A LITERATURE REVIEW OF RIPARIAN REVEGETATION TECHNIQUES

NECHAKO FISHERIES CONSERVATION PROGRAM

Report No. RM90-3.1

Prepared by:
Triton Environmental Consultants Ltd.

April 1993

Contents

List of Figures

List of Tables

List of Appendices

ABSTRACT

Literature concerning bioengineering approaches, which use vegetation to stabilize slopes and streambanks, was reviewed to identify revegetative techniques which could be applied to the upper Nechako River and its tributaries as a means of controlling sediment input. Re-establishing a healthy riparian habitat has the benefit of improving salmonid habitat. Few examples of the use of revegetative techniques to control erosion exist in North America, and fewer exist for British Columbia, although several have been widely employed in Europe since prior to the turn of the century. Identified revegetation techniques can be classified into methods for: shoreline protection, reconstructing streambanks, and slope stabilization. Techniques reviewed include methods to propagate vegetation and structural methods which incorporate propagative materials. Selecting the appropriate vegetation involves numerous criteria, but shrubs and grasses are most often recommended for streambank stabilization. Several species ideal for revegetation are native to British Columbia as well as the upper Nechako River watershed, particularly species within the genus *Salix* (willows), *Alnus* (alders), *Festucas,* (fescues), *Carex* (sedges), and *Trifolium* (clovers).

INTRODUCTION

In response to the expected lower-flow regime in the Nechako River following the Kemano Completion Project, the Nechako Fisheries Conservation Program (NFCP) Technical Committee has recognized that it may be prudent to control input of sediments from certain sources, especially tributary streams. The purpose of this literature review is to identify revegetative bank stabilization techniques and assess their applicability for use on the Nechako River.

Revegetation of riparian zones is an effective means of stabilizing eroding riverbanks, a major source of sediment. Rehabilitation of slopes and streambanks by revegetative techniques has been successfully used in Europe since prior to the turn of this century (Schiechtl 1980). These techniques are relatively new to North America but there are many examples where they have been employed (Mills and Tress 1988, Klingeman and Bradley 1976, Altpeter 1944). Most of these examples come from research conducted in the United States, initiated by Roosevelt's erosion control program during the 1930's (Keown 1983). More recently, the United States Army Corps of Engineers has studied methods to control streambank erosion mandated by the United States government's *Streambank Erosion Control and Evaluation Act* of 1974. This work generally involved structural methods as opposed to vegetative methods to control erosion. Various studies into methods for managing and rehabilitating riparian vegetation have been completed by the U.S. Forest Services, the Environmental Protection Agency and state and municipal agencies.

Much of the revegetative techniques performed in British Columbia are connected to slope protection along highways by hydroseeding. There is little documented information concerning revegetative rehabilitation of streambanks in Canadian streams and nothing concerning previous work completed on the Nechako River. Envirocon Ltd. revegetated parts of the Fraser River estuary in British Columbia in 1980, but this project was designed to provide suitable wetland habitat for fish and wildlife by planting sedges along river foreshore. Terrasol Consultants Ltd. revegetated sections of the Coldwater River (British Columbia) with willow cuttings with mixed success. Canadian Pacific used vegetation to stabilize slopes along double tracked sections of railroad in Glacier National Park (Butler 1990). The Shuswap Tribal Council is presently involved in a program of stabilizing streambanks with rooted Redosier Dogwood cuttings along Deadman Creek (a tributary of the Thompson River), results of which are still being reported (D. Moore; pers. comm.). Finally, a handbook for protecting fish habitat, related to work completed by Envirowest Consultants Ltd, includes references to revegetation of riparian zones along streams in British Columbia (Adams and Whyte 1990).

Information gathered on revegetation techniques and the types of plant species used in these techniques will be valuable in developing a testing program that can be implemented in the Nechako River watershed. Rehabilitating riparian vegetation in areas of erosion through revegetative rehabilitation can also benefit salmonids by improving water quality, reducing water temperatures, increasing food sources (such as invertebrates) and provide valuable overhead cover (Debano and Schmidt 1989, Platts and Rinne 1985, Knight and Bottoroff 1984, Mahoney and Erman 1984, Baltz and Moyle 1984).

METHODS

A series of keywords were used to create a computer program to search three data bases for the information used in this literature review. The program was designed to first select sources containing the words stream(s), creek(s), or river(s) in their titles or associated descriptions. This data was then searched for references to slope(s, ed), bank(s, ed), riverbank(s, ed), and riverside. The resulting information was again sorted to include sources with references to erosion, control, stability, protection, reclamation or reclaim. The last step was to select, from the last list of sources, any literature which included information concerning vegetation, revegetation, riparian, shrub(s, ed), tree(s, ed), plant(s, ed) and/or bioengineering.

This computer program was used to search three data bases. These included: The National Technical Information Service (NTIS); the Biosciences Information Service (BIOSIS PREVIEWS) and; the Geological Reference File (GEOREF). Each data base yielded a number of articles, manuscripts, and reports referenced by titles, authors, publishers, date published and descriptions of the material contained in each source. In some instances, articles deemed relevant to this review were located and read. In other instances, data bases were re-entered to extract abstracts to allow more accurate selections of reading material.

A total of 192 references were gathered from all three data bases. BIOSIS provided a list of 93 of these sources, of which 16 were reviewed and 4 were used as references for this report. Fifty-four references were listed by the NTIS search (17 reviewed and 8 used) and 45 references came from GEOREF (6 reviewed and 1 used).

In some instances, certain titles were found in more than one data base. The NTIS database also provided a reference to a bibliography containing 300 titles, including abstracts of sources concerning soil erosion published between 1977 and 1985.

In addition to literature obtained from the above methods, the University of British Columbia's Library Catalogue was searched for all subjects related to erosion, streams, rivers, streambanks, riverbanks, vegetation, revegetation, bioengineering and riparian vegetation.

REVEGETATION AS A METHOD TO CONTROL STREAMBANK EROSION

Criteria for Selecting Revegetation as an Erosion Control Method

Erosion can be controlled by vegetation, bank shaping, or engineered structures. Selecting the correct method depends upon the hydrology and geomorphology of the targeted stream, the effectiveness of the method to control erosion related to stream hydrology, and the cost-benefit analysis of the planned erosion control method (Gray and Leiser 1982, Klingeman and Bradley 1976, Keown et al. 1977).

Vegetation has many advantages over structures as a method for control of eroding streambanks. For example, it is less expensive than engineered methods, it is aesthetically pleasing, it regenerates itself, it requires less maintenance and it can often be implemented in areas not accessible to equipment sometimes necessary for construction and placement of structures.

There are limits determining the effectiveness of vegetation for stabilizing streambanks. Generally, the larger the stream, the less effect vegetation has in stabilizing a bank (Mills and Tress 1988, Bowie 1982, Klingeman and Bradley 1976). In such large streams however, vegetation can help stabilize erosion control structures used in critical areas and can still be used effectively to control sedimentation and erosion in non-critical sections (Schiechtl 1980, Keown et al. 1977, Klingeman and Bradley 1976). Early application of vegetative methods to control erosion is also important. If erosion is allowed to continue unchecked, it may exceed the point which precludes vegetation as a viable control alternative and structural methods may have to be employed (Klingeman and Bradley 1976).

It is important to first describe and classify a riparian area that has been degraded and then identify the cause of erosion before corrective measures are addressed (Platts and Rinne 1985). Van Haveren and Jackson (1986) stress that "stream riparian systems undergoing major geomorphic or hydrologic adjustments should not be treated with habitat improvements until the channel has reached a new dynamic equilibrium". This should be kept in mind before any large scale revegetation programs are considered for the Nechako River system. Desired results may be achieved by proper management techniques for riparian areas, such as decreasing irrigation of crops, managing livestock, or by installing protective fences around a sensitive area (Davis 1986, Platts et al. 1987). When erosion control cannot be achieved by such management techniques, riparian or stream rehabilitation may be necessary. This can involve structural techniques, vegetative techniques or an integration of techniques.

Methods of Propagating Vegetation

There is a choice of propagation methods available to the bioengineer, each with their own applicability to a particular site. The most common methods of propagation are described below.

Cuttings

The placement of cuttings or "live staking" is one of the oldest techniques employed for revegetation (Schiechtl 1980). Hardwoods from the genus *Salix* (willows), *Populus* (cottonwoods) and *Alnus* (alders) are best utilized for this method. Cuttings are most successful when taken during dormancy (between fall and spring) from branches and trunks of parent stocks. Root cuttings can also be used but require more post-planting care and have lower success rates than those from branches.

The size of the cutting can vary depending upon the species and the site (Gray and Leiser 1982). Mills and Tress (1988) successfully planted 3 m "poles" along the lower Colorado River to take advantage of a low water table. Schiechtl (1980) related the interdependence of growth to volume of a cutting, suggesting the larger the volume of a cutting, the better the growth. Average sizes of cuttings are approximately 40 to 100 cm long and 2 to 4 cm wide (Schiechtl 1980, Gray and Leiser 1982).

Cuttings are placed in pre-made holes and soil is firmly packed around them. No more than 1/4 to 1/3 the total length of a cutting should be exposed; less in dry areas to prevent dehydration. It is important to orient cuttings in the proper direction when planting vertically. Cuttings taken for spring planting should be kept moist until planted and should not be left exposed to the sun (Gray and Leiser 1982). Those taken during the fall can be frozen or kept in cold storage until needed.

Seeding

In instances where physical damage to the existing streambank is due to cattle or other artificial disturbances, isolating the site from the source of the damage may be all that is necessary for revegetation to occur through a process of natural recolonization. Leaving the bank opposite to a revegetated area untouched may facilitate faster establishment of native plants (Lewis and Williams 1984).

A quicker method to revegetate disturbed areas is to artificially seed the site. Seed choices are usually restricted to those species readily available, such as commercially supplied grasses and legumes. Choosing a mixture of various species is necessary to ensure a diverse riparian community (Gray and Leiser 1982, Schiechtl 1980).

Transplanting

Seedlings, rooted cuttings and root masses can be transplanted to streambanks to enhance establishment of desired plants. They compete better with undesired species than directly seeded plants or placement of cuttings, but there are significant pre- and post-planting expenses associated with seedlings and rooted cuttings which often preclude them from use for large areas (Platts et al. 1987).

Seedlings are normally grown for herbaceous or woody species that are not easily propagated by cutting or not commercially available. If seedlings cannot be bought commercially, greenhouse space will be required for germination and growth of cuttings or seeds taken from the wild (Gray and Leiser 1982). It is advisable that commercial contractors be hired for collecting seeds and growing seedlings.

Root masses or "plugs" are often the most efficient method for successfully establishing herbaceous species, especially sedges, rushes and grasses. This method is labour intensive and is usually applied to small areas, although initial clusters of desired species can provide a nucleus from which growth can spread to larger areas. Plugs of aquatic species need areas of still or low water velocities to become established.

Streambank Stabilization Techniques

Table 1 is a summary of the revegetative techniques described in the text that follows.

Bundling Branches and Stems

Live branches tied into bundles are described as wattles, faggots and fascines in the literature reviewed (Lewis and Williams 1984, Gray and Leiser 1982, Schiechtl 1980). The applications and descriptions of bundling techniques vary between authors, but there are many similarities. Whenever bundling of live branches is employed for streambank protection, stems and branches must be taken from dormant vegetation. Branches should be about 2 to 4 cm thick and 1 to 1.5 m long. The finished bundle is usually between 2 and 4 m long with a diameter of about 10 to 15 cm. As with all live material, bundles should be kept damp and out of the sun. They can be stored in a river prior to use. Bundles should not be prepared more than 1 or 2 days prior to planting (Gray and Leiser 1982, Schiechtl 1980).

Table 1
Revegetative Techniques for Stabilizing Streambanks

METHOD / DESCRIPTION	REFERENCES	ADVANTAGES	DISADVANTAGES	MAINTENANCE REQUIREMENTS	APPLICABILITY TO THE NECHAKO RIVER
A. REVEGETATIVE METHODS FOR PROTECTING SHORELINES					
<u>BRANCH BUNDLING METHODS</u>					
Wattling Staking bundled live branches lengthwise along trenches dug on contour of slopes or gullies. The Bundles are staked into place and partially buried.	Gray and Leiser 1982, Lake Tahoe, Calif.	>Provides immediate erosion control. >Slope stabilization increases as vegetation becomes established. >Traps sediments from overland erosion. >Increases infiltration of water. >Provides favourable microsite improvements for plant growth.	>Labour intensive. >Only stabilizes to shallow depths. >Will not stabilize slopes steeper than 1:1 grade. >Requires large amounts of live materials.	>Pruning. >Wattles should be monitored to correct any downslope movements.	>Large unvegetated sections of unstable slopes along streams. >Can be used for shoreline or slope protection. >Protecting the toe of brush mattresses.
Faggoting Staking bundled live or dead branches at a stream edge.	Lewis and Williams 1984: Ouse River, Eng.	>Immediate protection. >Suited to use at streambanks. >Diffuses currents impacting a stream bank. >Induces sedimentation. >Establishes riparian vegetation. >Protects toe of bank.	>Labour intensive. >Requires large amounts of live material. >Relatively short lifespan if non-growing material is used.	>Excessive growth in small channels should be pruned. >Non-growing faggots need replacement, especially in areas exposed to constant wetting and drying.	>At the egdes of fast water areas with no vegetation and little sediment to establish vegetation. >Protecting the toe of brush mattresses or undercut banks.
Live Fascines Similar to faggoting but placed on top of a brush layer. Also called Live wattle or Fisher fence.	Schiechtl 1980: Enns R. Austria.	>Same as wattling and faggoting >Useful for securing brush layers or brush mattresses as an alternative to rip-rap or rocks.	>Same as wattling and faggoting. >Reports wattles overated in effectiveness except when used as a Fisher fence.	>See faggoting.	>In conjunction with other vegetative methods such as brush mattresses or placement of cuttings. >Shoreline protection.
Placement of Cuttings Planting sections cut from branches and stems of shrubs.	Altpeter 1944: Winooski R. Vermont Mills and Tress 1988: Lower Colorado R. Klingman et al. 1976: Williamette R. Oregon. Lewis and Williams 1984: Upper Lugg R. Eng. Schiechtl 1980: Europe since 1781. Gray and Leiser 1982: Roadsides in California. Nature: Slopes beside railroads, Glacier National Park, B.C.	>Fast, easy placement. >Inexpensive. >Can be used in existing structures.	>Stabilization / protection occurs only after material becomes rooted. >Can only be placed when parent stocks are dormant. >Generally used for woody species. >Cuttings don't compete well with established vegetation. >Prone to dehydration.	>Usually require irrigation during the first weeks after planting in areas with low soil moisture content. >May require some pruning.	>Anywhere along banks or slopes which require vegetation. Best for areas which maintain moisture.

Table 1 (continued)
Revegetative Techniques for Stabilizing Streambanks

A. REVEGETATIVE METHODS FOR PROTECTING SHORELINES (continued)

NON-BRANCH BUNDLING METHODS

METHOD / DESCRIPTION	REFERENCES	ADVANTAGES	DISADVANTAGES	MAINTENANCE REQUIREMENTS	APPLICABILITY TO THE NECHAKO RIVER
Hydro Seeding Spray on application of seed-fertilizer mixture.	Throughout North America and Europe.	>Spreads seeds over hard to reach areas. >Fast method to seed an area.	>Restricted to areas accessible to machinery, or sprayer. >Equipment and labour intensive. >Seed types usually limited to those commercially available.	>Irrigation is usually necessary during first weeks after seeding. >Grass may have to be cut.	>Large unvegetated riverbanks, particularly steep rocky areas.
Broadcast Seeding Spreading seeds by handheld rotary seeder.	Throughout North America and Europe.	>Inexpensive method of seeding an area. >No machinery neccessary.	>Seed types usually limited to those commercially available. >Not efficient for large areas.	>Same as above method.	>In conjunction with other bank-stabilizatiuon techniques.
Brush Mattress A layer of live branches lying flat against a riverbank, secured by cross braces of wire or large branches staked into place.	Altpeter 1944: Winooski R. Vermont Keown et al. 1977: Mississppi River Schiechtl 1980. Gray and Leiser 1982 Lewis and Williams 1984, South Hampton Eng.	>Immediate protection of stream-banks from wind, waves and overland erosion from flooding and rainfall. >Slows dehydration of seeds or cuttings planted underneath the mattress. >Will eventually become dense vegetation.	>Top soil may be necessary. >Must be used with structural methods in fast water areas to protect against scouring and undercut. >Limited lifespan if non-growing material used. >Dense growth can constrict water flows or inhibit establisment of other plant species.	>Readjustment may be necessary after floods.	>Reshaped banks which need new vegetation.
Reed Roll Construction / Reed Planting Each method is a variation of incorporating reed clumps into gabions.	Schiechtl 1980. Lewis and Williams 1984: Ouse and Stort rivers, England.	>Establishment of reeds along shores. >Immediate protection of shore. >Helps purify water by intercepting runoff. >Prevents scour of riverbed. >Induces sedimentation. >Absorb wave\wash energy.	>Labour intensive. >Can only build during dormancy. >Limited protection to areas with slight fluctuations in water level. >Not effective in areas of high water velocity.	>Readjustments may be necessary after floods.	>Along slower sections of streams eroded by wave wash from boat.
Spiling A line of live willow posts driven along the base of an undercut bank interwoven with live willow branhes.	Lewis and Williams: Meece Brook, Eng.	>Supports and protects undercut banks.	>Requires long, thick live willow posts to be driven into ground without splitting.	>Should be checked for damage after floods. >Pruning may be necessary.	>Along outside (convex) curves of meanders, where undercutting is occurring at the toe of the riverbank.

Table 1 (continued)
Revegetative Techniques for Stabilizing Streambanks

METHOD / DESCRIPTION	REFERENCES	ADVANTAGES	DISADVANTAGES	MAINTENANCE REQUIREMENTS	APPLICABILITY TO THE NECHAKO RIVER
B. REVEGETATIVE METHODS FOR RECONSTRUCTING RIVERBANKS					
Branch Packing Creating a new river bank from alternating layers of branches and fill.	Schiechtl 1980: Inn R. Austria. Keown et al. 1977: Mississipi R.	>Withstands high flows such as during floods. >Fast and simple to construct compared to brush barriers or live siltation construction.	>Requires large amounts of live and dead branches. >Fill is required. >Machinery is necessary during construction.	>Should be checked for damage after floods.	>Where construction of new bank is required. >Suitable to protect toe of bank.
Wire Mesh and Willow Fill placed on top of wire mesh and willow log blanket. The wire / log blanket is then wrapped over fill to form a type of gabion forming a new bankline.	Lewis and Williams: Lugg R. Eng.	>Incorporates growing materials into construction of gabions.	>Breakdown of wire mesh before willow roots may lead to failure of the structure.	>Should be checked for damage after floods.	>Where new bankline is needed.
Live Siltation Construction A live brush layer placed in a trench perpendicular to a river bank. The branches are angled 45° to 60° to the water's surface and held in place by fascines or rocks.	Schiechtl 1980: Rivers in Austria prior to the19th century.	>Induces sedimentation. >Simple to construct. >Resists high flows.	>Prone to damge where high flows result in boulder movement. >Built during dormancy and low flows only.	>Should be checked for damage after floods. >Pruning promotes growth of brush and keeps branches flexible.	>Where siltation is required to fill in sections of washed out streambed or streambank.
Log Brush Barrier A series of large branches or tree trunks staked in the river perpendicular to the bank with live branches planted vertically into the ground, through the spaces between trunks.	Schiechtl 1980: Vyrava River Czech. Schwechat and Erlauf rivers, Austria.	>Induces sedimetation. >Establishes thick vegetation. >Simple to construct. >Immediately effective and resistant to strong flows. >Creates and protects new bank.	>High labour costs. >Construction limited to dormancy.		>For repair of bank and bed damage where water flow is fast with depths up to 3m.

Table 1 (continued)
Revegetative Techniques for Stabilizing Streambanks

METHOD / DESCRIPTION	REFERENCES	ADVANTAGES	DISADVANTAGES	MAINTENANCE REQUIREMENTS	APPLICABILITY TO THE NECHAKO RIVER
C. REVEGETATIVE METHODS FOR SLOPE STABILIZATION					
Wattling: See section A.					
Seeding: See section A.					
Placement of Cuttings: See section A.					
Brush Layering Placement of long live branches with tips pointing out in a series of trenches on a slope.	Gray and Lesier 1982: Along Calif. highways. Schiechtl 1980: Autoban, Germany.	>Provides penetrating stabilization of slopes. >Less labour intensive than wattling. >Lends itself to partial mechanization. >Can use on slopes up to 45° angle. >Can provide microsite conditions favourable for growth of other plants.	>Does not retain soils until under-story grows.	>Periodic checks to ensure survival and growth of plant materials. >Excessive growth in small channels will require pruning.	>Large unvegetated sections of steep unstable riverbanks. >More suitable for construction of new slopes or reconstruction of damaged slopes such as along roads and for mine tailings piles.

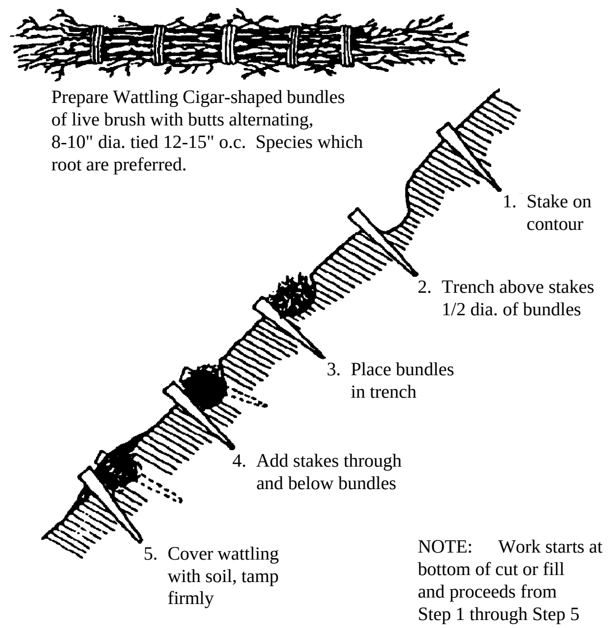
Wattling

Wattling involves bundling live stems and branches from woody vegetation and planting them in successive series of parallel trenches dug along a slope's contour (Gray and Leiser 1982). Eventually, the wattles (bundles) will root and grow as rows of shrubs along a hillside or streambank. In this technique, wattles are placed lengthwise in trenches with their ends overlapping, and staked into place. The stakes may be live or dead, and should be positioned on the down-slope side of trenches before wattles are placed. Stakes driven through wattles supply additional support (Figure 1). Wattles are buried with material excavated from trenches so that the top 10% of the bundle is exposed. If too much is exposed, stems will dry and sprouting will not occur; if too little is exposed, the wattling will be ineffective. Walking on bundles as filling proceeds helps pack soil into them. Other interim and climax species should be planted after wattling is completed.

Wattling provides immediate sediment control after placement since the exposed tops of the bundles intercept sediment carried downslope. Slope stability increases as the wattles take root and grow. Wattling also creates microsite conditions conducive to growth of other plants. The main disadvantage of wattling is that it only provides stabilization to shallow depth. It is low in material costs but labour intensive since trenches must be dug and wattles must be made, placed, and staked.

Wattling is very similar to live fascines (Fisher fences), except that it does not include a brush layer under the wattles during construction. Wattling was used primarily to stabilize hillsides, gullies and roadcuts in the Lake Tahoe area in California. Recently, it has been used in Roger's Pass to stabilize hillsides along Canadian Pacific rail lines in Glacier National Park. Wattles could be used to protect eroding banks along the Nechako River although Schiechtl (1980) suggests the effectiveness of wattles and faggots used without a brushlayer is overrated. Wattling may also be used to stabilize large unvegetated slopes such as some of the claybanks occurring along sections of the Nechako River.

Figure 1
Preparation and Installation of Wattles
(Gray and Leiser 1982)



Faggoting

Faggoting is the placement of faggots (or bundles of live branches) at the water's edge, and anchoring them to posts driven into the streambed (Lewis and Williams 1984). The faggots are placed parallel to the flow of water, with the butt ends of branches facing upstream (Figure 2). The main purpose of faggoting is to diffuse currents so as to trap silt and sediment thereby consolidating banks by the accretion of materials and protection of the toe. The resulting accumulation of sediment will eventually provide a base for thick growth originating from the bundles if propagating materials were used. Roots of this new growth will further stabilize the toe of the bank and help to prevent scouring. Faggoting subjected to continuous wetting and drying has a relatively short life span if non-propagating materials are used, and will have to be replaced if continued bank protection is needed. It is suggested that the choice of hardwood used depends upon whether rooting is desired or not, since faggots will sprout if willows or alders are used as building material. In some instances, non-growing bundles may be desired for protection only, such as in small channels, where excessive growth may constrict flow. Like all revegetation methods, faggoting should be checked occasionally to see if it is producing the desired effects and trimmed if excessive growth is constricting channel flows.

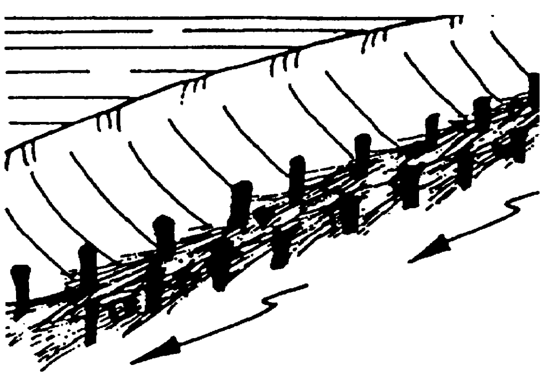
Faggoting has been successfully used on the Ure and Ouse rivers in England (Lewis and Williams 1984). Stabilized banks were as high as 2.5 m and varied in substrate composition from silt on the Ouse, to a sand-gravel mixture on the Ure. This method has also been used on the Enns River in Austria to protect lowlands from deposition of large floating debris during mild floods while still allowing nutrient-rich river alluvium to be deposited.

Live Fascines

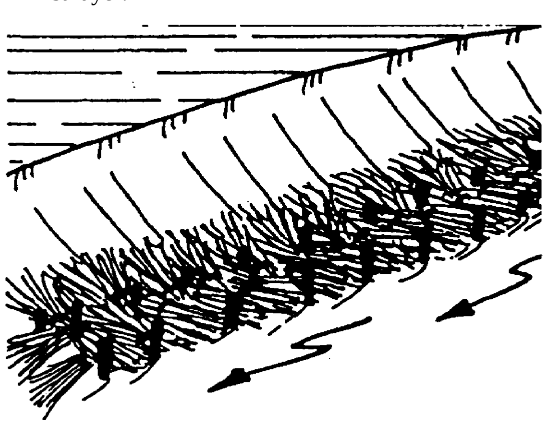
Live fascines, or Fisher fences, incorporate facets of wattling and faggoting. In this method, shown in Figure 3, bundles of live branches are staked into shallow trenches dug parallel to the stream flow at the water's edge, on top of a brush layer (Schiechtl 1980). Approximately one third of the fascine is left exposed. The brush layer can consist of propagating or non-propagating branches, which are arranged perpendicular to the fascine, and the stream flow. The higher the bank, the more rows of fascines that are placed. Fisher fences are an effective method to protect streambanks from wave wash and washouts during floods. The fascines protect the toe of a bank immediately upon placement while the brush layer protects the bank from wave wash. The fascines eventually root and grow, strengthening their effectiveness. Fascines are primarily used in conjunction with other techniques such as brush mattresses, brush layering, branch packing or live siltation fences. In each of these methods, fascines and stakes are used to secure branches placed under them, especially in areas where rocks or other suitable anchoring material is unavailable.

Figure 2
Faggoting (Lewis and Williams 1984)

A. Faggots staked parallel to the bank with butt ends of branches facing upstream.



B. For areas with deep erosion, additional faggots may be laid at right angles to the bank on top of the first layer.



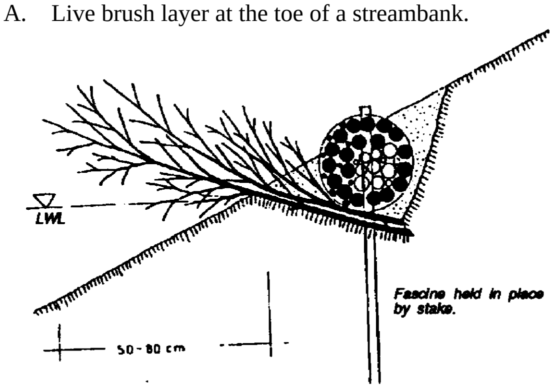
Placement of Cuttings

Cuttings are a basic building block to most revegetative techniques. Consecutive rows of cuttings from the water's edge, and up the slope, will eventually provide a dense growth of shrubs which will resist the erosional force of water while holding soils in place (Figure 4). Staggered placement of live stakes in each row results in greater effective coverage and is aesthetically pleasing.

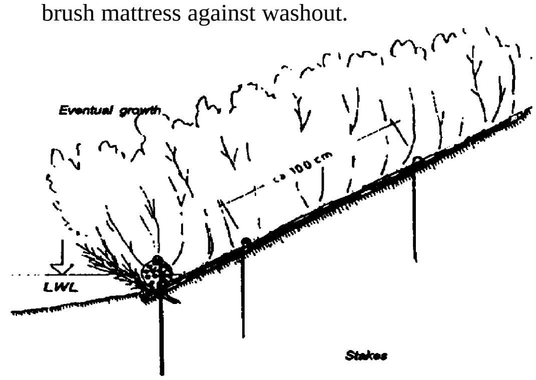
Cuttings are inexpensive, easy and fast to plant and can also be placed in cracks and joints of existing structures, such as rip-rap, gabions, jetties or rock wall revetments providing that some soil is present (Gray and Leiser 1982). The main disadvantage of cuttings is that stabilization does not begin until the plant is rooted (Schiechtl 1980). Placement of cuttings alone is not always sufficient to stabilize a riverbank.

Figure 3
Live Brush Layer (Schiechtl 1980)

A. Live brush layer at the toe of a streambank.



B. An example of a live brush layer used to protect a brush mattress against washout.



Cuttings may also require protection from flowing water before they can become established. For this reason, cuttings are often incorporated into various bioengineering techniques. Finally, cuttings do not compete well with existing vegetation, and in dry climates follow-up irrigation is required to promote rooting.

Placement of Transplants

Transplants or rooted cuttings may be substituted wherever cuttings are used. They have the same advantages as cuttings except that they grow faster and do not require as much irrigation as cuttings planted in dry areas.

The main disadvantage to planting rooted cuttings is that they must first be grown, thereby requiring greenhouse space. They also must be transported to sites to be planted. Finally, soil temperatures should be above 9.0°C before rooted cuttings are planted (D. Moore; pers. comm.).

Hydroseeding

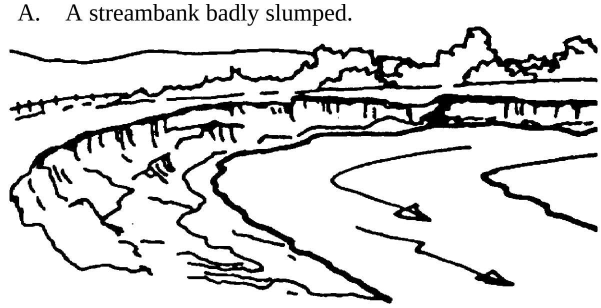
Hydroseeding uses pumps to spray a slurry of seeds, fertilizer and adhesives over a site. It has been used extensively in North America along roads and is effective for coverage on steep slopes or rocky terrain. Unfortunately, pumps used to propel seed/fertilizer mixtures often damage seeds, reducing germination success (Gray and Leiser 1982). Hydroseeding is labour and equipment intensive and more expensive than broadcast seeding. It is also restricted to use in areas accessible to hydroseeding equipment.

Broadcast Seeding

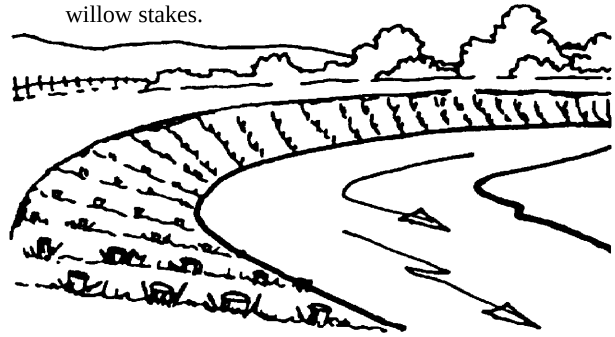
Small areas are sown inexpensively by broadcasting seeds by hand or with centrifugal spreaders. Broadcast seeding is usually most applicable to streambank rehabilitation. The site to be seeded should be free of other vegetation. If possible, the area should be raked before and after seeds are sown. Seeding should occur during spring or fall when the soil moisture content is highest. A cover of mulch will retain soil moisture thereby facilitating germination of seeds. Straw is most often used for this purpose although commercially manufactured mulches are also available. Uniformity of spread is best achieved if the seeded area is traversed twice in two directions. Like placement of cuttings, seeding is an effective means to establish vegetation, but it is often not suitable to stabilize riverbanks by itself. Rather, it is usually used in conjunction with other bioengineering techniques.

Figure 4
Replanting an Eroded Section of a Stream Bank
by Live Staking (Lewis and Williams 1984)

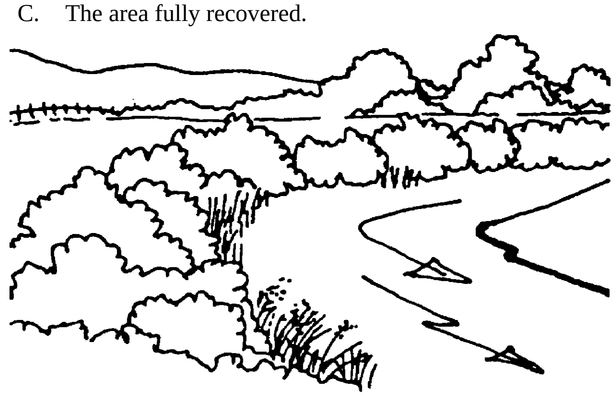
A. A streambank badly slumped.



B. The bank regraded and stabilized with willow stakes.



C. The area fully recovered.



Brush Mattresses

Brush mattresses consist of branches (greater than 1.5 m in length) placed close together (20 to 50 branches per meter) forming a layer of parallel branches which lie flat along a streambank (Figure 5). The butt ends of the branches are placed in soil while the branches lie firmly on the ground. Cross braces to hold the mattress in place may consist of either long stems or trunks of small trees anchored by wire and stakes or just wire held in place by stakes. Any planned planting of other species should occur prior to placement of the brush mattress. The mattress should be covered slightly with earth or fill but top soil is not necessary (Gray and Leiser 1982, Schiechtl 1980).

Keown et al. (1977) listed brush mattresses as obsolete since they only provide temporary protection until they break down. However, brush mattresses provide immediate protection from overland erosion, waves and wind. A thicket of brush with dense root development will grow from brush mattresses, forming an ideal buffer for streambanks, if easily propagated materials (willows or alders) are used during construction. Lewis and Williams (1984) describe a variation of brush mattresses woven from non-growing materials, called hurdles. These are used to provide initial protection against dehydration or water currents for newly planted seeds or cuttings. The hurdles eventually rot as vegetation becomes established. Hurdles were used successfully on small streams in Hedge End near South Hampton, England.

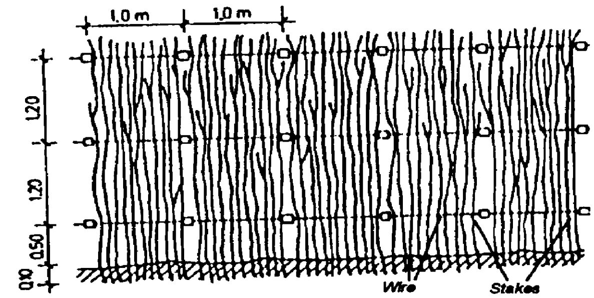
The drawbacks to brush mattresses are that they are labour intensive and require large amounts of live material during construction. In addition, they must be used in conjunction with other structural methods in fast water areas otherwise protection against scour and undercutting is not achieved (Gray and Leiser 1982).

For fast water areas, variations of brush mattresses include:

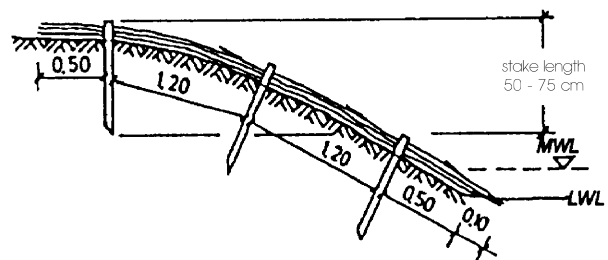
1. Using live fascines (Fisher fences) to secure the toe of the brush mattress,
2. Placing rip-rap at the toe of the brush mattress, and
3) Utilizing flexible rock construction as an alternative to rip-rap (This consists of a string of similar sized rocks joined by cable and concrete anchors. The cable is staked to the riverbank and bed. Flexible rock construction is an effective means of protecting brush matresses but it is labour intensive, requires specialized materials and equipment, and a supply of readily available rocks. Schiechtl 1980).

Figure 5
Brush Mattress Construction

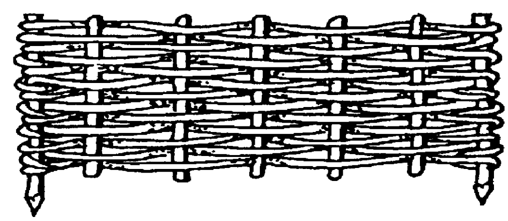
A. Top view of a brush mattress (Schiechtl 1980).



B. Side view of a brush mattress (Schiechtl 1980).



C. A hurdle of woven hardwood (Lewis and Williams 1984).



Reed Roll Construction

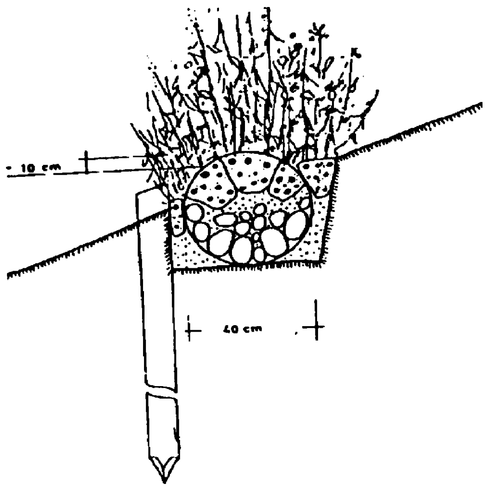
Schiechtl (1980) and Lewis and Williams (1984) describe a method of incorporating reed clumps (plugs) into wire mesh structures, known as gabions (Figure 6). Posts are driven into the streambed parallel to the shore to be protected. A trench is dug on the shore side of these posts and a layer of wire mesh is laid down in the trench, with extra mesh lying outside of the trench. A shallow layer of gravel is spread on the wire in the trench and reed clumps are placed on top of this. The excess wire mesh lying outside of the trench is wrapped around the fill and reed clumps, and then secured. The posts prevent the structure from moving.

Reeds absorb wave wash energy rather than deflect it. This serves to protect a riverbank from erosion at its toe. The dense root mass of reeds also helps retain soils on a streambed, thereby preventing scour while their foliage induces sedimentation (Lewis and Williams 1984). Reed rolls provide immediate protection of the shoreline upon placement. They allow transplanting of reeds in areas of moderately fast water velocities since reed rolls are more stable than transplanting only clumps or plugs (Schiechtl 1980). The disadvantages of reed planting using roll construction are that it is labour intensive and is therefore more expensive than transplanting reed plugs. Its usefulness is also limited to areas where water levels vary only slightly and bed load movement is slight (Schiechtl 1980).

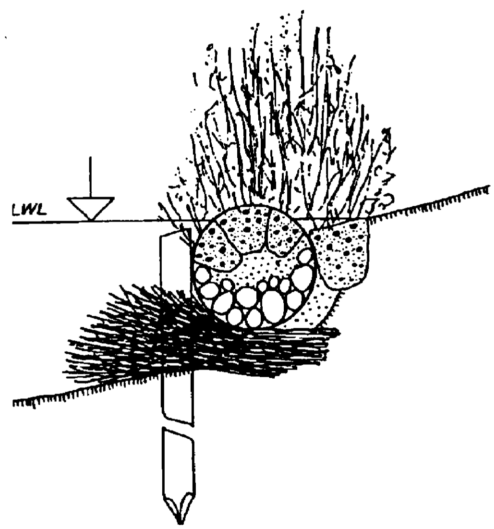
Variations of reed roll constructions for fast water areas include placement of the reed rolls on top of a brush layer, similar to the live fascines described earlier, or placement of a

Figure 6
Reed Roll Construction (Schiechtl 1980, Lewis and Williams 1984)

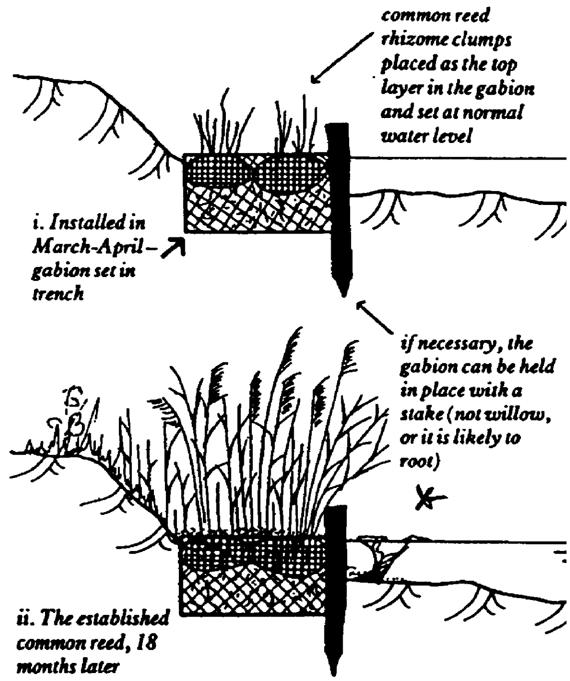
A. Reed roll construction as described by Schiechtl (1980).



B. A variation of reed roll construction for fast water areas. A brush layer is placed underneath the reed roll.



C. Reed clump planting described by Lewis and Williams (1980). This method is very similar to that described by Schiechtl (1980) except that square gabions are used.



rock gabion on the river side of the reed roll. Reed rolls should be checked occasionally, particularly after floods, to correct any movement. They are also prone to damage from beaver and muskrat, and may need to be isolated by fencing if such damage is occurring.

Spiling

Spiling is a fence constructed of protective vegetation created by driving sharpened live posts, interwoven with branches, vertically into a streambed, parallel to a streambank (Figure 7). Posts should be at least 10 cm in diameter and at least 50% of their total length should be driven into the ground. Using representatives from more than one species is recommended when weaving branches through upright posts. Members of the genus *Salix* are ideal for use in this method. Upon completion of the spiling, the area behind the structure is backfilled (Lewis and Williams 1984). Spiling is an effective means of supporting steep streambanks, and protecting against undercut. It was used successfully at Meece Brook in England where cattle frequent the stream edge. The main disadvantage of spiling is that large fluctuations in water level require longer posts to be driven into the ground. This requires numerous long stout posts which cannot be split during placement as this reduces their chances of survival. In areas which experience extensive freezing, such as the Vanderhoof region, driving live posts into the ground without splitting them might be a difficult task.

Branch Packing

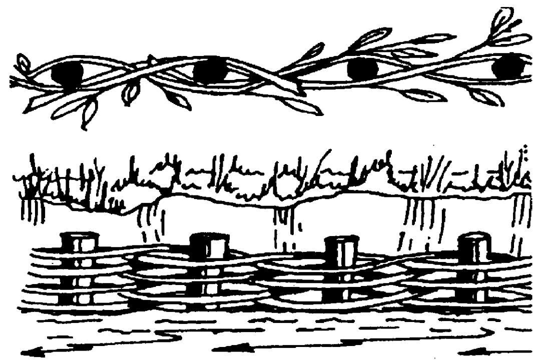
Branch packing is the placement of branches in layers 20 to 30 cm thick separated by layers of fill (Figure 8). Each branch layer is secured by either fascines staked parallel to packed branches or with stakes and wire (Schiechtl 1980). Individual layers of branches should be placed 90° to the preceding layer. The net result of branch packing is to create a new bank which is less susceptible to erosion by water currents. When using branch packing, it is important to place the tips of each branch layer in line with the slope of the planned shoreline. Dead branches are normally used if the base of the branch packing is below the low water level. Live branches are used above the low water level as they will eventually root and grow into new shrubs. Vegetation can also be planted on the surface of the new bank for further protection from erosion. In areas where water currents are extreme, the toe of the branch layer structure can be protected with rip-rap or other equivalent structural methods. Branch packings are resistant to high water flows and are especially suited to repair of breaks in streambanks, even where water depths exceed 3 m. They can also be used to repair gullies, however, branch packings require large amounts of branches and readily available fill (spoil from channel or bank shaping can be used). Mechanized equipment is necessary to transport and place fill. Accordingly, sites without adequate access may not be treatable by this method.

Wire Mesh and Willow

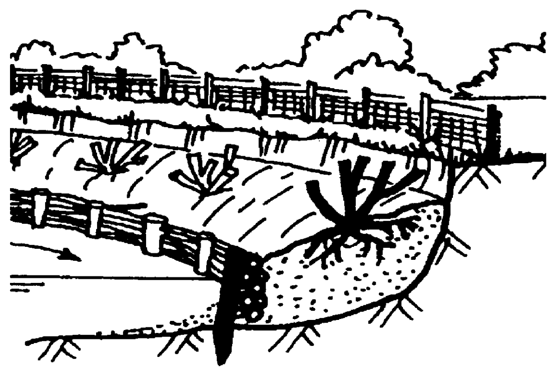
This method relies upon a framework of wire mesh and live cross timbers to create a new bank (Figure 9). The live cross timbers will eventually root and grow and can be supplemented by vegetation planted on top of the new bank (Lewis and Williams 1984). Wire mesh, stapled to willow-log cross members, is pegged to the toe of a bank and covered with spoil from bank shaping. Extra wire-mesh/willow-log material is allowed to extend uncovered, into the streambed. The fill is graded and the extra wire mesh is wrapped back overtop of the fill and anchored securely with stakes to the top of the bank. This is an effective method of repairing breaks in a bank by creating a new bank. Wire mesh and willow were used successfully in conjunction with spiling and placement of cuttings on the upper Lugg River in England (Lewis and Williams 1984). The disadvantages to wire mesh and willow construction are that: it requires access for machinery especially if large banks are to be treated since bank shaping and backfilling will be required; extra fill may be required if enough is not provided by the spoil from bank shaping; and if

Figure 7
Examples of Spilling (Lewis and Williams 1984)

A. Top view (above) and side view (below) of spiling.



B. Spiling used in conjunction with placement of live cuttings and protective fencing.



the integrity of the wire mesh is lost before vegetation can establish itself, the new bank may be subject to sudden failure.

Live Siltation Construction

Examples of live siltation barriers which were constructed during the eighteenth century exist in Austria. Live siltation barriers consist of live branches planted in trenches dug perpendicular to a floodplain, and pointing upstream at an angle 45° to 60° to the water surface (Figure 10). The branches form a solid wall of brush and are secured with rocks or fascines (Schiechtl 1980).

Live siltation barriers act much like jetties or tree revetments. A series of live siltation barriers are generally placed along an eroded streambank. The first is usually made at an acute angle (pointing downstream) to the bank followed by barriers placed 90° to the bank. The last barrier may point slightly upstream. They are commonly used to promote siltation of washouts. By reducing currents impacting on a bank and protecting the toe of a bank, siltation barriers assist development of riparian vegetation by creating conditions more favourable for natural

Figure 8
Branch Packing (Gray and Leiser 1982)

A. Side view

B. Top view

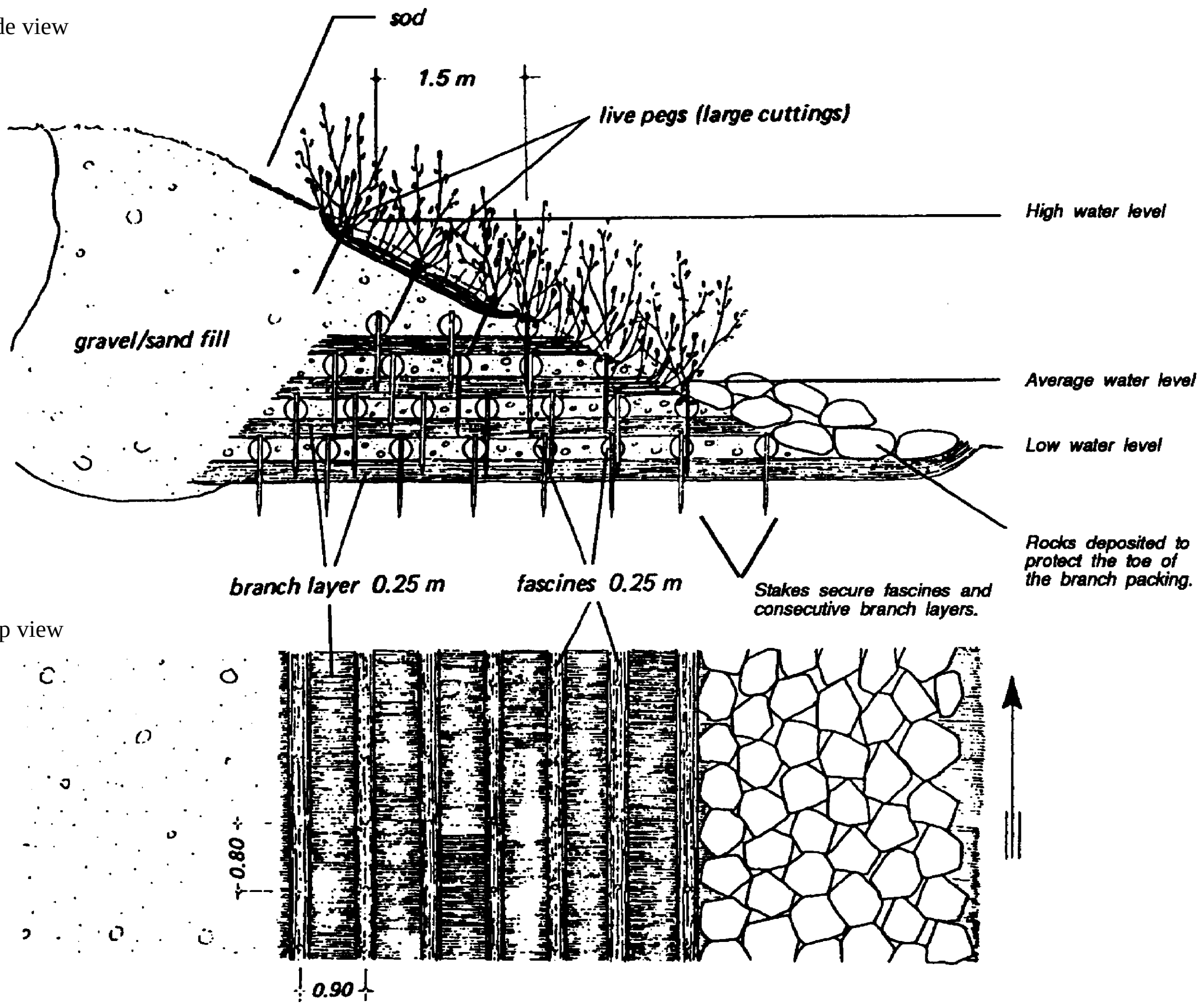
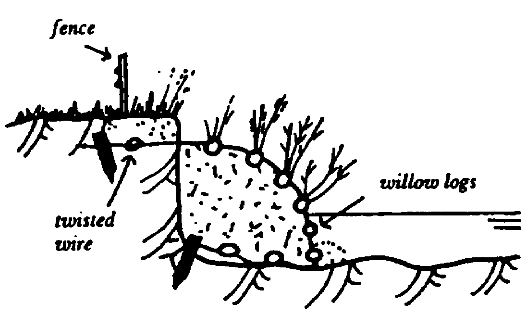


Figure 9
Side View of Wire Mesh and Willow Construction
(Lewis and Williams 1984)



re-establishment of plants, as well as protecting recently planted vegetation. Live siltation barriers are effective immediately upon placement and protection increases as vegetation in the barrier becomes established. Live siltation resists high flows and is inexpensive to construct, usually 1/50 to 1/100 the cost of conventional engineered structures such as dykes and jetties (Schiechtl 1980).

It is not advisable to use live siltation barriers in areas where flooding includes the movement of boulders. Also, although Schiechtl (1980) states they can be placed in flowing water, he is not clear on the method. Schiechtl (1980) also advises they be placed in the zone between the low water level and the average flood level. For these reasons, the construction of live siltation barriers is limited to periods of low water and when parent stock for live materials are dormant.

Tree Revetments

Tree revetments are not strictly a vegetative technique for bank stabilization since they act as structures, but they are an inexpensive effective means of utilizing on- site materials to protect the toe of a bank. A tree revetment acts as a permeable spur or jetty, reducing stream currents before they impact on a bank and inducing sedimentation (Mills and Tress 1988). This makes them suitable for establishing vegetation via increased sedimentation or by protecting a streambank until vegetation can establish itself. Trees are anchored to streambanks with stakes and cables, at approximately a 30° angle to the direction of the current with their butt end pointing upstream. The more branches and lusher the foliage on the tree, the more protection provided. Conifers are an ideal choice for tree revetments (Gore 1985). Unfortunately, tree revetments become less efficient as water velocity increases, and they are not suitable for streambanks exposed to strong currents. They may also create undesirable localized eddies which can enhance scouring and increase bank erosion if not placed properly (Klingeman and Bradley 1976). Tree revetments have a limited life span, of usually between 5 to 7 years.

There are projects presently studying the effectiveness of tree revet-ments for protection of streambanks in Idaho, Oregon and Washington but the results of these projects have not yet been presented.

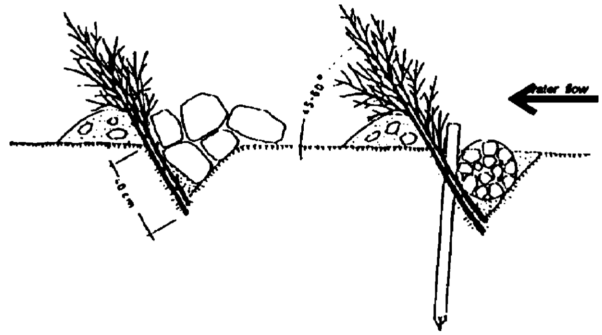
Log Brush Barrier

Log brush barriers were first used on the Vyrava River in Czechoslovakia and the Schewechat and Erlauf rivers in Austria. They consist of a series of logs or large branches, anchored by stakes placed perpendicular to a shoreline with their butt ends facing in. These branches should protrude about 80 cm out of the water. A second layer of live branches are then planted into the ground through the spaces between logs. A third layer of logs are placed 90° to the first layer of logs but on top of the live branches (Figure 11). The final step is to place a layer of rocks over the entire area of the log brush barrier. Extra rocks are placed at the front (upstream) end of the barrier since this is the area where water velocities are strongest (Schiechtl 1980).

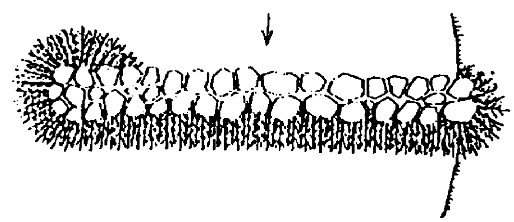
Log brush barriers are particularly suited for repairs to small or large breaks in a bank line. It is not necessary to cover the entire area of a large break with a log brush barrier, but just where the break begins. The area behind this can be protected by lighter elements such as live siltation barriers or tree revetments. The main advantage of log brush barriers is that they can withstand very high flows. Like other jetty type structures, log brush barriers will induce sedimentation while protecting the toe of

Figure 10
Live Siltation Barriers (Schiechtl 1980)

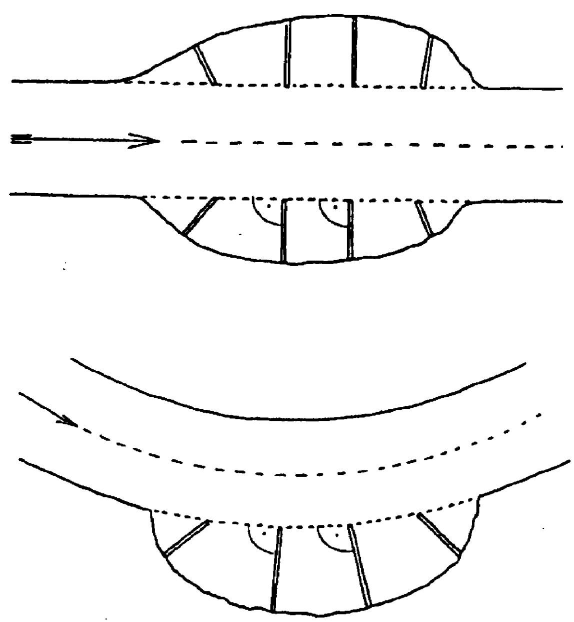
A. Side view showing construction with rip-rap (left) or fascines (right).



B. Top view of siltation barrier.



C. Proposed arrangement of live siltation barriers for restoration of a shore break.



a bank. Construction of these barriers is labour intensive, and limited to a period when parent stocks for branch cuttings are dormant and water levels are low. Also, the need for a final rock layer requires that rocks be available, and their placement may require a backhoe or other heavy machinery.

Brush Layering

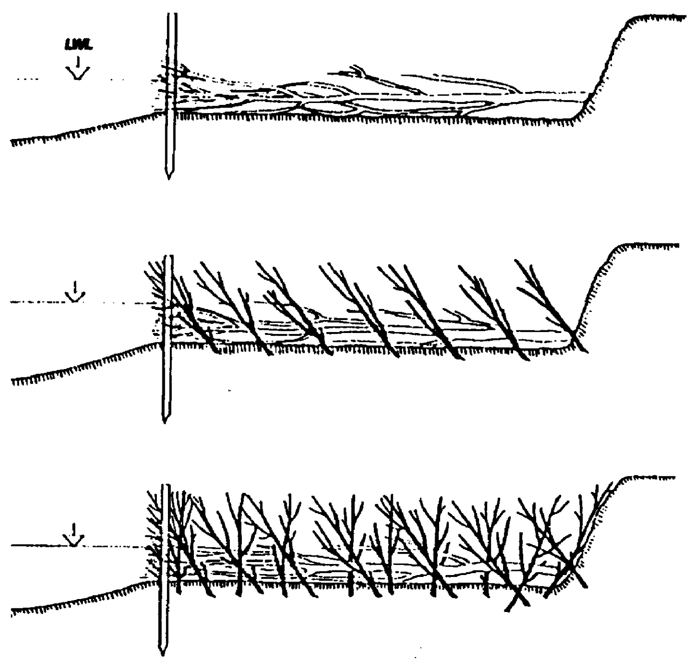
Brush layering is similar to wattling in that it embeds live materials along a series of trenches in a slope. In this method, rather than making bundles from live cuttings, live branches cut 1 to 1.3 m long and 2 to 5 cm thick are placed perpendicular in trenches dug on contour with the slope (Figure 12). Trenches are angled so branches point slightly up with only their tips protruding. The brush layer is covered with soil excavated from the trenches. Variations of brush layering include the use of wire mesh under and over successive layers of branches to provide added stabilizing strength, or the use of rooted plants suited to long term climax communities in conjunction with branches (hedge-brush layering). Fascines can also be staked into trenches, over the branch layer, to provide extra support and more material from which growth can originate (Schiechtl 1980).

The advantages of brush layering are that it is a simple method to provide immediate stabilization of slopes, it is less labour intensive than wattling since bundles need not be made, no staking is required, it uses less live material than wattling, trenches can be excavated and filled by machinery, and it can use short heavily branched twigs. The main disadvantage of this method is that soils are not retained until herbaceous cover grows.

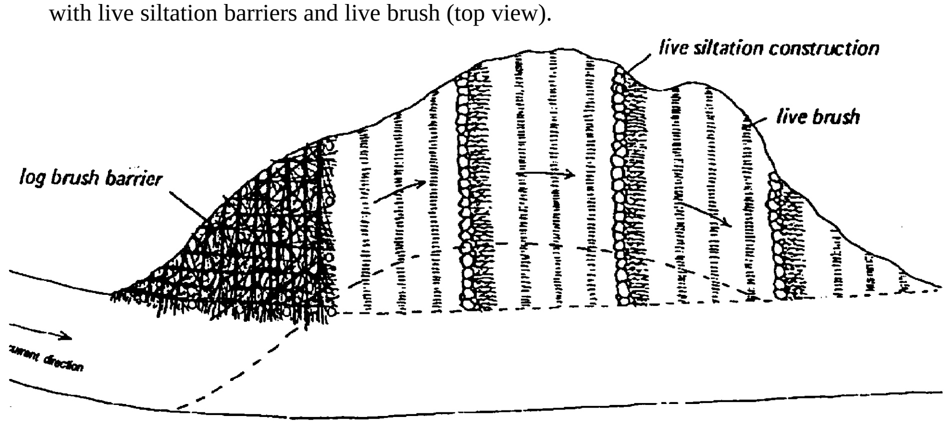
Brush layering is more applicable to stabilizing slopes of earth-filled dams or tailings piles as they are constructed. Otherwise, deep trenches must be dug to make this method effective and machinery would be preferred to dig such trenches. For this reason, wattling may be more applicable in hard to access areas or banks which do not require deep stabilization.

Figure 11
Log Brush Barrier (Schiechtl 1980)

A. Construction of a log brush barrier (side view).



B. Repairing a break in the shoreline using a log brush barrier in conjunction with live siltation barriers and live brush (top view).



Maintenance may include pruning, especially if revegetative plans include the introduction of climax species other than shrubs.

How Vegetation Controls Erosion

There are many ways in which vegetation controls erosion and increases sedimentation, the most important of which are described below.

Roots stabilize and hold soil in place (Gore 1985, Gray and Leiser 1982, Schiechtl 1980, Klingeman and Bradley 1976). Smith (1976) found that silty sediments with a 16 to 18 percent by volume of roots, and 5 cm of mat protection, had 20,000 times more resistance to erosion than comparable sediment without vegetation.

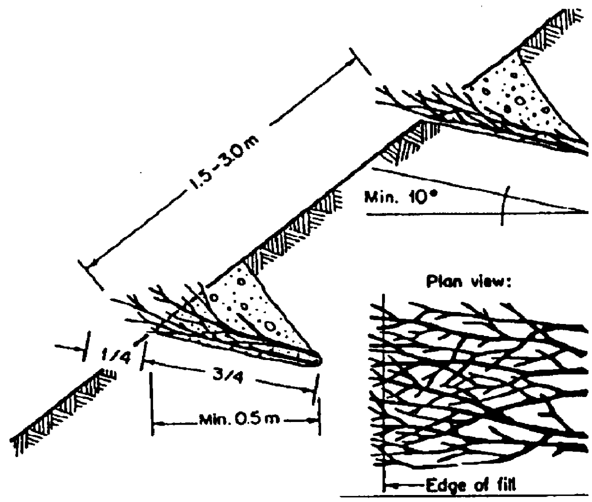
Hydraulic resistance, or "roughness", can be increased by exposed stems and stalks of herbaceous and woody plants, slowing water velocities of small channels and reducing localized velocities of larger channels. Roughness also deflects the force of water away from soil and stream-banks (Mills and Tress 1988, Van Haveren and Jackson 1986, Gray and Leiser 1982). Klingeman and Bradley (1976) demonstrated that woody plants reduced local stream velocities by as much as 50%. The reduction of water velocity also promotes sedimentation. Exposed vegetation acts as a buffer against abrasive forces in a river's sediment load (Mills and Tress 1988). This includes physical damage caused by floating debris such as trees or ice (Altpeter 1944).

The inherent ability of plants to hold water functions as a shallow aquifer, holding water during high flows and draining water during low flows (Van Haveren and Jackson 1986). The ability of plants to hold water, combined with the processes of evapo-transpiration, reduces soil moisture content and associated hydraulic pressure, thereby reducing the risk of massive failures on slopes and riverbanks (Gray and Leiser 1982).

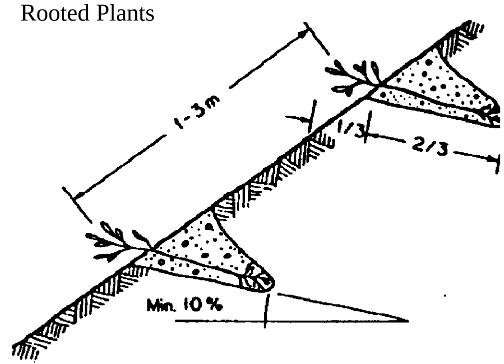
Vegetation reduces overland (surface) erosion by intercepting precipitation and increasing infiltration of runoff into the soil, thereby decreasing sediment input into a stream (Keown 1983, Mills and Tress 1988). Increased infiltration of runoff serves the added benefit of intercepting agricultural and industrial pollutants associated with surface runoff (Knight and Bottoroff 1984). This, in turn, has profound effects on water quality related to invertebrate and vertebrate biota (Baltz and Moyle 1984, Mahoney and Erman 1984). This is relevant to agricultural areas such as the Nechako River, where inputs from chemical fertilizers and livestock may have detrimental effects on water quality.

Figure 12
Slope Stabilization by Brush Layering
(Gray and Leiser 1982)

A. Branch Cuttings Only



B. Rooted Plants



Criteria for Selecting Species for Revegetative Work

Grasses and woody plants (shrubs) are most often recommended for bank stabilization. Various authors list factors which should be considered when selecting species for revegetative bank stabilization projects. These include:

1. Strength or the ability of the species to resist erosional forces (Mills and Tress 1988, Klingeman and Bradley 1976).

2. Adaptability to the environment, such as resilience to prolonged or intermittent wetting, disease and insects (Schiechtl 1980, Gray and Leiser 1982). The more adaptable a plant is, the more likely it will become established and the greater the effects towards the goal of bank stabilization.

3. Plant vigor affects the amount and type of streambank protection provided by a riparian community. The healthier a riparian community, the better the protection provided. Good root systems and lush foliage are facets of vigorous growth. Growth rate will also determine how long it will take before vegetation can provide protection from erosion, while reproductive ability will influence how easily vegetation can become established and regenerate (Mills and Tress 1988, Klingeman and Bradley 1976).

4. Flexibility is important in a plant's ability to resist damage. The more flexible a plant is, the less likely it will be uprooted or broken when impacted by large floating debris (Altpeter 1944).

5. Growth habits will determine the effectiveness of a selected plant for erosion control. Species with well developed root systems will provide better bank stability than those with sparse root systems (Kittredge 1948). Likewise, plants with taproots offer deeper stabilizing protection than surface rooting plants (Gray and Leiser 1982). The type of top growth is also important; evergreens retain vegetation year round and tall grasses slow water velocity more effectively than short grasses (Gray and Leiser 1982, Keown et al. 1977). Plants that are characteristically tall with small shallow root systems are not desirable features when selecting species for riparian rehabilitation.

6. Availability of various plants may be the limiting factor when deciding which species to use for a project. Native plants are more likely to succeed than introduced species, but are not always commercially available (Bowie 1982, Klingeman and Bradley 1976). Using introduced species could be an important consideration should suitable stocks of native species not be available. Introduced species also provide a wider range of selection to choose from (Gray and Leiser 1982). An inventory of available indigenous species should always be made prior to selection.

When the final choices are made of plants to be utilized for revegetation, it is important to consider the time required for the selected species to become established, especially in relation to the revegetative technique utilized for bank protection (Klingeman and Bradley 1976, Appendix A). Dense coverage by herbaceous species usually takes 2 years to become established, whereas shrubs can take from 3 to 5 years before they provide effective protection (Bowie 1982). For this reason, it is important to plan a climax community that will develop over the long term and provide lasting protection as well as an interim community to provide short-term protection (Gray and Leiser 1982).

A healthy riparian community has a diverse species composition, which is more stable and likely to succeed. Therefore, it is prudent to plant a mixture of grasses and shrubs during revegetative work (Schiechtl 1980, Altpeter 1944). Legumes are good interim plants since they are nitrogen fixers, an important facet for nutrient deficient soils. Shade tolerant species should not be mixed with shade intolerant species if differential growth rates and heights exist.

Recommended Plant Species

Choosing the right species may simply involve examining adjacent riparian areas to see which plants are present (Gray and Leiser 1982). In some instances, however, adjacent riparian zones may not be representative of natural conditions if the stream has already been altered by agriculture, logging or other activities.

Generally, the streambank to be replanted can be broken down into the toe, face and top of the bank (Klingeman and Bradley 1976). Shrubs are best suited for the toe, reducing the impact of water and protecting the bank from undercut. Grasses are normally planted on the face of the bank and trees at the top of the bank.

Appendix B provides lists of various plants used in revegetative work throughout North America. Only those common to the Nechako River basin are highlighted below.

Shrubs and Trees

Species from the genus *Salix* (willows) are the preferred shrub for most revegetative work since they are wide ranging, hardy, easy to propagate, fast growing and are natural components of most riparian plant communities (Platts et al. 1987, Bowie 1982, Gray and Leiser 1982, Schiechtl 1980, Klingeman and Bradley 1976, Kittredge 1948, Altpeter 1944). However, since willows are shade intolerant, availability of, or the incidence of sunlight must be considered when selecting sites and accompanying species. Altpeter (1948) found representatives from the genus *Populus* (cottonwoods) to be suitable trees for upper streambanks, but they can be stressed by rapidly varying water tables (Mills and Tress 1988). *Betula* (birch) and *Alnus* (alder) genus may also be considered for streambanks, although the latter is very aggressive and may choke out other useful, shade intolerant plants (Bowie 1982). Members of the genus *Pinus,* particularly the Ponderosa pine, are deep rooting and well suited to dry climates (Schiechtl 1980). Redosier Dogwood *(Cornus stolonifera)* is common throughout British

Columbia, naturally occurs along streambanks, and is easy to establish (Lyons 1952, Platts et al. 1987). Rooted Redosier Dogwood cuttings have been successfully grown and planted by representatives of the Shuswap Nation Tribal Council along Deadman Creek (D. Moore; pers. comm.).

Herbaceous Plants

There is a wide variety of commercially available introduced and indigenous species of grasses, legumes and plants available for revegetation.

Grasses suited to riparian management include members from the genus *Festucas* (Creeping red, Tall, and Hard fescues), *Poa* (Canada and Kentucky bluegrasses), *Bromus* (mountain and meadow brome) and *Agropyron* (also known as wheat grasses). Timothy (*Phelumn pratense*) and Red top (*Agrostis alba*) grasses have dense root systems and are excellent choices for stabilizing streambanks (Platts et al. 1987, EPA 1976, Kittredge 1948). An important point when selecting grass species is whether they are "clumping" or "creeping" in their growing habits. Creeping species provide denser coverage than clumping species, thus they have better soil stability, although, they make it more difficult for other desired plants to become established. Clumping types of grasses do not form a dense mat. They will allow other plants to become established, facilitating the development of a diverse plant community.

Legumes such as various types of *Trifolium* (clover) are recommended by Platts et al. (1987) and EPA (1976). *Trifolium hybridium* (Alsike clover) is commonly grown in the Vanderhoof area. Alfalfa (*Medicago sativa*) does well in dry climates although the site should be fertilized before planting.

Various *Carex* members (sedges) are also common components of streamside vegetation and are native to riparian areas on the Nechako River drainage. Other herbaceous plants common throughout British Columbia and recommended for revegetative purposes by Platts et al. (1987) include the asters (of which over 50 species exist in B.C.), Cow parsnip (*Heracleum lanatum*), Fireweed (*Epilobium angustifolium*) and yarrow (*Achillea millifolium*). Although none of the aforementioned are commercially available, they transplant and seed easily, and spread rapidly; the only exception being Cow parsnip (Platts et al. 1987).

Selecting an Appropriate Site

The choice of sites will have a profound effect on the successful establishment of vegetation. It may be necessary to complete some site preparations before revegetation is attempted.

A site should first be cleared of undesirable plant species before a new species is introduced (Platts et al. 1987). This can be part of other site preparations such as bank shaping. Vegetation will not take easily to slopes with grades greater than 30% or where bank overhang exists (Platts et al. 1987, Bowie 1982, Klingeman and Bradley 1976). Bank shaping will help to stabilize the slope, facilitate easier, safer planting, and speed establishment of new vegetation (Gray and Leiser 1982). Bank shaping is commonly used in conjunction with either structural or vegetative bank stabilizing methods. Changing the angle of a streambank can also determine its stability; the more gradual a slope, the less likely it is to fail (Iowa Department of Water, Air and Waste Management 1984). This stability is affected by soil type. Clay soils can have steep banks whereas sandy soils require a gradual slope (Klingeman and Bradley 1976). Protruding structures or objects (man-made or natural), also called "hard points", can create eddies or deflect flows, resulting in localized scour of streambeds and banks (Klingeman and Bradley 1976).

The aspect (north or south facing) of the slope to be replanted affects available light and temperature. North slopes are shady (in the northern hemisphere) and have lower air and soil temperatures, thereby increasing germination time and limiting the choice of plants to shade tolerant species (Gray and Leiser 1982). Aspect may also affect the exposure of a site to wind, which can blow seeds away. Stress created by the action of wind on streamside trees can increase streambank instability (Gore 1985, Gray and Leiser 1982).

Most plants establish best in fine, silty soils while clay soils offer little chance for root development (Altpeter 1944). Providing a thin layer of top soil or application of fertilizer can greatly increase germination success (Platts et al. 1987). Corrective liming may be required to increase pH, especially in coniferous forests such as in the Vanderhoof area.

Finally, revegetation should be restricted to small segments of streambank over a long time-frame as opposed to treating large areas over a short time frame (Platts et al. 1987). This will avoid damage by floods, especially if treatment consisted of de-nuding an area of undesirable vegetation first; the little protection a streambank had may be reduced considerably, worsening the effects of a flood.

Time of Planting

Planting and seeding should occur in the spring or the fall, when soil moisture content is generally higher and plants and shrubs are dormant. If possible, planting should occur after spring or fall freshets, to avoid the danger of flood damage (Platts et al. 1987).

Maintenance

Proper maintenance is required for revegetation projects to succeed (D. Moore; pers. comm., Debano and Schmidt 1989, Kindschy 1989, Mills and Tress 1988, Platts et al. 1987, Davis 1986, Goldner 1984, Gray and Leiser 1982, Schiechtl 1980, Klingeman and Bradley 1976, EPA 1976, Altpeter 1944). Periodic inspections of revegetated sites, especially after floods or severe storms, will determine if repairs or additional work is necessary. Maintenance may involve pruning, watering, or more complex tasks such as predation and disease control.

Goldner (1984) points out that rainfall alone should not be relied upon to establish plants. When planning revegetation projects, species which require little care should be selected. Irrigation systems can be the most expensive part of a revegetation project, but it is often necessary to provide some initial irrigation for seeds to germinate (D. Moore; pers. comm., Mills and Tress 1988). Provision of a mulch cover will help retain soil moisture and protect seeds from dehydrating (Gray and Leiser 1982, Schiechtl 1980, EPA 1976). Due to the dry summers experienced in the Nechako River basin, drought resistant species would help reduce post planting care.

Overgrowth can constrict or deflect flows and cause renewed erosion downstream or across the stream from the revegetated area, requiring occasional pruning (Klingeman and Bradley 1976). In most cases, this means once every 4 to 6 years. Pruning serves the additional advantage of supplying cuttings for further revegetative work.

The presence of both beaver and cattle along the Nechako River may necessitate the need for protective fencing around revegetated streambanks. Kindschy (1989) found that willows exposed to simulated beaver cutting during their active growing season demonstrated inhibited growth for 2 years. Mills and Tress (1988) reported extensive beaver damage to pole plantings of cottonwoods on the Colorado River. Cattle can destroy many months of growth in a short period of time (Davis 1986). Thus, fencing should be inspected on a regular basis to ensure it remains intact.

Altpeter (1944) found that cuttings with narrow diameters, cuttings split during planting and those planted improperly, either did not root or were subject to severe insect attack. He recommended a varied stock be used for revegetation and that cuttings have widths between 10 and 25 mm. Therefore, replanting is often necessary if seeds or cuttings fail to propagate (Klingeman and Bradley 1976). It may be necessary to reseed an area in the fall or later in the spring if seeds are blown away, eaten by birds, or do not germinate.

Weeding enhances the establishment of planted vegetation by reducing the competition for space, light and soil nutrients between desired plants and invader plants (Gray and Leiser 1982, Schiechtl 1980). Willows are particularly sensitive to competition from other species. Cuttings, while easy to place, are especially vulnerable to competition (Platts et al. 1987).

SUMMARY

The literature pertaining to a bioengineering approach for the protection of slopes by revegetation and the incorporation of vegetation into stabilization structures was reviewed to identify its applicability for the Nechako River watershed. Traditionally, Europeans have used this approach for erosion control and have developed techniques specifically for the protection of streambanks. Before revegetation of riparian areas proceeds, each site targeted for rehabilitation should be assessed to determine the cause of erosion and whether a bioengineering approach can be applied effectively to reduce erosion.

The protection of the toe, face and top of a bank may be achieved by utilizing one technique, but more often involves a combination of methods. In selecting a technique; simplicity in design and implementation should be considered. Other factors to consider include a cost-benefit analysis of the proposed technique related to the expected results, availability of required plant materials, hydrology of the stream at target site, and the biophysical aspects of the site.

Whenever possible, indigenous plant species should be selected over introduced species, for revegetation bank-stabilization projects . They are generally more suited to local climates and habitat, less expensive to use and aesthetically compatible with existing riparian communities. Regular monitoring and maintenance of revegetated areas is necessary to ensure successful results.

Methods utilized in Europe and North America, described in this text, are applicable to a broad range of areas and conditions, such as the streambanks of the Nechako River and its tributaries. The determining factor in any project is choosing the right species composition to plant in an eroded area and successfully establishing these plants. Unfortunately, the experiences gained from species used for such projects in other areas of the world are not easily transferred to the Nechako River, since growth rates and characteristics of selected plant species will vary with physical parameters such as soil type, climatic conditions and latitude particular to any one site. Using preferred species, such as those of the *Salix* genus, while maintaining sensitivity to specific physical parameters associated with proposed study sites that may effect plants selected for revegetation, will facilitate the successful establishment of a riparian community.

REFERENCES

Altpeter, L.S. 1944. Use of vegetation in control of streambank erosion in northern New England. J. of Forestry, 42 2: 99 - 107.

Adams, M.A. and I.W. Whyte. 1990. Fish Habitat Enhancement: A Manual for Freshwater, Estuarine and Marine Habitats. Department of Fisheries and Oceans Canada. DFO 4474. 330 p.

Bowie, A.J. 1982. Investigations of vegetation for stabilizing eroding streambanks. Trans. of the ASAE, 25 6: 1601 - 1606, 1611.

Baltz, D.M., and P.B. Moyle. 1984. The influence of riparian vegetation on stream fish communities of California. In: California riparian systems. Ecology, conservation, and productive management. Ed. Warner, R.E. and K.M. Hendrix. University of California Press, Los Angeles, California.

Butler, D. 1990. The greening of Rogers Pass. Nature Canada 19-4: 40 - 44.

Davis, J.D. 1986. Options for managing livestock in riparian habitats. Wildl. Soc. Bull. Trans. 51st N. A. Wildl. & Nat. Res. Conf. 290 - 297.

DeBano, L.F., and L.J. Schmidt. 1989. Improving southwestern riparian areas through watershed management. Gen. Tech. Rep. RM-182. U.S. Dept. of Agriculture, Forest Service. Rocky Mountain Forest and Range Station, Fort Collins, Colorado. 33 pp.

Environmental Protection Agency (EPA). 1976. Erosion and sediment control - surface mining in the eastern U.S. Environmental Protection Agency 625/3-76-006. 102 pp.

Goldner, B.H. Riparian restoration efforts associated with structurally modified flood control channels. In: California riparian systems. Ecology, conservation, and productive management. Ed. Warner, R.E. and K.M. Hendrix. 1984. University of California Press, Los Angeles, California.

Gore, J.G. 1985. The restoration of rivers and streams - theories and experience. Butterworth publishers, Stoneham, MA.

Gray, H.L. and A.T. Leiser. 1982. Biotechnical slope protection and erosion control. Van Nostrand Reinhold Company Ltd. New York, N.Y.

Iowa Department of Water, Air and Waste Management. 1984. How to control streambank erosion. Iowa Dept. of Water, Air and Waste Management. Des Moines, Iowa. 25 pp.

Keown, M.F. 1983. Streambank protection guidelines. U.S. Army Engineers Waterways Experiment Station. Vicksburg, Miss. 60 pp.

Keown, M.P., N.R. Oswalt, E.B. Perry, and E.A. Dardeneau, Jr. 1977. Literature survey and preliminary evaluation of streambank protection methods. Tech Rep. H-77-9. U.S. Army Engineer Waterways Experiment Station. Vicksburg, Miss. 261 pp.

Kindschy, R.R. 1989. Regrowth of willow following simulated beaver cutting. Wildl. Soc. Bull. 17: 290 - 294.

Kittredge, J. 1948. Forest influences. The effects of woody vegetation on climate, water and soil, with applications to the conservation of water and the control of flood and erosion. McGraw Hill, New York.

Knight, A.E. and R.L. Bottoroff. 1984. The Importance of riparian vegetation to stream ecosystems in: California riparian systems. Ecology, conservation, and productive management. Ed. Warner, R.E.; K.M. Hendrix. University of California Press, Los Angeles, California.

Klingeman, P.C. and J. B. Bradley. 1976. Willamette River basin streambank stabilization by natural means. Prep. for U. S. Dept. of the Army, Portland District, Corps of engineers by: Water Resources Institute, Oregon State University, Corvalis, Oregon. 233 pp.

Lewis, G. and Gwyn Williams. 1984. Rivers and wildlife handbook - A guide to practices which further the conservation of wildlife on rivers. Royal Society for the Protection of Birds and the Royal Society for Nature Conservation, Nettleham, Lincoln England. 295 pp.

Lyons, C.P. 1952. Trees shrubs and flowers of B.C. J.M. Dent & Sons (Canada) ltd. 193 pp.

Mahoney, D.L. and D.C. Enman. The role of streamside bufferstrips in the ecology of Aquatic biota. In: California riparian systems. Ecology, conservation, and productive management. Ed. Warner, R.E. and K.M. Hendrix. 1984 University of California Press, Los Angeles, California.

Mills, G.S. and J.A. Tress. 1988. Terrestrial ecology lower Colorado River bankline modifications. Prep. for the Bureau of Reclamation, lower Colorado River regional office, Boulder City, Nevada. by: SWCA, Inc. Environmental Consultants, Tuscon, Arizona. 179 pp.

Moore, D. 1991. Personal Communication. Biologist, Shuswap Tribal Council, Kamloops, B.C.

Platts, W.S., C. Armour, G.D. Booth, M. Bryant, J.L. Bufford, P. Cuplin, S. Jensen; G.W. Lienkaemper; G.W. Minshall, S.B. Monsen, R.L. Nelson, J.R. Sedell, and J.S. Tuhy. 1987. Methods for evaluating riparian habitats with applications to management. Gen. Tech. Rep. INT-221. U.S. Dept. of Agriculture, Forest Service, Intermountain Res. Stn. 132 pp.

Platts, S.P. and J.N. Rinne. 1985. Riparian and stream enhancement management and research in the Rocky Mountains. N. A. J. Fish. Mang. 5 2a: 115 - 125.

Schiechtl, H. 1980. Bioengineering for land reclamation and conservation. University of Alberta Press. Edmonton, Alta.

Smith D.G. 1976. Effect of vegetation on lateral migration of anastomosed channels of a glacier meltwater river. Geol. Soc. of Amer. Bull. 87: 857 - 860.

Van Haveren, B.P. and W.L. Jackson. 1986. Concepts in stream riparian rehabilitation. Wildl. Soc. Bull. Trans. 51st N. A. Wildl. & Nat. Res. Conf. 281 - 289.

APPENDIX A
A Comparison of the Strengths of Streambank Stabilization Techniques

Appendix A
A Comparison of the Strengths of Streambank Stabilization Techniques

Method	Strength (N/m²) at Construction	Stength Over Time (N/m²)		
		1st year	2nd year	3rd year
Grass	10	30	30	30
Placement of Cuttings	0	10	30	>30
Branch Layering	75	100	300	>300
Branch Packing	100	200	-	300
Wall Joint Planting	50	-	100	250
Brush Mattresses	50	150	300	300

Method	Tangential Power (N/m²)	Depth of Effect (m)
Roots	20	0.4
Tree Revetments	40	0.8
Faggoting (Live fascines)	60	0.6
Flexible Rock Construction	300	2.5

APPENDIX B
Various Species of Plants, Herbs, Shrubs and Trees Recommended for Revegetation Work

Table 1
Grasses Recommended for Planting of Riparian Sites (Platts et al. 1987)

Species	Areas of adaptation[1]	Origin	Seeding trait	Transplant capability	Growth rate	Rooting habit	Salinity tolerance[2]	Flooding tolerance	Palatability	Spreadability
Agropyron elongatum Tall wheatgrass	Mtn.B.-V	Introduced	Excellent	Good	Rapid	Large clump	MT	Moderate	Fair	Good
Agropyron repens Quackgrass	Asp.-V	Introduced	Fair	Excellent	Slow	Rhizomatous	MT	Moderate	Good	Excellent
Agropyron smithii Western wheatgrass	PP-SDS	Native	Poor	Excellent	Slow	Rhizomatous	MS	Moderate	Good	Good
Agropyron trachycaulum Slender wheatgrass	SF-PJ	Native	Excellent	Excellent	Rapid	Rhizomatous	MS	Sensitive	Excellent	Good
Agrostis stolonifera Redtop	Salp.-SF	Introduced	Fair	Good	Moderate	Rhizomatous	MS	Moderate	Good	Excellent
Alopecurus pratensis Meadow foxtail	Alp.-Mtn.B.	Introduced	Excellent	Good	Rapid	Rhizomatous	MT	Tolerant	Good	Excellent
Bromus carinatus Mountain brome	Alp.-PJ	Native	Excellent	Excellent	Rapid	Rhizomatous	MT	Moderate	Good	Good
Bromus erectus Meadow brome	Alp.-PJ	Introduced	Excellent	Excellent	Moderate	Rhizomatous	MT	Moderate	Good	Excellent
Bromus inermis Smooth brome	Alp.-Mtn.B.	Introduced	Good	Excellent	Moderate	Rhizomatous	MT	Moderate	Good	Excellent
Calamagrostis canadensis Bluejoint reedgrass	SF-Sage	Native	Good	Excellent	Moderate	Rhizomatous	MT	Tolerant	Good	Excellent
Calamagrostis epigeois Chee reedgrass	Alp.-PJ	Introduced	Poor	Good	Slow	Rhizomatous	MT	Tolerant	Good	Good
Dactylis glomerata Orchardgrass	Alp.-Sage	Introduced	Good	Good	Rapid	Bunch	MS	Sensitive	Excellent	Fair
Deschampsia caespitosa Tufted hairgrass	Alp.-SF	Native	Poor	Fair	Slow	Bunch	MT	Tolerant	Fair	Poor
Distichylis spicata Saltgrass	V	Native	Poor	Excellent	Slow	Rhizomatous	T	Tolerant	Fair	Excellent
Elymus cinereus Great Basin wildrye	Mtn.B.-V	Native	Good	Good	Moderate	Large clump	T	Moderate	Good	Fair
Elymus giganteus Mammoth wildrye	Mtn.B.-Sage	Introduced	Fair	Good	Moderate	Rhizomatous	T	Tolerant	Good	Good
Elymus junceus Russian wildrye	Mtn.B.-V	Introduced	Fair	Good	Moderate	Bunch	T	Moderate	Excellent	Fair
Elymus triticoides Creeping wildrye	JP-V	Introduced	Good	Excellent	Moderate	Rhizomatous	T	Tolerant	Poor	Good
Festuca arundinacea Reed fescue (alta or tall)	Asp.-SDS	Introduced	Excellent	Excellent	Rapid	Rhizomatous	T	Tolerant	Good	Excellent
Hordeum brachyantherum Meadow barley	Alp.-Asp.	Native	Excellent	Excellent	Moderate	Bunch	T	Tolerant	Fair	Good
Lolium perenne Perennial ryegrass	SF-PP	Introduced	Excellent	Good	Rapid	Small bunch	MT	Sensitive	Good	Good
Phalaris arundinacea Reed canarygrass	Asp.-V	Native	Poor	Excellent	Slow	Rhizomatous	T	Tolerant	Fair	Excellent

Table 1 (continued)
Grasses Recommended for Planting of Riparian Sites (Platts et al. 1987)

Phleum pratense										
Timothy	Asp.-Mtn.B.	Introduced	Good	Good	Rapid	Bunch	MS	Moderate	Good	Good
Poa pratensis										
Kentucky bluegrass	Asp.-PJ	Introduced	Fair	Good	Slow	Rhizomatous	MT	Moderate	Good	Excellent
Poa secunda										
Sandberg bluegrass	Mtn.B.-Sage	Native	Fair	Good	Slow	Bunch	MT	Moderate	Good	Fair
Sitanion hystrix										
Bottlebrush squirreltail	Mtn.B.-SDS	Native	Good	Fair	Moderate	Bunch	MT	Moderate	Good	Good
Sporobolus airoides										
Alkali sacaton		Native	Fair	Good	Slow	Bunch	MT	Moderate	Good	Excellent

[1]Areas of adaptation—Alp. = alpine; SF = spruce-fir; Asp. = aspen; Mtn.B. = mountainbrush; PJ = pinyon-juniper; PP = ponderosa pine; Sage = big sagebrush; Salp. = subalpine; SDS = salt desert shrub; V = valley bottom.

[2]Salinity tolerance—S = sensitive; MS = moderately sensitive; MT = moderately tolerant; T = tolerant.

Table 2
Broadleaf Herbs Recommended for Planting of Riparian Sites (Platts et al. 1987)

Species	Areas of adaptation[1]	Origin	Seeding trait	Transplant capability	Growth rate	Salinity tolerance[2]	Flooding tolerance	Palata-bility	Spread-ability
Achillea millefolium lanulosa Western yarrow	Alp.-V	Native	Excellent	Excellent	Rapid	MS	Moderate	Poor	Excellent
Artemisia ludoviciana ludoviciana Louisiana sagewort	Alp.-Sage	Native	Excellent	Excellent	Rapid	MS	Moderate	Poor	Excellent
Aster chilensis adscendens Pacific aster	Asp.-V	Native	Poor	Excellent	Moderate	MS	Moderate	Excellent	Excellent
Bassia hyssopifolia Fivehook bassia	PJ-SDS	Native	Excellent	Good	Rapid	T	Tolerant	Good	Good
Coronilla varia Crownvetch	PJ-Mtn.B.	Introduced	Good	Excellent	Rapid	MS	Moderate	Good	Good
Epilobium angustifolium Fireweed	Asp.-Mtn.B.	Native	Excellent	Good	Rapid	S	Moderate	Fair	Excellent
Heracleum lanatum Common cowparsnip	Alp.-Mtn.B	Native	Poor	Poor	Poor	S	Sensitive	Excellent	Fair
Linum lewisii Lewis flax	Asp.-Sage	Native	Excellent	Good	Moderate	S	Sensitive	Good	Good
Medicago lupulina Black medic	Asp.-Sage	Introduced	Excellent	Good	Moderate	MT	Moderate	Good	Good
Medicago sativa Alfalfa	Asp.-Sage	Introduced	Excellent	Good	Rapid	MT	Moderate	Excellent	Fair
Melilotus officinalis Yellow sweetclover	Asp.-Sage	Introduced	Excellent	Poor	Rapid	MT	Moderate	Good	Excellent
Potentilla glandulosa glandulosa Gland cinquefoil	Asp.-PP	Native	Good	Excellent	Moderate	S	Moderate	Fair	Good
Senecio serra Butterweed groundsel	Asp.-PP	Native	Good	Excellent	Moderate	S	Moderate	Good	Good
Sidalcea oregana Oregon checkermallow	Asp.-Mtn.B.	Native	Good	Good	Moderate	S	Moderate	Fair	Good
Smilacina racemosa amplexicaulis Western Solomons-seal	Asp.-Mtn.B.	Native	Poor	Fair	Slow	S	Moderate	Excellent	Fair
Trifolium fragiferum Strawberry clover	V	Introduced	Good	Fair	Moderate	MT	Moderate	Excellent	Excellent
Trifolium hybridum Alsike clover	Asp.-Mtn.B.	Introduced	Good	Fair	Moderate	S	Moderate	Good	Good
Valeriana edulis Edible valerian	Asp.-Mtn.B.	Native	Poor	Fair	Slow	S	Moderate	Fair	Fair

[1]Areas of adaptation—Alp. = alpine; Asp. = aspen; PP = ponderosa pine; Mtn.B. = mountainbrush; PJ = pinyon-juniper; Sage = sagebrush; SDS = salt desert shrub; V = valley bottoms.
[2]Salinity tolerance—S = sensitive; MS = moderately sensitive; MT = moderately tolerant; T = tolerant.

Table 3
Woody Species Recommended for Planting of Riparian Sites (Platts et al. 1987)

Species	Areas of occurrence: Zones[1]	Areas of occurrence: Habitat	Adaptation to disturbed sites	Methods[2] of culture	Establishment traits: Seedling establishment	Establishment traits: Growth rates	Establishment traits: Soil stability value	Comments
Alnus tenuifolia Thinleaf alder	SF-Mtn.B.	Stream edge and well-drained soils.	Excellent	NS, CS, DS	Excellent	Rapid	Excellent	Easily established, adapted to harsh sites, grows rapidly.
Amelanchier alnifolia Saskatoon serviceberry	Asp.-Mtn.B.	Well-drained soils, seeps occasional.	Good	NS, CS	Fair	Slow	Good	Slow to establish, sensitive to understory competition.
Artemisia cana viscidula Silver sagebrush	Asp.-Sage	Well-drained and moist soils, valley bottoms.	Fair	DS, NS, CS	Good	Rapid	Fair	Well adapted to exposed moist soils able to tolerate flooding for short time.
Artemisia tridentata tridentata Basin big sagebrush	Mtn.B.-SDS	Deep, well-drained soils, occasional flooding.	Excellent	DS, NS, CS	Good	Rapid	Fair	Useful for planting extremely disturbed and well-drained soils.
Artemisia tridentata vaseyana Mountain big sagebrush	Asp.-Mtn.B.	Well-drained soils, moist sites.	Excellent	DS, NS, CS	Good	Rapid	Fair	Adapted to disturbed sites, suited to moist but not saturated soils.
Artemisia tripartita Tall threetip sagebrush	Asp.-Mtn.B.	Well-drained soils, moist sites.	Excellent	DS, NS, CS	Excellent	Rapid	Fair	Well suited to eroded exposed soils, spreads quickly.
Atriplex canescens Fourwing saltbush	Mtn.B.-V	Well-drained soils, frequent flooding and shallow water table.	Good	DS, NS	Excellent	Rapid	Good	Useful for well-drained and disturbed soils.
Atriplex gardneri Gardner saltbush	SDS-V	Semiarid deserts. Withstands seasonal flooding, and alternating wet/dry period.	Fair	DS, NS, CS	Fair	Moderate	Fair	Adapted to arid sites subjected to seasonal saturated soils.
Betula occidentalis occidentalis Water birch	SF-Mtn.B.	Stream edges.	Good	NS	Excellent	Rapid	Excellent	Establishes well by transplanting, adapted to streambanks and bogs.
Ceanothus sanguineus Redstem ceanothus	SF-PP	Moist soils, seeps, well-drained soils.	Good	DS, NS, CS	Excellent	Rapid	Excellent	Not adapted to saturated soils but useful in planting disturbed streambanks.
Chrysothamnus nauseosus consimilis Thinleaf rubber rabbitbrush	Sage-V	Well-drained soils, sites occasionally flooded.	Good	DS, NS, CS	Excellent	Moderate	Fair	Suited to heavy saturated soils.
Cornus stolonifera stolonifera Redosier dogwood	SF-Mtn.B.	Stream edges and well-drained soils.	Good	DS, NS, CS, RC	Excellent	Rapid	Excellent	Easy to grow and establish, useful for disturbed sites, requires fresh aerated water.
Crataegus douglasii Douglas hawthorn	Asp.-Sage	Stream edges and well-drained soils.	Good	NS	Fair	Slow	Good	Slow growing, but well suited to disturbed streambanks.
Elaeagnus angustifolia Russian olive	Mtn.B.-V	Stream edges, seeps, flooded sites, and well-drained soils.	Excellent	DS, NS	Excellent	Rapid	Good	Easy to establish, can become weedy.
Elaeagnus commutata Silverberry	PJ-V	Stream edges and well-drained soils.	Excellent	NS, CS	Excellent	Rapid	Good	Easily established, grows rapidly, adapted to harsh sites.
Holodiscus discolor Rockspirea	SF-Mtn.B.	Well-drained and moist soils, occasional seeps.	Good	NC, CS	Fair	Moderate	Good	Erratic establishment, but suited to disturbed sites.
Lonicera tatarica Tatarian honeysuckle	Mtn.B.-Sage	Well-drained and moist soils, occasional wet sites.	Excellent	NC, CS, DS	Excellent	Rapid	Good	Easily established, provides immediate cover, well adapted to different soil conditions.

Table 3 (continued)
Woody Species Recommended for Planting of Riparian Sites (Platts et al. 1987)

Pachistima myrsinites Myrtle pachistima	SF-Asp.	Moist soils and seeps, requires some shade.	Fair	NS, CS	Fair	Slow	Good	Common to upland slopes, not well adapted to disturbances.
Physocarpus malvaceus Mallow ninebark	SF-Asp.	Moist and well-drained soils.	Fair	NS, CS	Fair	Moderate	Good	Requires good sites.
Populus angustifolia Narrowleaf cottonwood	Asp.-Sage	Well-drained and wet sites, edges of streams, ponds, bogs.	Good	NS, CS, RC	Good	Rapid	Good	Establishes easily, grows rapidly.
Populus fremontii fremontii Fremont cottonwood	Mtn.B.-V	Moist soils, seeps, frequently wet sites.	Good	NS, CS, RC	Good	Rapid	Good	Establishes easily, grows rapidly, furnishes good cover.
Populus tremuloides Quaking aspen	SF-Asp.	Well-drained and moist soils, occasionally occurs at edges of streams.	Fair	NS, CS, RC	Good	Rapid	Good	Considerable ecotypic differences, not well suited to highly disturbed sites, occupies wide range of moisture.
Potentilla fruticosa Bush cinquefoil	Alp.-PP	Stream edges, wet meadows.	Excellent	NS, CS	Good	Moderate	Excellent	Valuable species for riparian disturbances, establishes well and provides excellent site stability.
Prunus virginiana melanocarpa Black chokecherry	SF-PJ	Well-drained, moist soils, occasionally occurs at streams' edges.	Fair	NS, CS, RC	Good	Moderate	Good	Widely adapted, larger transplant stock establishes and grows rapidly.
Rhamnus purshiana Cascara buckthorn	SF-PP	Moist soils, frequently wet sites.	Fair	NS, CS	Fair	Moderate	Good	Limited plantings, plants perform well on disturbed sites.
Ribes aureum Golden current	Asp.-Sage	Well-drained moist sites.	Excellent	NS, CS	Excellent	Excellent	Good	Widely adapted, easily established, excellent site stablity.
Rosa woodsii Woods rose	Asp.-Mtn.B.	Moist and well-drained soils, seeps and frequently streambanks.	Excellent	NS, CS, W, RC	Excellent	Moderate	Good	Widely adapted, easily established, excellent site stability, principal species for riparian disturbances.
Rubus spp.	Asp.-PP	Well-drained soils, frequently wet sites	Excellent	NS, CS, W, RC	Excellent	Moderate	Good	Well adapted to eroded sites, limited range of distribution.
Salix								
Sambucus racemosa pubens microbotrys Red elder	Asp.-PP	Moist sites, occasional seeps and streambanks.	Good	NS, CS	Fair	Moderate	Good	Adapted to restricted sites, establishes slowly on disturbed sites.
Sarcobatus vermiculatus Black greasewood	SDS-V	Sites with shallow water tables, occasionally flooded sites.	Good	NS, W	Fair	Slow	Good	Difficult to establish, well adapted to valley bottoms and salty soils.
Shepherdia argentea Silver buffaloberry	Mtn.B-V	Well-drained sites, edges of streams and ponds.	Good	NS	Good	Moderate	Good	Adapted to valley bottoms and saline soils.
Sorbus scopulina scopulina Green's mountain ash	SF-Asp.	Moist soils, ocassional seeps and stream bottoms.	Fair	NS, CS	Fair	Slow	Good	Not well adapted to disturbed soils, establishes slowly.
Symphoricarpos albus Common snowberry	SF-Asp.	Moist sites and well-drained soils.	Good	NS, CS, W, RC	Fair	Moderate	Excellent	Not well suited to extreme disturbed soils, once established grows well, plant large 1-0 or 2-0 stock.
Symphoricarpos occidentalis Western snowberry	SF-Mtn.B.	Moist sites, occasionally streambanks and valley bottoms.	Good	NS, CS, W, RC	Fair	Slow	Excellent	Plants not well adapted to disturbed soils, provides excellent stability and spreads well.
Symphoricarpos oreophilus Mountain snowberry	Asp.-Sage	Well-drained soils, edges of streams.	Good	NS, CS, W, RC	Fair	Slow	Excellent	Plants not well adapted to disturbed soils, provides excellent stability and spreads well.

[1]Alp. = alpine; SF = spruce-fir; Asp. = aspen; PP = ponderosa pine; Mtn.B. = mountainbrush; PJ = pinyon-juniper; Sage = big sagebrush; SDS = salt desert shrub; V = valley bottoms.
[2]DS = direct seeding; RC = rooted cuttings; NS = nursery-grown seedling; CS = container-grown seedling; W = wilding.

Table 4
Areas of Occurence of Several Willow Species Useful in Riparian Revegetation (Platts et al. 1987)

	Areas of adaptation				Period required for:		
Species	Zones	Habitat	Origin of roots	Prevalence of roots	Root formation	Stem formation	Comments
					- - - - - - - Days	- - - - - - -	
Salix amygdaloides Peachleaf willow	Aspen—big sagebrush	Stream edges, pond margins, soils saturated seasonally.	Callus cut	Moderate	10-20	10	Moderate rooting capabilities
Salix bebbiana Bebb willow	Spruce-fir—aspen	Edges of streams, occasionally well-drained soils.	Roots throughout entire length of stem	Moderate	10	10-20	Roots freely
Salix boothii	Aspen—sagebrush	Stream edges and standing water, confined to wet soils.	Roots mostly at lower one-third of stem	Abundant	10-15	10-15	Roots freely
Salix brachycarpa Barrenground willow	Subalpine—spruce-fir	Wet sites and well-drained soils.	Roots throughout entire length of stem	Abundant	15-20	15-25	Roots freely
Salix drummondiana Drummond willow	Spruce-fir—upper sagebrush	Edges of streams and ponds.	Roots throughout entire length of stem	Abundant	10	10	Roots freely
Salix exigua Sandbar willow	Spruce-fir—sagebrush	Edges of streams, wet sites, sometimes well-drained soils.	Roots throughout entire length of stem	Moderate	10-15	10	Easily rooted
Salix geyeriana Geyer willow	Subalpine—aspen—upper sagebrush	Edges of streams, frequent wet meadows.	Roots throughout entire length of stem	Few to moderate	10	10-15	Fair rooting capabilities
Salix glauca Grayleaf willow	Subalpine—spruce-fir	Wet and dry sites, widely distributed, occupies seeps and edges of snowbanks.	Roots throughout entire length of stem	Few to moderate	10	10	Requires special treatment to root
Salix lasiandra Pacific willow	Aspen—upper sagebrush	Wet soils, edges of streams and ponds.	Roots throughout entire length of stem	Abundant	10	10-15	Easily rooted
Salix lasiolepis Arroyo willow	Aspen—mountainbrush	Restricted to stream edges.	Callus and lower one-third of stem	Few to many	10	10	Erratic rooting habits
Salix lutea Shining willow	Aspen—sagebrush	Mostly along streams, may occur on sites that remain dry for short periods.	Entire stem section, most abundant at lower one-third	Moderate	10	10	Roots easily
Salix planifolia Tealeaf willow	Subalpine—aspen	Wet sites, edges of streams, wet meadows.	Roots throughout entire length of stem	Few to moderate	10	10-15	Fair rooting capabilities
Salix scouleriana Scouler willow	Spruce-fir—aspen	Well-drained soils, forest understory.	Callus cut	Moderate	10-15	10-15	Requires special treatment to root
Salix wolfii Wolf willow	Spruce-fir—aspen	Stream edges and ponds.	Roots throughout entire length of stem	Few to moderate	10-15	10-15	Erratic rooting

Table 5
Grasses Commonly Used for Revegetation Recommened by EPA (1976)

Common name	Botanical name	Season: Cool	Season: Warm	Season: Dry (not droughty)	Site suitability: Well drained	Site suitability: Moderately well drained	Site suitability: Somewhat poorly drained	Site suitability: Poorly drained	Growth habit[b]	pH range[c]	Use suitability: Erodible areas	Use suitability: Waterways and channels	Use suitability: Agriculture[d]	Remarks
Bahiagrass	*Paspalum notatum*		X	X	X	X			P	4.5-7.5	X	X	X	Tall, extensive root system. Maintained at low cost once established. Able to withstand a large range of soil conditions. Scarify seed.
Barley	*Hordeum vulgare*	X			X	X			A	5.5-7.8	X		X	Cool season annual. Provides winter cover.
Bermuda grass	*Cynodon dactylon*		X	X	X	X	X		P	4.5-7.5	X	X	X	Does best at a pH of 5.5 and above. Grows best on well drained soils, but not on waterlogged or tight soils. Propagated vegetatively by planting runners or crowns.
Bluegrass, Canada	*Poa compressa*	X		X	X	X			P	4.5-7.5	X		X	Does well on acid, droughty, or soils too low in nutrients to support good stands of Kentucky bluegrass.
Bluegrass, Kentucky	*Poa pratensis*	X			X	X	X		P	5.5-7.0	X	X	X	Shallow rooted; best adapted to well-drained soils of limestone origin.
Bluestem, big	*Andropogon gerardi*		X		X	X	X		P	5.0-7.5	X		X	Strong, deep rooted, and short underground stems. Effective in controlling erosion.
Bluestem, little	*Andropogon scoparius*		X		X	X			P	6.0-8.0	X		X	Dense root system; grows in a clump to 3 feet tall. More drought tolerant than big bluestem. Good surface protection.
Bromegrass, field	*Bromus arvensis*	X			X	X	X		A	6.0-7.0	X		X	Good winter cover plant. Extensive fibrous root system. Rapid growth and easy to establish.
Bromegrass, smooth	*Bromus inermis*	X		X	X	X	X		P	5.5-8.0	X	X	X	Tall, sod forming, drought and heat tolerant. Cover seed lightly.
Buffalograss	*Buchloe dactyloides*		X			X	X		P	6.5-8.0	X		X	Drought tolerant. Withstands alkaline soils but not sandy ones. Will regenerate if overgrazed.
Canarygrass, reed	*Phalaris arundinacea*	X		X	X	X	X	X	P	5.0-7.5	X	X	X	Excellent for wet areas, ditches, waterways, gullies. Can emerge through 6 to 8 inches of sediment.
Deertongue	*Panicum clandestinum*		X	X	X	X	X	X	P	3.8-5.0	X	X		Very acid tolerant; drought resistant. Adapted to low fertility soils. Volunteers in many areas. Seed not available.
Fescue, creeping red	*Festuca rubra*	X		X	X	X	X		P	5.0-7.5	X	X	X	Grows in cold weather. Remains green during summer. Good seeder. Wide adaptation. Slow to establish.
Fescue, tall	*Festuca arundinacea*	X			X	X	X		P	5.0-8.0	X	X	X	Does well on acid and wet soils of sandstone and shale origin. Drought resistant. Ideal for lining channels. Good fall and winter pasture plant.
Grama, blue	*Bouteloua gracilis*		X	X	X	X	X		P	6.0-8.5	X			More drought resistant than sideoats grama. Sod forming. Extensive root system. Poor seed availability.
Grama, sideoats	*Bouteloua curtipendula*		X		X	X			P	6.0-7.5	X		X	Bunch forming; rarely forms a sod. May be replaced by blue grama in dry areas. Feed value about the same as big bluestem. Helps control wind erosion.
Indian grass	*Sorgastrum nutans*		X			X	X		P	5.5-7.5	X		X	Provides quick ground cover. Rhizomatous, tall. Seed available.
Lovegrass, sand	*Eragrostis trichodes*		X		X				P	6.0-7.5	X		X	A bunchgrass of medium height. Adaptable to sandy sites. Good for grazing. Fair seed availability.
Lovegrass weeping	*Eragrostis curvula*		X	X	X	X	X		P	4.5-8.0	X			Bunchgrass, rapid early growth. Grows well on infertile soils. Good root system. Low palatability. Short-lived in Northeast.

Table 5 (continued)
Grasses Commonly Used for Revegetation Recommened by EPA (1976)

Common name	Botanical name	Season			Site suitability				Growth habit[b]	pH range[c]	Use suitability			Remarks
		Cool	Warm	Dry (not droughty)	Well drained	Moderately well drained	Somewhat poorly drained	Poorly drained			Erodible areas	Waterways and channels	Agriculture[d]	
Millet, foxtail	*Setaria italica*		X	X	X	X			A	4.5-7.0	X		X	Requires warm weather during the growing season. Cannot tolerate drought. Good seedbed preparation important.
Oats	*Avena sativa*	X		X	X				A	5.5-7.0	X		X	Bunch forming. Winter cover. Requires nitrogen for good growth.
Oatgrass, tall	*Arrhenatherum elatius*	X		X	X				P	5.0-7.5	X		X	Short-lived perennial bunchgrass, matures early in the spring. Less heat tolerant than orchardgrass except in Northeast. Good on sandy and shallow shale sites.
Orchardgrass	*Dactylis glomerata*	X		X	X	X	X		P	5.0-7.5	X		X	Tall-growing bunchgrass. Matures early. Good fertilizer response. More summer growth than timothy or bromegrass.
Redtop	*Agrostis alba*	X		X	X	X	X	X	P	4.0-7.5	X	X	X	Tolerant of a wide range of soil fertility, pH, and moisture conditions. Can withstand drought; good for wet conditions. Spreads by rhizomes.
Rye, winter	*Secale cereale*	X		X	X	X			A	5.5-7.5	X		X	Winter hardy. Good root system. Survives on coarse, sandy spoil. Temporary cover.
Ryegrass, annual	*Lolium multiflorum*	X			X	X	X		A	5.5-7.5	X		X	Excellent for temporary cover. Can be established under dry and unfavorable conditions. Quick germination; rapid seedling growth.
Ryegrass, perennial	*Lolium perenne*	X			X	X	X		P	5.5-7.5	X		X	Short-lived perennial bunchgrass. More resistant than weeping love or tall oatgrass.
Sandreed, prairie	*Calamouilfa longifolia*		X	X	X				P	6.0-8.0	X			Tall, drought tolerant. Can be used on sandy sites. Rhizomatous. Seed availability poor.
Sudangrass	*Sorghum sudanense*		X	X	X	X	X		A	5.5-7.5	X		X	Summer annual for temporary cover. Drought tolerant. Good feed value. Cannot withstand cool, wet soils.
Switchgrass	*Panicum vergatum*		X		X	X	X		P	5.0-7.5	X	X	X	Withstands eroded, acid and low fertility soils. Kanlow and Blackwell varieties most often used. Rhizomatous. Seed available. Drainageways, terrace outlets.
Timothy	*Phleum pratense*	X			X	X	X	X	P	4.5-8.0	X		X	Stands are maintained perennially by vegetative reproduction. Shallow, fibrous root system. Usually sown in a mixture with alfalfa and clover.
Wheat, winter	*Triticum aestivum*	X		X	X	X	X		A	5.0-7.0	X		X	Requires nutrients. Poor growth in sandy and poorly drained soils. Use for temporary cover.
Wheatgrass, tall	*Agropyron elongatum*	X		X	X	X	X	X	P	6.0-8.0	X	X	X	Good for wet, alkaline areas. Tolerant of saline conditions. Sod forming. Easy to establish.
Wheatgrass, western	*Agropyron smithii*	X		X	X	X	X	X	P	4.5-7.0	X	X	X	Sod forming, spreads rapidly, slow germination. Valuable for erosion control. Drought resistant.

[a]Grasses should be planted in combination with legumes. Seeding rates, time, and varieties should be based on local recommendations.
[b]P = perennial; A = annual.
[c]Many species survive and grow at lower pH; however, optimum growth occurs within these ranges.
[d]Hay, pasture, green manure, winter cover, and nurse crops are primary agricultural uses.
Note.–Prepared in cooperation with Soil Conservation Service plant material specialists and State conservationists.

Table 6
Legumes[a] Commonly Used for Revergetation (EPA 1976)

Common name	Scientific name	Season			Site suitability				Growth habit[b]	pH range[c]	Use suitability			Remarks
		Cool	Warm	Dry	Well drained	Moderately well drained	Somewhat poorly drained	Poorly drained			Erodible areas	Waterways and channels	Agriculture[d]	
Alfalfa	*Medicago sativa*	X		X	X	X			P	6.5-7.5	X		X	Requires high fertility and good drainage.
Clover, Alsike	*Trifolium hybridium*	X			X	X	X	X	P	5.0-7.5	X		X	Good for seeps and other wet areas. Dies after 2 years.
Clover, red	*Trifolium pratense*	X			X	X			P	6.0-7.0	X		X	Should be seeded in early spring.
Clover, white	*Trifolium repens*	X			X	X	X		P	6.0-7.0	X		X	Stand thickness decreases after several years.
Flatpea	*Lathyrus sylvestris*	X		X	X	X	X		P	5.0-6.0	X			Seed is toxic to grazing animals. Good cover.
Lespedeza, common	*Lespedeza striata*		X		X	X			A	5.0-6.0	X			Low-growing, wildlifelike seed. Kobe variety most often used. Acid tolerant.
Lespedeza, Korean	*Lespedeza stipulacea*		X	X	X	X	X		A	5.0-7.0	X			Less tolerant of acid soils than common lespedeza.
Lespedeza, sericea	*Lespedeza cuneata*		X	X	X	X	X		P	5.0-7.0	X	X		Woody, drought tolerant, seed should be scarified. Bunchlike growth.
Milkvetch, cicer	*Astragalus cicer*			X	X	X	X		P	5.0-6.0	X		X	Drought tolerant. Low growing. No major diseases. Hard seed coat.
Sweetclover, white	*Melilotus alba*	X		X	X	X			B	6.0-8.0	X		X	Requires high-pH spoil. Tall growing. Produces higher yields. Less reliable seed production.
Sweetclover, yellow	*Melilotus officinalis*	X		X	X	X			B	6.0-8.0	X		X	Requires high-pH spoil. Tall growing. Can be established better than white sweetclover in dry conditions.
Trefoil, birdsfoot	*Lotus corniculatus*	X		X	X	X	X		P	5.0-7.5	X		X	Survives at low pH. Inoculate with special bacteria. Plant with a grass.
Vetch, crown	*Coronilla varia*	X		X	X	X			P	5.5-7.5	X		X	Excellent for erosion control. Drought tolerant. Winter hardy.
Vetch, hairy	*Vicia villosa*	X		X	X	X			A	5.0-7.5	X		X	Adapted to light sandy soils as well as heavier ones. Used most often as a winter cover crop.

[a]Legumes should be inoculated. Use four times normal rate when hydroseeding.

[b]A = annual; B = biennial; P = perennial.

[c]Many species survive and grow at lower pH; however, optimum growth occurs within these ranges.

[d]Hay, pasture, green manure.

Note.–Prepared in cooperation with Soil Conservation Service plant material specialists and State conservationists.

Table 7
Trees and Shrubs Commonly Used for Revegetation (EPA 1976)

Common name	Scientific name	Remarks
Shrubs:		
Amur honeysuckle	*Lonicera maacki podocarpa*	Good for wildlife. Shows more vigor and adaptability as plants mature.
Bristly locust	*Robinia fertilis*	Extreme vigor. Thicket former. Good erosion control. Rizomatous, 5-7 ft tall. Excellent on flat areas and outslopes.
Autumn-olive	*Elaeagnus umbellata*	Nitrogen-fixing nonlegume. Good for wildlife. Excellent fruit crops. Wide adaptation. Up to 15 ft tall.
Bicolor lespedeza	*Lespedeza bicolor*	Can be established from planting and direct seeding. Ineffective as a ground cover for erosion control.
Indigo bush	*Amorpha fruticosa*	Has high survival on acid spoil. Leguminous. Not palatable to livestock. Thicket former. Slow spreader. 8-12 ft tall.
Japanese fleeceflower	*Polygonum cuspidatum*	Grows well on many sites, especially moist areas. Excellent leaf litter and canopy protection. pH range of 3.5 to 7.0.
Silky dogwood	*Cornus amomum*	Grows best on neutral spoil pH. Can withstand pH range of 4.5 to 7.0. Some value as wildlife food and cover plants. Poor surface protection.
Tatarian honeysuckle	*Lonicera tatarica siberica*	Upright shrub, forms clumps. Does well on well-drained soils. Up to 12 ft tall. Takes 2 years for good cover.
Trees, conifers:		
Virginia pine	*Pinus virginiana*	Tolerant of acid spoil. Use for esthetics and where other species will not survive. Slow development. Good for wildlife.
Pitch pine	*Pinus rigida*	Deep rooted and very acid tolerant. Can survive fire injury. Deer like small seedlings. Plant in bands or blocks.
Loblolly pine	*Pinus taeda*	Very promising species, rapid early growth. Marketable timber products. Can survive pH 4.0 to 7.5. Susceptible to ice and snow damage.
Scotch pine	*Pinus sylvestris*	Good for Christmas trees if managed properly. Can be planted on all slopes and tolerates pH of 4.0 to 7.5.
Shortleaf pine	*Pinus echinata*	Some insect problems. Will sprout freely if cut or fire killed when young. Good marketable timber.
White pine	*Pinus strobus*	May be used for Christmas trees. Has poor initial growth but improves with time. Plant in bands or blocks.
Austrian pine	*Pinus nigra*	Can be planted on all slopes. Plant in bands or blocks. When planted near black locust, deer cause browse damage.
Japanese larch	*Larix leptolepis*	Should be planted on unleveled and noncompacted spoil. Provides good litter.
Red pine	*Pinus resinosa*	Sawfly damage in some areas. Plant on all slopes. Light ground cover.
Rocky Mountain juniper	*Juniperus scopulorum*	Has shown good survival on Kansas spoil materials. Compact growth varieties have from silver to purple colors.
Eastern red cedar	*Juniperus virginiana*	Tall, narrow growth. Best on dry, sandy soils. Good with black locust. pH 5.0 to 8.0.
Mugho pine	*Pinus mugo mughus*	Survives on acid spoil. Develops slowly. Low growing. Good cover for wildlife.
Trees, hardwoods:		
Black locust	*Robinia pseudoacacia*	Can be direct seeded. Wide range of adaptation. Rapid growth; good leaf litter. Use mixed plantings. Dominant stem clones preferred.
Bur oak	*Quercus macrocarpa*	Better survival with seedling transplants than acorns. Light to heavy ground cover.
Cottonwood	*Populus deltoides*	A desirable species for large-scale planting. Good cover and rapid growth. Pure stands should be planted.
European black alder	*Alnus glutinosa*	Rapid growing. Wide adaptation. Nitrogen fixing, nonlegume. Can survive pH 3.5 to 7.5. Adapted to all slopes.
Green ash	*Fraxinus pennsylvanica*	Very promising species. Use on all slopes and graded banks with compact loams and clays. Plant in hardwood mixture.
Hybrid poplar	*Populus spp.*	Rapid growth. Good survival at low pH. Marketable timber after 20 years. Cannot withstand grass competition. Good for screening.
Red oak	*Quercus rubra*	Makes slow initial growth. Good survival, plant on upper and lower slopes only. Can grow from pH 4.0 to 7.5.
European white birch	*Betula pendulata*	Makes rapid growth on mine spoil. Poor leaf litter and surface coverage.
Sycamore	*Platanus occidentalis*	One of the most desirable species for planting. Poor ground cover. Volunteer trees grow faster than planted ones.