EVALUATION OF THE STATE-OF-THE-ART STREAMBANK STABILIZATION

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INTRODUCTION

Accelerated streambank erosion is a principal source of sediment supplied to streams (Knighton 1984), and is responsible for the annual loss of over 41 million tons of soil in Wyoming (Binns 1986). Not only does the process itself cause the loss of valuable lands, buildings and public works, but the resultant rise in sediment concentrations can increase water treatment costs, degrade valuable riparian and aquatic habitat, decrease aquatic and riparian productivity, reduce esthetic qualities, deplete water storage capacity, and promote the transport of other pollutants. On a national scale, streambank erosion causes over $250 million in damages annually (Henderson 1986).

Over the last century, the most commonly used methods for stabilizing streambanks relied mainly upon inanimate materials such as wood, stone, concrete, and iron (Seibert 1968). The most widely used of these "structural" methods include: stone riprap, concrete pavement, articulated concrete mattresses, transverse dikes, fences, asphalt mixes, jacks, gabions, tree revetments, and bulkheads (Keown et al. 1977). While many of these methods may provide immediate bank protection, they are expensive to build and maintain (Seibert 1968, Grissinger and Bowie 1984). Their long-term effectiveness is especially doubtful, since they are exposed to progressive deterioration by natural agents (Seibert 1968). In addition, structural methods may adversely impact both the aquatic and terrestrial environment, as well as be esthetically displeasing (Henderson 1986).

More recently, however, non-structural techniques for stabilizing streambanks have been used. These include any form of bank protection that requires management by natural means. Examples of non-structural techniques for stabilizing streambanks include: beaver management (Munther 1982, Apple 1985, DeBano and Heede 1987, Platts et al. 1987), livestock management (Edminster et al. 1949, Marlow 1985, Marlow and Pogacnik 1985, Platts and Nelson 1985, Siekert et al. 1985), and enhancing the riparian (streamside) vegetation (Seibert 1968, Logan 1979b, Monsen 1983, Platts et al. 1987). While non-structural methods for stabilizing streambanks may not provide immediate bank protection, they do have several advantages over structural methods because they tend to be longer lasting, cheaper to install, and more esthetically pleasing (Seibert 1968, Heede 1981, Henderson 1986).

The purpose of our report was to assemble and review the current literature on streambank stabilization techniques, and to compile a state-of-the-art streambank stabilization bibliography. Classical treatments such as riprap, gabions, and tree revetments were included, but our primary emphasis was on the characteristics and requirements of plant species suitable for bank revegetation in the semiarid western United States. We hope this review will help private land owners, as well as public officials, to choose the most appropriate streambank stabilization technique for their situation.

The report is divided into two major sections: a summary of streambank stabilization techniques, and a bibliography. Streambank stabilization techniques were classified as either structural or non-structural. Some potential methods for establishing vegetation along streambanks were also included in the summary section. Since it would be impractical to include every citation in these summaries, a separate bibliography was developed and is included in the Appendix. This bibliography will also be entered into the Wyoming Water Bibliography (Wyoming Water Research Center 1984). The Wyoming Water Bibliography is a computerized bibliographic storage and retrieval system whose services are available free of charge.

A summary of every streambank stabilization technique ever tried would require more effort than was intended for this report. Many techniques, or variations of a technique, have been tried for protecting streambanks. In order to make the most efficient use of our resources, this report was limited to summarizing the most commonly used techniques, as well as a few of the more novel techniques directly applicable to Wyoming. Our bibliography, however, includes every verified reference located for techniques on bank stabilization. This report also does not attempt to summarize the impacts caused by various streambank stabilization techniques on the physical, chemical, or biotic environment of the stream. For references or studies concerning these impacts see Bulkley (1975), Witten and Bulkley (1975), Menzel and Fierstine (1976), Stern et al. (1980a), and Stern et al. (1980b).

METHODS

Information Collection

Information relating to streambank stabilization techniques was collected by using a four-part strategy. First, the personal libraries of the co-authors were reviewed for pertinent literature relating to streambank stabilization. Next, information was requested from appropriate state and federal agencies. Third, bibliographies listing streambank stabilization techniques were examined for pertinent citations, and finally a computer based literature search was conducted.

The principal investigators have accumulated many papers pertaining to streambank stabilization. These papers were reviewed, and any information even remotely relating to streambank stabilization (e.g. information regarding potentially suitable plant species) was compiled. In addition, the literature cited in each article was examined for pertinent citations relating to streambank stabilization techniques. These citations were also included in our report if they were found to be relevant.

After reviewing these personal libraries, the following state and federal agencies were invited to provide information regarding the streambank stabilization techniques used by their agency:

Wyoming Highway Department
Wyoming Game and Fish Department
U.S. Army Corps of Engineers
U.S. Bureau of Land Management
U.S. Bureau of Reclamation
U.S. Environmental Protection Agency
U.S. Fish and Wildlife Service
U.S. Forest Service
U.S. Soil Conservation Service

Agency personnel were requested to provide information regarding the types of treatments used by their agency, the criteria used to evaluate alternative treatments, construction and installation specifications, monitoring methods, the stream classification system used and how the classification affects the treatment chosen, and the cost for each treatment.

Several bibliographies containing citations relating to streambank stabilization are available: Keown et al. (1977), Wydoski and Duff (1978), Stern et al. (1980b), Dardeau (1981), Duff and Wydoski (1982), Johnston (1987), and National Technical Information Service (1987a, 1987b). These bibliographies were examined for pertinent literature, and all appropriate citations were included in our bibliography after verification. To verify a citation, the paper was located and then checked for relevant material.

The most thorough bibliographies relating to streambank stabilization techniques are those by Keown et al. (1977) and Dardeau (1981). These two bibliographies attempt to cover every possible streambank stabilization technique published through mid 1981. They list over 50 techniques used to stabilize streambanks, and cite over 2,300 references. Most of their citations, however, concentrate primarily on structural streambank stabilization techniques (e.g. riprap, gabions and dikes) for major rivers such as the Ohio and Mississippi Rivers. Since our bibliography was intended for use primarily in the semiarid west, we included many of their citations, but added structural techniques appropriate to smaller streams and rivers as well as including additional information on non-structural techniques used to stabilize streambanks (e.g. vegetation and grazing strategies).

The computer based literature search was conducted by searching several of the databases provided by the DIALOG Information Service, and the NTIS (National Technical Information Service) database. NTIS was searched both from a separate database (1983-88/#6), and through the DIALOG service. Appropriate key words relating to streambank stabilization techniques were used for the search. The DIALOG databases searched included:

DIALOG File No.	Database
8	COMPENDIX PLUS - 1970-88/June
6	NTIS - 1964-88/ISS15 (Restricted to 1981-82)
10	AGRICOLA - 1979-88/June
50	CAB ABSTRACTS - 1984-88/June

Bibliography

All verified references will be added to the Wyoming Water Bibliography (Wyoming Water Research Center 1984). A copy of the bibliography as it will be entered into the database is included in the Appendix. The format used for these citations includes author(s) (AUTH and SORT), year (YEAR), title (TITL), organization responsible for publishing the document (SRCE), keywords (DESC), the physical location of the document (LOCN), and the geographic area encompassed by the document (GEOG).

The principal keyword used to describe a citation was "Bank Stabilization." In addition, several qualifying keywords (Figure 1) may have been added to the citation. These keywords were selected from a standardized list of keywords suggested for indexing water related research (Cobb 1980, Wyoming Water Research Center 1984).

Some citations entered into this bibliography were not verified. These unverified citations were obtained from annotated bibliographies (National Technical Information Service 1987a,b; Medin and Torquemada 1988), or from other bibliographies devoted to streambank stabilization (Keown et al. 1977, Dardeau 1981). The citations were included without verification, so we could pursue additional citations. These unverified citations were the only ones not verified, and are identified in our bibliography by having the physical location of the document (LOCN) listed either as the bibliographic source (e.g. "Medin and

- Bank Stabilization
  - Bibliographies
  - Costs
  - Design Standards
  - Glossaries*
  - Suppliers*
  - Theoretical Analysis
  - Structure
    - Check Dams
    - Dikes
    - Filter Fabrics
    - Gabions
    - Groins
    - Jacks
    - Jetties
    - Retaining Walls
    - Revetments
    - Riprap
    - Soil Cement
    - Soil Stabilization
  - Beavers
  - Grazing
    - Fences
    - Livestock
      - Cattle
      - Sheep
  - Recreation
  - Wildlife
  - Vegetation
    - Flooding
    - Bulrushes
    - Grasses
      - Grassed Waterways
      - Barley
      - Bermudagrass
      - Bromegrass
      - Grama Grasses
      - Oats
      - Orchardgrass
      - Rice
      - Sorghum
      - Spartina
      - Wheat
      - Wheatgrass
    - Legumes
    - Shrubs
      - Rabbitbush
    - Trees
      - Beech Trees
      - Birch Trees
      - Cottonwood Trees
      - Fir Trees
      - Juniper Trees
      - Maple Trees
      - Oak Trees
      - Pine Trees
      - Spruce Trees
      - Tamarisk Trees
      - Willow Trees

Figure 1. Hierarchical list of keywords used for describing citations. *Keywords not recognized as standard descriptor terms by Cobb (1980) or Wyoming Water Research Center (1984).

Torquemada 1988"), or as "Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss)."

Streambank Stabilization Technique Summaries

Streambank stabilization techniques have been classified by several different systems. For example Keown et al. (1977) chose to classify techniques based on five categories: single-component revetments, multiple-component revetments, bulkheads, soil stabilization, and river training structures. DeBano and Heede (1987), however, prefer a more general approach based on three categories: bank armor, flow deflectors, and flow separators. For the purposes of our summaries we have chosen to use two main categories: structural, and non-structural. Structural techniques for streambank protection include any form of bank protection which requires the placement of inanimate objects on or near the streambank (e.g. riprap, gabions, dikes, and tree revetments). Non-structural techniques for streambank protection include any form of bank protection which requires management by natural means (e.g. beavers, grazing, and vegetation).

Within this classification of structural and non-structural, each technique was summarized individually. Individual summaries were divided into six sections: description, application, advantages, limitations, relative cost, and selected references. The methods used to establish vegetation along streambanks were also summarized in this way.

The description section provides a brief summary of the technique, and how the technique provides protection to the streambank. A more detailed description of the major steps required to establish the protective technique, as well as the stream size and bank position where the technique may be employed, is provided in the application section. Bank position, as used here, is divided into three levels (after Logan 1979b): lower bank, middle bank, and upper bank. The lower bank is inundated throughout most of the year, and is directly affected by the streamflow more often than the other two bank positions. The middle bank is usually above the average base flow, but high discharges are expected to cover the bank for up to 60 days once every two or three years. Groundwater is usually very close to the surface for the middle bank, even at normal flows. The upper bank is usually not exposed to the effects of streamflow, except occasionally during a true flood (recurrence interval ≥10 years). Drought, rather than flood tolerance is the major limiting factor for plant growth on the upper bank. The information provided in this section is not intended to provide all the details required to establish a particular bank protection technique, but rather to indicate what should be considered when this technique is used to stabilize streambanks.

The positive and negative aspects of using a particular streambank stabilization technique are listed in the advantages and limitations sections. Relative cost for implementing the technique is listed in the next section. These costs are presented in the units reported. A comprehensive cost comparison between individual techniques would be difficult, since the cost of a project depends upon so many factors. These factors include: planning, labor, site location, availability and cost of materials, size of project, and other on-site and off-site intangible costs (Jones and Franklin 1988). Comparing costs between methods, and even within a method, is further hampered by the units used to report costs. Costs for bank stabilization have been reported in units of volume (e.g. riprap), linear distance of bank protected (e.g. bulkheads), area (e.g. vegetation), and per plant. The final section, selected references, lists the documents used to summarize the technique. For our discussion on the structural techniques, we relied heavily upon Keown et al. (1977) and Dardeau (1981).

STREAMBANK STABILIZATION TECHNIQUES:

STRUCTURAL

DESCRIPTION:

Aggregate blankets consist of a layer of gravel, crushed rock, shell, or other suitable materials placed on the bank to be protected. This form of revetment allows vegetation to become established on the bank.

APPLICATION:

How

- Aggregate blankets are constructed in a manner similar to riprap, except finer materials such as gravel, crushed rock, or shell are used to form the protective bank cover.

Where

- Aggregate blankets can be used in lieu of riprap if the stream velocity, wave attack, and water level fluctuations are minimal.

ADVANTAGES:

- No Information.

LIMITATIONS:

- No Information.

RELATIVE COST:

- No Information.

SELECTED REFERENCES:

Dardeau 1981.

STRUCTURAL
ASPHALT BLOCKS

DESCRIPTION:

Asphalt blocks are constructed from river sand and petroleum products, or from broken pieces of asphalt. The blocks can be used as a substitute for rock riprap.

APPLICATION:

How

- Asphalt blocks are constructed from river sand and petroleum products, or from broken pieces of asphalt.

Where

- Used on the lower Mississippi River in 1918 and again in 1951.

ADVANTAGES:

- May be a useful substitute for rock riprap, if a supply of suitable rock is unavailable and a cheap source of petroleum products are nearby.

LIMITATIONS:

- Considered unsuitable for bank stabilization in Wyoming since it would almost certainly violate Section 29, the Oil and Grease standard, of Chapter I, The Wyoming Water Quality Rules and Regulations.
- Casting and dumping of asphalt blocks has proven to be uneconomical in the past, and has seldom been used for bank protection since the early 1950's.

RELATIVE COST:

- No Information.

SELECTED REFERENCES:

Fanning 1988; Keown et al. 1977.

ASPHALT (BITUMINOUS) MATTRESSES

DESCRIPTION:

Bituminous mattresses are constructed from compacted, cable-reinforced sections of asphalt which are placed on the bank to be protected.

APPLICATION:

How

- Bituminous mattresses are laid over the shaped riverbank below the low-water line.

Where

- Used to protect the lower bank on the lower Mississippi River from 1934 to 1945.

ADVANTAGES:

- The mattresses are continuous, impermeable, fairly flexible, and resistant to abrasion.

LIMITATIONS:

- Considered unsuitable for bank stabilization in Wyoming since it would almost certainly violate Section 29, the Oil and Grease standard, of Chapter I, The Wyoming Water Quality Rules and Regulations.
- Many failures occurred in the past because the impermeable mattresses did not sink properly in currents greater than 5 fps. The poorly positioned mattress eventually tore or folded over downstream.
- The impermeability of the mattress restricts natural bank drainage, and eventually causes the mattress to fail at weak points.
- Tying the mattress into the bank at all four edges is difficult, and may result in failures if not completed properly.
- Requires specialized equipment for laying the mattress.

RELATIVE COST:

- The high frequency of failures and the expensive equipment required for placement caused the termination of this method in 1945. Articulated concrete mattresses are now used instead of asphalt mattresses.

SELECTED REFERENCES:

Fanning 1988; Keown et al. 1977.

DESCRIPTION:

Uncompacted asphalt paving dumped from trucks or spreaders on the upper banks has proven to be a successful bank stabilization method.

APPLICATION:

How

- Banks are usually graded to a 1:3 slope before placing a nominal 5 inch thick layer of asphalt.
- The asphalt mix is generally made from riverbar sand and 6% (by weight) of 85-100 penetration asphalt.

Where

- Uncompacted asphalt paving has successfully protected banks exposed to floodwater velocities ≤7 fps. At velocities greater than 7 fps, total failure of larger sections may occur.
- Usually placed on the upper bank, although some limited success has been obtained by dumping 225-275°F hot mix containing 25% asphalt through a considerable depth of water onto the lower bank.

ADVANTAGES:

- No Information.

LIMITATIONS:

- Considered unsuitable for bank stabilization in Wyoming since it deteriorates without traffic and maintenance, and would almost certainly violate Section 29, the Oil and Grease standard, of Chapter I, The Wyoming Water Quality Rules and Regulations.
- Hydrostatic pressure from a rapid drawdown may cause failures since the porosity of the asphalt is limited, especially if the pavement becomes clogged with silt. The installation of a subsurface drainage system can help to eliminate this problem.
- Annual surface wearing ranges from 1/16 to 1/8 inches per year on the upper banks. This could limit the design life of the pavement to about 25 years, since the pavement covering the bank will then be about 2 inches thick.
- Impact from debris, hydrostatic pressure, penetration by vegetation, or deterioration of the asphalt binder may cause massive failures.

RELATIVE COST:

- $60 to $80 per cubic yard (1976) to place asphalt pavement on the upper bank, including bank preparation.

SELECTED REFERENCES:

Fanning 1988; Keown et al. 1977; Wacker 1988.

STRUCTURAL
AUTOMOBILE BODIES

DESCRIPTION:

Automobile bodies have been used as an emergency or low-budget method for streambank protection.

APPLICATION:

How

- The automobile bodies are usually placed on the bank in a random fashion, then tied together with wire cable and secured to deadmen or trees.
- A better method for installation would be to secure the car bodies vertically with the frame side out. Then fill the car bodies with graded rock. The bodies should extend below the predicted scour line.

Where

- Used most often along small streams in areas where riprap is not economically available, and where ice flows or excessive rust is not a problem.

ADVANTAGES:

- Car bodies may be readily available at some locations.

LIMITATIONS:

- Car bodies are considered unacceptable for bank stabilization by environmental agencies regulating waterways.
- The random placement and shapes of automobile bodies along the bank may actually increase erosion by directing the flow towards the bank instead of away from it.
- The use of automobile bodies for streambank protection would make the banks inaccessible and esthetically displeasing.
- Overall, car bodies are a very poor substitute for rock or tree revetments.

RELATIVE COST:

- No Information.

SELECTED REFERENCES:

Binns 1986; Keown et al. 1977; Wacker 1988.

DESCRIPTION:

Old automobile tires can be used to construct either a mattress covering the bank, or stacked against the bank to form a wall.

APPLICATION:

How

- Automobile-tire matting is constructed from used tires laid flat on the bank, and then tied together with wire or non-biodegradable rope to form a mattress. The mattress is constructed in-place over the bank to be protected. Deadmen are then anchored to the tires at various points so the mattress will not slide down the bank or float. Holes drilled into the side walls of the tires will help to prevent floating by releasing trapped air. Stone or rubble placed into the tires will also help to prevent floating. Finally, willow can be planted between tires to provide long-term stability.
- An alternative method of employing used tires for bank protection is to make modular units of tires by stacking the tires vertically on top of each other. The modular units are then placed side-by-side to form a gabion-like bulkhead (see also Bulkheads). The modular units are created by lacing a steel cable through the stacked tires. Then filling the core with sand and gravel, and finally sealing the ends of the unit with concrete.
- The tires can also be placed in rows along the bank, with each row stacked on top the other, and then stepped back 6-12 inches from the row below it.
- Another method of employing used tires for bank protection is to create a floating tire breakwater. Floating-tire breakwaters are constructed by filling the tires with buoyant material (e.g. rigid urethane foam), fastening the tires to each other, and then anchoring the whole structure to deadmen.

Where

- Modular units of vertically stacked tires can be used for either upper or lower bank protection. The other techniques may also be effective for upper or lower bank protection, but no direct references were found.

ADVANTAGES:

- Used tire mattresses and bulkheads have a good chance of successfully stabilizing the bank, and are economical.
- Used tires are durable, nontoxic, inexpensive (often free), and provide substrate and cover for aquatic organisms.

LIMITATIONS:

- The stability of automobile tire matting may be a problem until vegetation becomes established between the tires and sediment has built-up.
- Drilling relatively small holes into the tires to vent air is both costly and time consuming, and still does not effectively vent air from the tires.
- Used automobile tires are somewhat unsightly, but willow plantings and sediment build-up may eventually make the structure appear more natural.

RELATIVE COST:

- $30 (1980) to $56 (1976) to protect a linear foot of bank with a used tire mattress.
- $50 (1979) to protect a linear foot of bank with stacked used tires.

SELECTED REFERENCES:

Dardeau 1981; Keown 1983; Keown et al. 1977; Schnick et al. 1982.

DESCRIPTION:

Brush mat revetments are constructed from brush placed on the bank and then held in place with wire or rock ballast. Poles, logs, or lumber may also be woven into the brush mat for added strength, forming a timber-and-brush mattress. These revetments provide temporary bank protection, but their primary purpose is to provide a mulch for enhancing the establishment of vegetation. See also Tree Revetments.

APPLICATION:

How

- If riprap or vegetation is to be incorporated into the brush mat, the riprap should be placed first so it can be used as a base for the brush mat. Then vegetation should be planted on the sloped bank. Finally, brush should be laid in shingle-like fashion on the bank with the butt ends pointed upstream.
- Willow brush makes the best material.
- The mat should be 6-18 inches thick, and held down with interlaced galvanized wire attached to stakes driven into the ground.
- Timber-and-brush mattresses have been launched in mass from a barge, and then secured in place with wire and stone.

Where

- Timber-and-brush mattresses have been used extensively in the past to protect both the upper and the lower bank.

ADVANTAGES:

- No Information.

LIMITATIONS:

- Protection of streams subject to channel scour is not practical with this method because the riprap base will move downward into the deepening channel.
- Requires hand labor, which may become expensive.
- Has a short life, and is practical only where sufficient quantities of brush and rock are available.

RELATIVE COST:

- No Information.

SELECTED REFERENCES:

Edminster et al. 1949; Kautz 1969; Keown et al. 1977.

DESCRIPTION:

Bulkheads are vertical or nearly vertical structures used to protect steep, unstable bank slopes. A bulkhead prevents the bank from sliding into the stream, as well as protecting the bank from streamflow. They are also used as boat docks, or where land fill adjacent to the channel must be stabilized.

APPLICATION:

How

- Bulkheads are best constructed during low water.
- Bulkheads may be constructed from a variety of materials including timber, concrete, stone, gabions, reinforced earth, used tires, timber and concrete cribs, and prefabricated asbestos fiber or metal sheets.
- Timber bulkheads are constructed from timber treated with a preservative. Riprap should be used to protect the toe of the bulkhead, and both the up and down stream ends of the bulkhead should be tied into the bank.
- Stone bulkheads are constructed by fitting rectangular stone blocks together, forming a wall. The blocks should be large enough (about 100 lbs) to resist the force of high water. Smaller stone can be used, but the bulkhead must be skillfully constructed. Vertical joints should not extend beyond 2 layers into the stone wall.
- Gabion bulkheads are formed by a vertical or nearly vertical arrangement of stacked gabion baskets.
- Reinforced earth bulkheads are formed by introducing small quantities of foreign materials such bars, strips, or fibers into the bank. The most commonly used method, however, is to use vertical facing panels (e.g. precast concrete) with attached bars running perpendicular from the panels into the eroding streambank. Bank material is then back filled and compacted in lifts until the desired protection height is reached.
- Used tire bulkheads are formed by placing staggered rows of stacked tires, and then filling the tires with tamped gravel or other material. If the tires are not tied together, the bulkhead should not be greater than 4 feet high.
- Prefabricated asbestos fiber and metal bulkheads are formed by either working the sheet into the soil with a compressed air jet, or driving the sheet into the soil with a mechanical aid.

Where

- Bulkheads are recommended for use on secondary and major alluvial rivers. Bulkheads can also be used on small to medium sized streams with relatively stable channel locations.
- Bulkheads are used on vertical banks where space is limited.

STRUCTURAL
BULKHEADS

ADVANTAGES:

- Bulkheads can be used to increase the bank area adjacent to the channel by eliminating sloped banks, and can improve the land/water access.
- Stone bulkheads allow percolation of water, blend into the landscape, and provide a relatively rough surface to decrease velocities adjacent to the bank. A properly constructed stone bulkhead effectively stabilizes actively eroding banks.
- Used tire bulkheads can be constructed with limited funds and no heavy equipment. Since used tires are often available for free or for a minimal cost, this form of bank protection is especially economical for the landowner who is willing to invest his labor.
- Asbestos fiber or metal sheet bulkheads have an advantage over timber or concrete bulkheads because they do not require driving deep piles or constructing concrete forms.
- Aluminum bulkheads do not rot, rust or crack, and are not susceptible to the freeze-thaw cycle or changes in pH.

LIMITATIONS:

- Impervious bulkheads should be constructed with weep holes, so hydraulic pressure changes will not cause a failure.
- A timber bulkhead initially costs less than a concrete bulkhead, but requires more maintenance. The long-term cost (initial cost plus maintenance cost), however, is nearly the same for either bulkhead type.
- Stone bulkheads require extensive skilled hand labor and large stone.
- Bulkheads generally cause more adverse impacts on the environment than other types of bank stabilization techniques. For example bulkheads cause an abrupt land-water transition, reducing or eliminating riparian habitat.

RELATIVE COST:

- $14 (1976) to $750 (1975) to protect a linear foot of bank with a bulkhead. When materials are readily available, the average cost is $50 per linear foot (1976).
- Aluminum and asbestos bulkheads cost from $40 to $80 per linear foot (1975).
- Steel bulkheads cost from $250 to $750 per linear foot (1975).
- Timber bulkheads cost from $90 to $200 per linear foot (1975).
- Concrete-block bulkheads cost about $200 per linear foot (1975).

SELECTED REFERENCES:

Dardeau 1981; Edminster et al. 1949; Keown 1983; Keown et al. 1977; Pennsylvania Department of Environmental Resources 1986; Schnick et al. 1982.

DESCRIPTION:

Cellular blocks are precast concrete blocks with cavities. The cavities allow volunteer or planted vegetation to grow-up through the structure.

APPLICATION:

How

- Cellular blocks are provided with openings, so moisture can seep from the bank and vegetation can grow through. The use of solid blocks is not recommended.
- Place a filter cloth between the bank and the cellular blocks if the underlying bank material is likely to erode.
- Large scale installations requrire specialized equipment, but hand placement can be used where mechanized equipment is unavailable or where bank access is inadequate.
- Cellular blocks can also be bonded to rectangular sheets of filter fabric, forming a cellular-block mattress. The cellular-block mattress can then be lifted onto the streambank by a mobile crane.

Where

- Various types of cellular block have been used successfully to protect banks where the streamflow adjacent to the bank ranged between 3.2 to 15 fps. One manufacturer expects their product to protect banks with flows up to 30 fps.
- Massive ice flows apparently do not adversely affect properly placed cellular block.

ADVANTAGES:

- The holes in the blocks allow vegetation to grow-up through the structure, thus allowing the roots to enhance the structural integrity of the bank.
- Since the holes provide a measure of permeability, bank failures caused by hydrostatic pressure are minimized.
- Cellular blocks placed on the bank are sufficiently flexible to conform to minor changes in bank geometry.
- Cellular blocks may prove to be a viable alternative to riprap where suitable stone is not economically available.

LIMITATIONS:

- Wave action may produce uplift pressures sufficient to dislodge the blocks. In addition, receding waves may remove bank material from under the blocks.
- If a filter is required, technical assistance may be required to properly design the filter.

STRUCTURAL
CELLULAR BLOCKS

RELATIVE COST:

- May be up to 15% cheaper than a comparable design of riprap.
- \$1.10 to \$1.40 per ft^2 (1956) to install cellular blocks.
- \$320 to \$370 (1978) to protect a linear foot of bank up to 3 ft above the sustained high water mark for the Sacramento River, CA and its tributaries. Annual maintenance costs for a 50 yr project were estimated to be from \$23 to \$27 per linear foot.
- \$2.40 per ft^2 (1981) to install cellular-block mattresses. Costs may exceed \$102 per ft^2 (1981) for some applications.

SELECTED REFERENCES:

Dardeau 1981; Gray and Leiser 1982; Keown 1983; Keown et al. 1977; Schnick et al. 1982.

DESCRIPTION:

Ceramic materials are used as a substitute for riprap, or as a ceramic mattress constructed from slabs hinged together with erosion-resistant fasteners.

APPLICATION:

How

- Ceramic riprap is constructed from whole or broken ceramic blocks, or from slabs placed directly on the bank. Place a filter cloth between the bank and the ceramic riprap if the underlying bank material is likely to erode.
- Ceramic mattresses are constructed from slabs of ceramic hinged together with corrosion-resistant fasteners. The entire mattress is then placed onto the bank.

Where

- Ceramic riprap has been placed along the Ohio River, above Markland Dam.

ADVANTAGES:

- No Information.

LIMITATIONS:

- Ceramic materials have been used infrequently for streambank protection, and their effectiveness has not been evaluated.

RELATIVE COST:

- No Information.

SELECTED REFERENCES:

Keown et al. 1977.

DESCRIPTION:

Channel blocks are used to divert water away from a newly forming or recently abandoned channel by keeping the stream in the desired channel (old or new).

APPLICATION:

How

- Channel blocks are best constructed during low to normal streamflows.
- Channel blocks are constructed from a rectangular framework of logs and rock (similar to a crib), which is then anchored to the streambed at the mouth of the developing channel. The logs should be ≥6 inches in diameter, and the rock fill should be as large as can be conveniently handled. Riprap is then placed on the downstream side of the structure to prevent scouring. The structure should be lower than the adjacent bank to allow the passage of major floods through the secondary channel.
- Channel blocks can also be constructed from tree barricades. Tree barricades are constructed from trees anchored to the bank with cable, and then back filled with gravel from the streambed.

Where

- Channel blocks are used on small to medium sized streams.
- Tree barricades are particularly applicable where the conditions are not severe enough to warrant a stone-filled crib, or where the bank needing protection is very long.

ADVANTAGES:

- Channel blocks effectively direct streamflow into the desired channel.
- Unskilled labor can be used.
- Aquatic habitat may be enhanced by the deeper flows maintained in the main channel.

LIMITATIONS:

- Channel blocks are ineffective on large streams with large side channels.
- Tree barricades do not protect the bank as well as stone filled cribs during severe floods.
- Logs and rock must be economically available for construction.
- Logs placed above the water line must be periodically replaced as they deteriorate.

RELATIVE COST:

- No Information.

SELECTED REFERENCES:

Edminster et al. 1949; Pennsylvania Department of Environmental Resources 1986.

DESCRIPTION:

A clay blanket is a layer of impervious, compacted clay placed over erosive, cohesionless bank soils (e.g. sand). Clay blankets physically protect the bank by protecting the bank from the erosive streamflow.

APPLICATION:

How

- After removing the original top layer of soil from the bank, one or more layers of compacted clay is placed over the streambank. The clay should be free of plant growth, roots, and humus.
- To improve the esthetic appearance and structural intregrity of the bank, the clay blanket may be seeded and mulched to establish vegetation. The top soil may or may not be replaced over the clay blanket.

Where

- No Information.

ADVANTAGES:

- Clay blankets can be used _in situ_ to stabilize banks which have soils that are difficult to stabilize (e.g. sand).

LIMITATIONS:

- No Information.

RELATIVE COST:

- No Information.

SELECTED REFERENCES:

Dardeau 1981.

DESCRIPTION:

Articulated concrete mattresses are 4 ft wide by 25 ft long rectangular units composed of several smaller slabs of concrete held together by corrosion-resistant wire. Several of these rectangular units can be connected together forming a flexible mattress covering for the streambank.

APPLICATION:

How

- Shaping of submerged banks and mattress sinking should be conducted during low water.
- Several rectangular units are assembled on a barge, and then sunk in place.

Where

- Articulated concrete mattresses are only economically justified on large rivers because specialized construction equipment is required and the mattresses must be transported by truck or barge to the site.
- Used almost exclusively for underwater revetments on the lower Mississippi River.

ADVANTAGES:

- The mattress is capable of adjusting to irregularities in the bank and to scour pockets.
- Articulated concrete mattresses provide effective erosion control for banks subjected to excessive hydraulic flows, because of its weight and flexibility.

LIMITATIONS:

- Bank material may erode through the articulating joints, but the modified "V-type" mattress is much less susceptible to this problem.

RELATIVE COST:

- \$84 per 100 ft^2 (1976) average in-place cost, including bank preparation.
- \$260 (1978) to protect a linear foot of bank up to 3 ft above the sustained high water level for the Sacramento River, CA and its tributaries. Annual maintenance costs for a 50 yr project were estimated to be about \$19 per linear foot.

SELECTED REFERENCES:

Gray and Leiser 1982; Keown et al. 1977; Schnick et al. 1982.

STRUCTURAL
CONCRETE BLOCKS

DESCRIPTION:

Precast concrete blocks and recycled block (sidewalks, roadways, etc.) are used as a riprap substitute where suitable stone is not economically available or where salvaged blocks are readily available.

APPLICATION:

How

- Concrete block is precast whole, or constructed from broken concrete materials. The block is placed on the streambank using techniques similar to riprap.

Where

- No Information.

ADVANTAGES:

- No Information.

LIMITATIONS:

- Precast blocks generally cost more than riprap, since the blocks must be cast and then individually placed.

RELATIVE COST:

- No Information.

SELECTED REFERENCES:

Keown et al. 1977.

STRUCTURAL
CONCRETE PAVEMENT

DESCRIPTION:

Concrete pavement provides streambank stability by completely covering the bank with a layer of concrete.

APPLICATION:

How

- The bank is completely covered with a layer of concrete.

Where

- Concrete pavement is recommended for protecting banks along major alluvial rivers.
- Concrete pavement is used most often in heavily populated or industrialized areas where a large safety factor is required to protect banks, bridge abutments, and main-line levees.

ADVANTAGES:

- Provides a high degree of reliability over a long period of life with a minimum amount of maintenance.

LIMITATIONS:

- Generally an expensive method for protecting banks, because forms must be constructed and the concrete mix must be properly designed, batched, and cured.
- Scour may occur under the slabs if subsurface drainage is inadequate.
- Concrete may deteriorate, but this is usually not a problem.
- Banks completely covered with concrete may be considered esthetically displeasing and environmentally unacceptable.

RELATIVE COST:

- \$90 to \$125 per 100 ft^2 (1976) for in-place cost, including concrete pavement, bank preparation, and construction of forms.
- \$265 (1978) to protect a linear foot of bank up to 3 ft above the sustained high water level for the Sacramento River, CA and its tributaries.
- Annual maintenance costs for a 50 yr project were estimated to be about \$19 per linear foot (1978).

SELECTED REFERENCES:

Gray and Leiser 1982; Keown et al. 1977.

DESCRIPTION:

Cribs are open-framed structures constructed from timbers and then filled with soil or rock. Cribs protect the streambank by deflecting erosive currents away from the bank at low flows, and enhancing sediment deposition behind and downstream from the structure.

APPLICATION:

How

- Cribs are best constructed during low to normal water levels.
- Cribs are generally constructed in the shape of a 30-60-90° triangle, with the long side anchored to the bank and the short side facing downstream. If logs are used to construct the structure, they should be ≥6 inches in diameter and of durable wood. If rocks are used, they should be angular in shape and keyed 12-24 inches into the bank.
- When properly positioned, the crib should direct a float to the center of the channel. Flood flows should pass overtop the crib, but low flows should be deflected by the structure.

Where

- Cribs are used to divert water from an eroding bank, deepen a channel by increasing the velocity, or to enhance fish habitat.
- This method has been used primarily on smaller streams, and has only been used on a limited basis in the western United States.

ADVANTAGES:

- Cribs are an economical technique if the materials are locally available.
- Unskilled labor can be used.
- Cribs may effectively divert streamflow from an eroding bank, create meanders on small streams, deepen channels, remove silt (if two cribs are placed on opposite sides of the channel), and enhance aquatic life.

LIMITATIONS:

- Cribs may cause downstream scouring or erosion on the opposite bank if not properly constructed.
- Cribs are more expensive to build than simple riprap and are ineffective on banks with deep pools.
- Some skill is required to properly design a crib.
- Logs exposed above the water line may require periodic replacement.
- Some people may consider cribs esthetically displeasing.

STRUCTURAL
CRIBS OR CURRENT DEFLECTORS

RELATIVE COST:

- $80 (1976) to $200 (mid 1970's) to protect a linear foot of bank with a crib constructed from timbers.

SELECTED REFERENCES:

Binns 1986; Edminster et al. 1949; Gray and Leiser 1982; Keown et al. 1977; Pennsylvania Department of Environmental Resources 1986; Schnick et al. 1982.

DESCRIPTION:

Dikes promote bank stabilization by deflecting erosive currents away from the bank and by controlling the movement of bed material. There are two basic types of dikes: permeable and impermeable. Permeable dikes are usually constructed from timber piles and are designed to enhance sediment deposition behind the structrue by reducing the stream velocity as it passes through the dike. Impermeable dikes are usually constructed from stone and are designed to reduce the river width. Additional terms occasionally used to describe this same type of structure include: groins, jetties, sills, and spurs.

APPLICATION:

How

- Dikes extend (usually perpendicularly) into the channel past the point where the highest velocities occur. This moves the thalweg away from the eroding bank to an alignment controlled by the dike(s).
- The spacing/length ratio of the dike field is usually based upon the experience of the designer, and should direct the current away from the eroding bank.
- Timber pile dikes have been constructed of various designs using facing boards with horizontal bracing or as clumps of piles placed in single or multiple rows. The design selected is usually based upon the sediment load available.
- Stone dikes are constructed of various widths from quarried stone. The design selected depends upon the severity of expected flows, method of construction, and maintenance requirements.
- Earth core dikes are constructed from mounds of sand extending into the channel from the bank, and protected on the upstream face by a thin layer of stone.
- Vane dikes are constructed from stone or other suitable fill material. They are low-elevation, within-the-channel dikes, which direct the high velocity flows away from the bank and encourage sediment accumulation on the bank side of the dike. Water is allowed to flow around both ends and overtop the dike, which creates and preserves a shallow braided channel.

Where

- Dikes are recommended for bank protection on a variety of rivers ranging from low and high gradient tributaries to secondary alluvial rivers.
- Dikes are especially useful where the water adjacent to the bank is greater than four feet deep, and where the velocity next to the bank is too high for other techniques such as brush revetments.
- Permeable dikes are most effective on streams with heavy sediment loads, while impermeable dikes do not require as much sediment to protect banks.

STRUCTURAL
DIKES

ADVANTAGES:

- Dikes produce a narrower, deeper channel by constricting the streamflow.
- Dikes become more economical than riprap for bank protection as the water depth increases.

LIMITATIONS:

- Several dikes may be required to achieve proper bank protection, using just one dike usually causes more problems than it cures by creating destructive eddies.
- A professional engineer may be required to determe the most effective location and alignment for the dikes.
- For bank curvatures >30°, it is safer to use a continuous form of bank protection (e.g. riprap).
- Permeable dikes may have limited effectiveness on rivers with frequent rapid water level changes. Dikes become ineffective if they are overtopped by high water.

RELATIVE COST:

- Permeable dikes are usually less expensive than impermeable dikes, even though the maintenance costs are rather high.
- $38 (1988) to $75 (1975) per linear foot of dike.
- Pile board dikes cost from $40 to $55 per linear foot (1976).
- Timber pile dikes cost about $50 per linear foot (1976).
- Timber dikes cost about $75 per linear foot (1975).
- Untreated pile clumps cost from $1500 to $2300 (1976) per clump (three 60-ft piles per clump).
- Stone fill and vane dikes cost from $38 (1988) to $65 (1976) per linear foot.
- Earth core dikes cost about $63 per linear foot (1988).

SELECTED REFERENCES:

Edminster et al. 1949; Kautz 1969; Keown 1983; Keown et al. 1977; Remus 1988; Schnick et al. 1982.

DESCRIPTION:

Erosion-control mattings are blankets or netting supplied in rolls, applied in overlapping strips down the bank face, and then stapled to the ground. The structure of the matting is designed to allow vegetation to grow through the mat. This technique is usually considered a short-term method for bank protection, and is typically used to stabilize the bank until the natural vegetation becomes established. Erosion-control matting, using synthetic materials, has also been used occasionally to replace riprap.

APPLICATION:

How

- Erosion-control matting may be produced from a variety of materials including coconut fiber, jute, paper, wood shavings, nylon fiber, and fiber glass.
- The area should be seeded and fertilized prior to placement of the matting.
- The matting is generally installed by hand and secured to the bank with stakes or staples.
- Biodegradable matting, stakes, and staples are available which decompose, adding organic matter to the soil.

Where

- Erosion control matting can be used on a wide variety of stream channels ranging from low and high gradient tributaries to major alluvial rivers.
- Erosion control matting is recommended for upper bank protection, and may also be used to protect the lower banks on low-gradient tributaries.

ADVANTAGES:

- Provides immediate bank protection, allowing the vegetation time to become established and act as the permanent form of bank protection.
- Erosion-control matting provides all the benefits of mulches (e.g. increased infiltration and soil moisture, reduced runoff, added organic matter, and moderated soil temperatures). In addition, mattings are more stable and resistant to disturbance than mulches or chemical soil stabilizers.
- Erosion-control matting is easily placed by unskilled labor.
- Synthetic mats may provide a cost-effective non-degradable alternative to riprap.

LIMITATIONS:

- Erosion-control mattings provide only temporary bank protection (except some mats constructed from synthetic fibers), lasting only a few seasons.
- Inorganic mattings may hinder the mowing of re-established grasses, because the matting has a tendency to become tangled in the mower blades.
- Erosion-control mattings are expensive, and more labor intensive than similar soil stabilization techniques (e.g. mulches and chemical soil stabilizers).
- Probably not economical for large-scale projects where the banks are very steep and unstable, or where poor water management has caused confined streamflows.

RELATIVE COST:

- \$4.00 to \$7.25 per yd^2 (1981), including labor, materials, equipment, and grass seed.
- Materials cost from \$0.25 (1977) to \$0.65 (1976) per yd^2.
- Excelsior matting and staples cost from \$2,100 to \$2,760 (1984) per acre, and labor costs for anchoring were considered high. Between 32 to 55 person-hours were required to lay one acre of mat on 40-49% slopes.
- Jute netting and staples cost from \$2,830 to \$3,080 (1984) per acre, and labor costs for anchoring were considered high. About 48 person-hours were required to lay one acre of netting.
- Paper matting and staples cost from \$1,950 to \$2,850 (1984) per acre, and labor costs for anchoring were considered high. About 24 person-hours are required to lay one acre of mat.

SELECTED REFERENCES:

Keown et al. 1977; Long et al. 1984; North American Green 1986; Schnick et al. 1982; Wyoming Highway Department (date not available), 1987.

STRUCTURAL
FASCINE MATTRESSES

DESCRIPTION:

Fascine mattress are constructed from bundles of untreated brush, sticks, or timber tied together and then placed on the bank to be protected. Fascine mattresses differ from brush mat revetments in that they are bundles of material rather than losely placed brush. This method has been largely replaced by using live fascine mattresses (see Methods for Establishing Vegetation: live fascines).

APPLICATION:

How

- No Information.

Where

- This method has been used on the Lower Mississippi River.

ADVANTAGES:

- No Information.

LIMITATIONS:

- Requires an abundant supply of willow trees to construct the fascine mattresses.
- The design life for fascine mattresses may be limited by rot, especially on the upper banks where alternate wetting and drying may increase the rate of rot.

RELATIVE COST:

- No Information.

SELECTED REFERENCES:

Keown et al. 1977.

DESCRIPTION:

Fences are used to deflect the current away from the bank, and may be constructed either parallel to the bank or perpendicular to the bank. Fences constructed parallel to the bank are generally used as a temporary measure to allow sufficient time for the establishment of vegetation or to prevent bank sloughing. Perpendicular fences are used to promote sediment deposition, similar to dikes.

APPLICATION:

How

- Fences may be constructed from several different types of materials including treated or untreated wood, woven wire, used rails, pipe, steel beams, or concrete. Wood or wire is used most often to construct fences. The wood or wire facing should be placed on the channel side of the fence posts. The tensile strength of the wire depends upon the debris and the streamflow velocity. Field and welded wire are effective for medium and heavy loading, while chicken wire is acceptable for light loading.
- From 1/2 to 2/3 of the fence posts should be placed into the ground. On sandy bottoms, the posts should be placed at least 15 ft deep if 10-15 ft/sec streamflow velocities are expected. Posts should be spaced from 6 to 8 feet apart.
- Fences parallel to the streambank are often constructed in pairs, spaced 3 to 10 ft apart. Extra protection can be provided by stacking brush, hay, used tires, or rock between the fences.
- Fences perpendicular to the streambank are constructed so the debris is deflected downstream or is trapped. Streams with heavy debris should have the fence constructed so debris will float over the structure during high flows.
- Board fences with stone dikes are constructed by placing riprap perpendicular to the streamflow and then reinforcing it with treated wood piling to form the dike. A timber fence is then constructed on the channel side of the dikes and parallel to the streamflow. This technique deflects the streamflow away from the bank, and induces sedimentation between the fence and the bank.

Where

- Fences are used on low-gradient streams.
- Fences are normally used on the smaller streams, while jacks (see Structural: jacks and tetrahedrons) are used on the larger streams.
- Parallel fences are especially useful where the water depth next to the bank is greater than 3 to 4 feet.

STRUCTURAL
FENCES

ADVANTAGES:

- Fences are more economical than riprap or brush mats in deep water, because they eliminate the problem of constructing a stable foundation.
- Fences constructed parallel to the bank reduce streamflow velocity, encourage sediment deposition, and hold or create new bank alignment.
- Fences constructed perpendicular to the bank promote sediment deposition, and either deflect debris downstream (fences oriented downstream at an oblique angle) or trap debris (fences oriented upstream at an oblique angle).
- Simple construction using widely available materials makes this a commonly used method for bank protection.

LIMITATIONS:

- Fences are not considered to be one of the most effective techniques for protecting banks.
- They are easily damaged by ice flows or heavy flood debris, and therefore should not be used where these problems may occur.
- Channels must be wide enough to allow sediment deposition along the banks.
- Fences require periodic maintenance.

RELATIVE COST:

- $25 to $50 (1976) to protect a linear foot of bank with fences, if all new materials are used. This cost, however, can be substantially reduced by using secondhand or free materials commonly available in rural areas.
- Board fences with stone dikes cost from $34 to $49 per linear foot (1988).
- Board fence dikes (longitudinal revetments) cost about $150 per linear foot (1988).

SELECTED REFERENCES:

DeBano and Heede 1987; Kautz 1969; Keown 1983; Keown et al. 1977; Remus 1988; Schnick et al. 1982.

STRUCTURAL
GABIONS

DESCRIPTION:

Gabions are prefabricated cages or baskets constructed from wood, wire-mesh (most common), or cloth. The baskets are placed along the bank, and then filled with rock to form a structure which prevents erosive currents from contacting the bank.

APPLICATION:

How

- Gabions come in a variety of sizes and shapes, and can be wired into a variety of bank protection structures (e.g. bulkheads, weirs, jetties, deflectors, and mattresses). The gabion is usually constructed from galvanized steel wire, and may also be coated for protection from corrosive conditions.
- Gabions are best installed during low streamflows, so the structure can be properly keyed into the streambank.
- A support apron extending at least 6 ft past the toe of the gabion structure is first laid on the bank. The support apron is also constructed from gabion cages, and has a minimum height of 1.5 to 2 times the predicted depth of scour at the toe of the bank. The cages are wired to the support apron and to adjacent cages, then filled with stone.
- The stone fill should be slightly larger than the wire mesh, and should be able to physically withstand abrasion and freeze-thaw actions.
- A filter cloth placed between the bank and the gabion structure can be used to reduce excessive soil losses on erodible banks.
- Cuttings or seedlings can be used to enhance the appearance and durability of the structure.

Where

- Gabions are recommended for protecting banks on a variety of rivers, ranging from low and high gradient tributaries to secondary alluvial rivers.
- Gabions are used most often where locally available stone is too small to withstand flood flows, or where the bank is too steep.

ADVANTAGES:

- Gabions effectively stabilize banks, especially if they become vegetated.
- Gabion structures are somewhat flexible, so they can withstand minor changes in bank geometry.
- Gabions generally require less stone than riprap to protect a bank, and the stone can be of smaller size.
- Since gabions are porous, they allow the bank to drain, thus reducing the potential for bank failure caused by hydrostatic pressure.

- Unskilled labor can be used for the installation.
- Gabions in urban areas are impacted less by graffiti than channels lined with concrete or asphalt.

LIMITATIONS:

- Gabions cost more than riprap and they require extensive labor to construct.
- Skill is required to construct a gabion structure properly. The gabions must be tightly packed with proper-sized material or slumping will occur. If constructed improperly, gabions are expensive to rebuild.
- Rock fill must be economically available, and the structure is difficult to establish in deep water.
- Periodic maintenance may be required to maintain good bank protection, although gabions coated with PVC may last for several years (up to 75 years).
- In urban areas vandals may cut and remove the rocks from the gabions, and the wire used to tie the baskets together may be hazardous to bathers.
- Ice and heavy debris can tear the gabion, or break the wire coating.
- Gabions give the stream an "engineered" appearance if they are not vegetated.

RELATIVE COST:

- Gabion installation is in the medium range for bank stabilization structures, and costs 20% to 30% less than concrete pavement.
- $33 (1974) to $75 per cubic yard for rock filled gabion baskets, including gravel, bedding material, filter, and placement. The cost may be somewhat lower for very large projects near economical sources of stone.

SELECTED REFERENCES:

Binns 1986; Keown 1983; Keown et al. 1977; Klamm 1988; Pennsylvania Department of Environmental Resources 1986; Schnick et al. 1982; U.S. Soil Conservation Service 1975; Wyoming Highway Department 1987.

DESCRIPTION:

Grade-control structures reduce the potential for bank undermining along degrading streams, thereby maintaining bank stability. Log steps, trash collectors, and check dams are a few of the grade-control structures used to control the stream-channel gradient, and reduce the potential for scour or headcutting which undermines the bank slope.

APPLICATION:

How

- Grade-control structures are constructed from a variety of materials, depending upon their purpose and expected life. Larger projects are usually constructed from concrete, while smaller projects typically use simpler materials such as sand-cement bags, treated timber, gabions, or trash collectors.
- Grade-control structures are placed from bank-to-bank across the stream channel, usually with the central axis of the structure perpendicular to the flow. The structure must be properly keyed into the bank to prevent scour from eroding the downstream side of the structure.
- Log steps are constructed from logs placed across the stream channel, or more simply by naturally falling logs.
- Trash collectors are constructed from fence posts and wire strung across the channel to collect debris (trash) moving down stream. The collected debris helps to back-up the streamflow and form a grade-control structure. In some situations where the debris load is not sufficient, wire reinforced fabric can be substituted for the debris.

Where

- Check dams are generally used on smaller degrading streams, while massive concrete structures are generally used on larger streams.
- Log steps are most effective on small mountain streams.
- Trash collectors are used on narrow, incised stream channels which are usually less than 200 feet wide. Trash collectors can be used on wider streams if solid anchoring points exist for the structure.

ADVANTAGES:

- Grade control structures enhance the establishment of riparian plant communities by storing sediment, retaining water longer on the site, and reducing flow velocities.

STRUCTURAL
GRADE-CONTROL STRUCTURES (CHECK DAMS)

LIMITATIONS:

- The streambank immediately downstream from a check dam has a tendency to erode.
- Large structures are expensive to construct and require professional assistance.
- Structures built of logs will eventually rot.

RELATIVE COST:

- No Information.

SELECTED REFERENCES:

Dardeau 1981; DeBano and Heede 1987; Gray and Leiser 1982; Jones and Franklin 1988; Keown 1983.

DESCRIPTION:

Rigid or collapsible honeycomb material backfilled with soil shows promise as a new form of protection for either the upper or the lower bank. Erosion control is provided by the raised edges of the honeycomb.

APPLICATION:

How

- The honeycomb material is a three-dimensional, semi-rigid geomatrix made of non-woven polyester fabric. The hexagons form a honeycomb design with 8 inch sides and are 4 or 8 inches deep. Panels of the honeycomb are easily joined together with a commercial stapler.
- After the honeycomb mat is placed on the shaped bank, the honeycomb is filled with native soils, sand, gravel, fine rock, or other aggregate.

Where

- Honeycomb materials have been used successfully to line irrigation canals with flows ranging from 50 to 400 cfs, but turbulence at the higher flows may cause failures. A screen laid over the honeycomb might help to reduce failures due to turbulence.
- Both the upper and lower banks have been successfully protected by honeycomb materials.

ADVANTAGES:

- Honeycombs are permeable, lightweight and rot-proof, and are claimed to provide virtually permanent erosion protection.
- Honeycombs provide inexpensive bank protection when compared to concrete or riprap.
- Honeycomb revetments can be installed rapidly.

LIMITATIONS:

- This is a relatively new method which has not been extensively evaluated for its effectiveness as a streambank stabilization technique.
- Extremely turbulent flows may cause failures.

RELATIVE COST:

- Honeycomb materials cost about $5 per foot (1986) to install. A panel (140 yd^2) costs about $870.

SELECTED REFERENCES:

Anonymous 1987; Keown et al. 1977; Presto Products Incorporated 1985.

DESCRIPTION:

Jacks and tetrahedrons form permeable structures which protect the streambank by reducing the streamflow velocity. Jacks are constructed from three poles fastened together at their midpoints so they form a jack. Wire is then strung around the ends of the jack and the jacks are tied to each other with wire. Arrays of jacks placed parallel to the streamflow are called diversion lines, while arrays of jacks placed at an angle to the flow are called retard lines. The resulting system is called a Kellner jack field. This field is considered a "river training" aid, since the thalweg is moved by the field. Tetrahedrons are constructed and arranged in a manner similar to jacks, but are constructed from six cross members rather than three.

APPLICATION:

How

- Jacks may be constructed from a variety of materials including wood, angle iron, pipe, railroad rails, rebar, or concrete.
- Individual jacks are constructed from three cross members, while tetrahedrons are constructed from six.
- Poles 10 to 16 feet in length are commonly used to construct the jack. (Multiply stream depth by 1.4 to determine the exact pole length to use).
- Jacks should be spaced closely together, and the upper and lower ends of the string of jacks should be anchored with deadmen.

Where

- Jacks are recommended for protecting banks on a variety of rivers, ranging from the lower gradient tributaries to secondary alluvial rivers, but are not recommended for use in corrosive situations, where extremely high velocity flows are experienced, or where the banks are taller than the jacks.
- Jacks are commonly used in the southwestern and midwestern United States to protect wide, shallow, silt-laden streams which are subjected to severe scour during high flows.
- Jacks are normally used on the larger streams, while fences (see Structure: fences) are used on the smaller streams.

STRUCTURAL
JACKS AND TETRAHEDRONS

ADVANTAGES:

- Jacks are permeable, extremely flexible, and readily conform to the channel geometry.
- Streamflow velocities may be reduced from a peak of 5 fps to 0.50 - 0.25 fps in an effective jack field. Sediment deposition on the banks is enhanced by the reduced velocity.
- Jacks can remove debris, which improves the effectiveness of the field for sediment deposition.
- Vegetation usually becomes rapidly established in the deposited sediment behind the retard lines.
- The useful life of a properly constructed jack field constructed from railroad rails should exceed 50 years.
- Jacks have proven effective in locations were timber and riprap are not economically available, but scrap materials are.
- Tetrahedrons are more stable than jacks, because they have six cross members.

LIMITATIONS:

- The channel must be wide enough to allow deposition on the banks.
- Debris damage may require the replacement of some sections within the jack field.
- Jack fields are not esthetically harmonious with the floodplain landscape.
- Tetrahedrons are more expensive to construct than jacks, since they have six cross members.

RELATIVE COST:

- Steel jacks cost from $16 to $47 per linear foot (1976), depending upon the availability of materials. This cost includes the jacks, cable, deadmen, and labor.
- The cost per steel jack (1962) was determined to be $24 ($205,000/8500 jacks), plus about $0.15 per year for maintenance ($20,000 for 16 years / 8500 jacks).
- Concrete jacks cost from $30 to $40 per linear foot (early 1970's).

SELECTED REFERENCES:

DeBano and Heede 1987; Kautz 1969; Keown 1983; Keown et al. 1977; Schnick et al. 1982.

DESCRIPTION:

Polypods are precast concrete formed in various shapes (tetrapods, quadripods, tribars, and dolosse), and used for breakwaters, groins, revetments, and jetties. These structures interlock and have great mass, so they provide greater bank stability than stone of the same size. This technique has been used most often to protect the upper banks in tidal areas, but has also been used on a limited basis for streambank protection.

APPLICATION:

How

- Tetrapods are large precast concrete components consisting of four legs joined at a central block. Each leg of the tetrapod makes an angle of 109.5° with the other three. One tetrapod may weigh from 10 to 43 tons.
- Quadripods are shaped similar to tetrapods, except three of the legs are in one plane while the axis of the fourth leg is perpendicular to the plane of the other three legs.
- Tribars are constructed with three parallel legs attached to a base bar. One tribar may weigh from 35 to 50 tons.
- Dolosse are precast H-shaped units (dolos).
- Sta-pods are barrel-shaped, with four feet placed at 45° angles to the center portion. In areas subjected to severe wave action or scouring, the sta-pods must be placed on plastic filter material and stone.

Where

- Polypods have not been widely used for streambank protection.

ADVANTAGES:

- The mass and geometric configuration of polypods provides excellent protection from hydraulic forces.

LIMITATIONS:

- Polypods require a casting facility for fabrication and heavy equipment for placement.
- Transportation cost can be excessive if the polypods are constructed far from the placement site.

RELATIVE COST:

- 160 linear feet of beach can be covered with sta-pods in 3 hours by a small crew using a front-end loader.

SELECTED REFERENCES:

Keown et al. 1977; Schnick et al. 1982.

DESCRIPTION:

Riprap is course, angular stone placed on the streambank to provide erosion protection from moving water. When sufficient quantities of suitable stone are available, riprap is usually the preferred method for bank protection.

APPLICATION:

How

- Riprap is best applied at low streamflow.
- The bank is usually graded prior to riprap placement if the slope is irregular, or too steep. The slope should not be steeper than $1\frac{1}{2}$:1, and the pressure from the rock should be mainly against the bank rather than against the rock at the toe of the slope.
- A filter (gravel or porous synthetic cloth) should be placed between the bank and the riprap if the underlying bank material is likely to erode. This will allow seepage while still providing erosion control of the bank material.
- The shape, size, and weight of the stone must provide a layer of riprap which will withstand the velocity and debris impact from excessive flows. Angular stone is preferred over round stone. Stones weighing between 20 to 200 pounds generally provided good protection from streamflow velocities less than 10 fps. Slag, a by-product of iron ore smelting, can be used in place of rock to form riprap if a source of slag is near the site. The riprap blanket should be at least 1 to 1.5 times the maximum diameter of the largest stones, and keyed 3 feet into the streambed.
- Normally riprap is dumped from trucks on to the bank, but hand-placed stone is preferred where a more natural arrangement of stone is desired.
- Riprap must be properly terminated at the up and down stream ends, as well as at the toe. Placement should be along the entire length of the outside curve, otherwise bank scour may occur just down stream.
- Riprap may be used in conjunction with live cuttings.

Where

- Riprap can be used as an effective bank protection measure for a large variety of stream channels ranging from low and high gradient tributaries to major alluvial rivers.
- Riprap is not recommended for use on steep banks, but can be used to protect upper and lower banks elsewhere.
- In the arid West, riprap is normally used for bank protection in close proximity to valuable structures threatened by bank failure (e.g. bridges, and pipeline crossings)

STRUCTURAL
RIPRAP

ADVANTAGES:

- Riprap is one of the most effective methods for streambank protection if placed properly.
- Riprap is flexible, and its protection is not affected by slight changes in bank geometry caused by settling.
- Damage is easily repaired by the placement of more rock.
- Relatively simple construction and requires no special equipment.
- Riprap appears more natural than many other structural methods, and therefore may be more acceptable for use in recreational areas. In addition, sediment may eventually cover the riprap with soil, enhancing revegetation.
- Vegetation may grow in-between the rocks, providing a more natural appearance as well as restoring the natural roughness and adding to the structural value.
- Riprap may be recovered and stored for future use.
- Riprap provides substrate and cover for aquatic organisms.

LIMITATIONS:

- Riprap may be costly if stone of suitable quality and gradation is not available within 15 miles of the site.
- Straight forward design procedures have yet to be developed to meet every situation, but on-site experience and engineering manuals can provide design guidance.
- The stone must be large enough to withstand floods.
- Riprap may not be compatible with other land uses, and too much riprap can reduce habitat diversity for wildlife.

RELATIVE COST:

- $3.50 to $30 per cubic yard of stone riprap (1976), depending upon whether the stone is readily available or must be hauled long distances. These costs include bank preparation, bedding material, hauling, and placement.
- $25 to $30 per linear foot of bank protected by stone riprap, when the riprap is placed up to 10 ft high.

SELECTED REFERENCES:

Binns 1986; Brown 1986; Dardeau 1981; Jones and Franklin 1988; Kautz 1969; Keown et al. 1977; Klamm 1988; Pennsylvania Department of Environmental Resources 1986; Schnick et al. 1982; Wyoming Highway Department 1984b, 1987.

DESCRIPTION:

Rubble created by urban renewal projects and other redevelopment projects can be used as a substitute for stone riprap.

APPLICATION:

How

- Rubble consists of rough, irregular fragments of random-sized broken slabs of concrete, masonry, or other similar materials. Garbage, waste vegetation, scrap lumber, gypsum board, roofing, and metal refuge are not acceptable for use as rubble for streambank protection.
- Rubble can be used as a substitute for riprap as long as the gradation of the rubble is controlled, and the same design criteria for riprap are used.

Where

- Rubble may be used wherever riprap can be used.

ADVANTAGES:

- Rubble can provide excellent bank protection where minimal funds are available.

LIMITATIONS:

- Rubble is esthetically displeasing.
- Limited control over the size and material used for rubble may result in insufficient bank protection or water pollution.

RELATIVE COST:

- Low cost when compared to riprap, if the proper-sized materials are available.

SELECTED REFERENCES:

Brown 1986; Keown 1983; Keown et al. 1977.

DESCRIPTION:

Sacks filled with soil, soil-cement, sand, or sand-cement mixtures have been used for many years as bank protection around hydraulic structures and for the emergency protection of levees and streambanks during floods. Sack revetments are also used where other bank protection measures (e.g. riprap) are not available or economically feasible. See also Synthetic Mattresses, Matting, and Tubing.

APPLICATION:

How

- Sacks may be constructed from burlap, paper, or nylon.
- Sack revetments are generally used on bank slopes $\leq$1:1.
- The individual sacks are stacked on the bank and allowed to conform to the bank geometry. Normally the sacks are placed in horizontal rows, with each successive row stepped back about half a bag width. A cement-mix fill can be used to help bond the sacks to each other after they have been wetted, forming a pavement over the bank.
- For permanent placement, a mixture of at least 15% cement and 85% sand should be used for fill. Since cement sacks form an impervious revetment, weepholes (openings) should be integrated into the revetment so hydrostatic pressure buildup will not damage the revetment.

Where

- No Information.

ADVANTAGES:

- Where suitable stone is not economically available, on-site construction of sand-cement bags can be an effective alternative method for bank protection.
- Sacks filled with sand-cement mixtures can provide lasting bank protection if the cement sets properly.

LIMITATIONS:

- Since the burlap bag eventually deteriorates, only soil-cement or sand-cement filled bags provide long-term bank protection.
- Sack revetments are not economically competitive with riprap in areas where suitable stone is available.

RELATIVE COST:

- $305 to $310 (1978) to protect a linear foot of bank up to 3 ft above the sustained high water level for the Sacramento River, CA and its tributaries. Annual maintenance costs for a 50 yr project were estimated to be about $23 per linear foot.

SELECTED REFERENCES:

Dardeau 1981; Gray and Leiser 1982; Keown 1983; Keown et al. 1977.

DESCRIPTION:

Soil mixed with cement is used to form a protective pavement over the bank. Soil-cement blocks have also been used to a lesser extent as a substitute for riprap.

APPLICATION:

How

- Bank soil is mixed with 8 to 15% portland cement and then compacted to provide a stable soil surface.
- A bank drainage system should be designed into the project so hydrostatic pressure buildup will not damage the revetment.
- Blocks of soil cement are constructed from soil cement laid in the vicinity of the bank to be protected. The soil cement is then cut or broken into blocks and placed on the streambank.

Where

- Soil cement has been used primarily on the upper banks, and to a much lesser extent on the lower banks.

ADVANTAGES:

- Soil cement is easy to apply, relatively inexpensive, and the materials are readily available.
- Soil cement is an economical and effective bank stabilization technique if vegetation is difficult to establish and the bank is composed mostly of sand.
- Outperforms riprap during large floods, and could potentially be used as a substitute for riprap where suitable stone is not economically available.

LIMITATIONS:

- Soil cement is not flexible, so it can not adjust to changes in bank geometry and can not be used where traffic is expected.
- The low permeability of soil cement precludes its use where the bank must drain to maintain stability.
- The effectiveness of soil-cement blocks has not been adequately evaluated.

RELATIVE COST:

- $210 to $220 (1978) to protect a linear foot of bank up to 3 ft above the sustained high water level for the Sacramento River, CA and its tributaries. Annual maintenance costs for a 50 yr project were estimated to be about $16 per linear foot.

SELECTED REFERENCES:

Dardeau 1981; Gray and Leiser 1982; Keown 1983; Keown et al. 1977; Schnick et al. 1982; Wacker 1988; Wyoming Highway Department 1984a, 1987.

DESCRIPTION:

Soil stabilization reduces the potential for bank erosion by increasing the stability of the soil surface. Several techniques are available to increase the stability of the soil including chemicals, fiber glass, and lime.

APPLICATION:

How

- Many methods for improving the stability of the soil (bank) surface have been used. The following methods are discussed in their own section: uncompacted asphalt paving, soil cement, temperature control, and vegetation. The remaining methods used for soil stabilization are discussed in this section, and are not used as frequently to stabilize streambanks as the previously mentioned techniques.
- Chemicals (e.g. acetates, resins, and latexes) can be used to increase the cohesiveness of the soil, and shift the particle-size distribution to coarser fractions.
- Fiber glass sprayed on to the bank using compressed air can be used to coat the bank with fine strands of fiber glass. The fine strands of fiber glass form a protective web over the bank, which helps to control bank erosion.
- Lime (CaO) mixed with the streambank soil forms a hydrophobic or water-resistant layer which resists erosive streamflows. Both clays and silts can be mixed with lime to stabilize the soil. A thin layer of topsoil can be placed over the soil-lime mixture if the growth of vegetation is desired.

Where

- Lime soil stabilization has been used both on the upper and the lower bank.

ADVANTAGES:

- Chemical soil stabilizers reduce sediment production, preserve top soil, and help to achieve a more environmentally acceptable condition after construction is completed.
- Materials for chemical stabilizers are fairly inexpensive and are easily applied.
- Fiber glass soil stabilization provides a chemically inert coating over the bank surface which stabilizes the soil until vegetation becomes established.

LIMITATIONS:

- Professional assistance is required to properly protect a streambank with lime.
- Many soil stabilizers are more effective on soils subjected to sheet flow, rather than concentrated flow.
- A method for choosing the most durable and applicable chemical soil stabilizer for protecting streambanks has not been fully developed.

RELATIVE COST:

- Chemical stabilizers cost from $157 to $242 per acre (1979), including materials only. Expenses for application should be minor since the stabilizers are easily applied.
- Elastomeric polymers cost from $300 to $750 per acre (1977) installed.
- Other types of chemical stabilizers tested cost from $0.41 to $17.50 per square yard (1977).

SELECTED REFERENCES:

Dardeau 1981; Keown 1983; Long et al. 1984; Schnick et al. 1982.

DESCRIPTION:

Synthetic mattresses are formed from semiflexible casings filled with grout or sand and placed on the streambank for erosion protection. Synthetic materials offers longer term protection than burlap filled sacks.

APPLICATION:

How

- Synthetic casings are filled in place or on the bank with locally available sand.
- Most synthetic mattress are constructed from a variety of long tubes ranging from 28 to 69 inches in diameter. The tubes can be sewn together as well as to the filter fabric, forming one integrated unit.
- Many trade names are applied to the various forms of synthetic mattresses available.

Where

- This method has been used to protect the upper banks in tidal areas, and is now being used to protect streambanks where sand is available.
- One brand (Fabriform) has withstood streamflow velocities ranging from 13 to 18 fps.

ADVANTAGES:

- Synthetic mattresses can be used in areas where suitable stone for riprap is not economically available, but a cheap source of sand or soil is.
- Adjusts to minor shifting in bank geometry.
- Installation can be done quickly with a minimum of crew and equipment. A five or six person crew can average 5,000 ft^2 per 8 hour shift, with only a pickup truck, a grout pump and hose, and a small portable sewing machine.

LIMITATIONS:

- Some synthetic mattresses are not designed to protect against continuous wave action and streamflow, so their use should be restricted to the upper bank.

RELATIVE COST:

- 5,000 ft^2 can be installed in 40 to 50 person-hours, with minimal equipment.
- Longard tubes and giant sandbags can be installed for $25 (mid 1970's) to $80 (1978) per linear foot of bank.
- $235 to $250 (1978) to protect a linear foot of bank up to 3 ft above the sustained high water level for the Sacramento River, CA. Annual maintenance costs for a 50 yr project were estimated to be about $18 per linear foot.

SELECTED REFERENCES:

Gray and Leiser 1982; Keown et al. 1977; Schnick et al. 1982.

DESCRIPTION:

Temperature control may be used to stabilize the streambank in situ by freezing or fusion. Only limited experiments have been conducted to determine the feasibility of this method of bank protection.

APPLICATION:

How

- In polar climates, freeze probes have been inserted into the bank during the summer months to prevent the bank from thawing.
- In warmer climates, heat has been used to increase the strength and resistance of the bank soil to erosion.

Where

- Freeze probes have only been used in polar locations where stone is not available, and the bank must be stabilized (e.g. near structures or property).

ADVANTAGES:

- No Information.

LIMITATIONS:

- Freeze probes are expensive to install and operate, and can only function properly in polar climates.
- Expensive fuels must be used for heat stabilization of soils, and this process may have limited potential for effective bank stabilization.

RELATIVE COST:

- No Information.

SELECTED REFERENCES:

Keown et al. 1977.

DESCRIPTION:

Whole trees cabled together and anchored by deadmen buried into the bank are used to form a pervious revetment which protects the streambank from erosion. This may be one of the cheapest forms of semi-permanent protection, at least with respect to materials.

APPLICATION:

How

- Trees with at least a 12 inch diameter trunk provide the best protection, but require heavy equipment for installation. Smaller diameter trees (≤6 inch diameter) can be used on smaller streams, and can be placed by hand.
- Bushy top trees are best (conifer trees are preferred). A variation of the tree revetment, called log and cable, has a very similar design except the tree tops are removed so logs are used instead of whole trees.
- Use green trees, since limb loss will be less during installation.
- Lay trees along the bank, butts upstream, so that the trees overlap from one-third to one-half their lengths.
- Anchor the trunks to a deadman or a pile driven well below the point of maximum bed scour. Rock can be placed with the trees to help prevent bank scour behind the trees.
- Willow cuttings planted prior to revetment placement are often successful.
- An alternative method for using trees to stabilize banks would be to place the trees perpendicular to the bank. When constructed this way, the tress function similar to a permeable dike.

Where

- Medium to large streams, because channel capacity will be reduced by the placement of trees.
- Tree revetments are especially useful in streams with a heavy sediment load, because the trees enhance sediment deposition.
- Tree revetments work well where the water at the toe of the bank is deep.

ADVANTAGES:

- Relatively low cost for a semi-permanent form of streambank protection.
- This form of pervious revetment enhances sediment deposition, which prolongs the life of the treatment.
- Mean water velocities adjacent to the bank can be reduced to between 66-73% by tree revetments.
- Can improve habitat conditions for aquatic organisms.

STRUCTURAL
TREE REVETMENTS

LIMITATIONS:

- Trees need to be replaced periodically, requiring constant maintenance and inspection.
- Tree revetments may not effectively stabilize the outside curve of meanders, since most tree revetment failures occur there. Structural treatments should be considered for stabilizing outside curves.
- Heavy ice flows may cause severe damage.
- Channel width may be narrowed, which may be undesirable on some streams because it reduces the carrying capacity of the channel.
- The life of the revetment depends upon the size of the trees used, the cable strength, and the stability of the deadmen.

RELATIVE COST:

- $8 to protect a linear foot of bank with a tree revetment, including trees, cable, clamps, anchors, and placement; plus an additional $20 per cubic yard of rock riprap required to tie down the tree revetment.
- $20 (1980) to protect a linear foot of bank with a tree retard (perpendicular to bank), if trees are readily available.
- 450 work days were required to treat 1,500 yards of eroded bank.

SELECTED REFERENCES:

Binns 1986; Edminster et al. 1949; Kautz 1969; Keown et al. 1977; Klamm 1988; Schnick et al. 1982; Sheeter and Claire 1981.

DESCRIPTION:

Windrow and trench-fill revetments are placed in anticipation of a bank failure or the encroachment of an undercut bank. Stone is placed on the bank adjacent to the eroding area, but does not provide bank protection until the eroding bank reaches the stone. After the stone has been undercut, it forms a riprap armor.

APPLICATION:

How

- Stone, concrete, or ceramic materials may be used to construct these revetments.
- Windrow revetments are constructed by placing a row of stone (windrow) immediately adjacent and parallel to the general alignment of the eroding bank. Eventually the windrow may be undercut by the eroding bank, causing the stone to be launched down the bank and act as armor.
- Trench-fill revetments are constructed by placing stone in a trench dug behind and parallel to the eroding bank. Eventually the erosive action of the stream may cut into the bank and reach the trench. Material placed in the trench will then retard further erosion.

Where

- Windrow and trench-fill revetments can be used to protect mild channel bends where the toe of the bank is undercutting.

ADVANTAGES:

- If the bank becomes stabilized before the stone is undercut, the stone can be recovered and used at another location.
- Windrow and trench-fill revetments can provide effective temporary or emergency bank protection.

LIMITATIONS:

- No Information.

RELATIVE COST:

- $84 to $103 (1988) to protect a linear foot of bank.

SELECTED REFERENCES:

Brown 1986; Dardeau 1981; Keown et al. 1977; Remus 1988.

STRUCTURAL
VEGETATION (HAY BALE) MATTRESS

DESCRIPTION:

Vegetation mattresses are formed by fastening vegetative materials, such as hay bales, together to form a protective mattress. The mattress is then anchored to the bank.

APPLICATION:

How

- Large rectangular hay bales (≈8x4x4 ft) are placed into a flat, 4 ft wide trench dug along the eroding bank. A backhoe is used to dig the trench, set the bales, and pack the bales firmly into place. Two layers of bales, with their seams off-set, should be used where the bank height is >4 ft.

Where

- Large rectangular hay bales have been used on the Upper Green River and the Bear River in Wyoming.

ADVANTAGES:

- Hay bales should encourage bank revegetation.
- Large hay bales on the Green River are into their third year and are doing well.

LIMITATIONS:

- This method of streambank protection has had only limited use, so its effectiveness has not been evaluated.

RELATIVE COST:

- $20 to $30 (1988) to protect a linear foot of bank on the Bear River. 700 ft of bank took two days with a crew of ≈5 and 2 pieces of heavy equipment.

SELECTED REFERENCES:

Dardeau 1981; T.A. Wesche and Q.D. Skinner, personal communication.

STREAMBANK STABILIZATION TECHNIQUES:

NON-STRUCTURAL

DESCRIPTION:

Proper beaver management reduces the potential for bank undermining along degrading streams, thereby maintaining bank stability. A beaver dam protects the streambank the same way a grade-control structure (check dam) does.

APPLICATION:

How

- Beavers can be relocated from over populated areas to streams requiring bank stability.
- Sufficient food and building materials must be present prior to beaver relocation, or supplied on a regular basis. Livestock may need to be excluded by fencing, to encourage the re-establishment of willows and other vegetation.

Where

- Beaver management for controlling streambank erosion can only be successful where beavers are able to build dams (e.g. the smaller mountain streams). In western Montana beaver ponds are most successful on fourth order and smaller streams, and channel gradients <4%.

ADVANTAGES:

- Beaver dams may improve bank stability by decreasing streamflow velocity, spreading flood water over a wider area, enhancing sediment deposition, and decreasing peak flows by storing water.
- Beaver dams help to improve the riparian zone by reducing bank erosion, and by raising the water table.

LIMITATIONS:

- Beavers may be difficult or impossible to establish at new locations where bank stabilization is desired.
- Building materials for dam construction and food (e.g. aspen or willow) must be supplied if a source is not readily available.
- Effective beaver management may require human assistance.
- Beavers may completely remove nearby aspen and willow stands.
- Beaver dams frequently collapse due to poor construction and/or maintenance. A failure upstream may cause multiple beaver dam failures downstream.
- Bank erosion may occur at the dam site itself or immediately downstream.

RELATIVE COST:

- Beaver management costs are not available, but should include trapping, transportation, and periodically providing building materials and dam reinforcement.

SELECTED REFERENCES:

Apple 1985; Bartlett and Bartlett 1974; DeBano and Heede 1987; Jones and Franklin 1988; Medin and Torquemada 1988; Munther 1982; Platts et al. 1987.

DESCRIPTION:

Channel clearing and snagging is normally one of the first steps used to prevent or reduce bank erosion. Objects in the channel such as sediment bars, snags, stumps, debris drifts, or trees may direct the streamflow towards an unstable bank. Once these objects have been removed, the bank may stabilize itself without further intervention.

APPLICATION:

How

- Remove large trees which are in danger of being undercut and falling into the channel, or which might collect debris along the bank.
- Brush and grasses are generally left for bank protection.

Where

- No Information.

ADVANTAGES:

- Channel clearing and snagging may promote more uniform water depths and improve the conveyance efficiency of the stream.

LIMITATIONS:

- Extensive removal of streambank vegetation and instream obstructions may destabilize the stream channel and its banks.
- Aquatic habitat diversity may be reduced.

RELATIVE COST:

- No Information.

SELECTED REFERENCES:

Kautz 1969; Schnick et al. 1982.

DESCRIPTION:

Grazing management is a technique used to stabilize streambanks by altering the level of wildlife or livestock grazing and trampling on the bank. Grazing removes the protective cover of vegetation, and trampling physically disturbs the bank stability. Several strategies are available for altering the level of trampling on streambanks including fencing, herding, and grazing systems.

APPLICATION:

How

- Fences may be required to exclude livestock or wildlife from unstable streambanks until the vegetation can provide adequate bank protection. Research has shown that fencing and protection from grazing can rehabilitate and enhance streambanks.
- Preferred areas, such as streambanks, are more heavily grazed than the adjacent uplands. The grazing system, therefore, should be based upon the wildlife or livestock actually using the streambanks and not upon the entire pasture. For example, in Montana cattle primarily use the uplands during June and July and then primarily use the streambank area from late July through early October.
- The grazing system should also account for periods when the banks are most susceptible to damage by trampling. Bank susceptibility to trampling is more a function of bank moisture content, than the number of cattle using the area. Banks are most susceptible to trampling when the soil moisture content exceeds approximately 10%. When the banks are frozen, however, trampling has little effect on bank stability.

Where

- Fencing is used where exclusion from grazing will allow the natural vegetation to become re-established, and where sediment deposition can be enhanced by the re-established vegetative cover.

ADVANTAGES:

- Proper grazing management provides long-term streambank protection, healthier riparian vegetation, reduces downstream flood protection costs, and may increase streambank storage of water.
- Careful timing and management of livestock grazing on streambanks has the potential to change streambanks from steep to more rounded.

LIMITATIONS:

- Fencing is costly and may be detrimental to wildlife.
- Proper grazing management requires more on-the-ground management of wildlife and livestock.

RELATIVE COST:

- $7,000 (1988) per fence mile in Wyoming. The annual maintenance costs are variable.
- $6,000 (1984) per stream mile, both sides fenced with 4 wires. The annual maintenance costs range from $60 to $200 per stream mile.

SELECTED REFERENCES:

Edminster et al. 1949; Jones and Franklin 1988; Marlow 1985; Marlow and Pogacnik 1985; Platts and Nelson 1985; Platts and Raleigh 1984; Platts and Rinne 1985; Platts and Wagstaff 1984; Siekert et al. 1985; Skovlin 1984.

DESCRIPTION:

Vegetation plays an important role in the long-term stability of a stream bank. Plants may be used alone, or in combination with other streambank stabilization techniques. The aerial portions of the plants (stems and branches) protect the streambank from fast-moving water and transported materials, while the roots improve the structural integrity of the bank. In addition, plants help to stabilize banks by removing water from the bank through the evapo-transpiration process. Grasses require less time to become established than woody species, but grasses may provide less protection during high-velocity flows because the woody species generally have more extensive root systems.

APPLICATION:

How

- Revegetated banks should not have slopes greater than 1:1.
- Banks should not be reshaped if the existing plant cover has the potential to stabilize the site. If the banks are to be reshaped, however, the top soil should be stockpiled; then replaced to a depth of 4 inches.
- The optimum buffer-zone width for streambank vegetation needs to be tested in a variety of diverse watersheds. One suggestion, however, is that buffer zones should be at least as wide as the stream channel for the larger streams, and never less than 15 ft wide on each bank for the smaller streams.
- Locally adapted species suitable for protecting streambanks should be used. When selecting plant species for bank protection consider the climate, precipitation (total and distribution), soil type, soil depth, soil moisture, soil temperature, bank slope, expected flow rate, seed or stock availability, ease of establishment, growth habits, plant cover, and persistence after establishment.
- Plant communities are more desirable than a monoculture for streambank protection.
- Plants must be stored and handled properly to assure healthy plantings.
- Plant used to stabilize the lower bank are best established by transplanting (e.g. sprigging and reed rolls), since water will carry off the seeds.
- Planting vegetation in combination with temporary bank stabilization measures such as mulches, soil stabilizers and erosion control matting may help to improve the rate of plant establishment.
- Protection from grazing may be necessary to help establish and perpetuate the stand.
- Structural bank stabilization techniques may be required to stabilize critical areas, rather than using vegetation alone to stabilize banks.

- The site should be monitored for at least three years after the vegetation has been planted. Monitoring is used to verify that the vegetation has become established, and that it is protecting the streambank from erosion. Follow-up plantings may be required if flooding occurs before adequate plant establishment.
- Establishing woody plants at the toe of the bank and grasses on the slope has proven to be a good method of bank protection where scour is a problem.

Where

- Vegetation is recommended for bank protection along a wide variety of rivers ranging from low and high gradient tributaries to major alluvial rivers.
- Vegetation is most successful above the normal water line, and should be considered for protecting any bank that is not subjected to frequent inundation. Lower banks may also be protected by vegetation (e.g. cattails and bulrushes), but plant establishment may be difficult.
- Vegetation should be planted behind revetments and jetties in the area where silt deposition will occur.

ADVANTAGES:

- In many cases, vegetation is the most economical, esthetically pleasing, and least complex method of bank protection.
- Vegetation is the only self-renewable method of bank protection. Repair and maintenance of vegetation is natural and requires little or no cost once established.
- Streambank vegetation traps silt, helps to regulate water temperature and discharge, and provides shelter and food for fish and wildlife.
- Streambank vegetation is preferable as a final product over structural materials since vegetation utilizes dissolved nutrients, thereby providing a net reduction in the eutrophication potential in downstream impoundments.
- Banks with dense meadow grass and scrub willow roots (16-18% roots by volume) are as much as 20,000 times more resistant to erosion than comparable bank soils without vegetation along some glacial meltwater rivers in Canada.

LIMITATIONS:

- Establishment of a protective stand may be difficult or impossible (e.g. arid climates), and the degree of bank protection provided by the plants may be limited at first.
- Streams subject to high flow velocities and steep banks are not effectively protected by vegetation alone.
- Stabilizing the bank below the normal water line may be difficult, resulting in undercut and sloughing banks.
- Vegetation may dislodge riprap and create pathways for eroding currents to undermine a revetment.

- Although no levee failure has ever been directly attributed to the existence of riparian vegetation on levee slopes, vegetation can inhibit the efficient inspection of levees for potential failure sites.
- Wildlife and livestock grazing must be excluded from the banks at least until the vegetation becomes established.
- Vegetation has not been highly effective for protecting streambanks on some of the larger rivers (e.g. Colorado River).

RELATIVE COST:

- Costs vary with the number of plants, availability of species and seed, method of propagation, nursery over head, etc. Transportation costs are usually about 20% of the plant costs.
- $500 to $650 per acre (1976) to plant grasses, including soil preparation and fertilizer.
- ≈$1500 to $1950 per acre (1976) to plant woody vegetation and grasses together, including soil preparation and fertilizer.

SELECTED REFERENCES:

Binns 1986; Carter and Anderson 1984; Fanning 1989; Gray and Leiser 1982; Haslam 1978; Kautz 1969; Keown 1983; Keown et al. 1977; Logan 1979a; Logan 1979b; McKown and Rinne 1988; Monsen 1983; Platts et al. 1987; Schnick et al. 1982; Schiechtl 1980; Seibert 1968; Smith 1976; Temple et al. 1987; Thorne and Osman 1988; Wyoming Highway Department 1987.

DESCRIPTION:

Grasses and other herbaceous vegetation provide streambank protection by reducing the streamflow velocity at the boundary layer between the water and the soil, and by reinforcing the soil to the depth of the root system. The protection provided by these plants is directly related to their length, width, and density of blades (leaves), the aerial density of the plants, and the depth of the root system. Potential grass, grasslike, and broadleaf forb species for stabilizing streambanks are listed in Tables 1-3. Additional references on the flooding tolerance of these species are: Whitlow and Harris 1979; Stevens and Waring 1985; Lester et al. 1986.

APPLICATION:

How

- Species selection should consider the length of growing season, soil and air temperature, total and seasonal distribution of rainfall, flood tolerance, soil type and ability to provide moisture during dry periods, bank slope, life cycle (e.g. annual or perennial), seedling vigor and establishment, time required for establishment of a stand, physical characteristics of species (e.g. stem length, number of stems, root density, and stiffness), and availability of seed or transplants. "Tame grasses" (e.g. reed canary grass, foxtail, and kentucky bluegrass) can be obtained from commercial seed lots. "Natively adapted species" (e.g. western wheatgrass, little bluestem, and big bluestem) should be obtained from a source within a 200 mile radius of the site if possible.
- Plants with heavy root systems are preferred for streambank protection.
- Grasses should not be planted on a bank slope steeper than 4:1.
- Seeding date depends upon the streamflow conditions and the climate. If the area is subject to spring flooding, then seed should be planted after spring run-off or in the fall. Otherwise, consider planting when the maximum seedling establishment will be expected.
- Grasses can be planted by sodding, sprigging, or by mechanical broadcasting (hydro seeding) of mulches consisting of seed, fertilizer, and other organic mixtures. On slopes steeper than 1:1, Hydro seeding is most effective. Where the streamflow is expected to directly affect the bank, sodding is recommended, otherwise direct seeding methods can be used.
- Direct seeding of herbaceous plants is generally more successful if applied after late fall (15 October in North Dakota).

- Fertilizers can be incorporated into the hydro seeding mixture, or applied in the late fall at a rate of ≤15 lbs/ac of available nitrogen (N) so excessive salts will not build-up. Using fertilizer with a high phosphate content is encouraged. Follow-up applications of fertilizer will promote heavier grass cover if applied late in the fall or early spring at a rate of 40-50 lbs/ac of available nitrogen (N). Maintenance treatments of fertilizer may be necessary every 2-5 years.

Where

- Grasses have proven to be an excellent deterrent to soil erosion above the mean high-water line on bank slopes, and in the back-water areas where soil erosion results from alternate wetting and drying as well as wind.

ADVANTAGES:

- Streamflow velocity at the boundary layer between water and soil can be reduced as much as 90% by a well established stand of selected grasses.

LIMITATIONS:

- Several months, or even years, may be required before an erosion resistant stand becomes established.
- Competition from other plants (e.g. weeds or woody vegetation) may reduce the effectiveness of the stand.
- Some feel that grasses alone are not sufficient to protect streambanks (usually eastern states). They believe that woody plants provide a better root structure for stabilizing streambanks than do grasses.

RELATIVE COST:

- $500 to $650 per acre (1976) to plant grasses, including soil preparation and fertilizer.
- $250 per acre (1988) to broadcast seed in Wyoming.

SELECTED REFERENCES:

Jones and Franklin 1988; Keown et al. 1977; Logan 1979b; Long et al. 1984; Platts et al. 1987; Schnick et al. 1982; U.S. Soil Conservation Service 1983.

Table 1. Potential grass species for stabilizing streambanks and their characteristics (after Platts et al. 1987).

Species	Origin	Zones of Adaptation[1]	Bank Position[2]	Method of Planting[3]	Growth Rate	Salinity Tolerance[4]	Comments	References[5]
Agropyron cristatum or *Agropyron desertorum* Crested wheatgrass	Introduced	Silty clays esp. sands	U	S	Slow	MT	Bunch, deeply rooted, cool season grass, can be planted on exposed or prepared sand and gravel banks.	2,3,6,10, 12,13
Agropyron elongatum Tall wheatgrass	Introduced	Mtn.B.-V	M	S(E),T(G)	Rapid	MT	Large clump, deeply rooted, spreads good, cool season grass.	1,5,6,10, 12,13
Agropyron intermedium Intermediate wheatgrass	Introduced	≤3000 m	M-U	S	-	MT	Rhizomatous, deeply rooted, sod forming, grows on a variety of soils, can be planted on exposed or prepared sand and gravel banks, tolerates 3-5 weeks of early spring flooding, water table=3 ft.	2,3,6,12, 13
Agropyron repens Quackgrass	Introduced	Asp.-V	M	S(F),T(E)	Slow	MT	Rhizomatous, spreads excellent, Weed - not for sale in some states.	1,2,12
Agropyron riparium Streambank wheatgrass	Native	Mtn.B.-Sage	U	S,T	-	-	Rhizomatous, tolerates temporary flooding.	2,4,5,12
Agropyron smithii Western wheatgrass	Native	PP-SDS	U-M	S(P),T(E)	Slow	MS	Rhizomatous, sod forming, spreads good, grows on a variety of soils, should be planted on prepared seed beds, cool season grass, tolerates winter flooding.	1,6,10,12, 13
Agropyron trachycaulum Slender wheatgrass	Native	SF-PJ	M-U	S(E),T(E)	Rapid	MS	Rhizomatous, spreads good, can be planted on exposed or prepared sand and gravel banks.	1,5,10,12
Agrostis stolonifera Redtop	Introduced	Salp.-SF	M-U	S(F),T(G)	Moderate	MS	Rhizomatous, roots 30 (60) cm deep, spreads excellent.	1,2,5,12, 13
Alopecurus arundinaceus Creeping foxtail	Introduced	Alp.-Mtn.B	M	S,T	Slow	MT-T	Rhizomatous, sod forming, flood tolerant, cool season grass, sprigs do better than seeds on saline soils.	2,3,6,11

Table 1. (Continued)

Alopecurus pratensis Meadow foxtail	Introduced	Alp.-Mtn.B	M	S(E),T(G)	Rapid	MT	Rhizomatous, spreads excellent, flood tolerant, can be planted on exposed sand and gravel banks.	1,5,10,12
Andropogon gerardi Big bluestem	Native	PP-SP	U-M	S(F),T(F)	Slow	MT	Rhizomatous, roots to 10 cm deep, sod forming, sandy soils, fertile soils and south facing slopes in eastern Wyoming, warm season grass.	2,3,6,12,13
Andropogon hallii Sand bluestem	Native	Low elev.	U	S(F),T(G)	Moderate	-	Rhizomatous, sod forming, sandy soils, warm season grass.	3,6,12
Andropogon scoparius Little bluestem	Native	Low elev.	U	S(G),T(G)	Fast	MS	Bunch, sandy to silty-clay soils, warm season grass.	2,3,6,12,13
Avena sativa Oats	Introduced	-	M-U	S	-	-	Annual, provides temporary cover, requires mild winters.	6
Bothriochloa caucasica Caucasian bluestem	Introduced	-	M-U	S(G)	Fast	MT	Bunch, warm season grass, silty-clay soils.	6,13
Bothriochloa ischaemum Yellow bluestem	Introduced	-	M-U	S(G)	Fast	-	Bunch, silty-clay soils, considerable variation within the species.	6
Bouteloua curtipendula Sideoats grama	Native	≤8,000 ft	U	S(G),T(G)	Fast	MS-MT	Rhizomatous, sandy to silty-clay soils, warm season grass.	3,6,12,13
Bouteloua gracilis Blue grama	Native	SP	U	S(F)	Slow	MT	Tufted, sod forming, warm season grass.	3,6,13
Bromus carinatus Mountain brome	Native	Alp.-PJ	M	S(E),T(E)	Rapid	MT	Rhizomatous, spreads good.	1,5
Bromus erectus Meadow brome	Introduced	Alp.-PJ	M	S(E),T(E)	Moderate	MT	Rhizomatous, spreads excellent.	1,5
Bromus inermis Smooth brome	Introduced	Alp.-Mtn.B	M-U	S(G),T(E)	Moderate	MT	Rhizomatous, extensively deep roots, sod forming, spreads excellent, grows on a variety of soils, can be planted on exposed or prepared sand and gravel banks.	1,2,5,6,10,12,13

Table 1. (Continued)

Buchloe dactyloides Buffalograss	Native	SP	M-U	S(G),T(G)	Fast	-	Stoloniferous, sod forming, grows on a variety of soils, warm season grass.	3,6
Calamagrostis canadensis Bluejoint reedgrass	Native	SF-Sage	L-M	S(G),T(E)	Moderate	MT	Rhizomatous, spreads excellent, flood tolerant.	1
Calamagrostis epigeois Chee reedgrass	Introduced	Alp.-PJ	L-M	S(P),T(G)	Slow	MT	Rhizomatous, spreads good, flood tolerant.	1,5
Calamagrostis inexpansa Northern reedgrass	Native	SF-Sage	M	S,T	-	-	Rhizomatous.	2,3
Cynodon dactylon Bermudagrass	Introduced	Warm areas	M-U	S(G),T(G)	Fast	MT	Rhizomatous, sod-forming, warmer regions of the U.S., regarded as a serious weed in some states, grows well on a variety of soils, warm season grass.	6,7,12
Dactylis glomerata Orchardgrass	Introduced	Alp.-Sage	M-U	S(G),T(G)	Rapid	MS	Bunch, deeply rooted, spreads fair, can be planted on exposed or prepared sand and gravel banks.	1,5,10,12
Deschampsia caespitosa Tufted hairgrass	Native	Alp.-SF	M	S(P),T(F)	Slow	MT	Bunch, roots to 100 cm, spreads fair, flood tolerant.	1,5,12
Distichylis spicata Saltgrass	Native	V	M	S(P),T(E)	Slow	T	Rhizomatous, spreads excellent, flood tolerant (3-5 weeks inundation), depth to groundwater ≈3-8 ft, moisture stress ≈5-6 weeks.	1,8
Elymus cinereus Great Basin wildrye	Native	Mtn.B.-V	M	S(G),T(G)	Moderate	T	Large clump, spreads fair, optimal in silty clayey soils.	1,5,12,13
Elymus giganteus Mammoth wildrye	Introduced	Mtn.B.-Sage	M-L	S(F),T(G)	Moderate	T	Rhizomatous, spreads good, flood tolerant.	1,5,12
Elymus junceus Russian wildrye	Introduced	Mtn.B.-V	M	S(F),T(G)	Moderate	T	Bunch, densely rooted, spreads fair, cool season grass, slow to establish, rapid recovery after grazing.	1,5,6,12
Elymus triticoides Creeping wildrye	Introduced	JP-V	M	S(G),T(E)	Moderate	T	Rhizomatous, spreads good, flood tolerant.	1,5,11

Table 1. (Continued)

Eragrostis curvula								
Weeping lovegrass	Introduced	0-2500 m	M-U	S(G)	Fast	T	Bunch, sandy soils, warm season grass, fairly easy to establish.	4,6,12,13
Festuca arundinaceae								
Reed fescue (alta or tall)	Introduced	Asp.-SDS	M	S(E),T(E)	Rapid	T	Rhizomatous, deeply rooted, spreads excellent, flood tolerant.	1,5,6,12,13
Festuca elatior								
Meadow fescue	Introduced	-	M	S	-	-	-	2,4
Glyceria grandis								
American mannagrass	Native	-	L	S	-	-	Rhizomatous.	2,3
Glyceria striata								
Fowl mannagrass	Native	-	L	S	-	-	Rhizomatous.	2,3
Hordeum brachyantherum								
Meadow barley	Native	Alp.-Asp.	M	S(E),T(E)	Moderate	T	Bunch, spreads good, flood tolerant.	1,5
Hordeum vulgare								
Barley	Introduced	-	M-U	S	-	-	Annual, provides temporary cover, early fall growth.	6
Leptochloa dubia								
Green sprangletop	Native	-	U	S(G)	Fast	MT	Bunch, sandy to silty clay soils, warm season grass.	4,6,13
Lolium perenne								
Perennial ryegrass	Introduced	SF-PP	U	S(E),T(G)	Rapid	MT	Small bunch, roots to 120 cm deep, spreads good, should be planted on prepared seed beds.	1,5,10,12
Panicum coloratum								
Kleingrass	-	-	U	S(F)	Slow	-	Bunch, warm season grass, silty clay soils.	6
Panicum obtusum								
Vine mesquitegrass	Native	-	M-U	S(F),T(G)	Moderate	-	Tufted with stolons, sod forming, grows on a variety of soils.	4,6
Panicum virgatum								
Switchgrass	Native	SP	U-M	S(G),T(G)	Fast	MT	Rhizomatous, sod forming, warm season grass, tolerates temporary flooding.	2,3,6,12, 13
Paspalum notatum								
Bahiagrass	Introduced	-	M-U	-	-	-	Rhizomatous, sod forming, grows well on variety of soils.	6

Table 1. (Continued)

Phalaris arundinacea Reed canarygrass	Native	Alp.-V	M-L	S(P),T(E)	Slow	T	Rhizomatous, deeply rooted, sod forming, spreads excellent, flood tolerant, often on banks with fast flowing water, grows on a variety of soils, does not tolerate compaction.	1,2,5,6,9, 12,13
Phleum pratense Timothy	Introduced	Asp.Mtn.B	M-U	S(G),T(G)	Rapid	MS	Bunch, spreads good, roots are very fragile, can be planted on exposed sand and gravel banks.	1,5,10,12, 13
Phragmites communis Common reed	Native	Low elev.	L	S,T	-	-	Rhizomatous, able to withstand long periods of inundation, depth to groundwater 0-4 ft., moisture stress <1 week.	2,3,8
Poa pratensis Kentucky bluegrass	Introduced	Asp.-PJ	M-U	S(F),T(G)	Slow	MT	Rhizomatous, roots to 65 (100) cm deep, sod forming, spreads excellent, grows on a variety of soils, can be planted on exposed or prepared sand and gravel banks, long-lived.	1,2,5,6,10, 12,13
Poa secunda Sandberg bluegrass	Native	Mtn.B-Sage	M-U	S(F),T(G)	Slow	MT	Bunch, spreads fair.	1,5,13
Secale cereale Rye	Introduced	-	M-U	S	-	-	Annual, provides temporary cover.	6
Setaria macrostachya Plains bristlegrass	Native	-	U	S(F)	Slow	-	Bunch, sandy to silty-clay soils, warm season grass.	4,6
Sitanion hystrix Bottlebrush squirreltail	Native	Mtn.B-SDS	M-U	S(G),T(F)	Moderate	MT	Bunch, spreads good.	1,5
Sorghastrum nutans Indiangrass	Native	PP-SP	M-U	S(G),T(G)	Fast	MT	Rhizomatous, sod forming, fertile soils, warm season grass, south facing slopes in eastern Wyoming.	3,6,12,13
Sorghum sudanensis Sudangrass	Introduced	-	M-U	S	-	-	Annual, provides temporary late-summer cover.	6
Spartina pectinata Prairie cordgrass	Native	-	M	S,T	-	-	Rhizomatous, flood tolerant.	2,3

Table 1. (Concluded)

Sporobolus airoides								
Alkali sacaton	Native	SDS	M	S(F),T(G)	Slow	MT	Bunch, spreads excellent, Alkali flats.	1,2,5,13
Stipa viridula								
Green needlegrass	Native	≤9,000 ft	U	S	Slow	MS-MT	Bunch, grows on disturbed areas, cool season grass.	3,6,13
Triticum aestivum								
Wheat	Introduced	-	M-U	S	-	-	Annual, provides temporary late summer cover.	6

[1]Zones of Adaptation: Alp.=alpine; Salp.=subalpine; SF=spruce-fir; Asp.=aspen; Mtn.B.=mountainbrush; PJ=pinyon-juniper; PP=ponderosa pine; Sage=big sagebrush; SP=shortgrass prairie; SDS=salt desert shrub; V=valley bottoms.
[2]Bank Position: L=lower bank; M=middle bank; U=upper bank.
[3]Method of Planting: S=seeding; T=transplanting (e.g. root pads, sodding, or sprigging). Letters in parenthesis indicate probable success rate for each method: E=excellent; G=good; F=fair; P=poor.
[4]Salinity Tolerance: S=sensitive; MS=moderately sensitive; MT=moderately tolerant; T=tolerant.
[5]References: 1=Platts et al. 1987; 2=Logan 1979b; 3=Hallsten et al. 1987; 4=Hitchcock and Chase 1950; 5=Monsen 1983; 6=Temple et al. 1987; 7=Mason 1957; 8=Bayha and Schmidt 1983; 9=Pennsylvania Department of Environmental Resources 1986; 10=Ward et al. 1986; 11=U.S. Soil Conservation Service, Bridger Plant Materials Center 1981; 12=Schiechtl 1980; 13=Wasser 1982.

Table 2. Potential grasslike species for stabilizing streambanks and their characteristics (after Platts et al. 1987).

Species	Zones of Adaptation[1]	Bank Position[2]	Method of Planting[3]	Comments	References[4]
Carex spp. Sedges	Alp.-V	L-U	S,T	Diverse genus occupying many habitats, inundation tolerance $\approx 1-\infty$ weeks, depth to groundwater 0-1 ft., moisture stress <1 week.	3
Carex aquatilis Water sedge	SF-Asp.	M	-	Caespitose with long rhizomes, excellent streambank stability, highly palatable, principal species for revegetation.	1
Carex aurea Golden sedge	SF-V	M	-	Caespitose with long rootstocks, widely distributed, good ground cover.	1
Carex disperma Softleaved sedge	Alp.-Asp.	M	-	Caespitose with long rhizomes, shady areas, solid mat, moderate vigor.	1
Carex douglasii Douglas sedge	Asp.-PJ	U	-	Creeping rootstocks, alkali tolerant, long culms, adapted to compacted soils, increases under grazing, low palatability.	1
Carex elynoides Black sedge-root	Alp.	U	-	Caespitose, vigorous, abundant.	1
Carex hoodii Hood sedge	SF-Mtn.B.	M-U	-	Densely caespitose, excellent ground cover, useful forage species.	1
Carex lanuginosa Wooly sedge	SF-V	M-U	-	Caespitose with long rootstocks, very robust, principal species for streambank stabilization.	1
Carex lenticularis Kellogg sedge	SF-Mtn.B.	M	-	Caespitose with long rootstocks, pioneer species, invades water's edge.	1
Carex microptera Smallwing sedge	Asp.-Mtn.B.	M-U	S	Densely caespitose, good cover for streambanks, palatable, spreads by seeds, widely distributed.	1
Carex nardina Hepburn sedge	Alp.	M	-	Densely caespitose, short stature, open cover.	1

Table 2. (Continued)

Carex nebrascensis Nebraska sedge	Asp.-V	M-L	-	Strongly rhizomatous, excellent soil stabilizer, alkali tolerant, palatable, widely distributed.	1
Carex nigricans Black alpine sedge	Alp.-SF	M-U	-	Creeping rootstock, good cover for wet areas.	1
Carex praegracilis Slim sedge	Asp.-V	M	-	Long creeping root stocks, large plant, dense, persistent, alkali tolerant, moderately palatable.	1
Carex rostrata Beaked sedge	SF-V	M-L	-	Stout long rhizomes, principal species for streambank stabilization, tolerates shallow standing water and fluctuating water levels, wide elevational range low palatability.	1
Carex rupestris Rock sedge	Alp.	M-U	-	Short rhizomes, vigorous, spreads rapidly, limited distribution.	1
Carex saxatilis	SF-LPP	M-L	-	Long creeping rootstocks, excellent streambank cover, limited distribution.	1
Carex scirpoidea Downy sedge	Alp.	M-U	-	Rhizomatous, vigorous, spreads rapidly.	1
Carex simulata Analogne sedge	SF-PP	M-L	-	Long creeping rootstocks, calcareous soils, excellent cover, widely distributed.	1
Carex vallicola Valley sedge	Asp.-Sage	U	-	Caespitose, spreads onto dry grass-sage sites.	1
Eleocharis palustris Spikerush	SF-V	M-L	-	Rhizomatous, alkali tolerant, spreads rapidly, wide elevational range, low palatability.	1
Juncus spp. Rushes	Alp.-V	L-U	-	Inundation tolerance $\approx$1-∞ weeks, depth to groundwater 0-1 ft., moisture stress <1 week.	3
Juncus arcticus var. *balticus* Baltic rush	Asp.-V	M	-	Rhizomatous, principal species for stabilization, spreads aggressively, persists with grazing, use adapted ecotypes.	1

Table 2. (Concluded)

Juncus drummondii Drummond rush	Alp.-LPP	M-U	-	Caespitose, spreads after disturbance, occupies infertile soil.	1
Juncus ensifolius Swordleaf rush	SF-Sage	M-L	-	Strongly rhizomatous, wide elevational range, moderately palatable.	1
Juncus longistylis Longstyle rush	SF-Sage	M	-	Rhizomatous, moderately palatable.	1
Juncus torreyi Torrey rush	PJ-V	M-L	-	Strongly rhizomatous, alkali tolerant, spreads onto disturbances.	1
Scirpus acutus Tule bulrush	Mtn.B.-V	L	T	Rhizomatous, tall, rank, dense patches, restricted to water's edge.	1,2
Scirpus americanus American bulrush	-	L	T	-	2
Scirpus maritimus Saltmarsh bulrush	Mtn.B	L	-	Rhizomatous, alkali tolerant, dense patches, spreads rapidly.	1
Scirpus validus Softstem bulrush	-	L	T	-	2
Typha latifolia Cattail	-	L	T	Inundation tolerance $\approx$1-∞ weeks, depth to groundwater 0-1 ft., moisture stress <1 week.	2,3

[1]Zones of Adaptation: Alp.=alpine; Salp.=subalpine; SF=spruce-fir; Asp.=aspen; LPP=lodgepole pine; Mtn.B.=mountainbrush; PJ=pinyon-juniper; PP=ponderosa pine; Sage=big sagebrush; SP=shortgrass prairie; SDS=salt desert shrub; V=valley bottoms.
[2]Bank Position: L=lower bank; M=middle bank; U=upper bank.
[3]Method of Planting: S=seeding; T=transplanting (e.g. root pads, sodding, or sprigging). Letters in parenthesis indicate probable success rate for each method: E=excellent; G=good; F=fair; P=poor.
[4]References: 1=Platts et al. 1987; 2=Logan 1979b; 3=Bayha and Schmidt 1983.

Table 3. Potential broadleaf forbs for stabilizing streambanks and their characteristics (after Platts et al. 1987).

Species	Origin	Zones of Adaptation[1]	Bank Position[2]	Method of Planting[3]	Growth Rate	Salinity Tolerance[4]	Comments	References[5]
Achillea millefolium Western yarrow	Native	Alp.-V	M-U	S(E),T(E)	Rapid	MS	Spreads excellent, roots 10-90(400) cm deep, can be planted on exposed sand and gravel banks.	1,5,6,7
Artemisia ludoviciana ludoviciana Louisiana sagewort	Native	Alp.-Sage	M	S(E),T(E)	Rapid	MS	Spreads excellent, can be planted on exposed sand and gravel banks.	1,5
Aster chilensis adscendens Pacific aster	Native	Asp.-V	M	S(P),T(E)	Moderate	MS	Spreads excellent.	1,3
Bassia hyssopifolia Fivehook bassia	Native	PJ-SDS	M	S(E),T(G)	Rapid	T	Spreads good, flood tolerant.	1,3
Coronilla varia Crownvetch	Introduced	PJ-Mtn.B.	U-M	S(G),T(E)	Rapid	MS	Spreads good, roots to 90+ cm, provides soil fertility (nitrogen) to grasses on higher banks, pioneer, poisons sheep.	1,2,3,6,7
Epilobium angustifolium Fireweed	Native	Asp.-Mtn.B.	M	S(E),T(G)	Rapid	S	Spreads excellent.	1
Heracleum lanatum Common cowparsnip	Native	Alp.-Mtn.B.	M-U	S(P),T(P)	Poor	S	Spreads fair.	1,3
Linum lewisii Lewis flax	Native	Asp.-Sage	U	S(E),T(G)	Moderate	S	Spreads good.	1,7
Medicago lupulina Black medic	Introduced	Asp.-Sage	M	S(E),T(G)	Moderate	MT	Spreads good, roots 10-30(50) cm deep, thin taproot, pioneer, resistant to grazing.	1,3,6
Medicago sativa Alfalfa	Introduced	Asp.-Sage	M-U	S(E),T(G)	Rapid	MT	Spreads fair, roots 2(5)-10 m deep, creeping type preferred, inundation tolerance <1 week, depth to groundwater ≈6-15 ft, moisture stress ≈3-5 weeks, can be planted on exposed or prepared sand and gravel banks, fixes nitrogen when inoculated.	1,3,4,5,6,7

Table 3. (Continued)

Melilotus alba White sweetclover	Introduced	to ≈1000 m	M-U	S	-	MT	Pioneer, roots to 70 cm, grows on most soils, woody, provides soil fertility (nitrogen) to grasses on higher banks, often considered unattractive.	2,6
Melilotus officinalis Yellow sweetclover	Introduced	Asp.-Sage	M-U	S(E),T(P)	Rapid	MT	Spreads excellent, provides soil fertility (nitrogen) to grasses on higher banks, can be planted on exposed or prepared sand and gravel banks.	1,2,5,6,7
Polygonum coccineum Swamp smartweed	-	-	L	S	-	-	-	2
Polygonum lapathifolium Pale smartweed	-	-	L	S	-	-	-	2
Potentilla glandulosa glandulosa Gland cinquefoil	Native	Asp.-PP	M	S(G),T(E)	Moderate	S	Spreads good.	1
Senecio serra Butterweed groundsel	Native	Asp.-PP	M	S(G),T(E)	Moderate	S	Spreads good.	1
Sidalcea oregana Oregon checkermallow	Native	Asp.-Mtn.B.	M	S(G),T(G)	Moderate	S	Spreads good.	1
Smilacina racemosa amplexicaulis Western Solomons-seal	Native	Asp.-Mtn.B.	M	S(P),T(F)	Slow	S	Spreads fair.	1
Trifolium fragiferum Strawberry clover	Introduced	V	M	S(G),T(F)	Moderate	MT	Spreads excellent, any soil type, prefers salty soils.	1,3,6
Trifolium hybridum Alsike clover	Introduced	Asp.-Mtn.B.	M-U	S(G),T(F)	Moderate	S	Pioneer, spreads good, strong tap root, many side roots, clay and compacted heavy clay soils, susceptible to wet and flooded soils.	1,3,6
Valeriana edulis Edible valerian	Native	Asp.-Mtn.B.	M	S(P),T(F)	Slow	S	Spreads fair.	1,3

Table 3. (Concluded)

[1]Zones of Adaptation: Alp.=alpine; Salp.=subalpine; SF=spruce-fir; Asp.=aspen; Mtn.B.=mountainbrush; PJ=pinyon-juniper; PP=ponderosa pine; Sage=big sagebrush; SP=shortgrass prairie; SDS=salt desert shrub; V=valley bottoms.
[2]Bank Position: L=lower bank; M=middle bank; U=upper bank.
[3]Method of Planting: S=seeding; T=transplanting (e.g. root pads, sodding, or sprigging). Letters in parenthesis indicate probable success rate for each method: E=excellent; G=good; F=fair; P=poor.
[4]Salinity Tolerance: S=sensitive; MS=moderately sensitive; MT=moderately tolerant; T=tolerant.
[5]References: 1=Platts et al. 1987; 2=Logan 1979b; 3=Monsen 1983; 4=Bayha and Schmidt 1983; 5=Ward et al. 1986; 6=Schiechtl 1980; 7=Wasser 1982.

DESCRIPTION:

Woody plants (shrubs and trees) provide streambank protection by helping to reduce the streamflow velocity adjacent to the bank, and reinforcing the soil to the depth of the root system. They generally provide a more long-term form of bank protection than grasses, as well as a protective overstory for many herbaceous plant species. Potential woody plant species for stabilizing streambanks are listed in Table 4. Additional references on the flooding tolerance of woody plants are: Teskey and Hinckley 1978; Whitlow and Harris 1979; Walters et al. 1980; Stevens and Waring 1985; Lester et al. 1986.

APPLICATION:

How

- Woody plants may be purchased from private companies, or collected locally from existing stands.
- Planting woody species more than one year after grasses is normally discouraged because the woody plants can not compete with the establishing grasses.
- Many woody plant species are not readily available, so "phase planting" should be considered. This entails planting as soon as possible with the plants readily available, and then plant with additional species as they become available from other sources (e.g. nurseries).
- Planting rooted stock is generally preferred over planting unrooted cuttings. Bare-root nursery stock and dormant wildlings are most successfully established if planted in the spring or fall. Cuttings may be planted in the spring or fall, but spring cuttings generally survive better. Container grown stock is best planted in the spring if it is still dormant, or planted after the danger of sever frost and before freeze-up if it is not dormant. Full or partially leafed root pads and wildlings should be planted in the late summer or early fall in order to allow some time for root growth before freeze-up.
- Willow stock should be collected from local stands. Seedlings or tube packs are usually harder to obtain, more expensive, and are less locally acclimated. Cuttings should come from large vigorous plants, rather than young or old plants. Rooted willow stock is harder to plant than willow cuttings, but the survival is higher and they provide more rapid site stabilization.
- Willows should not be planted on a bank having a slope steeper than 3:1.
- Woody plants should be systematically planted every 6-10 feet apart.
- Using fertilizer low in nitrogen and high in phosphate will encourage greater root growth and less top growth during the first few years. One 9-gram "starter" tablet can be effective for establishing individual woody plants.

- Irrigation may help increase the initial survival of woody plants until they become established. Planting trees in augered holes decreases the required watering time in desert situations from ≥3 years to perhaps 8-10 months.
- Shrubs are most successfully established if planted in the early spring, before plant dormancy is broken. Container stock can be planted throughout the summer.

Where

- Shrubs are most successfully established on the upper bank, but a few species can also become successfully established on the middle bank.
- Trees are most successfully established on the upper bank. Planting is not recommended in areas with a high water table, because it causes an imbalance of hormones and nutrient uptake which results in poor plant growth. Better establishment occurs if the transplants are placed in moist, but not saturated soils.
- The streambank to be planted should have the potential to support woody vegetation. Planting willow slips anywhere except on the best of sites is a waste of time and money. Good willow habitat must have sufficient moisture throughout the growing season, and be warm enough to promote good growth. Extremely cobbley alluvial deposits or nearly vertical cut banks should not be planted without reworking first.

ADVANTAGES:

- Woody plants provide more effective long-term bank protection than grasses.
- Woody plants provide a protective overstory for many herbaceous plant species, without which they can not survive and provide streambank stability.
- Flexible woody plants such as willows can act as a skid surface for ice and debris to slide over the bank surface.
- Hardwood-tree roots in North Carolina have been found to protect a portion of the streambank equal to about five times the diameter of the tree. This amounted to 73% of the streambank being protected by the trees alone.

LIMITATIONS:

- Initial cost is generally higher than grasses.
- Many woody plant species are not readily available.
- Few native shrubs have been examined for streamside plantings, and on-site evaluations and adaptability studies for most species are limited.
- Handling live plant material requires special attention. Planting full or partially leafed root pads or wildlings requires special care, and is not recommended unless other methods are not feasible.

- Large trees on steep banks add additional weight to the bank. This added weight may actually decrease the short-term stability of the bank, and offset any reinforcement properties provided by the roots. The long-term stability of the bank may be improved, however, since slumping reduces the bank gradient. Intense management of the riparian forest may be justified, but only if the values associated with forest succession and the unique plant community associated with that succession are recognized.

RELATIVE COST:

- Bare-rooted stock cost from 5-15 cents per plant to plant (1979). Hand planting container stock costs from about one-half the cost of bare rooted plants to equal or exceeding the cost of container seedlings (1979). From 200-400 plants can be planted per person each day.
- $95 to $100 per mile (1983) to plant willow cuttings on both sides of the stream.
- $200 per ha to auger holes for every plant.
- Bare-rooted stock cost from $0.08 (1979) to $1.75 per plant, for shrubs or trees ranging in height from 1.2 ft to >4 ft.
- Container-grown stock cost from $0.40 (1979) to $7.50 (1979) per plant, for shrubs or trees grown in small (2x2x8") to large containers.
- Golden or native willow cost about $0.50 per cutting.
- Willow cost about $0.50 per plant (1988) in Wyoming, plus a minimal cost for planting.
- Bare root or containerized willow cost from $12 to $20 per 100 (1983).

SELECTED REFERENCES:

Anderson and Ohmart 1979; Fanning 1989; Jones and Franklin 1988; Keller and Swanson 1979; Keown et al. 1977; Klamm 1988; Logan 1979b; Long et al. 1984; McCluskey et al. 1983; Platts et al. 1987; U.S. Soil Conservation Service 1983; Ward et al. 1986; Wyoming Highway Department 1986.

Table 4. Potential woody species for stabilizing streambanks and their characteristics (after Platts et al. 1987).

Species	Zones of Adaptation[1]	Bank Position[2]	Method of Planting[3]	Growth Rate	Disturbed Site Adaptation	Soil Stability Value	Comments	References[4]
Acer negundo Boxelder	-	U	S,T,(P)	Variable	-	Poor	Damaged by ice, inundation tolerance ≈1-2 weeks, depth to groundwater ≈4-40 ft, moisture stress ≈3-5 weeks.	2,7,8,11
Alnus incana Speckled alder	-	M	-	-	-	Excellent	-	8
Alnus tenuifolia Thinleaf alder	SF-Mtn.B.	M-U	S,T,(E)	Rapid	Excellent	Excellent	Easily established, adapted to harsh sites, grows rapidly.	1,3
Amelanchier alnifolia Saskatoon serviceberry	Asp.-Mtn.B.	U	T,(F)	Slow	Good	Good	Slow to establish, sensitive to understory competition.	1,2,4,12
Artemisia cana viscidula Silver sagebrush	Asp.-Sage	M-U	S,T,(G)	Rapid	Fair	Fair	Well adapted to exposed moist soils, able to tolerate flooding for short time.	1,3,12
Artemisia tridentata tridentata Basin big sagebrush	Mtn.B.-SDS	U	S,T,(G)	Rapid	Excellent	Fair	Useful for planting extremely disturbed and well-drained soils.	1,12
Artemisia tridentata vaseyana Mountain big sagebrush	Asp.-Mtn.B.	M-U	S,T,(G)	Rapid	Excellent	Fair	Adapted to disturbed sites, suited to moist but not saturated soils, should be planted on prepared seed beds.	1,10,12
Artemisia tripartita Tall threetip sagebrush	Asp.-Mtn.B.	M-U	S,T,(E)	Rapid	Excellent	Fair	Well suited to eroded exposed soils, spreads quickly.	1
Atriplex canescens Fourwing saltbush	Mtn.B.-V	U	S,T,(E)	Rapid	Good	Good	Useful for well-drained and disturbed soils, >30 hours of inundation causes high mortality, should be planted on prepared seed beds.	1,4,5,10, 11,12
Atriplex gardneri Gardner saltbush	SDS-V	M-U	S,T,(F)	Fair	Fair	Fair	Adapted to arid sites subjected to seasonal saturated soils.	1,3

Table 4. (Continued)

Betula occidentalis occidentalis Water birch	SF-Mtn.B	M-L	T,(E)	Rapid	Good	Excellent	Establishes well by transplanting, adapted to streambanks and bogs.	1
Ceanothus sanguineus Redstem ceanothus	SF-PP	M-U	S,T,(E)	Rapid	Good	Excellent	Not adapted to saturated soils but useful in planting disturbed streambanks.	1,3,4
Celastrus scandens Bittersweet	-	U	T	-	-	-	-	2
Chrysothamnus spp. Rabbitbrush	Sage-V	M	S,T,(E)	Moderate	Good	Fair	Inundation tolerance ≈2-3 weeks, depth to groundwater ≈8-15 ft, moisture stress ≈3-4 weeks.	7
Chrysothamnus nauseosus consimilis (or *albicaulis*) Thinleaf rubber rabbitbrush	Sage-V	M-U	S,T,(E)	Moderate	Good	Fair	Suited to heavy saturated soils, well-drained soils, or occasionally flooded sites, should be planted on prepared seed beds.	1,10,12
Clematis ligustifolia Virgins bower	-	U	S,(F)	Fair	Excellent	-	Shallow-fibrous root systems, probably does better with shade and support.	2,12
Cornus stolonifera stolonifera Redosier dogwood	SF-Mtn.B.	M	S,T,(E)	Rapid	Good	Excellent	Easy to grow and establish (70-85% survival), resprouts and layers, useful for disturbed sites, protects banks from spring ice flows, requires fresh aerated water, inundation tolerance ≈1-3 weeks, depth to groundwater ≈1-10 ft, moisture stress ≈2-4 weeks, recommended for planting.	1,2,3,4,7,8
Crataegus chrysocarpa Hawthorn	-	M-U	T	-	-	-	Species adds diversity to stand.	2
Crataegus douglasii Douglas hawthorn	Asp.-Sage	M	T,(F)	Slow	Good	Good	Slow growing, but well suited to disturbed streambanks.	1

Table 4. (Continued)

Elaeagnus angustifolia								
Russian olive	Mtn.B.-V	M-U	S,T,(E)	Rapid	Excellent	Good	Easily established, can become weedy, flooded sites (<1 week) to well-drained soils, depth to groundwater ≈4-20 ft, moisture stress ≈4-8 weeks, estimated long-term survival ≈15-18% in southwestern Wyoming, considered to be a pest in some areas.	1,2,3,6,7,11
Elaeagnus commutata								
Silverberry	PJ-V	M-U	T,(E)	Rapid	Excellent	Good	Easily established, grows rapidly, adapted to harsh sites, sand and gravel soils.	1,2,11
Fraxinus pennsylvanica								
Red (Green) ash	-	M-U	T	Slow	-	-	Estimated long-term survival <1% in southwestern Wyoming, eaten by almost everything.	2,6,12
Holodiscus discolor								
Rockspirea	SF-Mtn.B.	M	T,(F)	Moderate	Good	Good	Erratic establishment, but suited to disturbed sites.	1
Juniperus communis								
Juniper	0-4000 m	U	T	-	-	-	Useful in control of gully erosion.	2,11
Juniperus scopulorum								
Rocky Mountain juniper	-	U	T	-	-	-	Very valuable for erosion control.	2,4,11
Lonicera tatarica								
Tatarian honeysuckle	Mtn.B.-Sage	M-U	S,T,(E)	Rapid	Excellent	Good	Easily established, provides immediate cover, well adapted to different soil conditions.	1,2,3
Pachistima myrsinites								
Myrtle pachistima	SF-Asp.	U	T,(F)	Slow	Fair	Good	Common to upland slopes, not well adapted to disturbances, requires some shade.	1,3
Parthenocissus inserta								
Virginia creeper	-	U	T	-	-	-	-	2
Physocarpus malvaceus								
Mallow ninebark	SF-Asp.	U	T,(F)	Moderate	Fair	Good	Requires good sites.	1,3
Pinus ponderosa								
Ponderosa pine	PP	U	S,T	Slow	-	-	Extensively and moderately deeply rooted, clay loams to loamy sands.	2,11,12

Table 4. (Continued)

Populus spp.								
Cottonwood	Asp.-V	M-U	T	Rapid	Good	Good	Roots often ≥20 ft deep, inundation tolerance <1 week, depth to groundwater ≈4-20 ft, moisture stress 2-4 weeks, hybrid poplars tend to be disease prone.	7,8
Populus angustifolia								
Narrowleaf cottonwood	Asp.-Sage	M-U	T,(G)	Rapid	Good	Good	Establishes easily, grows rapidly.	1
Populus deltoides								
Cottonwood	-	U	T	-	-	-	Estimated long-term survival in southwestern Wyoming ≡ 3% (beavers, livestock, disease, and dewatering responsibe for poor survival).	2,6
Populus fremontii fremontii								
Fremont cottonwood	Mtn.B.-V	M	T,(G)	Rapid	Good	Good	Establishes easily, grows rapidly, furnishes good cover.	1
Populus tremuloides								
Quaking aspen	SF-Asp.	M-U	T,(G)	Rapid	Fair	Good	Considerable ecotypic differences, not well suited to highly disturbed sites, occupies wide range of moisture.	1,2,3,12
Potentilla fruticosa								
Bush cinquefoil	Alp.-PP	M-U	T,(G)	Moderate	Excellent	Excellent	Establishes well, valuable for disturbed areas, provides excellent site stability.	1,3,12
Prunus virginiana melanocarpa								
Black chokecherry	SF-PJ	U	T,(G)	Moderate	Fair	Good	Widely adapted, larger transplant stock establishes and grows rapidly.	1,2,3,11,12
Quercus macrocarpa								
Bur oak	-	U	T,S	-	-	-	Deep and extensive roots, broad physical and chemical soil range, seedlings often killed by floods.	2,11,12
Rhamnus davurica								
Buckthorn	Asp.-Mtn.B.	U	T	-	-	-	-	2,3
Rhamnus purshiana								
Cascara buckthorn	SF-PP	M	T,(F)	Moderate	Fair	Good	Limited plantings, plants perform well on disturbed sites.	1
Rhus trilobata								
Skunkbrush	Mtn.B-PJ	U	T,S,(P)	Fair	Excellent	-	Tolerant of most soil textures, deep and extensively branched roots.	2,4,12

Table 4. (Continued)

Ribes aureum Golden current	Asp.-Sage	U-M	T,(E)	Excellent	Excellent	Good	Widely adapted, easily established, excellent site stability.	1,4,12
Rosa woodsii Woods rose	Asp.-Mtn.B	M-U	T,(E)	Moderate	Excellent	Good	Widely adapted, easily established, excellent site stability, principal species for riparian disturbances.	1,2,3,4,12
Rubus spp. Raspberry, Blackberry	Asp.-PP	M-U	T,(E)	Moderate	Excellent	Good	Well adapted to eroded sites, limited range of distribution.	1,11
Salix spp. Willow	Alp.-V	L-U	T	-	-	-	Roots rarely >3-4 ft below the surface, inundation tolerance ≈2-4(∞) weeks, depth to groundwater ≈1-12 ft, moisture stress tolerance ≈2-4 weeks.	7
Salix alba White willow	-	M	-	Rapid	-	Good	Poor to excellent survival, native of Europe and central Asia.	8,9
Salix amygdaloides Peachleaf willow	Asp.-Sage	M	T	-	-	-	Moderate rooting capabilities, seasonally saturated soils.	1,2
Salix bebbiana Bebb willow	SF-Asp.	M	T	-	-	-	Roots freely.	1,2
Salix boothii	Asp.-Sage	L-M	T	-	-	-	Roots freely, grows in standing water, confined to wet soils.	1
Salix brachycarpa Barrenground willow	Salp.-SF	M-U	T	-	-	-	Roots freely.	1
Salix drummondiana Drummond willow	SF-Sage	M	T	-	-	-	Roots freely.	1
Salix exigua Sandbar willow	SF-Sage	M	T	-	-	-	Roots easily.	1,2
Salix geyeriana Geyer willow	Salp.-Sage	M	T	-	-	-	Fair rooting capabilities.	1
Salix glauca Grayleaf willow	Salp.-SF	M-U	T	-	-	-	Requires special treatment to root, occupies seeps and snowbank edges.	1

Table 4. (Continued)

Salix lasiandra Pacific willow	Asp.-Sage	M	T	-	-	-	Roots easily.	1
Salix lasiolepis Arroyo willow	Asp.-Mtn.B.	M	T	-	-	-	Erratic rooting habits.	1
Salix lutea Shining willow	Asp.-Sage	M	T	-	-	-	Roots easily.	1,2
Salix planifolia Tealeaf willow	Salp.-Asp.	M-L	T	-	-	-	Fair Rooting capabilities	1
Salix purpurea Purpleosier willow	Asp.-Sage	M	-	Rapid	-	Good	Outstanding plant for streambank control, good-excellent survival, protects banks from spring ice flows.	3,8
Salix rigida Diamond willow	-	M	T	-	-	-	Species adds diversity to stand.	2
Salix scouleriana Scouler willow	SF-Asp.	U	T	-	-	-	Requires special treatment to root.	1,3,4
Salix wolfii Wolf willow	SF-Asp.	M	T	-	-	-	Erratic rooting.	1
Sambucus racemosa pubens microbotrys Red elder	Asp.-PP	M	T,(F)	Moderate	Good	Good	Adapted to restricted sites, establishes slowly on disturbed sites.	1
Sarcobatus vermiculatus Black greasewood	SDS-V	M	T,(F)	Slow	Good	Good	Difficult to establish, well adapted to valley bottoms and salty soils, shallow water tables (≈4-40 ft), occasionally flooded (≈1-3 weeks), and moisture stress ≈3-4 weeks.	1,3,7
Shepherdia argentea Silver buffaloberry	Mtn.B.-V	M-U	T,(G)	Moderate	Good	Good	Adapted to valley bottoms and saline soils.	1,2,3,4,12
Sorbus scopulina scopulina Green's mountain ash	SF-Asp.	M	T,(F)	Slow	Fair	Good	Not well adapted to disturbed soils, establishes slowly.	1,3

Table 4. (Concluded)

Symphoricarpos albus Common snowberry	SF-Asp.	M-U	T,(F)	Moderate	Good	Excellent	Not well suited to extremely disturbed soils, once established grows well, plant large stock.	1,4
Symphoricarpos occidentalis Western snowberry	SF-Mtn.B.	M-U	S,T,(F)	Slow	Good	Excellent	Not well adapted to disturbed soils, provides excellent stability and spreads well.	1,2,3,12
Symphoricarpos oreophilus Mountain snowberry	Asp.-Sage	M-U	T,(F)	Slow	Good	Excellent	Not well adapted to disturbed soils, provides excellent stability and spreads well.	1,3
Ulmus americana American elm	-	U	T	-	-	-	-	2,11
Viburnum lentago Nannyberry	-	U	T	-	-	-	-	2
Vitis riparia Wild grape	-	U	T	-	-	-	-	2

[1]Zones of Adaptation: Alp.=alpine; Salp.=subalpine; SF=spruce-fir; Asp.=aspen; Mtn.B.=mountainbrush; PJ=pinyon-juniper; PP=ponderosa pine; Sage=big sagebrush; SDS=salt desert shrub; V=valley bottoms.
[2]Bank Position: L=lower bank; M=middle bank; U=upper bank.
[3]Method of Planting: S=seeding; T=transplanting (e.g. cuttings, bare rootstock, root pads, and container stock). Letters in parenthesis indicate probable seedling establishment rate: E=excellent; G=good; F=fair; P=poor.
[4]References: 1=Platts et al. 1987; 2=Logan 1979b; 3=Monsen 1983; 4=Shaw 1984; 5=Aldon 1970; 6=Anonymous no date; 7=Bayha and Schmidt 1983; 8=Edminster et al. 1949; 9=Elias 1980; 10=Ward et al. 1986; 11=Schiechtl 1980; 12=Wasser 1982.

STREAMBANK STABILIZATION TECHNIQUES:

METHODS FOR ESTABLISHING VEGETATION

DESCRIPTION:

Branch packing is a technique used to establish vegetation on streambanks by alternately packing layers of live branches and soil into a washout on the bank.

APPLICATION:

How

- Branch packing is best accomplished during the dormant season, and during low streamflow.
- Live branch cuttings from ½ - 3 inches in diameter, and long enough to extend 12 inches above the original bank, are mixed with soil and gravel in alternate layers to fill in the washout. Branches placed above the water line will take root, providing permanent protection, while the branches placed below the water line provide initial stability. Live stakes (wattles) are placed at regular intervals to bind the packing to the bank.

Where

- Branch packings are especially useful for repairing washouts less than 12 feet long by 5 feet wide by 4 feet deep.
- This technique is effective even where there is moderately deep, fast moving water, and can provide protection both above and below the water line.

ADVANTAGES:

- Branch packings are one of the most effective methods available for revegetating holes scoured into a streambank.
- Economical if cuttings are available locally.
- The branches provide immediate bank protection which eventually forms a permanent, naturally appearing installation once the vegetation becomes established.

LIMITATIONS:

- Branch packing requires a large supply of branches and a considerable amount of labor.

RELATIVE COST:

- No Information.

SELECTED REFERENCES:

Pennsylvania Department of Environmental Resources 1986; Schiechtl 1980.

LIVE CRIBWALLS

DESCRIPTION:

Live cribwalls are a technique used to establish vegetation along streambanks by incorporating live cuttings (e.g. willows) into a rectangular framework of logs and rocks. This technique is similar to the structural cribs, and provides bank protection by protecting the eroding bank from the streamflow or by preventing the formation of a split channel.

APPLICATION:

How

- Live cribwalls are best constructed during the dormant season and during low streamflows.
- Cribs should be constructed from bark-free logs at least 6 inches in diameter and the fill should support plant growth. The crib is constructed by alternating layers of logs, cuttings, and fill until the desired height is reached. Crib heights are normally 50-60% of the bank height. Both the upstream and downstream ends of the crib should be protected with riprap.

Where

- Live cribs are used on all types of channels including outside bends of main channels, and where an eroding bank threatens to form a split channel.

ADVANTAGES:

- Live cribwalls provide very effective bank protection on fast flowing streams, and can be economically constructed if local materials and unskilled labor are used.
- Once the woody vegetation begins to grow, the structure will have a more natural appearance than a simple structural crib.
- The log framework provides immediate protection, while the plants will eventually provide the long-term bank protection.

LIMITATIONS:

- Locally available logs and rocks are required for construction.
- Live cribwalls are more complex to construct than fascines or branch packings.
- Even if the structure is properly keyed into the streambed, live cribwalls do not provide effective bank protection from an actively eroding streambed because they are easily undercut.

RELATIVE COST:

- No Information.

SELECTED REFERENCES:

Pennsylvania Department of Environmental Resources 1986.

DESCRIPTION:

Live fascines are bundles of live cuttings wired together and secured to the bank with live stakes (wattles). Normally they are placed on the bank parallel to the contour. Live fascines may also be used in conjunction with other vegetation establishment techniques.

APPLICATION:

How

- Live fascines must be placed during the dormant season only.
- Four to six foot long stems from 2-3 year old willows, or other sprouting species, are packed together into a tight, continuous roll ranging from 10-60 feet long by 4-8 inches in diameter. The rolls are held together by wire and then buried in the bank at regular contour intervals starting at the mean low water line and proceeding up slope. Twigs from the stems should protrude above the soil. Live willow stakes (wattles) 2-3 feet long are anchored through the bundle, and used to support the fascine on the downhill side.
- An alternative from of a fascine, called a barrier, is constructed similar to a fascine, but is placed across the contour intervals and perpendicular to the stream.

Where

- Fascines or barriers are used where the streamflow may uproot small transplanted stock, particularly at the edge of the stream. They can be used on all sizes and character types of streams.
- Fascines are not recommended for use on banks which have surface drainage over the face of the bank.

ADVANTAGES:

- Live fascines provide effective, long-term, naturally appearing bank stability once the plants become rooted, while the cuttings provided immediate short-term protection.
- Fascines conform to the bank geometry since they are flexible, and their installation requires minimal bank disturbance.
- Fascines effectively deter downslope surface movement of soil caused by streamflow, wind, livestock or wildlife trampling, and gravity.
- Economical if cuttings are locally available.

LIMITATIONS:

- Hand labor is required to install the fascines.
- Installation must be during the dormant season.
- Woody species with wide, spreading branches are not easily formed into fascines.

RELATIVE COST:

•No Information.

SELECTED REFERENCES:

Logan 1979b; Pennsylvania Department of Environmental Resources 1986; Schiechtl 1980.

DESCRIPTION:

Live stakes (wattles) are woody plant cuttings that are capable of quickly rooting and are large enough to be tamped into the bank. The live stakes stabilize the streambank by taking root and growing into mature shrubs or trees.

APPLICATION:

How

- Live stakes are placed during the dormant season, and at low streamflow.
- The cuttings are usually ½-1½ inches in diameter, and 2-2½ feet long. Branches should be cleanly removed, and at least two bud scars should be near the top of the stake. The cuttings should be fresh (≤1 day), and kept moist.
- Cleanly cut the butt end at a 45° angle, and cut the top square. Tamp about 80% of the stake into the bank at a right angle to the slope. Start at the water line and work up slope. Normally the stakes are placed off center in rows, with about 2-6 stakes placed per square yard.
- Plant live stakes in original bank soil, not fill.

Where

- Live stakes are best used in conjunction with other bank stabilization techniques, but may be used alone on banks with limited active erosion.
- All sizes and character types of streams may be planted with live stakes. Normally live stakes are planted on the middle and upper banks.

ADVANTAGES:

- Live stakes effectively protect banks once they become established, providing a permanent, naturally appearing form of bank protection.
- Installation is economical if the cuttings are locally available, and requires minimal labor.
- Effective when construction time is limited.

LIMITATIONS:

- Live stakes offer poor initial bank protection.
- Actively eroding banks, or streambanks subjected to large flow variations are not adequately protected by this technique.
- Combining live stakes with other streambank stabilization techniques is often not feasible.

RELATIVE COST:

- No Information.

SELECTED REFERENCES:

Gray and Leiser 1982; Logan 1979b; Pennsylvania Department of Environmental Resources 1986.

DESCRIPTION:

Mulching is a temporary bank stabilization technique used to protect freshly planted seed and unstable soil from erosion until the vegetation becomes established.

APPLICATION:

How

- Materials which have been used for mulches include: straw, hay, leaves, sawdust, wood shavings, manure, bagasse, paper scraps, cotton refuse, hardwood-bark chips, and annual plant species.
- Straw or clean grass hay is uniformly applied to the bank by a mulch spreader. The straw or hay should be free of mold, fungus, or weed seed.
- Wood chips are spread by hand, mechanical air blower, or manure spreader. They should be free of weed seed, salt, and toxic substances.
- Hydromulches are used to apply a slurry of lime, fertilizer, seed, water, and a tackifier (if used) all in one single application.
- Mulching should be completed within 24 to 48 hours after seeding.

Where

- Woven mesh or net-type mulches (see also Erosion-Control Matting) are generally more effective on the steeper slopes than mulch applied with a spreader.

ADVANTAGES:

- Mulching helps to absorb the erosive impact of rain drops, and reduce sheetwash.
- Mulches help to increase infiltration, reduce runoff, replenish soil moisture, and insulate the soil from extremes in temperature.
- Mulching encourages faster seed germination due to the more thermally moderate and moist environment it promotes.
- Straw mulches are almost as effective as erosion control blankets, and are much more economical.
- Wood-chip mulches are long lasting, resistant to wind movement, and easy to apply.
- Hydromulches have the lowest application cost per acre and are easy to apply. A hydroseeder can apply mulches and treatments to more than 5 acres in about 30 minutes.

LIMITATIONS:

- Artificial fiber-type mulches are usually ineffective without supplemental irrigation, and their use should be discouraged.
- Some mulches, especially if incorporated into the soil, may deplete the soil nitrogen through the microbial action on cellulose.
- Hydromulches have not been as effective at controlling soil erosion as originally anticipated. Additional testing is needed to determine the optimum combination of hydromulch and chemical stabilizers.

RELATIVE COST:

- Straw and tackifier mulches cost from $277 to $604 per acre (1977), including the cost of materials only.
- Hydromulches cost from $84 to $120 per acre (1977), includes the cost of materials only.

SELECTED REFERENCES:

Logan 1979b; Long et al. 1984; Schnick et al. 1982.

DESCRIPTION:

Reed rolls are a planting technique similar to sod planting, and is used to establish vegetation on streambanks by planting rolled-up sections of sod, rhizomes and shoots.

APPLICATION:

How

- Placement should occur during dormancy, preferably just before the growing season starts.
- Wire netting is stretched across a trench dug about 16" wide in the bank. The plant material (sod, rhizomes, and shoots) is placed onto the netting, along with coarse gravel. Then the netting is rolled up, tied with wire, and laid into the trench.
- A row of stakes is used to attach the roll to the bank until the plants become rooted.

Where

- Reed rolls should only be established where water level fluctuations are minor, and where bedload movement is minimal.
- Reed rolls can be used to establish vegetation along the average water line.

ADVANTAGES:

- Reed rolls provide bank protection immediately after placement.

LIMITATIONS:

- More labor is required to place reed rolls than with clump plantings.
- Placement is limited to during the dormant season.

RELATIVE COST:

- Costs are considered to range from cheap to moderate.

SELECTED REFERENCES:

Logan 1979b; Schiechtl 1980.

ROOT PADS

DESCRIPTION:

Root pads are a technique used to establish vegetation by transplanting large clumps of woody plants to the bank.

APPLICATION:

How

- A front-end loader or "Veimeer" type spade is used to transplant the large clumps of woody plants, or whole trees up to 4 inches in diameter.
- On slopes greater than 6:1, the root pads should be staked to the bank.
- Root pads should be placed as soon as possible after seedbed preparation. The best time to place root pads is late fall or early spring, but not when the ground is frozen.
- Woody plants from 4 to 6 feet tall appear to have better survival when planted with a front-end loader than do larger woody plants (>10 ft) with deep tap roots.
- Several species of woody plants have been transplanted with this technique including willow, red osier dogwood, cottonwood, rose, hawthorn, and silver buffaloberry.

Where

- Root pads are used on a supplemental basis for the lower, middle, and upper banks.

ADVANTAGES:

- Mature shrubs and tree can be placed on site immediately.
- Commercially unavailable species, or locally adapted stock can be planted.

LIMITATIONS:

- The area used to provide the root pads may be permanently degraded by the removal of the pads.
- The soil surface must be smooth and free of debris so the root pad will contact the soil properly.
- Revegetating large areas with root pads may not be feasible.

RELATIVE COST:

- Costs will vary, depending upon the distance from the root-pad source to the planting site. Three pads per hour were dug, moved, and planted in one field trial.
- Requires 25-40% less labor than for planting commercially available shrubs and trees.

SELECTED REFERENCES:

Logan 1979b; Long et al. 1984.

DESCRIPTION:

Sod planting is a technique used to establish vegetation by removing sections of grass or herbaceous plants from existing beds, and then transplanting the sections to the disturbed bank.

APPLICATION:

How

- Plugs 2-4 inches wide by 4-6 inches long are placed into depressions made in the bank. The aerial portions of the plants should be exposed after the plug is placed in the bank.
- Alternatively, large rolls of sod can be placed onto banks requiring more critical surface stability.
- Sod can be stored for a limited time period if protected from drying and freezing, otherwise it should be placed within 24 hours of cutting.
- Sod should not be placed when the soil is frozen.
- Stakes are used to hold the sod to the bank until the plants become rooted into the bank.

Where

- No Information.

ADVANTAGES:

- Sodding can be used to rapidly establish vegetation.

LIMITATIONS:

- The soil surface must be smooth and free of debris so the sod will contact the soil properly.
- Sod will not withstand high velocity or severe abrasion from sediment.
- Sodding is labor intensive and may require supplemental watering.
- Sodding may not be feasible for revegetating large areas.

RELATIVE COST:

- Sodding is more expensive than seeding.

SELECTED REFERENCES:

Logan 1979b; Long et al. 1984.

DESCRIPTION:

Sprigging is used to establish vegetation by planting the rhizomes and shoots of reeds and grasses into holes or narrow trenches on the bank. This method should provide a greater chance of establishment under severe physical and physiological conditions than seeding, because roots are more mature and have more carbohydrate reserves than seeds.

APPLICATION:

How

- The best time to plant is during dormancy.
- The rhizomes and shoots of reeds and grasses are placed into holes or narrow trenches approximately 10 cm deep, so that only the aerial portions are above the soil.
- Cultivation loosens the soil and breaks-up native sod (may be undesirable for bank stabilization), and controls weeds.
- Weed control (herbicides, cultivation) should be used for a couple of years after planting.
- Rhizomes must be covered immediately with firm, moist soil.
- A sprig planter, a machine similar to a potato planter, can be used to plant rhizomes on the more level banks.

Where

- Sprigs can be hand planted along the wet and moderately wet zones of the bank, while a sprig planter can be used to plant the drier sites.

ADVANTAGES:

- Sprigging has successfully established plants on saline-alkaline soils when the site was prepared properly.
- Reeds can be established on the lower banks using this method.
- Sprigging provides the opportunity to establish commercially unavailable plant species.

LIMITATIONS:

- Sprigging is more costly than direct seeding.
- Rhizomes and shoots may be susceptible to damage from flooding during the first year.
- Woody plants with long taproots are usually destroyed when a mechanical sprigger is used.

RELATIVE COST:

- Costs will vary, depending upon the distance from the sprig source to the planting site.
- $60 per acre (1985) for using a sprig planter in Wyoming; $95 per acre if herbicide and fertilizer are included.

SELECTED REFERENCES:

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* Did not respond to our request for streambank stabilization techniques used by their agency.

APPENDIX:

A Streambank Stabilization Bibliography

AUTH Ahrens, J.P.
SORT Ahrens J.P.
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DESC Bank Stabilization, Structure, Revetments, Riprap.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
GEOG
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TITL Synthetic Material Filters in Coastal Protection.
SRCE Proceedings, ASCE 87(WW1):111-123.
DESC Bank Stabilization, Structure, Dikes, Riprap, Revetments.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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AUTH Albertson, M.L., and G.L. Smith.
SORT Albertson M.L., Smith G.L.
YEAR 1957.
TITL Principles of Energy Dissipation on Erosion-Control Structures.
SRCE Colorado Agricultural and Mechanical College, Civil Engineering Department, Fort Collins, Colorado; Prepared as Paper No. 15 for Joint ARS-SCS Irrigation-Drainage Conference, Colorado Springs, Colorado, 14-15 Jan. 1957.
DESC Bank Stabilization, Structure, Revetments.
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GEOG
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AUTH Alders, D.J.
SORT Alders D.J.
YEAR 1973.
TITL New Machines Halt Erosion with Woodchip Mulch.
SRCE Contractors and Engineers Magazine.
DESC Bank Stabilization, Structure, Soil Stabilization.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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AUTH Aldon, E.F.
SORT Aldon E.F.
YEAR 1970.
TITL Fourwing saltbush survival after inundation.
SRCE USDA Forest Service Research Note RM-165, Rocky Mountain Forest and Range Experiment Station. 2pp.
DESC Bank Stabilization, Vegetation, Shrubs.
LOCN Tom Wesche Wyoming Water Research Center (Laramie).
GEOG Regional, Western U.S.
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AUTH Allen, H.H.
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SRCE Soil Conservation 41(9):4-5.
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SRCE Concrete Highways and Public Improvements 35(1):11-12.
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SRCE EPA 440/3-78-003, U.S. Environmental Protection Agency, Washington, D.C.; prepared by California Department of Conservation, Sacramento, Calif.
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AUTH Anderson, A.G.
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SRCE Project Report No. 1, University of Minnesota, St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minn.
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GEOG Regional, Southwestern U.S.
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SRCE Institute of Civil Engineering, Vol. 173.
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AUTH Andrews, E.D.
SORT Andrews E.D.
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SRCE Water Rsources Research 18(4):1184-1192.
DESC Bank Stabilization.
LOCN Quentin Skinner Department of Range Management University of Wyoming (Laramie).
GEOG Water Division 4, Sublette County, Colorado River Basin, Green River Basin, East Fork River.
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AUTH Anonymous?
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YEAR No date.
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SRCE None given (possible USDI-BLM, Rock Springs, Wyoming).
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SRCE California Highways 2(11):8.
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SRCE Engineering New-Record 94(20):822-823.
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GEOG National, International, Canada.
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SRCE Construction Methods 15(10):34-37.
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SRCE Engineering News-Record 115:470-471.
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LOCN Tom Wesche Wyoming Water Research Center (Laramie).
GEOG Water Division 2, Campbell County, Crook County, Missouri River Basin, Belle Fourche River.
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YEAR 1935.
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SRCE Bulletin of the American Engineering Railway Association 37(379):92-95.
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YEAR 1936.
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SRCE Engineering 141(3666):428-429.
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SRCE Wood Preserving News 17(6):70-71.
DESC Bank Stabilization, Structure, Revetments, Riprap.
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YEAR 1939.
TITL Paved Banks Line Channels for Los Angeles River Floods.
SRCE Construction Methods and Equipment 21(7):72.
DESC Bank Stabilization, Structure, Revetments, Riprap.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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YEAR 1939.
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SRCE Southwest Builder and Contractor 94(5):10-13.
DESC Bank Stabilization, Structure, Revetments, Riprap.
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YEAR 1940.
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SRCE Concrete Highways and Public Improvements 21(2):6-7.
DESC Bank Stabilization, Structure, Revetments, Riprap.
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TITL Pile Dike Protects Caving River Bank.
SRCE Contractors and Engineers Monthly 44(8):52-55.
DESC Bank Stabilization, Structure, Revetments.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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YEAR 1948.
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SRCE Rock Products 51(11):80-81.
DESC Bank Stabilization, Structure, Revetments, Riprap.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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SRCE Roads and Streets 91(2):92-94.
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LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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SRCE Railway Engineer and Maintenance 46(8):744-746.
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SRCE Construction Equipment 6(2):30-31.
DESC Bank Stabilization, Structure, Revetments, Riprap.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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YEAR 1955.
TITL Pile Dikes and Riprap Control Bank Erosion.
SRCE Contractors and Engineers 52(1):16-17.
DESC Bank Stabilization, Structure, Revetments, Riprap.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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YEAR 1957.
TITL New Riprap Idea at Ice-Harbor Dam.
SRCE Western Construction 32(1):114.
DESC Bank Stabilization, Structure, Revetments.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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AUTH Anonymous.
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YEAR 1958.
TITL Flood control structures, plus watershed management control Utah's Pleasant Creek.
SRCE Western Conservation Journal 15(4):24-25.
DESC Bank Stabilization, Design Standards, Costs.
LOCN Tom Wesche Wyoming Water Research Center (Laramie).
GEOG Regional, Western U.S.
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YEAR 1960.
TITL How to Wrap Up a Riprap Job.
SRCE Construction Methods and Equipment 42(6):135-136.
DESC Bank Stabilization, Structure, Revetments, Riprap.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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TITL Angular Submerged Tree Planting.
SRCE Canadian Engineer 51(18):606-607.
DESC Bank Stabilization, Structure, Soil Stabilization, Vegetation, Revetments.
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TITL Cold Weather Aids Bank Protection Work.
SRCE Contractors and Engineers 61(10):76.
DESC Bank Stabilization, Structure, Revetments, Riprap.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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AUTH Anonymous.
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TITL New Construction Method Protects River Banks.
SRCE Construction 33(8):66.
DESC Bank Stabilization, Structure, Revetments.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
GEOG
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AUTH Anonymous.
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YEAR 1966.
TITL Snake River Bank Stabilization.
SRCE Journal, Waterways and Harbors Division, Proceedings, ASCE 92(WW1):1.
DESC Bank Stabilization, Structure, Revetments, Riprap.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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SRCE Construction Methods and Equipment.
DESC Bank Stabilization, Structure, Dikes.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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AUTH Anonymous.
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YEAR 1969.
TITL Grout-Filled Mattress System for River Banks.
SRCE Civil Engineering and Public Works Review, Vol 64, No. 752.
DESC Bank Stabilization, Structure, Revetments.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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YEAR 1972.
TITL Sheet Piles Driven Through Ice Stabilized Banks.
SRCE Contractors and Engineers 57(10):38-39.
DESC Bank Stabilization, Structure, Retaining Walls.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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YEAR 1973.
TITL Rubber Riprap on the Riverbank.
SRCE Automotive News 48(4448):11.
DESC Bank Stabilization, Structure, Revetments.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
GEOG
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SORT Anonymous.
YEAR 1973.
TITL Tired of Riprap? Try...
SRCE Pacific Builder and Engineer 79(14):26-27.
DESC Bank Stabilization, Structure, Revetments.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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YEAR 1975.
TITL Quicklime Stabilizes Canal Lining.
SRCE Roads and Streets.
DESC Bank Stabilization, Structure, Soil Stabilization.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
GEOG
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TITL Wood Chips Control Berm Erosion.
SRCE Roads and Streets, p 86.
DESC Bank Stabilization, Structure, Soil Stabilization.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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YEAR 1976.
TITL Ecology Preserved With Gabion Embankment.
SRCE California Builder and Engineer 82(5):18-19.
DESC Bank Stabilization, Structure, Revetments, Gabions.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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TITL Gabions Control Erosion.
SRCE The Military Engineer 68(441):28-29.
DESC Bank Stabilization, Structure, Revetments, Gabions, Retaining Walls.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
GEOG
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AUTH Anonymous.
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YEAR 1977.
TITL Gabions: Modern Resurrection of a Thing of the Past.
SRCE Construction Digest 50(14):20-23.
DESC Bank Stabilization, Structure, Revetments, Dikes, Retaining Walls, Gabions.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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TITL New Erosion Controls Work Well, Look Good.
SRCE Highway and Heavy Construction, p. 56.
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LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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YEAR 1977.
TITL Is Riprap Being Miscalculated?
SRCE New Civil Engineer, p 7.
DESC Bank Stabilization, Structure, Revetments, Riprap.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
GEOG
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AUTH Anonymous.
SORT Anonymous.
YEAR 1978.
TITL A Soil Cement Extravaganza.
SRCE Construction Contracting, McGraw-Hill, New York, N.Y., p 31-32.
DESC Bank Stabilization, Structure, Soil Stabilization, Soil Cement.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
GEOG
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YEAR 1978.
TITL Erosion Control Devices, Methods, and Practices.
SRCE Highway and Heavy Construction, pp. 25-34.
DESC Bank Stabilization, Structure, Revetments, Riprap, Gabions, Vegetation, Soil Stabilization, Retaining Walls.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
GEOG
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YEAR 1978.
TITL Fighting an Uphill Battle Against Washouts and Slides.
SRCE Construction Contracting, McGraw-Hill, New York, N.Y., pp 64-65.
DESC Bank Stabilization, Structure, Revetments.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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SORT Anonymous.
YEAR 1978.
TITL Fabric Forms, Mortar Simplify Slope Paving, State of the Art Report.
SRCE Highway and Heavy Construction.
DESC Bank Stabilization, Structure, Revetments.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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AUTH Anonymous.
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YEAR 1978.
TITL Vegetation a Bluff Stabilization Technique.
SRCE Lake Michigan Current, p 3.
DESC Bank Stabilization, Structure, Soil Stabilization, Vegetation.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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AUTH Anonymous.
SORT Anonymous.
YEAR 1979.
TITL Mortar-Filled Fabric Mattress Guards Bridges in Flood Programs.
SRCE Rural and Urban Roads, pp 58-59.
DESC Bank Stabilization, Structure, Revetments.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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AUTH Anonymous.
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TITL Slope Paving Placed Under Water.
SRCE Highway and Heavy Construction.
DESC Bank Stabilization, Structure, Revetments.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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SORT Anonymous.
YEAR 1980.
TITL Corps Breaks in Soil-Cement as New Riverbank Riprap.
SRCE Engineering News Record 205(10):11.
DESC Bank Stabilization, Structure, Revetments, Soil Cement.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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AUTH Anonymous.
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YEAR 1980.
TITL Mats Help Colliery Waste Support a Wall.
SRCE New Civil Engineer, p 20.
DESC Bank Stabilization, Structure, Retaining Walls.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
GEOG
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AUTH Anonymous.
SORT Anonymous.
YEAR 1980.
TITL Reinforced Earth Research and Practice.
SRCE Ground Engineering 13(4):17-27.
DESC Bank Stabilization, Structure, Retaining Walls.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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AUTH Anonymous.
SORT Anonymous.
YEAR 1983.
TITL Beavers: a dam site better on erosion.
SRCE Science '83 4(9):7.
DESC Bank stabilization, Beavers.
LOCN Medin and Torqemada 1988.
GEOG Regional, Southwestern Wyoming, Utah.
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AUTH Anonymous.
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YEAR 1983
TITL Beavers enlisted by BLM.
SRCE Blair and Ketchums Country Journal 10:35.
DESC Bank Stabilization, Beavers.
LOCN Medin and Torqemada 1988.
GEOG Statewide, Muddy Creek.
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AUTH Anonymous.
SORT Anonymous.
YEAR 1984.
TITL New faith in beaver ecology.
SRCE Science Digest 92(7):36.
DESC Bank Stabilization, Beavers.
LOCN Medin and Torquemada 1988.
GEOG Water Division 4, Colorado River Basin, Green River, Current Creek.
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AUTH Anonymous.
SORT Anonymous.
YEAR 1987.
TITL Erosion control along the Rio Grande.
SRCE Irrigation Journal, March/April 1987. (Reprinted in 1988 by USDI Bureau of Reclamation, Water Operation and Maintenance Bulletin No. 143, pp. 18-22).
DESC Bank Stabilization, Structural, Revetments, Costs.
LOCN Tom Wesche Wyoming Water Research Center (Laramie).
GEOG National.
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AUTH Anseth, B.
SORT Anseth B.
YEAR 1983.
TITL Rancher fences creek to slow erosion.
SRCE Rangelands 5(5):204.
DESC Bank Stabilization, Structure, Riprap, Grazing, Fences.
LOCN Tom Wesche Wyoming Water Research Center.
GEOG Regional, Western U.S.
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AUTH Apple, L.L.
SORT Apple L.L.
YEAR 1985.
TITL Riparian habitat restoration and beavers.
SRCE Riparian ecosystems and their management: reconciling conflicting uses. R.R. Johnson et al., eds. USDA Forest Service General Technical Report RM-120. pp 489-490.
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GEOG Regional, Western U.S.
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AUTH Armstrong, J.M., and R.C. Petersen.
SORT Armstrong J.M., Petersen R.C.
YEAR 1978.
TITL Tire Module Systems in Shore and Harbor Protection.
SRCE Journal, Waterway, Port, Coastal and Ocean Division, ASCE 104 (WW4):351-374.
DESC Bank Stabilization, Structure, Revetments.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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AUTH Arnold, R.
SORT Arnold R.
YEAR 1974.
TITL Pulp Industry Taps New Fiber Source - Hardwoods.
SRCE Western Conservation Journal, pp 16-21.
DESC Bank Stabilization, Structure, Soil Stabilization.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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AUTH Atkins, M.D.
SORT Atkins M.D.
YEAR 1957.
TITL Permanent waterways.
SRCE Crops and Soils 10:14-15.
DESC Back Stabilization, Vegetation, Grasses, Grassed Waterways, Bromegrass, Wheatgrass.
LOCN Tom Wesche Wyoming Water Research Center (Laramie).
GEOG Regional, Central U.S.
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AUTH Atkins, M.D., and J.J. Coyle.
SORT Atkins M.D., Coyle J.J.
YEAR 1960.
TITL Grass Waterways in Soil Conservation.
SRCE USDA Leaflet No. 477, U.S. Government Printing Office, Washington, D.C.
DESC Bank Stabilization, Vegetation, Soil Stabilization.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
GEOG
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AUTH Bailey, R.W., and O.L. Copeland.
SORT Bailey R.W., Copeland O.L.
YEAR 1961.
TITL Vegetation and Engineering Structures in Flood and Erosion Control.
SRCE U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT. Paper Presented at 13th Congress of International Union of Forest Research Organizations, Viena, Austria. Sept. 10-17, 1961.
DESC Bank Stabilization, Vegetation, Soil Stabilization.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
GEOG
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AUTH Barnes, R.C., Jr.
SORT Barnes R.C. Jr.
YEAR 1963 (1968?).
TITL Streambank Erosion.
SRCE Soil Conservation 33(6):126-128.
DESC Bank Stabilization.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
GEOG
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AUTH Barnes, R.C., Jr.
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YEAR 1971.
TITL Erosion Control Structures.
SRCE River Mechanics II, Institute on River Mechanics, Colorado State University, H.W. Shen, ed., Fort Collins, Colorado, 1971.
DESC Bank Stabilization, Structure, Revetments, Riprap.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
GEOG
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AUTH Barsdale, R.W.
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YEAR 1960.
TITL Bank Protection on Central Valley Streams.
SRCE Journal, Waterways and Harbors Division, ASCE 86(WW4):1-15.
DESC Bank Stabilization, Structure, Revetments, Riprap, Design Standards, Costs, Filter Fabrics, Soil Stabilization.
LOCN Tom Wesche Wyoming Water Research Center (Laramie), Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
GEOG National.
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AUTH Bartles, H.
SORT Bartles H.
YEAR 1971.
TITL Gabion Weir at Dimbulah.
SRCE Queensland Agricultural Journal 97(12):627-632.
DESC Bank Stabilization, Structure, Revetments, Gabions.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
GEOG
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AUTH Bartlett, D., and J. Bartlett.
SORT Bartlett D., Barteltt J.
YEAR 1974.
TITL Nature's aquatic engineers: beavers.
SRCE National Geographic 145(5):716-732.
DESC Bank Stabilization, Beavers.
LOCN Quentin Skinner Department of Range Management University of Wyoming (Laramie).
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SRCE Roads and Streets 70(5):171-172.
DESC Bank Stabilization, Structure, Revetments, Gabions.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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TITL Streambank Stabilization in Michigan - A Survey.
SRCE USDA Forest Service, Station Paper 84. Lake States Forest Experiment Station and Michigan Department of Conservation. 14 pp.
DESC Bank Stabilization, Vegetation, Grasses, Trees, Willow Trees, Grazing, Livestock, Cattle, Recreation, Structure, Riprap.
LOCN Tom Wesche Wyoming Water Research Center (Laramie).
GEOG Regional, Michigan.
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GEOG Regional, Western U.S.
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DESC Bank Stabilization, Structure, Revetments, Riprap, Vegetation, Soil Stabilization.
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SRCE Journal of the Waterways and Harbors Division, ASCE 91(WW1):7-37.
DESC Bank Stabilization, Design Standards, Glossaries, Structure, Dikes, Groins, Jacks, Jetties, Revetments, Vegetation.
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GEOG National, Water Division 3, Fremont County, Missouri River Basin, Big Horn River Basin, Five Mile Creek, Muddy Creek.
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TITL Stabilization of an Eroded River Bank.
SRCE Journal, Soil and Water Conservation 22(6):249-250.
DESC Bank Stabilization, Structure, Revetments, Riprap, Dikes, Vegetation, Soil Stabilization.
LOCN Tom Wesche Wyoming Water Research Center (Laramie), Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
GEOG Regional, Midwest, Michigan.
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AUTH Temple, D.M.
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TITL Tractive, Force Design of Vegetated Channels.
SRCE Paper No. 79-2068, American Society of Agricultural Engineers and Canadian Society of Agricultural Engineering, Joint Summer Meeting, University of Manitoba, Winnipeg, Canada.
DESC Bank Stabilization, Structure, Soil Stabilization, Vegetation.
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GEOG National.
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GEOG National.
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SRCE Transactions of the ASCE 26(4):1064-1069.
DESC Bank Stabilization, Vegetation, Grasses, Grassd Waterways, Design Standards, Bermudagrass, Legumes.
LOCN Tom Wesche Wyoming Water Research Center (Laramie).
GEOG National.
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YEAR 1986.
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SRCE Journal of Hydraulic Engineering 112(3):193-205.
DESC Bank Stabilization, Grasses, Grassed Waterways, Theoretical Analysis.
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YEAR 1987.
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SRCE USDA Agriculture Handbook 667, 175 pp.
DESC Bank Stabilization, Vegetation, Grassed Waterways, Grasses, Wheat, Barley, Oats, Bromegrass, Wheatgrass, Bermudagrass, Design Standards.
LOCN Quentin Skinner Department of Range Management University of Wyoming (Laramie).
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YEAR 1978.
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GEOG Regional, Great Plains.
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GEOG National, Regional, Great Lakes Region.
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SRCE Journal of Hydraulic Engineering 114(2):151-172.
DESC Bank Stabilization, Theoretical Analysis.
LOCN Quentin Skinner Department of Range Management University of Wyoming (Laramie).
GEOG National.
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YEAR 1973.
TITL Comparative Costs of Erosion and Sediment Control, Construction Activities.
SRCE EPA-430/9-73-016, U.S. Environmental Protection Agency, Office of Water Programs, U.S. Government Printing Office, Washington, D.C.
DESC Bank Stabilization, Structure, Revetments, Gabions, Riprap, Soil Stabilization, Check Dams.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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TITL Bank stabilization of Mississippi River between the Ohio and Missouri Rivers.
SRCE Proceedings of the Federal Inter-Agency Sedimentation Conference, Jackson, Mississippi, 28 January - 1 February 1963. USDA Miscellaneous Publication No. 970. pp. 387-399
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GEOG Regional, Middle Mississippi River Basin.
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SRCE Committee on Channel Stabilization, Technical Report No. 2, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
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SRCE California Highways and Public Works 17(8):10-12.
DESC Bank Stabilization, Structure, Revetments, Jacks.
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SRCE Pacific Road Builder and Engineering Review 51(1):31-34.
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LOCN Tom Wesche Wyoming Water Research Center (Laramie).
GEOG National.
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TITL Verification of Empirical Method for Determining Riverbank Stability, 1970 and 1971 Data.
SRCE Potamology Investigations Report 12-22, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
DESC Bank Stabilization.
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SRCE Engineering News-Record 119:759-761.
DESC Bank Stabilization, Structure, Revetments.
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GEOG
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YEAR 1966.
TITL Bank Erosion in Soils of the Lower Mississippi Valley.
SRCE Journal, Soil Mechanics and Foundation Engineering Division ASCE 92(SM1):121-136.
DESC Bank Stabilization.
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YEAR 1976.
TITL Control of Water Erosion, Wind Erosion, and Sedimentation.
SRCE ARS-NRP No. 20800, Washington, D.C.
DESC Bank Stabilization, Structure, Check Dams.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss.).
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SORT U.S. Army Corps of Engineers.
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TITL The Streambank Erosion Control Evaluation and Demonstration Act of 1974.
SRCE Interim Report to Congress.
DESC Bank Stabilization, Structure, Revetments.
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GEOG
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SORT U.S. Army Corps of Engineers.
YEAR 1966.
TITL Channel Stabilization Publications Available in Corps of Engineers Offices.
SRCE Technical Report No. 4, Vicksburg, Miss.
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SRCE Office, Chief of Engineers, U.S. Army, Washington, D.C. Various Pagnation.
DESC Bank Stabilization, Bibliographies, Glossaries, Structure, Riprap, Dikes, Jacks, Vegetation, Gabions, Theoretical Analysis, Revetments, Costs, Retaining Walls, Soil Cement, Soil Stabilization, Suppliers, Check Dams.
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SRCE Office, Chief of Engineers, U.S. Army, Washington, D.C. Various Pagination.
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SRCE Office, Chief of Engineers, U.S. Army, Washington, D.C.
DESC Bank Stabilization, Theoretical Analysis, Soil Stabilization, Vegetation, Structure, Revetments, Riprap, Filter Fabrics.
LOCN Tom Wesche Wyoming Water Research Center (Laramie) - Summaries Only.
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SRCE Office, Chief of Engineers, U.S. Army, Washington, D.C. Various Pagination.
DESC Bank Stabiliztion, Design Standards.
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GEOG Regional, Ohio River.
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SRCE Office, Chief of Engineers, U.S. Army, Washington, D.C. Various Pagination.
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GEOG Regional, Missouri River.
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TITL Final Report to Congress: The Streambank Erosion Control Evolution and Demonstration Act of 1974, Section 32, Public Law 93-251, Appendix F: Yazoo River Basin Demonstration Projects.
SRCE Office, Chief of Engineers, U.S. Army, Washington, D.C.
DESC Bank Stabilization, Structure, Jacks, Riprap, Revetmetns, Vegetation, Trees, Willow Trees, Dikes, Costs, Check Dams, Retaining Walls, Theoretical Analysis, Birch Trees, Shrubs, Grasses.
LOCN Tom Wesche Wyoming Water Research Center (Laramie) - Summaries Only.
GEOG Regional, Tennessee, Mississippi, Yazoo River.
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AUTH U.S. Army Corps of Engineers.
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YEAR 1981.
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SRCE Office, Chief of Engineers, U.S. Army, Washington, D.C. Various Pagination.
DESC Bank Stabilization, Vegetation, Structure, Riprap, Dikes, Revetments Gabions, Jacks, Soil Cement.
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GEOG National, Regional, Lower Yellowstone River.
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AUTH U.S. Army Corps of Engineers.
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YEAR 1981.
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SRCE Office, Chief of Engineers, U.S. Army, Washington, D.C. Various Pagination.
DESC Bank Stabilization, Structure, Riprap, Vegetation, Revetments, Gabions, Dikes, Soil Cement, Jacks, Filter Fabric.
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GEOG National.
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AUTH U.S. Army Corps of Engineers.
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YEAR 1986.
TITL Specifications (For Construction Contract), Solicitation No. DACW45-86-B-0086. Emergency Streambank Protection, Marne Creek, Yankton, South Dakota.
SRCE U.S. Army Corps of Engineers, Omaha District. Various Pagination.
DESC Bank Stabilization, Structure, Revetments, Design Standards, Vegetation, Grasses, Wheatgrass.
LOCN Tom Wesche Wyoming Water Research Center (Laramie).
GEOG Regional, South Dakota.
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AUTH U.S. Army Corps of Engineers.
SORT U.S. Army Corps of Engineers.
YEAR 1987.
TITL Operation and Maintenance Manual: South Platte River Near Fort Lupton, Colorado. Section 14 Emergency Streambank Protection.
SRCE U.S. Army Corps of Engineers, Omaha District. 15 pp + 7 exhibits and 3 plates.
DESC Bank Stabilization, Structure, Design Standards.
LOCN Tom Wesche Wyoming Water Research Center (Laramie).
GEOG Regional, South Platte River.
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AUTH U.S. Army Engineer District, Portland.
SORT U.S. Army Engineer District, Portland.
YEAR 1946.
TITL Report on Experiment Slope Protection for River Banks and Levees.
SRCE U.S. Army Engineer District, Portland, Oregon.
DESC Bank Stabilization.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
GEOG
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AUTH U.S. Army Engineer District, Rock Island, CE.
SORT U.S. Army Engineer District Rock Island CE.
YEAR 1980.
TITL Streambank Erosion Control Methods.
SRCE U.S. Government Printing Office, Washington, D.C.
DESC Bank Stabilization, Structure, Revetments, Soil Stabilization, Vegetation, Dikes, Riprap, Gabions.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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AUTH U.S. Army Engineer Waterways Experiment Station, CE.
SORT U.S. Army Engineer Waterways Experiment Station CE.
YEAR 1933.
TITL Investigations of Certain Proposed Methods of Bank and Embankment Protection.
SRCE Waterways Experiment Station Paper No. 12.
DESC Bank Stabilization, Structure, Revetments.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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AUTH U.S. Army Engineer Waterways Experiment Station, CE.
SORT U.S. Army Engineer Waterways Experiment Station CE.
YEAR 1964.
TITL Feasibility Study of Improved Methods for Riverbank Stabilization.
SRCE Contract Report 3-81, Vicksburg, Miss.; prepared by Harza Engineering Co., Chicago, Ill.
DESC Bank Stabilization.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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AUTH U.S. Bureau of Land Management.
SORT U.S. Bureau of Land Management.
YEAR No Date.
TITL Riparian Area Management.
SRCE USDI Bureau of Land Management. 4 pp.
DESC Bank Stabilization, Grazing, Vegetation, Beavers.
LOCN Quentin Skinner Department of Range Management University of Wyoming (Laramie).
GEOG Regional, Western U.S.
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SORT U.S. Bureau of Land Management.
YEAR 1968.
TITL Stream preservation and improvement.
SRCE USDI Bureau of Land Management, Washington, D.C., Manual 6760. 39 pp. + illustrations + appendix.
DESC Bank Stabilization, Check Dams, Gabions, Fencing, Riprap, Design Standards, Structure.
LOCN Tom Wesche Wyoming Water Research Center (Laramie).
GEOG National.
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AUTH U.S. Bureau of Reclamation, Region 7.
SORT U.S. Bureau of Reclamation Region 7.
YEAR 1963.
TITL Frenchman Creek Channelization Studies.
SRCE Prepared by Hydrology Branch and Office Engineering Branch, Kansas River Projects, McCook, NE.
DESC Bank Stabilization, Structure, Revetments.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss.).
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AUTH U.S. Bureau of Reclamation, Upper Missouri Region.
SORT U.S. Bureau of Reclamation Upper Missouri Region.
YEAR 1974.
TITL Lower Yellowstone Riverbank Stabilization Program.
SRCE Review Board Report, Billings, Mont.
DESC Bank Stabilization, Structure, Dikes.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss.).
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AUTH U.S. Department of Transportation, Federal Highway Administration.
SORT U.S. Department of Transportation Federal Highway Administration.
YEAR 1978.
TITL Control of Slope Erosion Using Fiberglass Roving with Vegetation.
SRCE Report No. FHWA-CA-TL-78-4, Washington, D.C.; prepared by California Department of Transportation, Sacramento, Calif.
DESC Bank Stabilization, Structure, Soil Stabilization, Vegetation.
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AUTH U.S. Environmental Protection Agency.
SORT U.S. Environmental Protection Agency.
YEAR 1972.
TITL Guidelines for Erosion and Sediment Control Planning and Implementation.
SRCE EPA-R2-72-015, U.S. Government Printing Office.
DESC Bank Stabilization, Structure, Revetments.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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YEAR 1973.
TITL Processes, Procedures, and Methods to Control Pollution Resulting From All Construction Activities.
SRCE EPA 430/9-73-007, U.S. Government Printing Office; Prepared by Hittman Associates, Inc., Columbia, Md.
DESC Bank Stabilization, Structure, Revetments, Riprap.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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YEAR 1975.
TITL Methods of Quickly Vegetating Soils of Low Productivity, Construction Activities.
SRCE EPA 440/9-75-006, U.S. EPA Office of Water Planning and Standards, Washington, D.C.
DESC Bank Stabilization, Structure, Revetments, Vegetation.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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AUTH U.S. Environmental Protection Agency.
SORT U.S. Environmental Protection Agency.
YEAR 1976.
TITL Erosion and Sediment Control, Surface Mining in the Eastern U.S.
SRCE EPA-625/3-76-006 (in two volumes), Washington, D.C.
DESC Bank Stabilization, Structure, Soil Stabilization, Vegetation.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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AUTH U.S. Environmental Protection Agency, Office of Water Programs.
SORT U.S. Environmental Protection Agency Office of Water Programs.
YEAR 1971.
TITL Control of Erosion and Sediment Deposition From Construction of Highways and Land Development.
SRCE U.S. Government Printing Office.
DESC Bank Stabilization, Structure, Revetments, Riprap.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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AUTH U.S. Forest Service.
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YEAR 1969.
TITL Watershed Structural Measures Handbook.
SRCE USDA Forest Service Handbook No. 2509.12, U.S. Government Printing Office, Washington, D.C.
DESC Bank Stabilization, Structure, Retaining Walls, Gabions.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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AUTH U.S. Soil Conservation Service.
SORT U.S. Soil Conservation Service.
YEAR Not Available.
TITL Standard Engineering Job Plans for Streambank Protection (5); List of Plans: 1. Guide, Plan, 2. Riprap, 3. Riprap with trees in bottom of Riprap, 4. Riprap with trees at top of Riprap, 5. Tree revetment with/without riprap, 6. Fencing and plantings.
SRCE USDA Soil Conservation Service, Federal Building Room 3124, 100 East B Street, Casper, WY 82601.
DESC Bank Stabilization, Design Standards, Riprap, Revetments, Vegetation, Structure.
LOCN Tom Wesche Wyoming Water Research Center (Laramie).
GEOG Statewide.
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AUTH U.S. Soil Conservation Service, Engineering and Watershed Planning Unit.
SORT U.S. Soil Conservation Service.
YEAR 1959.
TITL Streambank Protection.
SRCE Technical Release EWP-No. 3, Upper Darby, PA.
DESC Bank Stabilization, Structure, Soil Stabilization, Vegetation.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss.).
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AUTH U.S. Soil Conservation Service.
SORT U.S. Soil Conservation Service.
YEAR 1975.
TITL Wyoming construction specification for (11.0) rock-filled gabions or mattresses.
SRCE Technical Guide Section IVB, USDA Soil Conservation Service, Casper, WY. 3 pp.
DESC Bank Stabilization, Design Standards, Gabions, Structure.
LOCN Tom Wesche Wyoming Water Research Center (Laramie), USDA Soil Conservation Service (Casper).
GEOG Statewide.
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AUTH U.S. Soil Conservation Service.
SORT U.S. Soil Conservation Service.
YEAR 1979.
TITL Plant Materials for Conservation.
SRCE Program Aid No. 1219, U.S. Government Printing Office, Washington, D.C.
DESC Bank Stabilization, Structure, Soil Stabilization, Vegetation.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss.).
GEOG
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AUTH U.S. Soil Conservation Service.
SORT U.S. Soil Conservation Service.
YEAR 1980.
TITL A Guide to: Conservation Plantings on Critical Erosion Areas.
SRCE USDA Soil Conservation Service, Syracuse, New York. 31 pp.
DESC Bank Stabilization, Vegetation, Grasses, Bromegrass, Shrubs, Trees, Willow Trees, Legumes.
LOCN Tom Wesche Wyoming Water Research Center (Laramie).
GEOG Regional, Eastern U.S.
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AUTH U.S. Soil Conservation Service.
SORT U.S. Soil Conservation Service.
YEAR 1983.
TITL Streambank and shoreline protection (580).
SRCE USDA-SCS-WY, F.O. Standards and Specifications, Technical Guide, Section IV, Revised January 1983. 4 pp.
DESC Bank Stabilization, Design Standards.
LOCN Tom Wesche Wyoming Water Research Center (Laramie), USDA Soil Conservation Service (Casper).
GEOG Statewide.
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AUTH University of Arizona, School of Renewable Natural Resources.
SORT University of Arizona School of Renewable Natural Resources.
YEAR 1976.
TITL Selected References on Soil Erosion.
SRCE WAMIS Abstract No. 3, Tucson, AZ.
DESC Bank Stabilization, Bibliographies.
LOCN Hydraulics Laboratory U.S. Army Engineer Waterways Experiment Station (Vicksburg, Miss).
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