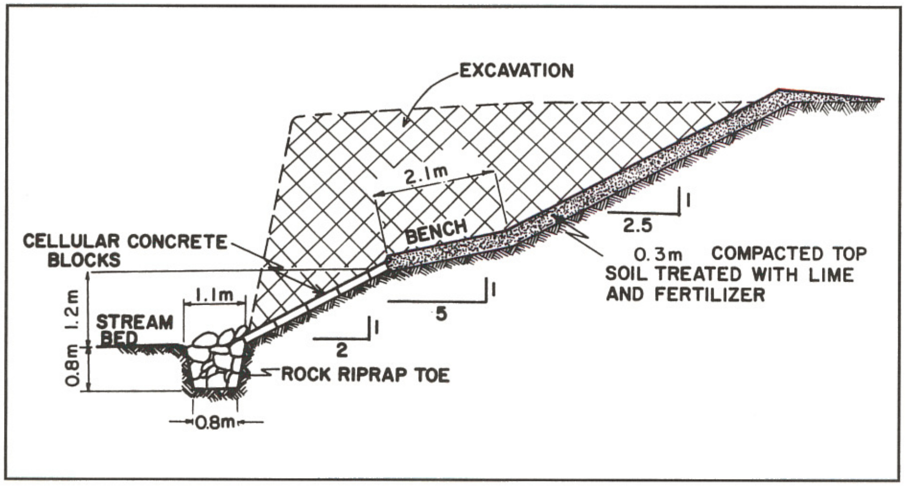

Figure 10. Johnson Creek study reach no. 2: Cross section of excavated bench, with lower bank and entrenched toe protected with structural materials

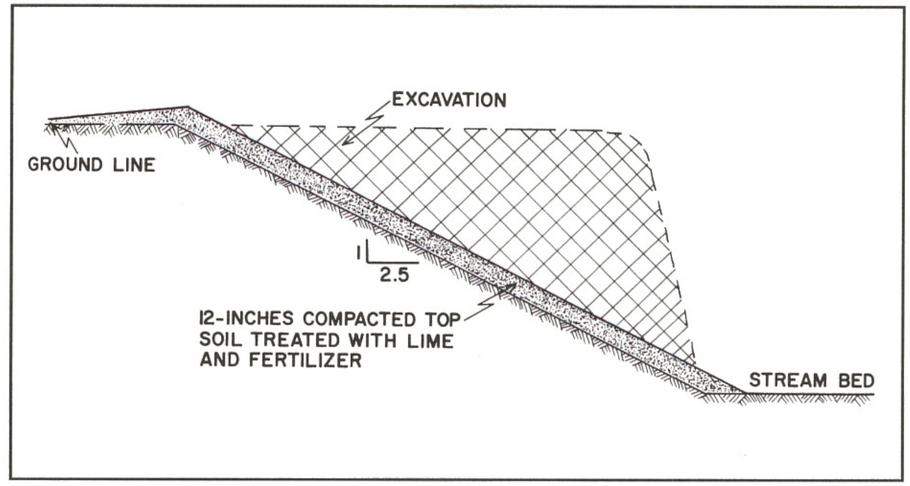

Figure 11. Johnson Creek study reach no. 2: Cross section of typical sloped bank without structural materials

Figure 12. Downstream view of Johnson Creek study reach no. 2 before construction

Figure 13. Downstream view of Johnson Creek study reach no. 2 after construction

Figure 14. Downstream view of Johnson Creek study reach no. 2 after nine growing seasons

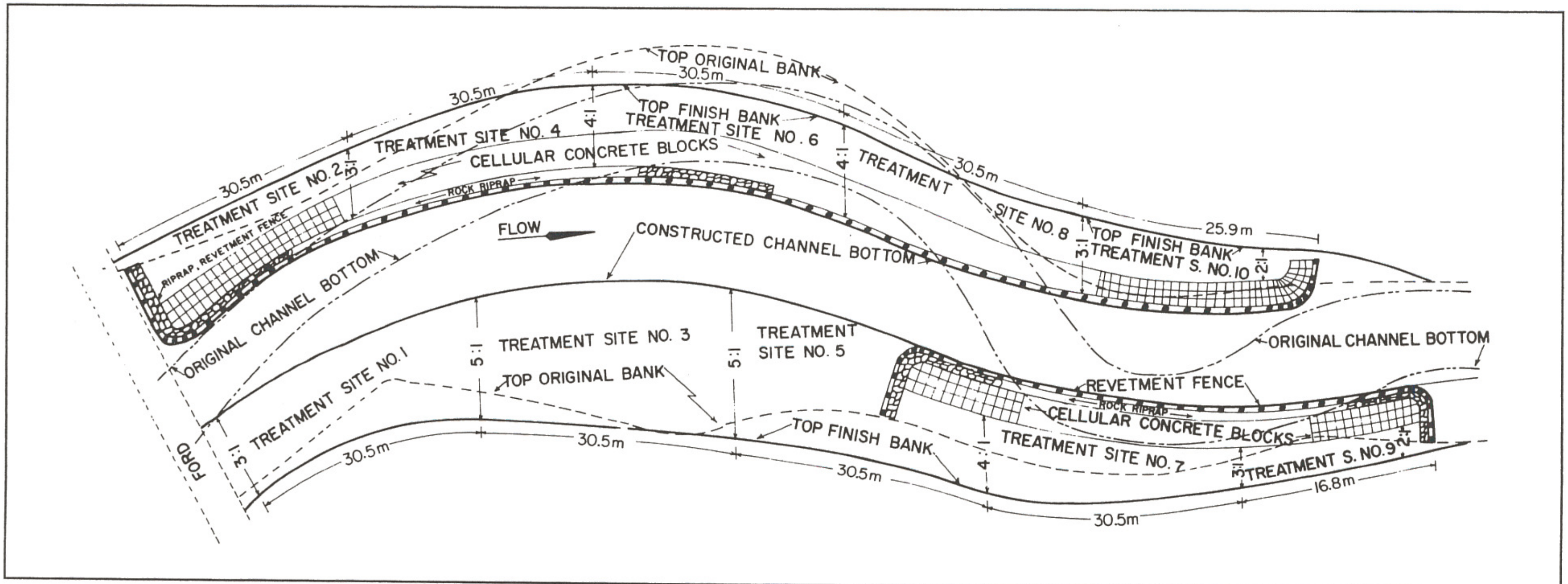

Figure 15. Site plan of Goodwin Creek study reach

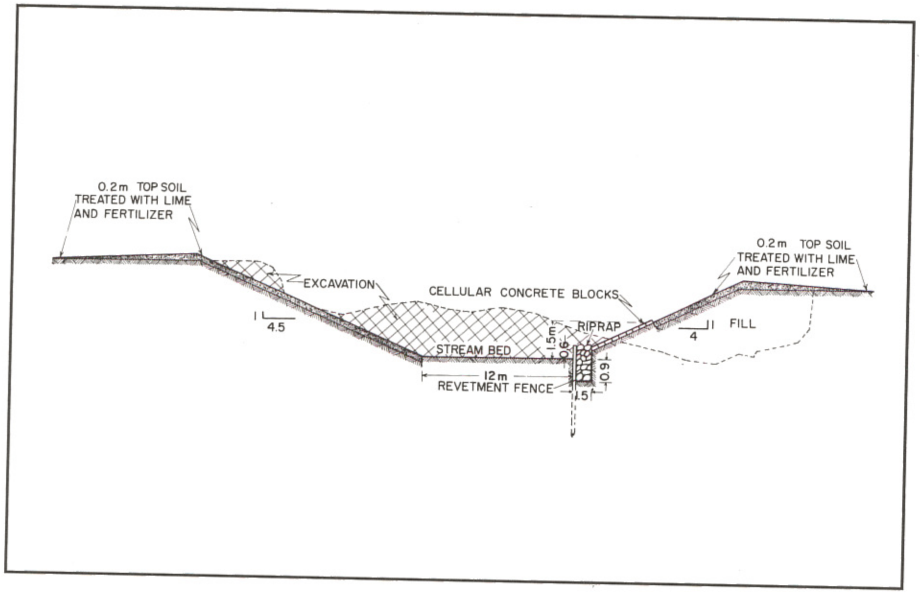

Figure 16. Cross section of typical treatment of Goodwin Creek study reach

Figure 17. Downstream view of Goodwin Creek study reach before construction

Figure 18. Downstream view of Goodwin Creek study reach after construction

Figure 19. Downstream view of Goodwin Creek study reach after six growing seasons