ENVIRONMENTAL AND WATER QUALITY
OPERATIONAL STUDIES

TECHNICAL REPORT E-86-13

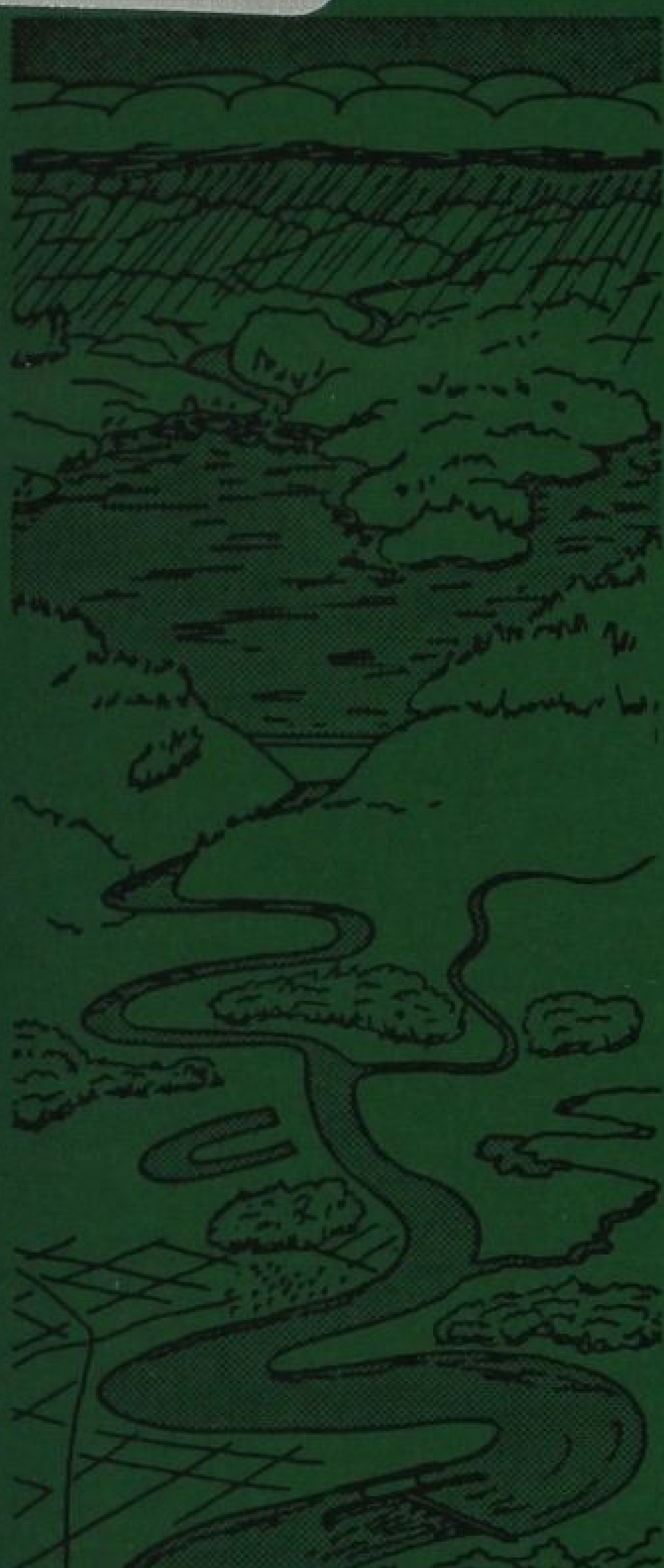
RESERVOIR SHORELINE REVEGETATION GUIDELINES

by

Hollis H. Allen, Charles V. Klimas

Environmental Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631



November 1986

Final Report

Approved For Public Release; Distribution Unlimited

Prepared for DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

Under EWQOS Work Unit IIE.1

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report E-86-13	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) RESERVOIR SHORELINE REVEGETATION GUIDELINES		5. TYPE OF REPORT & PERIOD COVERED Final report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Hollis H. Allen, Charles V. Klimas		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Engineer Waterways Experiment Station Environmental Laboratory PO Box 631, Vicksburg, Mississippi 39180-0631		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS EWQOS Work Unit IIE.1
11. CONTROLLING OFFICE NAME AND ADDRESS DEPARTMENT OF THE ARMY US Army Corps of Engineers Washington, DC 20314-1000		12. REPORT DATE November 1986
		13. NUMBER OF PAGES 87
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Reservoirs
Revegetation
Shorelines
Vegetation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

As part of the Environmental and Water Quality Operational Studies Program, three reservoirs were selected for investigating the feasibility of establishing vegetation on shorelines subject to varying water levels. Study sites were established at Lake Oahe, South Dakota; Lake Texoma, Oklahoma/Texas; and Lake Wallula, Oregon/Washington. This report synthesizes the results of the revegetation trials at these study sites and pertinent

(Continued)

DD FORM 1473 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT (Continued).

revegetation concepts reported elsewhere. Guidelines for developing vegetation on reservoir shorelines having fluctuating water levels are presented in five parts: (a) planning, (b) site preparation, (c) planting, (d) post-planting operations and maintenance, and (e) costs. Emphasis is placed on reduced costs, proper planning, procurement of plant materials, appropriate planting times and methods, and special planting techniques for erodible shorelines.

PREFACE

This study was performed under the Environmental and Water Quality Operational Studies (EWQOS) Program, Work Unit IIE.1, "Environmental Effects of Fluctuating Reservoir Water Levels," sponsored by the Office, Chief of Engineers (OCE), US Army, and assigned to the Environmental Laboratory (EL), US Army Engineer Waterways Experiment Station (WES). The OCE Technical Monitors were Mr. Earl Eiker, Dr. John Bushman, and Mr. James L. Gottesman.

This report was prepared by Messrs. Hollis H. Allen and Charles V. Klimas, Botanists, Wetlands and Terrestrial Habitat Group (WTHG), EL. Technical review was provided by Drs. Dana R. Sanders, Sr., and Mary C. Landin, both of the WTHG. The report was edited by Ms. Jessica S. Ruff of the WES Information Products Division.

The work was conducted under the direct supervision of Dr. Hanley K. Smith, Chief, WTHG, and the general supervision of Dr. Conrad J. Kirby, Chief, Environmental Resources Division, and Dr. John Harrison, Chief, EL. Dr. Jerome L. Mahloch was the Program Manager of EWQOS and Mr. Kenneth G. Hall was the Assistant Manager.

The authors of this report wish to express appreciation to the US Soil Conservation Service for providing plant propagules for various study sites and to the US Fish and Wildlife Service for partial funding support of the study at Lake Wallula, Oregon/Washington. The US Army Engineer Districts, Omaha, Tulsa, and Walla Walla, are also acknowledged for administrative and logistical support during various phases of the study. The following Resource Managers at the reservoir study areas provided outstanding assistance: Mr. David Kadlecek, Lake Oahe; Mr. Herbert Smith, Lake Texoma; and Mr. Darrel Sunday, Lake Wallula.

COL Allen F. Grum, USA, was the previous Director of WES. COL Dwayne G. Lee, CE, is the present Commander and Director. Dr. Robert W. Whalin is Technical Director.

This report should be cited as follows:

Allen, H. H., and Klimas, C. V. 1986. "Reservoir Shoreline Revegetation Guidelines," Technical Report E-86-13, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square metres
feet	0.3048	metres
miles (US statute)	1.609347	kilometres
pounds (mass) per acre	0.000112	kilograms per square metre

RESERVOIR SHORELINE REVEGETATION GUIDELINES

PART I: INTRODUCTION

1. Over 65 percent of the Corps of Engineers (CE) Districts experience problems associated with varying frequencies and durations of fluctuating water levels.* Fluctuating water levels contribute to problems such as shoreline erosion and water turbidity, a lack of or degradation of fish and wildlife habitat, and degraded aesthetics. Bare shorelines result from die-off of flood-intolerant plants and wave action. Some reservoirs, primarily in the Western United States, have steep, bare banks with a 30- to 85-m** drawdown zone (Figure 1). Numerous other reservoirs have bare banks covering a vertical range of 15 m or less. Some of the more shallow reservoirs have several hundred hectares of bare mudflats that are exposed during drawdowns. Grenada Lake in northern Mississippi is an example of such a reservoir (Figure 2). Allen and Aggus (1983) and Ploskey (1983) summarize the effects and problems of fluctuating reservoir water levels on reservoir ecosystems.

2. Investigation of approaches to revegetate reservoir shorelines affected by fluctuating water levels was the subject of a comprehensive research project begun in 1979 under the auspices of the Environmental and Water Quality Operational Studies (EWQOS) Program. This report synthesizes information from several tasks within that project, including: (a) a literature review of flood tolerance and flood-tolerant plants, (b) field trials at selected reservoirs across the United States, (c) a workshop on the environmental effects of fluctuating reservoir water levels, and (d) an investigation of planting methods for soil stabilization purposes.

---

* Based on a 1979 telephone survey conducted by the Environmental Laboratory of the US Army Engineer Waterways Experiment Station.

** Both non-SI and SI (metric) units are used in this report, as appropriate to the source cited. A table of conversion factors is presented on page 4.

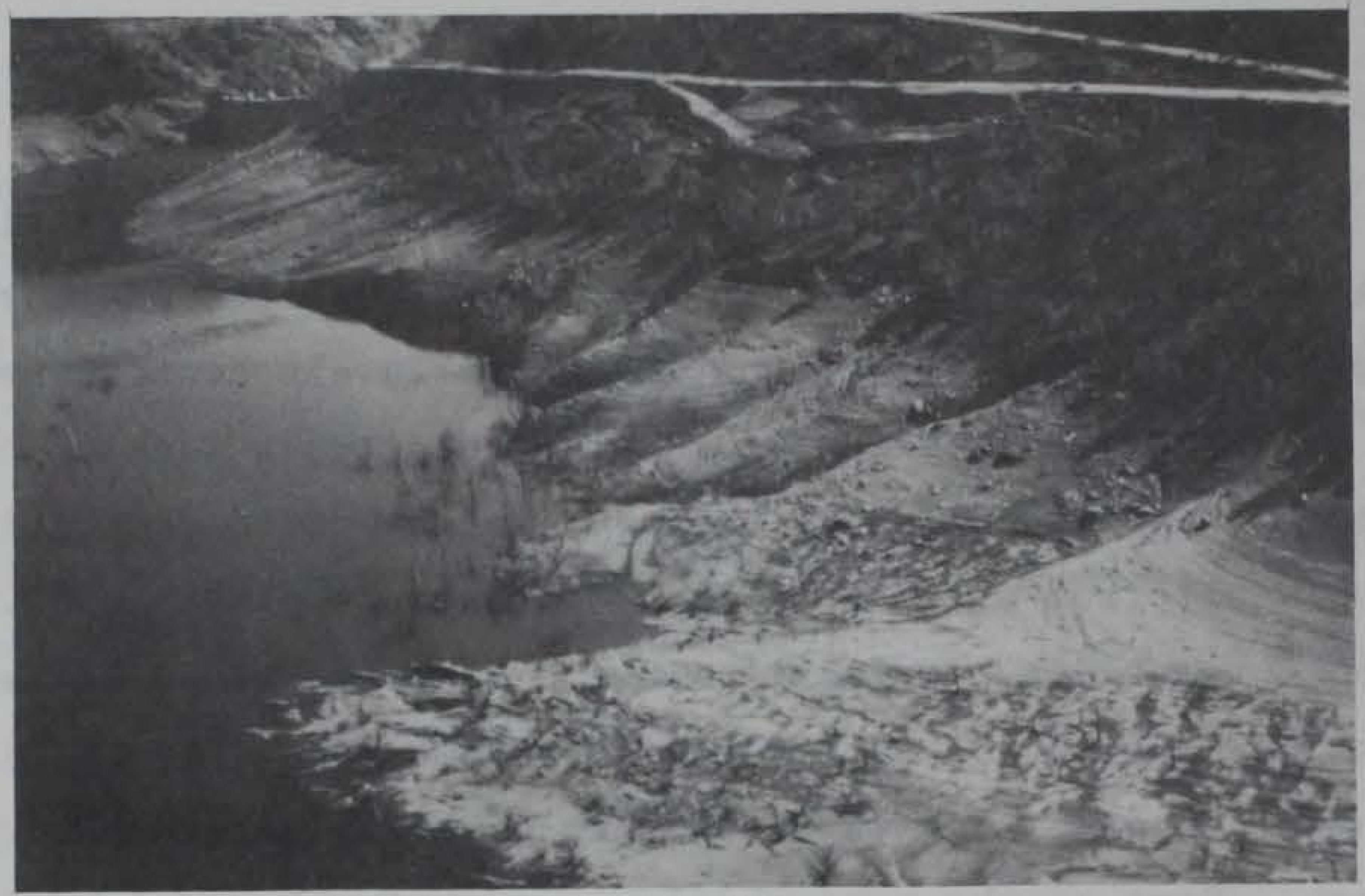
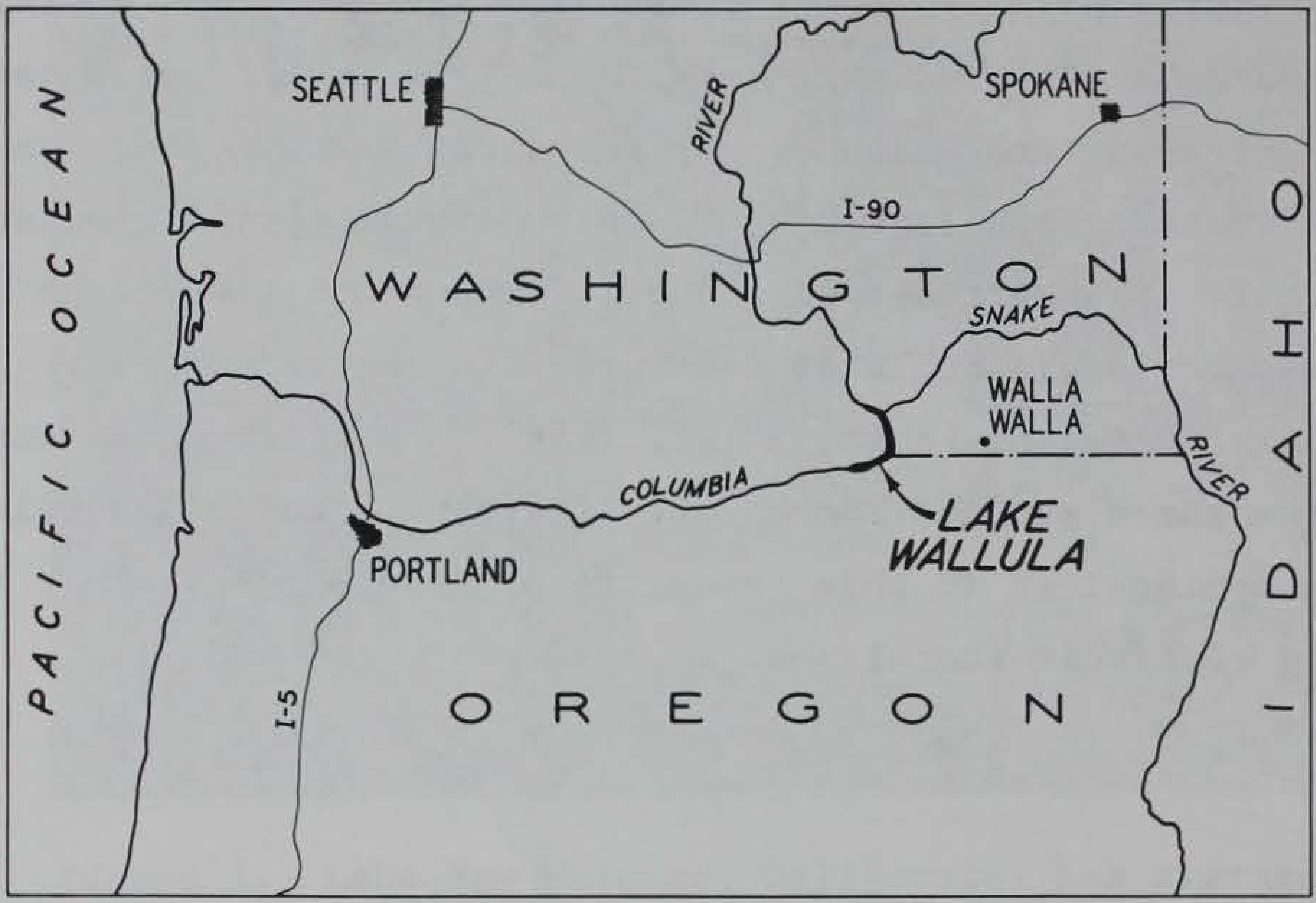


Figure 1. Lake New Melones, California, has average annual drawdown of 34 m from gross pool and maximum drawdown of 84 m

Figure 2. Grenada Lake, Mississippi, where several hundred hectares of mudflats are exposed during drawdown

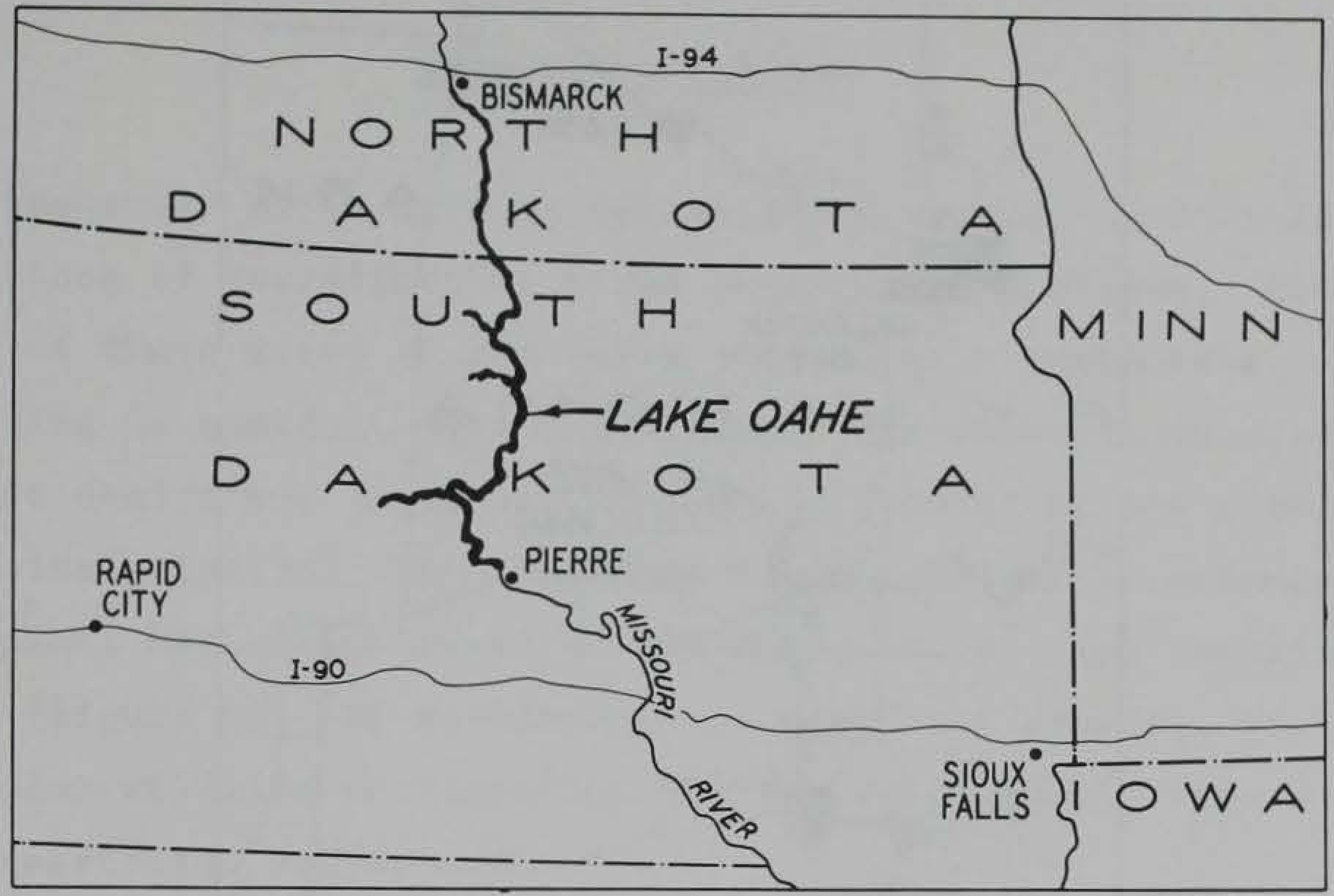
3. The cornerstone of the research project was the series of field trials located at three sites across the United States: Lake Wallula, Oregon/Washington (Figure 3); Lake Oahe, South Dakota (Figure 4); and Lake Texoma, Oklahoma/Texas (Figure 5). At these locations, various woody and herbaceous plant species known from the literature review to have some degree of flood tolerance were transplanted along the shorelines of reservoirs and in impoundments near the reservoir where water levels could be controlled (Comes and McCreary 1986, Hoffman et al. 1986, and Lester et al. 1986). Experience and data obtained from these studies, pertinent literature, and other relevant studies are synthesized in this report to provide a methodology for revegetating reservoir shorelines.



a. Location

b. Shoreline view during drawdown

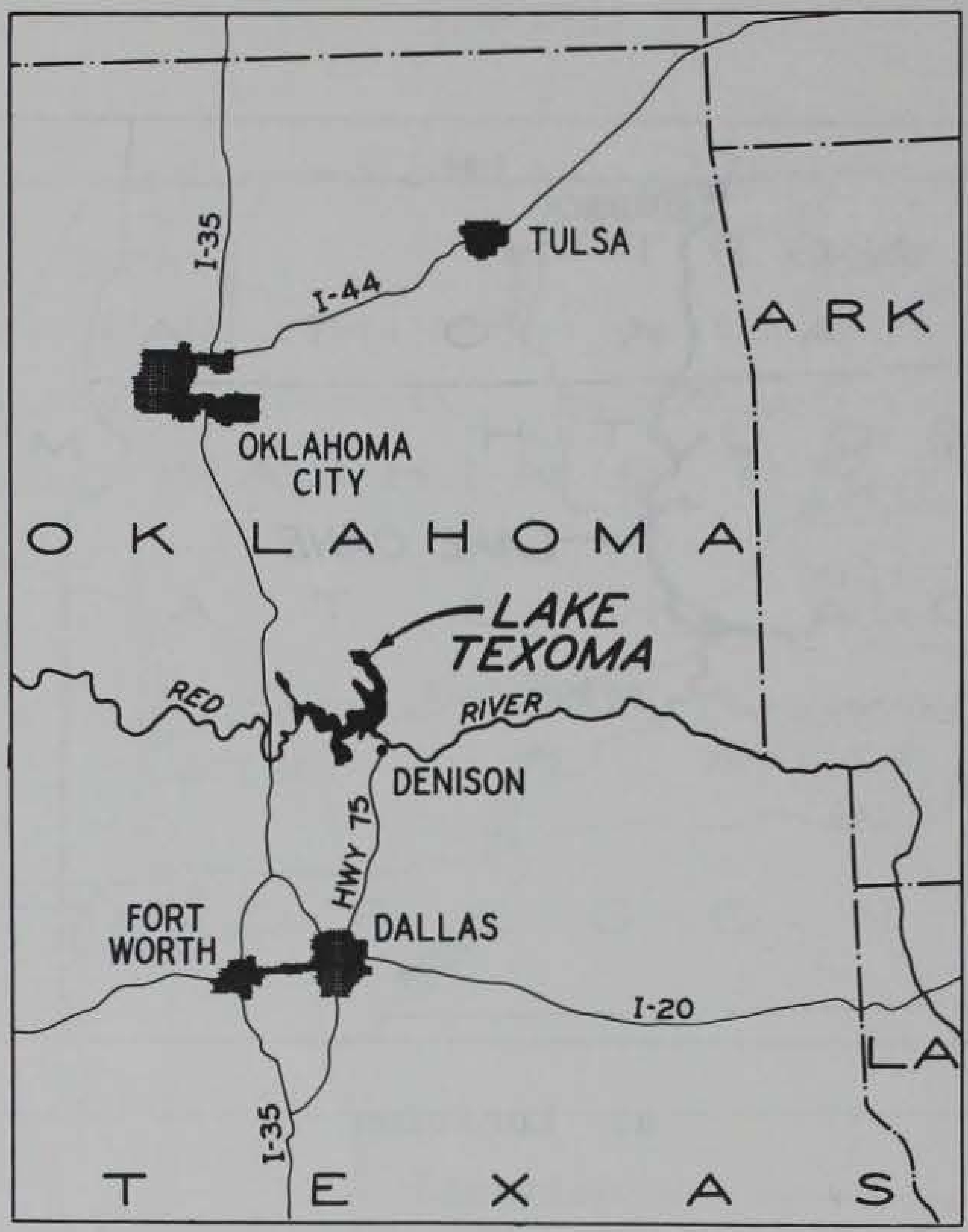
Figure 3. Lake Wallula, Columbia River, Oregon/Washington



a. Location

b. Shoreline view during drawdown

Figure 4. Lake Oahe, Missouri River, South Dakota



a. Location

b. Shoreline view during drawdown

Figure 5. Lake Texoma, Red River, Oklahoma/Texas

PART II: PLANNING

Selection of Sites

4. Reservoir sites needing revegetation usually include long linear expanses of shorelines or broad acreages of mudflats. Revegetating all of these areas is generally economically impractical unless aerial seeding is possible during drawdown. The resource manager or planner must decide how large an area can be planted in any given year and prioritize potential sites based on predicted loss or enhancement of value. Typical high-priority sites are those where: (a) facilities are threatened (Figure 6), (b) archaeological sites are eroding, or (c) high-value wildlife or fisheries habitat would result from a successful revegetation project.

Figure 6. Eroding shoreline adjacent to valuable camping and picnic area at Lake Texoma

5. Site factors to be considered in planning a revegetation effort include fluctuation range and period; bank morphometry (i.e., steepness and shape); wave climate; animal depredation potential; and soil texture, fertility, and moisture status. Success rates are highest

on sites that are gently sloping (i.e., bank slopes not greater than 1V:3H), are protected from extreme wave action, have soils conducive to plant growth, and do not support high populations of potentially destructive animals, e.g., beavers, muskrats, and cattle. Sites with adverse characteristics such as steep or vertical banks can be vegetated but will require more effort and expense. Techniques for revegetating troublesome areas will be addressed in Part IV of this report.

6. Appropriate soil conditions are a critical precondition for successful revegetation, and certain sites may be precluded due solely to adverse soil characteristics. Examples include soils consisting predominantly of shrinking and swelling clays or those having high concentrations of sodium salts. Soil analyses should be conducted to check for such prohibitive characteristics and to aid in choosing sites to be revegetated and species to be planted. Soil analyses will also help determine what soil amendments, if any, are needed for best growth. Soil analyses should include particle size, available nutrients, pH, salinity, percent organic matter, and contaminants, if suspected to be present.

Selection and Acquisition of Plant Species and Materials

7. Selection of the proper plant species is the key to successful shoreline revegetation. The most important factor to consider is the plant's tolerance to alternate periods of flooding and drying, since plantings will be installed in the reservoir drawdown zone somewhere between conservation and gross pool (flood pool) levels.*

8. Whitlow and Harris (1979) review flood tolerance of plant species by CE Division; other reviews are available in Schiechtl (1980) and Hook (1984). Teskey and Hinckley (1977a,b,c; 1978a,b,c) also review flood-tolerant woody plants that can be used for revegetation by major

---

* Conservation pool is the lowest allowable water level within a reservoir which allows it to maintain its intended primary purpose; gross pool is the highest allowable water level within a reservoir.

physiographic regions. Kadlec and Wentz (1974) and the Environmental Laboratory (1978) tabulate soil and moisture conditions, geographic regions of best adaptation, morphological characteristics, potential uses, and planting techniques for numerous plant species.

9. Of the plant species tested in the EWQOS Program field trials mentioned above, approximately 40 have demonstrated sufficient flood tolerance and survival to merit consideration in shoreline revegetation programs in the Pacific Northwest, north-central United States, and the south-central United States. Table 1 lists these species along with information affecting their potential use. The planner or manager who is implementing a shoreline revegetation program should review the above references and Table 1 to develop a list of species suitable for planting on the target site.

10. The literature and EWQOS field trial experience give insight into the kinds of plant species to be considered in developing a revegetation plan. A plant species to be used for substrate stabilization should have an extensive system of roots or rhizomes and should be easy to establish. One may want to consider plants thought of as weedy or pest species under other conditions because they tend to have wide ranges of tolerance and are adapted to a fairly broad spectrum of habitats (Kadlec and Wentz 1974). Pest plants are often highly adapted for rapid dispersal, fast growth, and hardiness. Species such as common reed (*Phragmites australis*), giant reed (*Arundo donax*), reed canary grass (*Phalaris arundinacea*), and willow (*Salix spp.*) can become pests under certain conditions, but the very characteristics that make these species potential problems facilitate their establishment on new or bare substrates. Careful consideration should be given to whether the advantages of introducing these species outweigh the disadvantages with respect to wildlife use, irrigation, navigation, or aesthetics.

11. In addition to having the ability to develop extensive roots or rhizomes, a selected plant species should be capable of rapid height growth. At Lake Texoma, the two tallest herbaceous species, giant reed and switchgrass (*Panicum virgatum* var. Kanlow), were clearly the best and most consistent performers across a broad range of flooding

Table 1

Characteristics of Flood-Tolerant Plant Species Tested at Three EWQOS Field Sites

Species	Flood Tolerance	Erosion Control Value*	Wildlife Value	Habitat Requirements/Remarks
	Lake Wallula, Columbia River, Oregon/Washington (Comes and McCreary 1986)**			
Herbaceous				
Carex aperta	V	Low	Food and cover	Periodically wet soils that partially dry out in the growing season
Carex nebraskensis	M	Low	Food and cover	Same as for *C. aperta*
Carex rostrata	V	Low	Food and cover	Same as for *C. aperta*

(Continued)

* Erosion control values are based on the literature and authors' experience.

** Lake Wallula is a power-production reservoir with daily water-level fluctuations of up to 1.52 m. Inundation tolerance is expressed as follows:

- V - Very tolerant: under experimental conditions, plants showed adequate survival and coverage with daily inundation to depths of 1.37 m for up to 22 hr.
- M - Moderately tolerant: under experimental conditions, plants maintained 50-percent survival or cover with daily inundation to depths of 0.9 m for up to 14 hr.
- S - Somewhat tolerant: under experimental conditions, maintained 50-percent survival or cover with daily inundation to depths of 0.46 m for up to 6 hr.

"Food and cover" refers to seeds that are eaten by song and game birds; stems and leaves are eaten by grazing herbivores such as muskrats and nutria; roots and tubers are eaten by burrowing or digging rodents such as rice rats and birds such as Canada geese. Plants provide cover for all animal species using wetland habitats in which they occur.

(Sheet 1 of 6)

Table 1 (Continued)

Species	Flood Tolerance	Erosion Control Value	Wildlife Value	Habitat Requirements/Remarks
		Lake Wallula (Cont.)		
Herbaceous (Cont.)				
Carex obnupta	V	Moderate	Food and cover, including waterfowl nesting	Fresh to brackish water
Carex vulpinoidea	M	Low	Food and cover	Same as for *C. aperta*
Deschampsia caespitosa	M	Moderate	Food and cover	Fresh to brackish water; forms dense clumps
Eleocharis coloradoensis	V	Low	Waterfowl food	Fresh water
Eleocharis palustris	M	Low	Food and cover	Fresh water; poor root systems
Juncus balticus	S	Moderate	Cover	fresh water; forms clumps
Juncus effusus	S	Moderate	Cover	Fresh water; forms dense clumps; fine-grained substrate
Polygonum persicaria	S	Low	Very high food value	Fresh water; spreads widely by seeding
Sagittaria latifolia	M	Moderate	Very high food value	Fresh water; fine-grained substrates preferred

(Continued)

(Sheet 2 of 6)

Table 1 (Continued)

Species	Flood Tolerance	Erosion Control Value	Wildlife Value	Habitat Requirements/Remarks
		Lake Wallula (Cont.)		
Herbaceous (Cont.)				
Scirpus americanus	S	Moderate	Food and cover	Same as *S. latifolia*
Scirpus validus	M	Moderate	Food and cover	Same as *S. latifolia*
Typha latifolia	S	High	Excellent cover; seeds and tubers eaten	Extensive stands may be of relatively low value for waterfowl
Woody				
Cornus stolonifera	S	Moderate	Food and cover; deer browse	Fresh water; best growth in partial shade
Morus alba	S	Moderate	Food (browse) and cover	Appropriate only for briefly flooded sites
Rosa multiflora	S	Moderate	Excellent food and cover	Potential agricultural pest
Salix fragilis	V	High	Food and cover	Wide tolerance to inundation; easily planted using cuttings
Salix lasiandra	M	High	Food and cover	Plant with cuttings
Salix purpurea var. *nana*	V	High	Food and cover	Shrubby growth habit

(Continued)

(Sheet 3 of 6)

Table 1 (Continued)

Species	Flood Tolerance	Erosion Control Value	Wildlife Value	Habitat Requirements/Remarks
Lake Texoma, Red River, Oklahoma/Texas (Lester et al. 1986)*				
Herbaceous				
Arundo donax	7	High	Cover	Very tall, dense thickets formed
Cyperus esculentus	6	Moderate	Excellent food	Prefers fine-grained soils
Panicum hemitomon	2	Moderate	Food and cover	Widely adaptable
Panicum obtusum	4	Moderate	Food and cover	Vigorous; spreads by long stolons
Panicum virgatum	7	Moderate	Food and cover	Widely adaptable
Phragmites australis	6	High	Cover	May form extensive stands; habitat value minimal in such cases
Spartina pectinata	6	High	Food and cover	Fresh to alkaline water; forms clumps
Woody				
Amorpha fruticosa	3	Moderate	Food and cover	Shrubby growth habit
Diospyros virginiana	3	Moderate	Food and cover	Can be planted at the upper margins of reservoirs

(Continued)

* Lake Texoma is a flood-control reservoir, primarily. Inundation tolerance is expressed as the number of weeks each plant species can satisfactorily tolerate inundation during its growing season.

(Sheet 4 of 6)

Table 1 (Continued)

Species	Flood Tolerance	Erosion Control Value	Wildlife Value	Habitat Requirements/Remarks
		Lake Texoma (Cont.)		
Woody				
Quercus macrocarpa	2	Moderate	Food and cover	Same as *D. virginiana*
Salix nigra	6	High	Food and cover	Easily established from cuttings
		Lake Oahe, Missouri River, South Dakota (Hoffman et al. 1986)*		
Herbaceous				
Buchloe dactyloides	2	High	Food and cover	Can be planted at the upper margins of reservoirs
Phalaris arundinacea	8	High	Food and cover	Widely adaptable; can form dense stands
Phragmites australis	6	High	Cover	Can form very dense stands minimizing habitat value; widely adaptable
Poa pratensis	4	Low	Food and cover	Cool-season grass
Scirpus americanus	6	High	Food and cover	Occurs in fine-grained substrates; fresh water; high food value

(Continued)

* Lake Oahe is primarily a flood-control reservoir. Inundation tolerance is expressed as the number of weeks each species can satisfactorily tolerate inundation during its growing season under experimental conditions.

(Sheet 5 of 6)

Table 1 (Concluded)

Species	Flood Tolerance	Erosion Control Value	Wildlife Value	Habitat Requirements/Remarks
		Lake Oahe (Cont.)		
Herbaceous (Cont.)				
Spartina pectinata	6	High	Food and cover	Fresh to alkaline water; forms clumps
Woody				
Fraxinus pennsylvanica	8	Moderate	Food and cover	Appropriate habitat limited to protected sites, e.g. coves, in Northern Prairie; Occurs freely south of there.
Populus deltoides	6	Moderate	Food and cover	Same as *F. pennsylvanica*

(Sheet 6 of 6)

conditions. Whitlow and Harris (1979) state that tree age is a factor in determining survival during flooding because older, taller trees generally have their leaves above water and are subjected to relatively less severe conditions than seedlings. At Lake Wallula, taller willow transplants (86 cm) survived and grew much better than shorter transplants (36 cm).

12. Whenever possible, transplants should extend above maximum reservoir fill levels in order to ensure maintenance of physiological processes within the plant (Comes and McCreary 1986), or plants should be placed at elevations within the drawdown zone that would minimize the duration of complete submersion. This is especially important during the first growing season when plants are becoming established. If plants are submersed in shallow and sufficiently clear water, they can often withstand flooding for longer durations than if they are submersed in deep and/or muddy water.

13. When considering woody plant species for a site, species that typically leaf out late in the season should be favored. Broadfoot and Williston (1973) state that seedlings of species that leaf out late, such as green ash (*Fraxinus pennsylvanica*), water hickory (*Carya aquatica*), and overcup oak (*Quercus lyrata*), will survive spring floods lasting into July. At the Lake Oahe EWQOS field site, green ash was the most successful woody transplant and performed well with up to 8 weeks of flooding (Figure 7).

14. The location from which plant species and their propagules are acquired will often dictate how flood tolerant and potentially successful the species will be on reservoir shorelines. Species should be selected that are commonly associated with riparian habitats or wetlands in the general geographic area of consideration. Collection of seeds and/or transplant material should be done in areas that have been subjected to alternate periods of wetting and drying to maximize the likelihood of obtaining well-adapted ecotypes. This is important because most studies of plant species with a wide geographical range (altitudinal, latitudinal, climatic) have shown wide differences in the

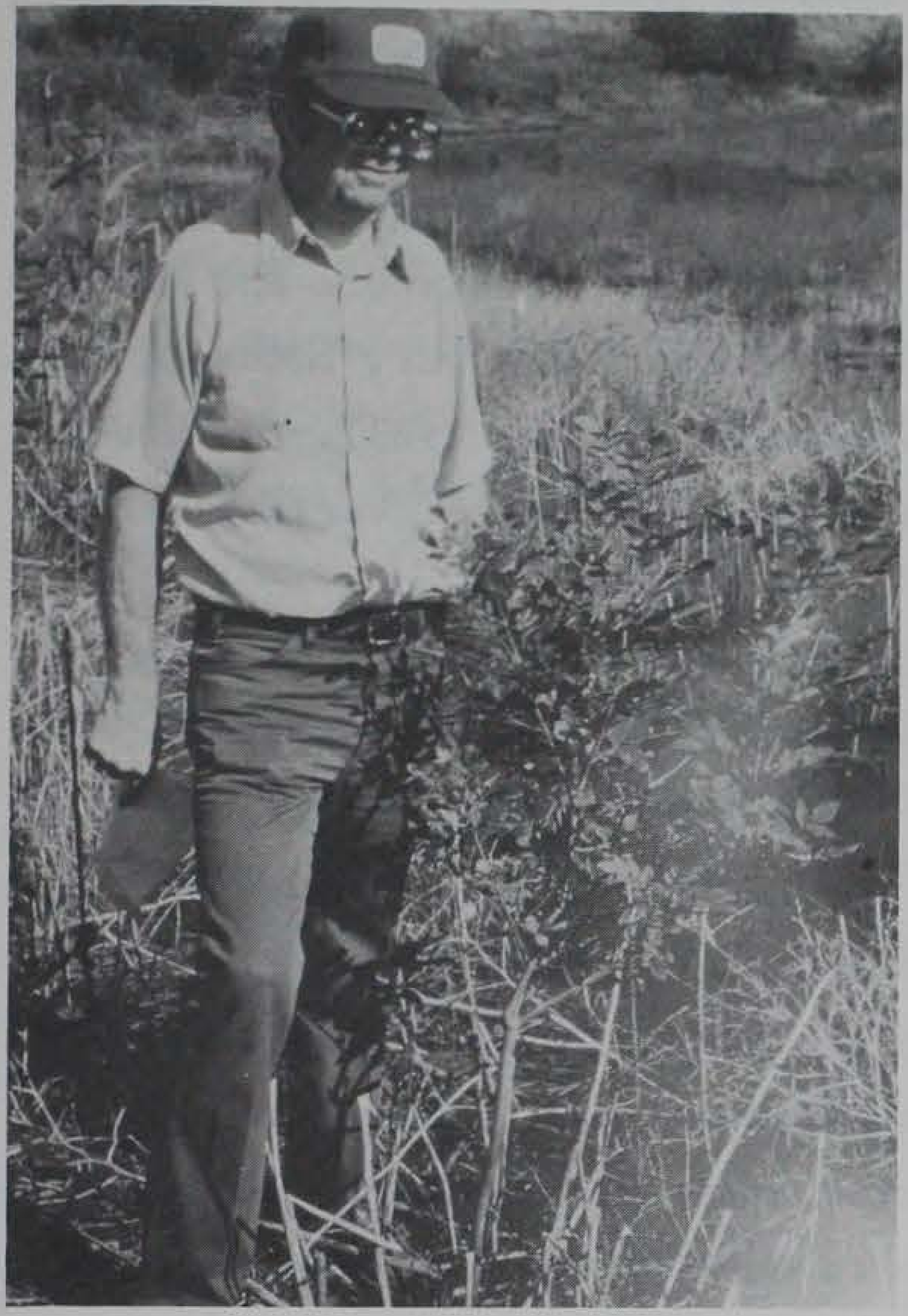


Figure 7. Green ash transplant that survived and grew well at Lake Oahe after 8 weeks of flooding

response of individual plants to a variety of environmental factors, e.g., heat, cold, drought, soils, and flooding tolerance (Leiser 1983).

15. Leiser (1983) also reported that red-osier dogwood (*Cornus stolonifera*) is a riparian species ranging from Alaska to Newfoundland, south to Virginia and west to California. Studies of this species indicate wide variation in hardiness. Some differences relate to latitudinal distribution, while others relate to climatic differences. Collections of the species from western Washington and Minnesota, which are at about the same latitude, showed that absolute hardiness in midwinter was similar; however, the Washington collection did not attain this degree of hardiness until much later in the season.

16. Leiser (1983) noted that green ash (*Fraxinus pennsylvanica*) is sometimes considered of two varieties: red ash (*F. pennsylvanica*) on

upland sites and green ash (*F. pennsylvanica* var. *lanceolata*) on riparian sites. The species range extends from Cape Breton Island and Nova Scotia west to Alberta and Montana and south to central Texas and northern Florida. Studies of plant varieties and their original source of propagation show pronounced ecotypic differences in moisture and low-temperature tolerances. The variety *F. pennsylvanica* var. *lanceolata* appears to have a wide tolerance to wet soils (Leiser 1983). As stated above, in the EWQOS field study at Lake Oahe, the latter variety exhibited excellent flood tolerance.

17. As an alternative to collecting transplants in the field, plants may be acquired from commercial nurseries that specialize in wetland plants. Appendix A presents a listing of nurseries that furnish seeds or grow native plants suitable for reservoir shorelines. Plants may also be acquired from the USDA Soil Conservation Service Plant Material Centers upon request, with approval from the State Soil Conservationist in the state in which the center is located. If raising transplants from seed is selected as the preferred approach, sufficient leadtime (1 to 2 years) must be given to collect the seed and grow the plants if large quantities of materials are needed. When plants are acquired from nurseries, the contract or agreement should include a requirement that the nursery will provide evidence of the source location of their plant materials. For field-collected seeds, dormancy and scarification requirements must be met for successful germination. Many of the desired plant propagules, especially woody cuttings, may not be readily available from commercial nurseries and may have to be acquired from donor sites. In such cases, advance planning activities will have to be conducted, such as ensuring regulatory compliance for environmental and cultural resource protection and proper acquisition of rights-of-entry.

PART III: SITE PREPARATION

18. Site preparation includes development of a generalized project layout or landscape plan according to project and revegetation objectives prior to any work being done at the site. It also includes any work necessary to prepare the site for planting, such as preparing the slopes, shaping the banks, protecting the site from animals that could destroy new plantings, or temporarily protecting the site from wave action. It may be necessary to temporarily prevent wave action so that the integrity of the site is preserved during planting and new plant establishment. Waves can undercut the bank, particularly when the bank is steep to vertical. After the plants have become well established at the base, they will provide a good erosion control system. Wave protection for erodible sites is discussed further in paragraphs 20-21.

Project Layout

19. A generalized project layout or landscape plan should be the first step in site preparation and should be based largely on the revegetation objectives and the planning considerations discussed in Part II. The primary factor that will influence the landscape plan will be the availability of suitable flood-tolerant plant species that meet the site development and management goals. A project layout for erosion control may be quite different than for habitat development or aesthetic improvement. By this stage in the project, plant species and materials to be used will have already been located and selected. If time allows, the field layout may be tested in a one-season pilot project to avoid errors that may be costly in large-scale field application. The project layout described in paragraphs 20-24 below is a general layout and may be subject to change depending on site-specific conditions.

Erodible sites

20. For sites subject to erosive wave action, it is better to use flood-tolerant grasses or grasslike plants lakeward of flood-tolerant shrubs and trees (Figure 8) in a zone that is just below mean water

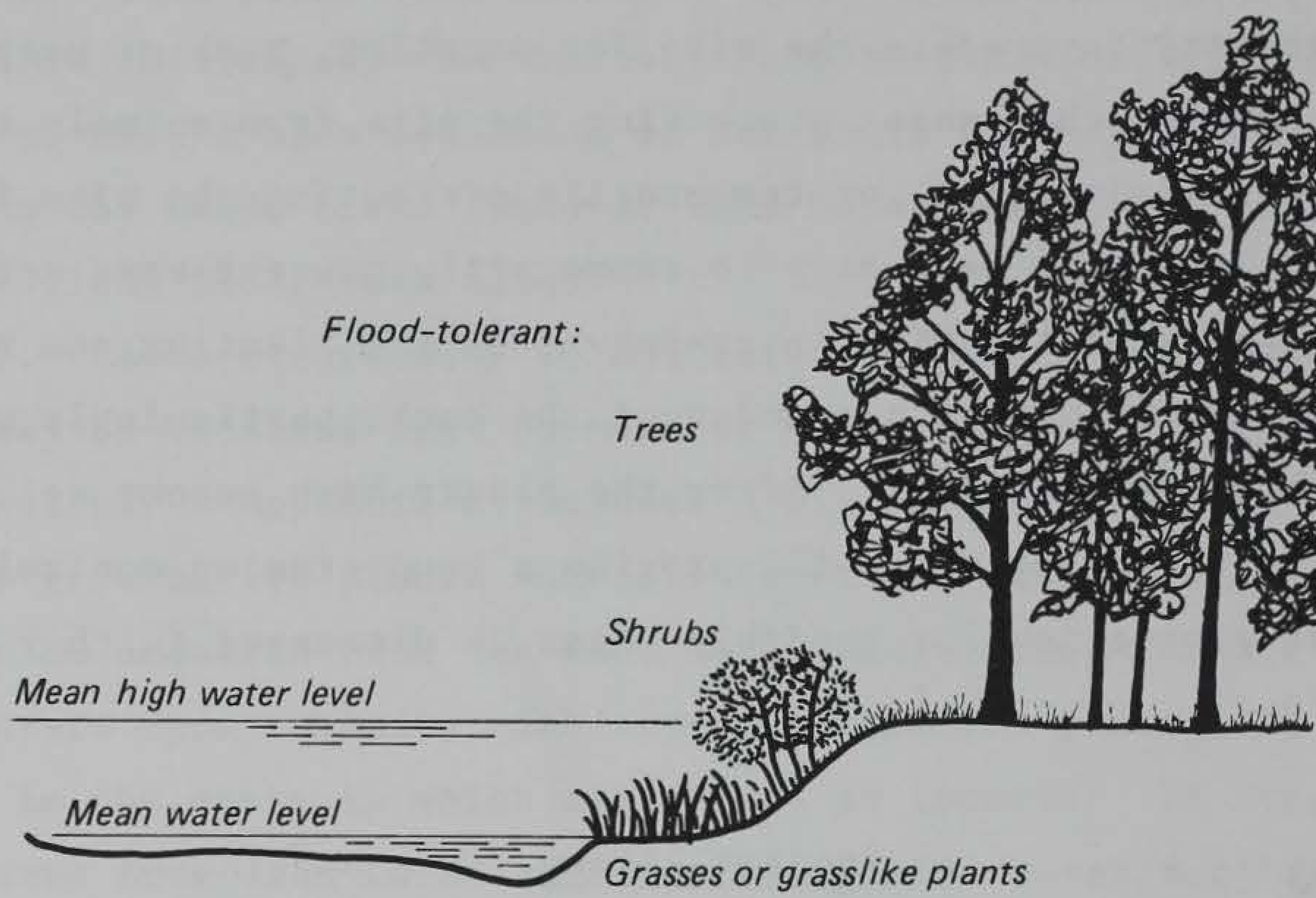


Figure 8. Layout of vegetation placement on a shoreline subject to erosion

level to just above mean high water level. Use of grass or grasslike plants lakeward of flood-tolerant shrubs and trees takes advantage of their resilient attribute of damping waves. Once established, these plants also help trap fine sediments that are conducive to the natural colonization of other plants. The grass or grasslike plants should have large, erect stems or form dense bunches or turf and should be able to tolerate expected water-level fluctuations. Some grasses or grasslike plants may withstand wave washout better if they are used in combination with plant rolls (described in paragraph 77) or are anchored with 40- to 50-cm U-shaped pins made from material similar to clothes hangers. Suitable plants for erodible sites include reeds such as common reed or giant reed, reed canary grass, maidencane (*Panicum hemitomon*), softstem bulrush (*Scirpus validus*) or other *Scirpus* species, rush (*Juncus*) species, taller sedge (*Carex*) species, and switchgrass.

Selection of particular species will depend upon climate and other site-specific characteristics.

21. This zone of grasses or grasslike plants for reservoir shorelines is very similar to the zone Seibert (1968) describes for streambanks. Seibert called this zone a "reedbank" zone and described its protection attributes. Plants within this zone are able to bind the soil with their roots both above and below existing water levels. Seibert (1968) noted that the reedbank plants form a permeable underwater obstacle which slows down current and waves by friction, thereby reducing soil erosion. Active protection of the bank can be ensured by reeds only in an area that is almost constantly submersed, i.e., below the average water level. Achieving plant establishment in this zone is difficult and may require some initial wave protection.

22. Flood-tolerant shrubs and shrublike trees are the next group of species to consider in the project layout behind the reedbank zone. They should be placed immediately landward or up the slope from the reedbank zone in areas that are still within that portion of the drawdown zone that is frequently flooded or flooded for relatively long durations. These species normally include buttonbush (*Cephalanthus occidentalis*), shrublike willow species such as purple-osier willow (*Salix purpurea*) and sandbar willow (*Salix interior*), and water elm (*Planera aquatica*).

23. Once established, the woody plants, with deeper penetrating roots, will prevent the soil from being washed away and will reinforce the reedbank zone (Seibert 1968, Gray and Leiser 1982). These plants will assist the reedbank zone plants because they have resilient attributes, such as springy branches that resist wave action. They are also prolific and spread rapidly due to their ability to sprout easily. These attributes enable the species to form vegetative banks that are difficult to undercut by waves, particularly when planted using the bioengineering techniques discussed in Part IV.

24. Taller trees such as green ash, cottonwood (*Populus* spp.), red maple (*Acer rubrum*), and persimmon (*Diospyros virginiana*) should be planted in the third zone back from the lowest lake levels. These

should be placed upslope from the shrubs and shrublike trees. Larger trees placed further up the slope offer benefits of improved slope stability and increased shear strength of soils due to their root reinforcement (Gray 1977). As a result, they help preserve the integrity of streambanks (Sigafoos 1964) and should not be deemphasized as stabilizers of reservoir shorelines.

25. Site preparation may include protecting the site from waves. In a natural lake, where water levels fluctuate little, waves build up a natural terrace or berm over a long period of time at a specific lake elevation. Conversely, the wave zone occurs at varying shoreline elevations in reservoirs used for flood control or for power generation, e.g., in most CE reservoirs. Consequently, waves do not occur at one elevation for sufficient duration to form natural terraces. This is unfortunate because natural invasion of flood-tolerant plants can occur behind terraces that offer some wave protection (Figure 9). It may be necessary to prepare a wavebreak for effective revegetation in very erodible situations, such as shorelines with steep silt or loess banks, and long wind fetches. Project costs, however, may be sharply increased.

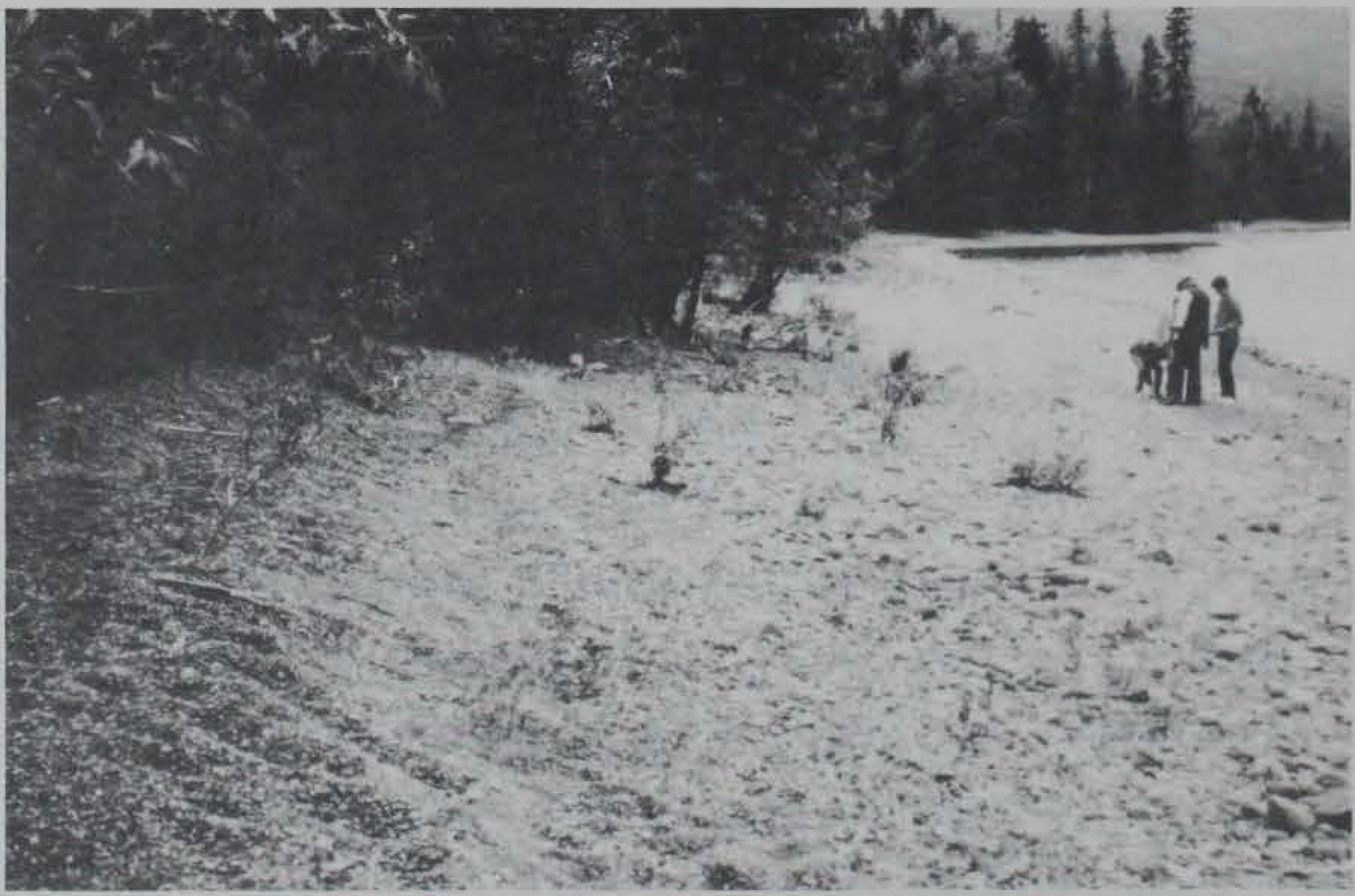


Figure 9. Invasion of flood-tolerant plants behind a natural terrace at Lake McDonald, a natural lake in Glacier National Park, Montana

26. A type of wavebreak structure that has been successfully applied in estuaries is a floating tire breakwater (FTB) (Figure 10a) (Allen, Webb, and Shirley 1984). It was used to afford protection to salt marsh grass planted behind it, along a dredged material dike (Figure 10b). The dike was in an area that had low probability of establishment success due to wind fetches of 4.8 to 6.4 km. This kind of breakwater may have application to reservoir shorelines having fluctuating water levels because it floats and can be assembled rapidly and at relatively low cost. More importantly, it breaks wave action regardless of water levels, giving protection to plants across the full range of reservoir fluctuation. Another advantage of this type of breakwater is that it can be disassembled into smaller modules of 18 tires each and floated to other parts of the reservoir for reuse, which reduces overall costs. Experience indicates that it takes about two growing seasons, on the average, for plants to become sufficiently established before the breakwater can be moved. Figure 11 illustrates how an FTB is constructed. For more detail on construction, see Shaw and Ross (1977). Since some shoreline residents and users may not appreciate the visual appearance of a tire breakwater or since FTB's may not be compatible with other shoreline uses, other breakwaters may be preferred. An example is a breakwater made from floatable wooden poles strapped together in long cylinders.

Nonerodible sites

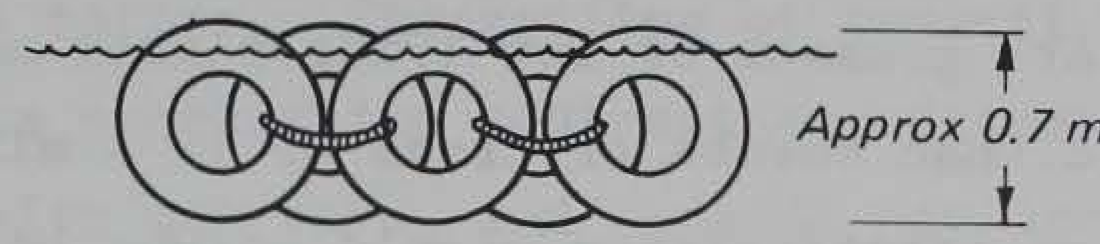
27. Plant layouts for purposes of shoreline habitat development or aesthetic improvement are usually not so rigorously designed as for erosion control on shorelines. The key to habitat development is to use flood-tolerant plant species that can provide food and/or cover for wildlife species of interest. Table 1, which lists some of the flood-tolerant plants used in EWQOS field trials, denotes whether selected plants have wildlife value, but the planner or manager is advised to investigate the specific wildlife or fisheries benefits of plants under consideration.

28. When aesthetic improvement of the shoreline is of primary interest, a resource manager or planner will have to consider the needs

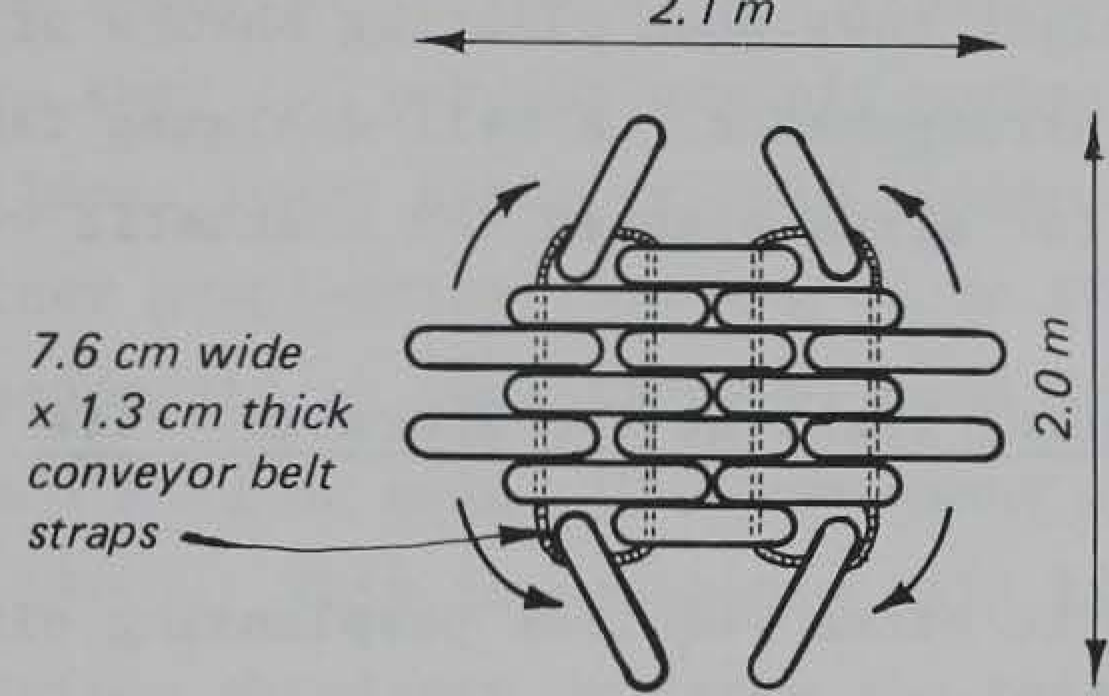
a. Placement of FTB to damp waves in front of a planted marsh

b. Two years later, development of Marsh behind FTB is successful

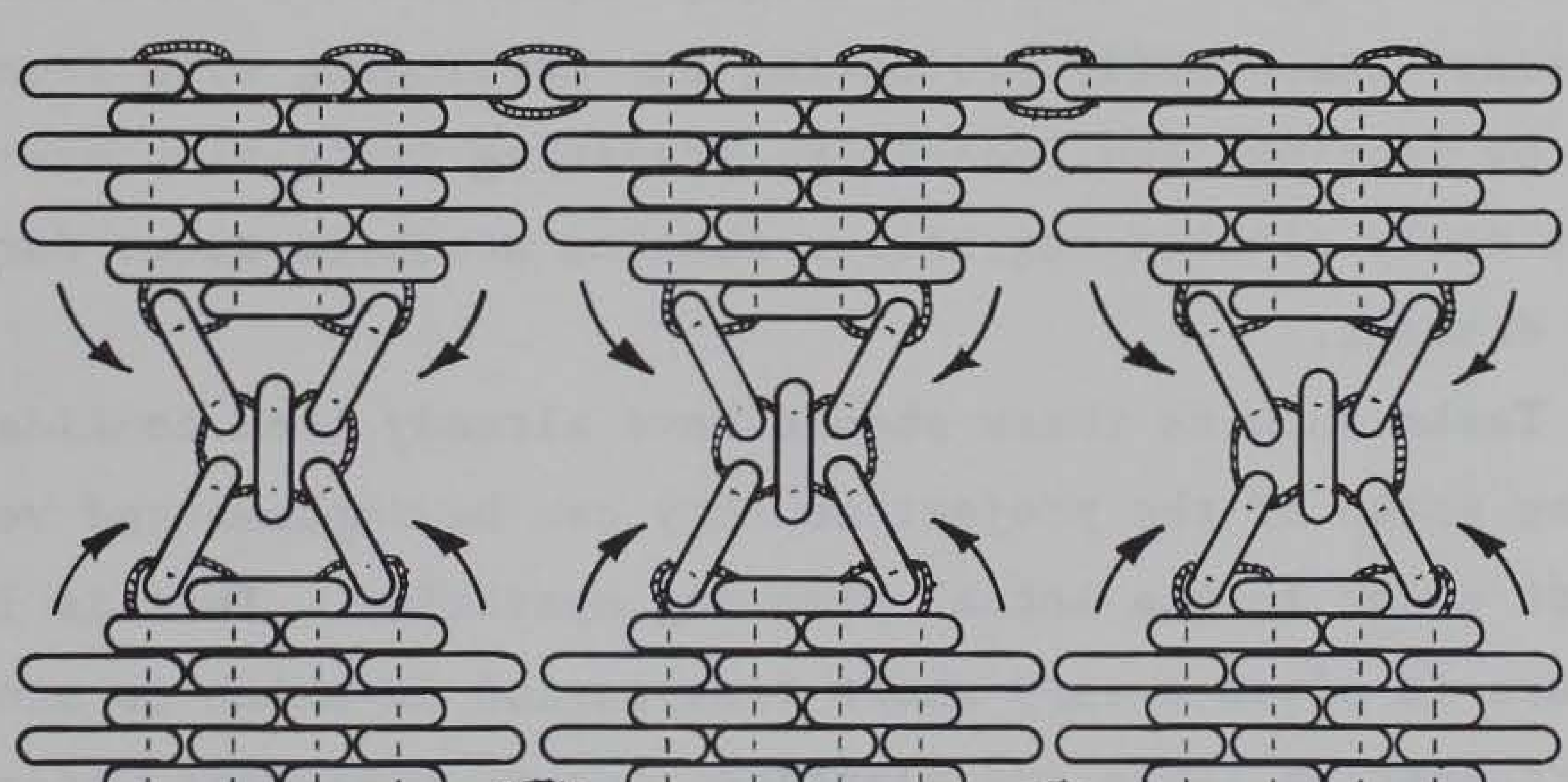
Figure 10. Application of floating tire breakwater in Mobile Bay, Alabama



PROFILE SCHEMATIC OF ONE FTB MODULE



PLAN SCHEMATIC OF ONE FTB MODULE



PLAN SCHEMATIC OF SEVERAL FTB MODULES

Figure 11. Profile and plan schematics of an FTB, illustrating its construction by strapping tires and tire-modules together

and uses of the public using the reservoir as well as residents along the shoreline. Are grasses or low-lying plants more apt to be appealing to the public than shrubs or trees or is a mixture preferable? Again, the primary consideration should be whether the plants can tolerate varying conditions of flooding frequency and duration along with periods of dryness. As a general rule when aesthetics are of concern, it is best to avoid straight rows when planting shrubs or trees and to favor random or clumped arrangements. A well-designed landscape plan is of utmost importance for sites planted for aesthetic value.

Preplanting Tasks at the Shoreline Site

29. A shoreline site often requires preplanting site preparations. These may include tasks such as sloping and shaping the bank; incorporating fertilizer or other soil amendments such as lime or gypsum; eliminating undesirable existing vegetation by mechanical or chemical means; temporarily protecting the developing site from animals and people by fencing; and, possibly, preparing irrigation systems to ensure that newly planted vegetation obtains adequate water during periods of drought.

30. Tasks such as these should have already been considered in the planning phase of the project so they can be implemented very quickly just prior to the actual planting operation. This is important because there is often a very short time period in which to accomplish the site preparation tasks and planting, due to reservoir water-level management requirements, i.e., water levels may rise rapidly. For instance, if bank sloping and shaping by machinery are required, the machinery must be procured and mobilized on schedule so that planting can occur before optimum planting conditions (temperature, moisture) have passed. If cattle graze the shoreline, fencing needs to be installed prior to planting to prevent destructive browsing of the newly planted vegetation.

31. When the shoreline is to be sloped and shaped, areas to be vegetated should have a minimum of 10 cm of topsoil, if possible.

Usually, the topsoil is considered to be the surface of undisturbed soil that is high in organic matter. Stockpiling of topsoil by the planting contractor may be a site preparation contract requirement. Availability of topsoil at a given site may vary, and topsoil may have to be moved from one area to another. Thus, the contractor could stockpile topsoil in one area for use in another. Depending on the economic practicality, topsoil could be imported to the site. Preferably, imported topsoil should have more than 1.5 percent organic matter and have a textural class of sandy loam, loamy sand, or loam (Logan 1979).

32. Another preplanting task may be to treat the site with various soil amendments or conditioners, such as fertilizers, lime, and gypsum, or to add sand or mulch (US Department of Agriculture (USDA), Forest Service 1980). This is necessary only if the site is considered poor in various nutrients or lacks the necessary physical/chemical properties for good plant growth. Possible problems relating to the site's soil should be identified in the planning phase, as discussed in Part II.

PART IV: PLANTING

33. The site is ready for planting after landscape plans have been completed, soils evaluated, plant propagules located, any needed bank shaping or sloping completed, fences constructed (if needed), and any other tasks completed to ensure the best conditions for plant establishment and site stability.

Timing

34. Seeding and planting, as a general rule, should be conducted at a time when favorable soil-moisture and temperature conditions are going to occur and when reservoir water levels are at their lowest. If water levels are expected to drop in the fall and rise rapidly in the spring before planting operations could be mobilized, it would be better to seed or plant in the fall just after water levels drop so the planting substrate is still moist. Conversely, if reservoirs are at their lowest level during December or January and rise very slowly during the spring, seeding and/or planting could occur during late winter to early spring, depending on rainfall availability and temperature conditions. Some grass and herbaceous species can be seeded or transplanted in either the spring or the fall, while others establish better in a particular season.

35. If the grasses and forbs are to be planted in the upper margins of the drawdown zone when reservoir water levels are too low to provide moist soil conditions, the best approach is to plant just prior to the normal high-rainfall period. Woody transplants, either bare-root or balled-and-burlapped, should be planted while dormant, either after the first killing frost or before growth resumes in the spring.

36. Seeding and planting times may vary with particular species and site-specific situations. Assistance regarding site-specific requirements or species information can often be obtained from the

regional plant materials specialists of the Soil Conservation Service (SCS).

Seeding Methods

37. The time to seed and the methods of seeding are determined by location, size, and topography of the reservoir shoreline; time of drawdown; water level; seed mixture; and soil conditions. If the revegetation site will be subjected to fluctuating water levels or wave action soon after planting, seeding is probably not the best plant establishment alternative because the seeds are likely to wash out. Seeding in these cases should be done only to augment transplanting. If reservoir water levels are lowered long enough for seeds to germinate and plants to grow, seeding will be the most cost-effective means of establishing plants, particularly grasses and forbs. Fowler and Maddox (1974) and Fowler and Hammer (1976) were successful in seeding mudflats in Tennessee reservoirs using various techniques, some of which are described below. The following seeding methods are described in more detail by Shetron, Allen, and Landin (1986).

Broadcasting

38. The most common method of seeding on large areas is to disperse seed from a tractor-mounted broadcast seeder. Broadcasting by hand with a knapsack seeder is usually restricted to small areas, 1 to 2 acres or less, or inaccessible sites such as steep slopes. Broadcasting by hand is labor intensive and should be used only when no other method can be used. Because of the relatively harsh growing conditions on reservoir shorelines, three to five times the normally recommended amounts of seed should be thoroughly mixed with fertilizer, sawdust, or sand and broadcast over the site. The sand or sawdust serves as an indicator of areas already seeded and promotes a more even distribution of seed. Broadcasting in the spring should be followed by mechanical cultipacking or rolling. This will firm up the seedbed and give a better soil/seed contact for germination. Use of equipment should be minimized to avoid compaction.

39. Broadcast seeding is rapid and easy, but is not recommended for large or fluffy seeds that may plug the equipment, blow away, or be lost to scavenging animals.

Drill seeding

40. Drill seeding is generally preferred to broadcast seeding. Drill seeding will place seeds in the soil at the desired depth for germination. A tractor-mounted drill is recommended that has several seed boxes designed to seed various seed sizes and mixtures (small and dense, light and fluffy, or medium-heavy seeds) with fertilizer at the time of seeding. Drills also have coulters that will lay open the surface soil for seed placement, leading to better seed-soil contact. Areas that are drill seeded should be lightly rolled to ensure proper seed/soil contact.

41. Drill seeding has been successful on some reservoirs and can be done cost effectively if terrain and soil conditions permit. For example, the South Dakota Game, Fish, and Parks Department in coördination with the CE, successfully drill-seeded reed canary grass on a shoreline at Lake Oahe, South Dakota.* Reed canary grass was planted because it provides spawning substrate for northern pike** (Figure 12).

Hydroseeding

42. Hydroseeding, the process of spraying a slurry of seed, fertilizer, mulch, and water onto a site, is commonly used for seeding steep roadbanks or the uneven terrain of surface-mined lands. It may be used to vegetate reservoir shorelines by mounting the equipment on a barge that can be towed to otherwise inaccessible sites (Figure 13). Fowler and Hammer (1976) described modified hydroseeding equipment, the aquaseeder, which was developed for the Tennessee Valley Authority (TVA) and was tested successfully along the reservoir drawdown zones in eastern Tennessee during the late summer and fall of 1973 and 1974.

---

* Personal Communication, December 1985, Mr. Robert Hanten, Fisheries Specialist, South Dakota Game, Fish, and Parks Department, Pierre, S. Dak.

** Personal Communication, December 1985, Mr. Jim Suedkamp, US Army Corps of Engineers, Regulatory Functions Branch, Pierre, S. Dak.

Figure 12. Successfully drill-seeded reed canary grass at Lake Oahe, South Dakota

Figure 13. Hydroseeding shorelines from a barge, Lake Ouachita, Arkansas

43. Hydroseeding has the advantages of using a one-step application of seeding materials and the ability to seed large areas of rough terrain. Disadvantages are that it will often damage seeds unless caution is used, and extensive mudflats may be largely inaccessible to hydroseeding equipment. Because of potential soil erosion associated with steeply sloping reservoir shorelines, mulching over the seeds is often required to protect the surface soil. However, mulching should be used only if water levels will remain down until the plants are growing well.

Aerial seeding

44. Seeding from aircraft is a very specialized technique and can be quite expensive unless it is applied to large areas (i.e., more than 40 ha). It is often used where site features prevent conventional methods from being used.

45. The TVA used this technique successfully on an experimental basis in 1973 and 1974 to vegetate over 1,000 acres of mudflat with a helicopter and a hopper-spreader unit. The helicopter operated 20 ft above the ground over a 30-ft swath at the speed of 30 mph and spread 20 lb per acre of annual rye-grass.

46. A possible disadvantage of using helicopters for aerial seeding on reservoirs, particularly where drawdowns are erratic, is the difficulty of scheduling (Fowler and Hammer 1976). Also, steep shorelines may be difficult to seed with this method because of the inability to achieve a uniform spread and obtain good seed/soil contact. Shorelines other than mudflats would have to receive extensive followup treatments after seeding to ensure success (e.g., rolling and mulching).

Transplanting Methods

47. Transplanting utilizes one or more of the following kinds of planting stock: bare-root seedlings, rooted or uprooted cuttings, balled-and-burlapped plants, containerized plants, sprigs, plugs, rhizomes, and tubers. These are defined and discussed below.

Transplanting is generally more effective than other establishment techniques since root system development and height growth are maximized during the first growing season, or prior to inundation of the site.

Grasses and other herbaceous plants

48. The four forms of propagule types commonly used to establish grasses and other herbaceous plants as transplants on reservoir shorelines are described below.

49. Sprigs. This propagule is the entire plant dug and removed from its natural habitat and transplanted to the new site (Figure 14). The term "sprig" generally refers to smaller transplants that are obtained by breaking multistemmed plants into smaller clumps containing one to five stems. It is best to leave soil on transplant roots when they are dug to minimize root loss and disturbance. Plants dug during the dormant (winter) season usually suffer less from stress and shock than those dug in the late spring and summer. The transplant should be as large as it is practical to handle and transport. Since plant material is obtained by manual labor and is difficult to transport, it is

Figure 14. Transplanting flood-tolerant grasses using sprigs

recommended that transplants have root clumps no larger than 10 to 15 cm in diameter, with top shoots of a compatible size (Environmental Laboratory 1978). Much smaller clumps can be used successfully if adequate roots are associated.

50. Rootstocks (plugs). Rootstocks consist of the root system of a plant, including that portion of stem normally growing below ground. The propagule may be divided into sections or clumps for planting; new growth will generate from the old root systems. Plugs are obtained by extracting rootstocks with some type of coring device, similar to those used in commercial nurseries (Figure 15).

51. Pierce (1983) successfully applied this approach to planting marsh in western New York, using cores of wetland soil that were about 1,000 to 3,000 cu cm each. These were transplanted in a grid pattern on 1-m centers and subsequently flooded. The cores contained various types of propagules that were present in the source wetland, including rootstocks, rhizomes, seeds, and whole plants.

52. Plugs can be carried in plastic bags to a shoreline to be vegetated and planted in or out of water (Figure 16). Planting in water, however, is very time consuming and more costly. Using plugs and the coring method described by Pierce (1983) would have its greatest utility in reservoir areas shallowly covered by water, such as some mudflats and shallow-sloped shorelines.

53. Rhizomes. This propagule type is similar to rootstocks and refers to underground stems that often grow horizontally. The rhizomes are dug and divided into sections, taking care to keep at least one viable growth point (node) on each to ensure new growth (Environmental Laboratory 1978).

54. Tubers. Tubers are large, fleshy underground stems often associated with rhizomes. They should be dug near the end of the growing season (Environmental Laboratory 1978). In the EWQOS field trials, giant reed tubers were planted in the early spring at the Lake Texoma field site; these remained dormant for several weeks until flooding had receded. At that point, the tubers sprouted new stems and grew well.

a. Plug of wetland plant rootstocks being obtained with a coring device

b. Plug is dropped out of coring device and stored for later planting

Figure 15. Obtaining plugs with a coring device made from a 10-cm-diam polyvinyl chloride pipe (Pierce 1983)

Figure 16. Plug transplanting operation in water. (Two-person teams are most effective when planting in saturated or submerged soils)

Trees and shrubs

55. Four propagule types for trees and shrubs are recommended for use on reservoir shorelines.

56. Bare-root seedlings. Bare-root seedlings are young plants with exposed root systems that are transplanted from nursery beds or from natural stands to the planting site. Seedlings of trees and shrubs are usually hand planted, using either a mattock or planting bar (dibble) for making the holes (Figures 17 and 18). The planting hole should be large enough to allow the roots of the seedling to spread out and not be crowded, rolled, or doubled under (Figure 19) (USDA, Forest Service, undated). Soil should be firmly tamped around the planted seedling. This propagule type was used most commonly during the EWQOS field trials (Figure 20).

57. Bare-root transplants are successful for many tree and shrub species, but since site conditions are often so restrictive, survival will probably be higher with container-grown stock (Leiser 1982). The advantages of using bare-root stock are that seedlings are easier to handle, take less time to acquire, are less costly, and are easier to plant. These characteristics make bare-root materials appropriate for larger projects.

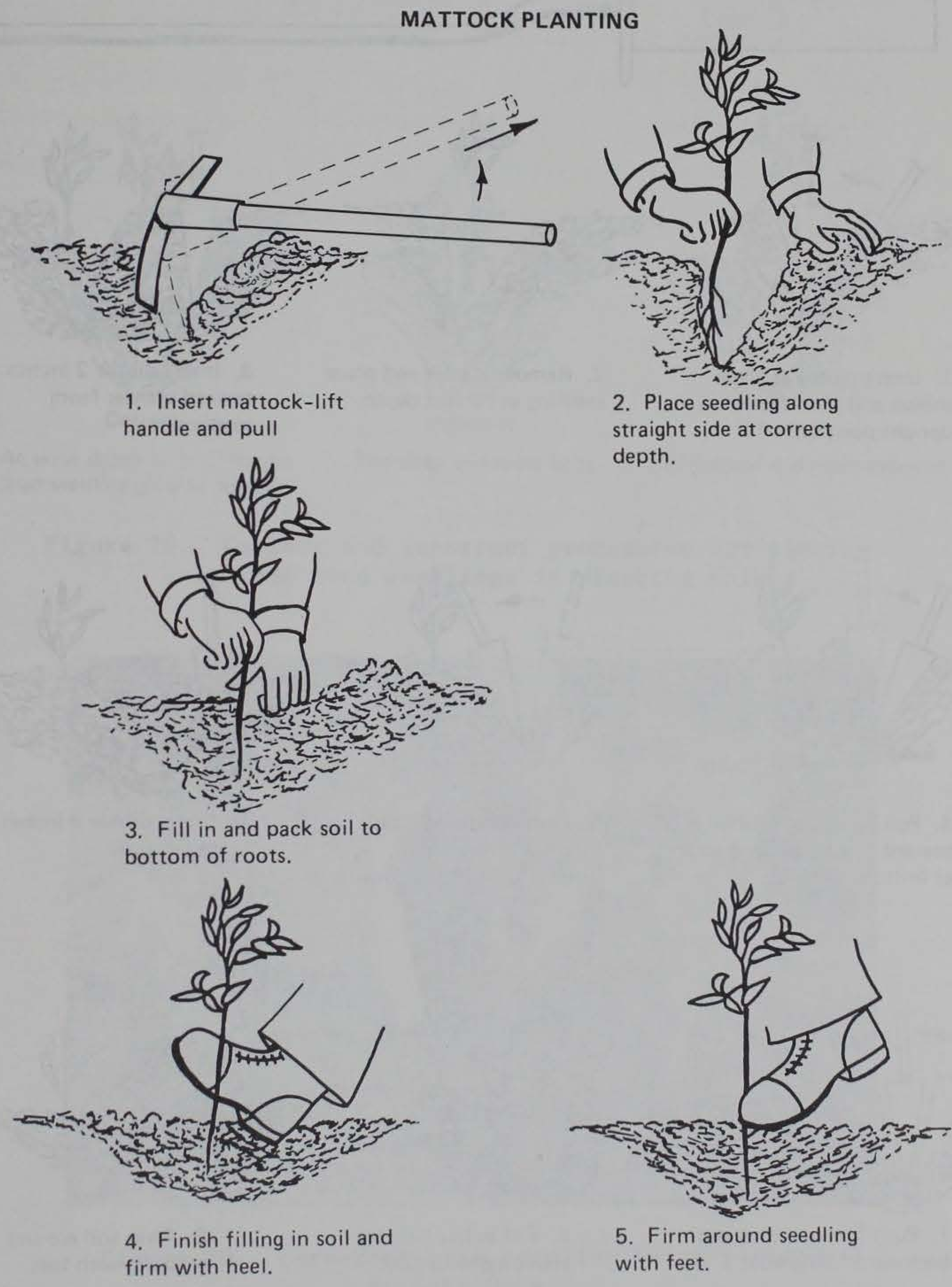


Figure 17. Procedure for planting bare-root tree seedlings with a mattock (illustrations courtesy of US Forest Service)

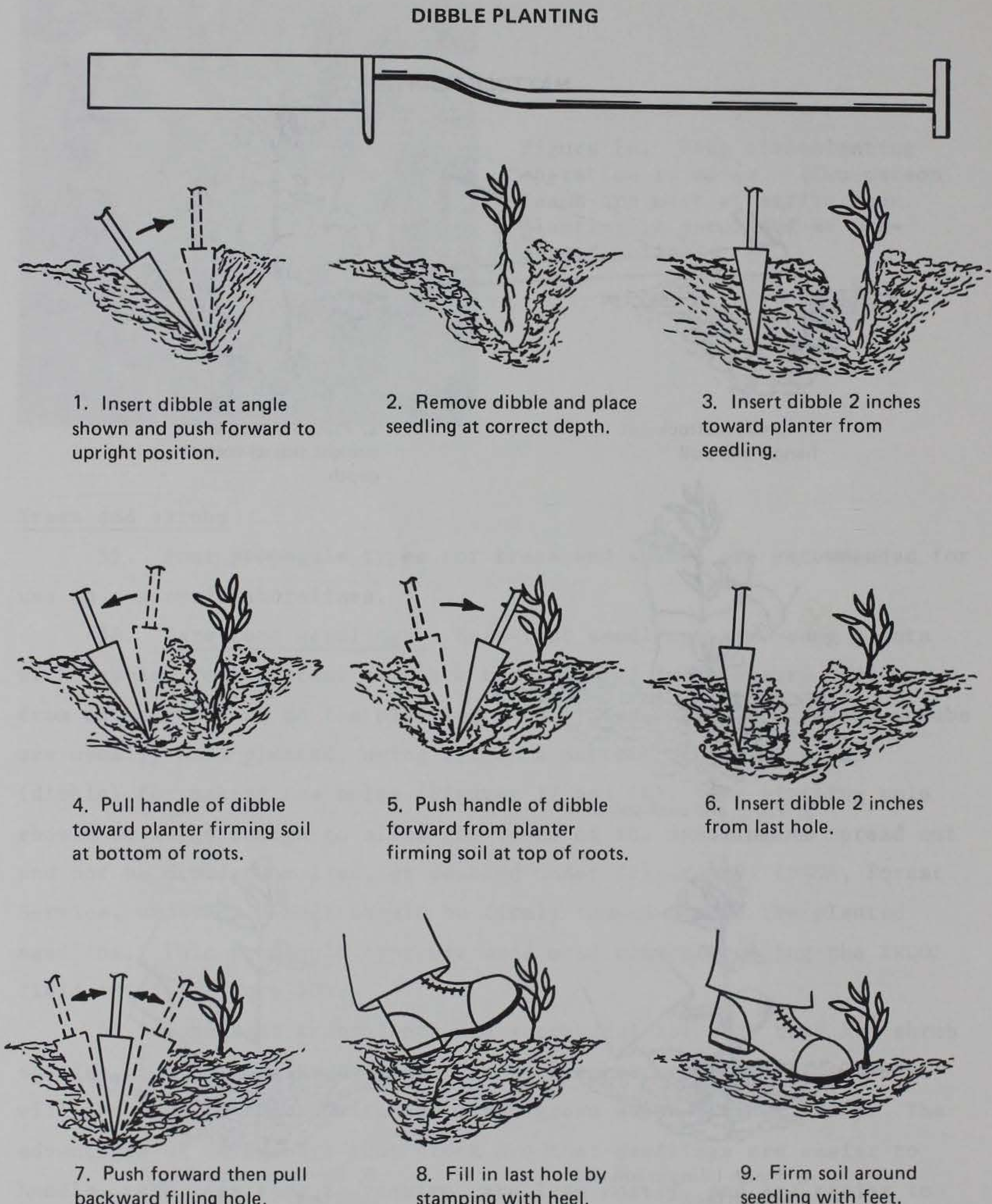


Figure 18. Procedure for planting bare-root tree seedling with a dibble bar (illustrations courtesy of US Forest Service)

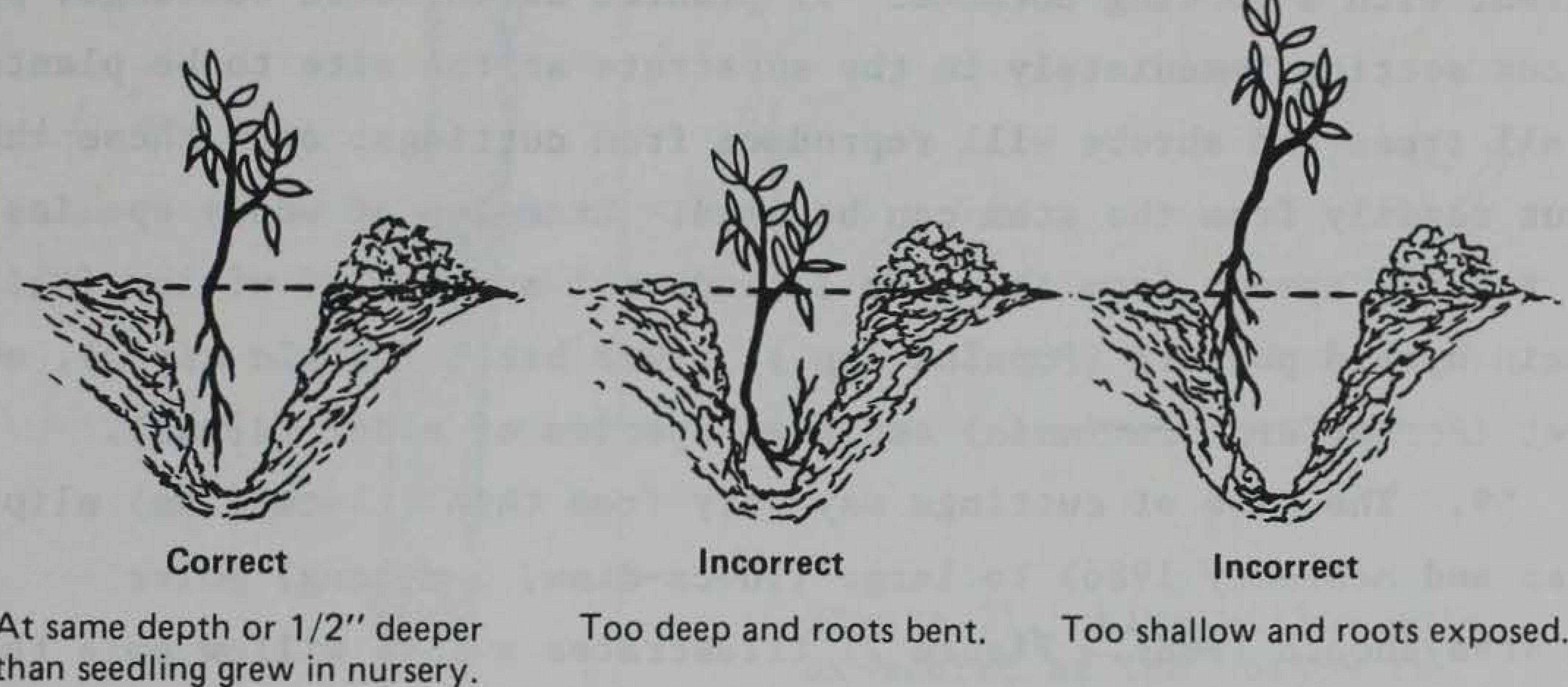


Figure 19. Correct and incorrect procedures for placing bare-root tree seedlings in planting hole

Figure 20. Bare-root tree seedling being planted at Lake Oahe

58. <u>Cuttings.</u> Cuttings are sections of the shoots of a plant, and must include nodes in the section cut. Cuttings may be unrooted or rooted. To obtain rooted cuttings, allow roots to develop in an appropriate rooting medium. For some woody species, it may be advantageous to treat with a rooting hormone. If planted as unrooted cuttings, place the cut section immediately in the substrate at the site to be planted. Not all trees and shrubs will reproduce from cuttings; only those that sprout readily from the stem can be used. Examples of woody species that readily sprout from the stem include all species of willow (*Salix*), certain hybrid poplars (*Populus spp.*), river birch (*Betula nigra*), swamp privet (*Forestiera acuminata*) and some species of alder (*Alnus*).

59. The size of cuttings may vary from thin (<1-cm-diam) slips (Comes and McCreary 1986) to large (10-cm-diam, 3-m-long) poles (Van Kraayenoord 1968). Figure 21 illustrates a live willow pole that is ax-scored at the bottom to facilitate treatment with a rooting hormone, if considered necessary. They are planted in a hole deep enough to reach the water table. Gray and Leiser (1982) had good results using 1- to 2-cm-diam willow cuttings at Lake Tahoe. The length of cuttings may vary with site conditions, but they should generally be long enough to maintain contact with moist soil. Cuttings over 15 to 20 cm long are difficult to embed in compacted soils, and longer cuttings should be used on dry sites with sandy soils (Gray and Leiser 1982).

60. When cuttings are planted, they should extend deep enough into the soil to be firm and relatively difficult to pull out; only 3 to 6 cm should be left aboveground to prevent moisture loss due to wicking. Any excess should be pruned off. Gray and Leiser (1982) provide the following recommendations regarding planting of cuttings:

> They may be pushed directly into soft soils, but in hard, cemented, or rocky soils, a hole will need to be made with a dibble or even a star drill. Holes should be no deeper than the length of the cutting, which should be in the bottom of the hole to avoid an air pocket. This would allow the base of the cutting to dry. The soil around the cutting should be tamped firmly to eliminate any air pockets.

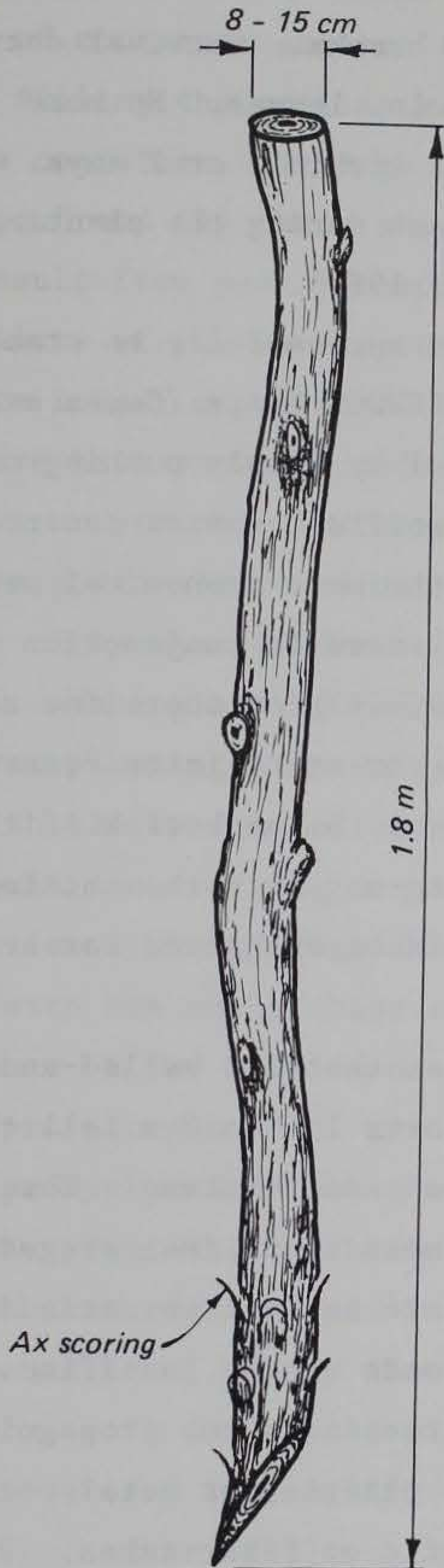


Figure 21. Live willow pole ax-scored at the bottom to facilitate root growth after treatment with rooting hormone

61. Because cuttings are live material that has been severed from the root system, special care must be exercised between the time the cutting is made and planted to the site or rooting medium. Careful handling to prevent drying is essential. The cuttings should be stored in water or kept moist by covering with wet burlap or other wet material

while being stored for planting. Cuttings survive and develop better if they are planted before the vegetative bud breaks. Survival decreases if the cuttings are planted after they develop leaves. No more materials should be cut than can be planted within 1 or 2 days. The cuttings should be exposed to the air and sun during the planting process as short a time as possible (Leiser 1983).

62. Rooted willow cuttings were used successfully to stabilize a sandy shoreline at Lake Wallula during the EWQOS tests (Comes and McCreary 1986). Others have been successful by simply pushing unrooted cuttings of easy-to-root species into the soil on erosion control projects. Use of unrooted cuttings is one of the most economical methods of plant establishment. Cuttings are commonly used in conjunction with bioengineering techniques (see paragraphs 75-76) for shoreline stabilization on erodible sites. Use of cuttings for stabilizing reservoir banks should proceed from the top of the bank to the bottom if there is a chance that soil disturbance from planting may bury the cuttings. Also, rows of cuttings across a slope should be staggered for best erosion control.

63. Balled-and-burlapped. Propagules that are balled-and-burlapped refer to large trees and shrubs over 1.5 to 2 m tall that have been nursery-grown with balled-and-burlapped root systems. These propagule types are normally too expensive for most shoreline revegetation projects, except in recreation areas that are subject to periodic inundation and for which higher planting costs can be justified.

64. Containerized. Containerized tree and shrub propagules are those that have been grown in fiber, clay, plastic, or metal pots or cans, or in relatively small and deep plastic or fiber tubes. Plants grown in gallon-sized or larger containers are often available for tree and shrub species used in regular commercial landscaping, but are limited in variety. Consequently, they may not be best for use on reservoir shorelines that are periodically inundated, unless a nursery has been contracted to grow flood-tolerant species for 1 or more years. Survival is frequently reduced because of limited root systems in relation to size of the tops of the plants (Leiser 1983).

65. Two factors are of particular importance with regard to the quality of container stock: (a) roots should be well developed, adequately filling the soil mass so that it holds together when removed from the container, although they should not be so overgrown as to be "potbound," and (b) there should be no kinked, bound, or girdling roots, which result from poor transplanting of seedlings or rooted cuttings and from failure of the nursery to remove circling roots when shifting plants to larger containers (Leiser 1983). In the latter case, such roots have been shown to reduce growth and survival because they girdle the crown or promote windthrow. Transplants should appear to be vigorous, have good color, and not appear stressed or nutrient-deficient in any way. They should have well-developed branches.

66. When planting containerized stock, the container should be removed at planting time unless it is biodegradable. Biodegradable containers should be trimmed so as not to protrude above ground level, which could cause drying due to wicking (Leiser 1983). If roots have not penetrated the biodegradable container sufficiently to make good contact with the soil, those containers should also be removed. Circling roots on the outside of the rootball must be removed at planting time to prevent potential girdling of the stem. Plants should be planted promptly after holes are dug to minimize drying of the soil both around the plant and in the hole. Holes should be of sufficient size and depth that root systems are not disturbed and rootballs are slightly below ground level. They should be backfilled and tamped intermittently to firm the soil around the plant and prevent air pockets. Plants should be watered thoroughly. Berms may be formed around the plants to trap water (Leiser 1983).

67. The main advantage of containerized plants is that they have developed root systems and stems that are ready to grow when they are placed into the ground. However, containerized plants cost considerably more than other propagule types and, because of this, should be reserved for high-priority recreation sites or other such sites requiring greater assurance of success.

Rates and spacing

68. Several factors cause planting rates and spacing to vary, including growth habit, establishment rate, time of planting, species and propagule type, and project goals. These are discussed in the following paragraphs.

69. Growth habit. In general, the spacings given below will provide good cover in 2 to 3 years but are not applicable to some of the shrubs and trees that grow very fast and sprout roots from the stem (e.g., willow and hybrid poplar). On noneroding reservoir mudflats, grass and forb transplants or plugs should be placed on 0.5- to 1.0-m centers. When transplant spacing is reduced from 1.0 to 0.5 m, four times as much effort, material, and time is required.

70. Where considerable wave action and erosion are likely, grass and forb transplants should generally be placed on 0.5-m centers. Where trees and shrubs are desired and erosion is not of overriding concern, transplants are usually placed on about 3-m centers; 1.5-m centers are appropriate on erodible slopes. Other specialized techniques of planting and spacing for eroding shorelines are discussed in the final section of Part IV.

71. Rate of establishment. If rapid cover is needed for stabilization, such as within 1 year, distance between centers should be reduced. Larger spacings can be used if a longer time for achieving complete cover is acceptable (Hunt et al. 1978).

72. Time of planting. This applies primarily to grasses and forbs that have a more flexible planting window, in general, than do trees, shrubs, and other woody plants. Larger distances between centers are feasible when planting occurs at the beginning of the growing season, since rapid new growth will compensate for the spacing. Plantings at midseason or at the end of the growing season will require closer spacings (Hunt et al. 1978) to achieve more rapid closure and to aid in preventing erosion.

73. Propagule types and species. Some propagule types, such as unrooted cuttings, will grow or spread more slowly than others. When this situation is expected, spacing should be closer. Some species,

such as willow, will grow and spread much faster than other species; in such cases, spacing can be greater. The planner and resource manager can rely on local US Forest Service personnel, state forestry extension agents, or local SCS conservationists for assistance in determining proper spacing.

74. Project goal. Proper spacing is significantly influenced by the project goal. Spacing for aesthetic improvement of a project area is apt to be much different from spacing solely for erosion control. Likewise, spacing strictly for habitat development will vary according to the target wildlife or fish species as well as the plant species being developed for those animal species.

Special Plant Establishment Techniques in Erodible Environments

75. Most CE reservoirs with fluctuating water levels have some eroding banks. The extent and degree of erosion depend on wind fetch, soil type, depth of adjacent water, and the influence of man's activities on the shoreline. This section provides some techniques that can be applied for vegetative control of reservoir shoreline erosion. Techniques referred to in this section are sometimes called "bioengineering" or "biotechnical" techniques because they employ both plants and construction materials.

76. These techniques have been used extensively in Europe for streambank protection (Seibert 1968) and other erosion control projects, and some were tested at CE reservoirs under the EWQOS Program. In the last 35 years, some of these techniques have been practiced in the United States, but only to a limited extent. This is primarily because other engineering options, such as the use of riprap, have been commonly accepted practices. However, with the costs of labor, materials, and energy rapidly rising in the last two decades, less costly alternatives of stabilization are being sought. Additionally, emphasis is being placed on vegetative stabilization because it provides food and cover

for fish and wildlife and a more aesthetically appealing environment than traditional approaches.

Plant rolls

77. Plant rolls are adaptations of "reed rolls" described by Seibert (1968), which have been used extensively in Europe for streambank erosion control. Plant rolls are cylinders of plant clumps in soil that are wrapped by burlap, secured by hog rings or wire, and placed in a trench. Allen, Webb, and Shirley (1984) described the use of these in marsh establishment for erosion control of a dredged material dike in a moderate wave-energy environment. Such a technique is considered to be applicable to CE reservoir shoreline stabilization because plant rolls can withstand considerable wave action (at least 0.3- to 0.6-m-high waves). Plant rolls can be pregrown in the greenhouse or lathehouse to develop root systems, installed in water with a jet pump or shovel, and treated with fertilizer without excessive leaching of the fertilizer.

78. Plant rolls are constructed onsite as follows:

a. A length of burlap (about 1 m wide by 4 m long) is laid on the ground.

b. Sand or soil is placed on the strip of burlap, and six to seven clumps of plants are spaced at 0.5-m intervals on the burlap.

c. About 28 g of 18-6-12 slow-release fertilizer is applied to each plant clump by hand.

d. The sides of the burlap are brought together around the plants and fastened with hog rings creating a 3-m-long roll of plants and soil.

e. The plant rolls are positioned at the toe of the bank or upon any existing shallow benches lakeward of the toe and are oriented parallel to the bank.

f. The rolls are buried in the reservoir substrate by a jet pump or by shovel.

Figure 22 shows the steps involved in constructing and planting a plant roll.

79. Plant rolls are spaced about 1 to 2 m apart with the option of placing individual transplants between them. The rolls are more difficult to dislodge and to wash away than single transplants because the whole structure acts as one bed of plants and is much more massive;

a. Clumps of several sprigs are dug from a nearby stand of plants or are procured from a nursery

b. Clumps placed on burlap at intervals, along with soil and fertilizer

Figure 22. Procedures for constructing and planting a plant roll (Sheet 1 of 3)

c. Burlap is brought together around plants and fastened with hog rings

d. A trench is dug deep enough to accommodate the burlap cylinder

Figure 22. (Sheet 2 of 3)

e. Plant roll installed parallel to shoreline

Figure 22. (Sheet 3 of 3)

the entire roll would have to be undercut to be dislodged. Plant rolls with single transplants or sprigs of grasses and herbs between them would potentially speed establishment of the grass and forb zone at the toe of a reservoir bank.

Erosion control fabrics

80. Erosion control fabrics are often used, with herbaceous plants either seeded or sprigged on them after the fabric has been secured to a shore. A biodegradable mat, trade name Paratex, consisting of 0.1 kg/m^2 natural fibers, was laid like carpet by WES on coastal shores near Mobile, Ala. (Allen, Webb, and Shirley 1984) and Galveston, Tex. Then, single-stemmed marsh grass transplants were inserted into slits cut through the material on 0.5-m centers. The edges of the mat were nailed between 2.5- by 10-cm boards that were placed on their edge and buried in the sediment. The use of the fabric and plant combination showed promise for coastal erosion control in moderate wave-energy environments (Figure 23) and should also have application to reservoir shores subject to severe wave action.

Bioengineering techniques using woody plants

81. All of the following techniques utilize woody plants that have the ability to sprout adventitious roots from the stem. Gray

Figure 23. Smooth cordgrass (*Spartina alterniflora*) in fabric mat on Galveston Bay shore near Galveston, Tex., 15 months after planting

(1977), Allen (1978), and Gray and Leiser (1982) discuss the advantages of woody plants for erosion control. These include root reinforcement of the soil, restraint and filtering of soil particles, restraint of soil masses on slopes by soil arching effects, interception of precipitation, and depletion of soil water. The following techniques can stabilize reservoir shorelines if employed properly and in the correct site-specific combination.

82. Willow/fence combination. This is a technique where live willow switches (cuttings) are laced through the spaces of a partially buried woven-wire fence (Figure 24). Allen (1983) discussed a successful application of this technique in stabilizing a sandy shoreline at the Lake Wallula field site. Rooted coyote willow (*Salix exigua*) cuttings averaging 122 cm in length were used. The sequence for planting the rooted cuttings was as follows:

a. Trenches that were about 60 cm deep, 40 cm wide, and 6 m long were dug perpendicular to the shoreline.

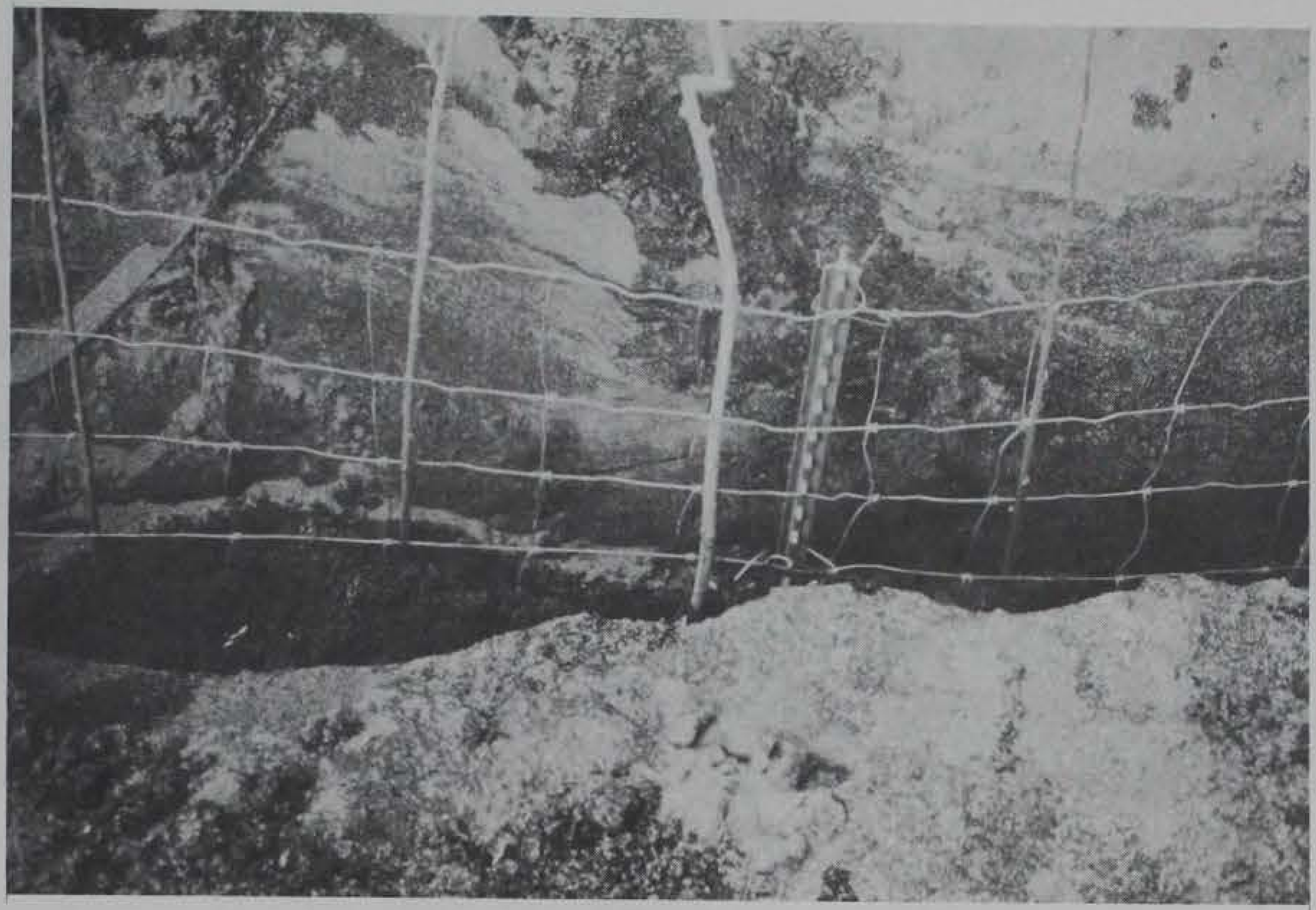


Figure 24. Rooted willow (*S. exigua*) cuttings woven through a partially buried hog-wire fence. About half the length of each cutting is buried

b. Woven hog wire (10-cm mesh), 60 cm tall and 6 m long, was placed in an upright position in the trench and anchored with 120-cm-long steel posts woven through the wire in the center and at both ends.

c. Posts were driven 60 cm into the sand at the bottom of the trench, and then the hog wire was tied to the posts with galvanized wire.

d. Twenty willow switches (cuttings, basal end down) were woven through the wire at 30-cm intervals, and the trench was filled with sand. About half of each cutting was buried.

83. Four of these willow/fence combinations were installed and monitored at Lake Wallula. Three of the structures were laid perpendicular to the shoreline; the fourth consisted of willow interwoven in the spaces of a snowfence installed parallel to the shore (Figure 25a). They were located in a diurnal, 0.9-m water-level fluctuation zone where the willows were subjected to considerable wave action. Results after 3 months showed that this planting technique worked extremely well

a. Willows immediately after planting in the early spring of 1981

b. Willows about 4 months after planting

Figure 25. Willow/fence combination at Lake Wallula

(USDA, Agriculture Research Service 1981). Survival varied between 75 and 100 percent, and the willows increased considerably in size and sprouted many new branches. The willow/fence combination improved shoreline stability (Figure 25b), as evidenced by less change in the shoreline and reduced sand movement after 4 months.

84. This type of structure has several advantages: (a) it can be used at the toe of reservoir banks to deflect debris that may damage newly planted vegetation, (b) it acts as an anchor, i.e., helps prevent undercutting, at the toe of the slope once the vegetation is well established, (c) the fence with the interwoven willow branches resists ice damage and upheaval from freezing and thawing cycles, and (d) the fence prevents beavers and other animals from completely decimating the vegetation. A disadvantage is that it may pose a navigation hazard and create a fishing bait or lure trap unless it is well marked with snag signs.

85. Wattling bundles. Wattling bundles are cigar-shaped bundles of live switches of willow or other easy-sprouting woody species that are tied (Figure 26) and placed in trenches, staked, and partially covered with soil. Wattling bundles are usually placed on contour, starting at the bottom of a slope and working up (Figures 27 and 28). They are installed in accordance with the specifications given in Appendix B.

86. Wattling bundles have several advantages (Leiser 1983): energy dissipation, temporary stabilization to allow establishment of other vegetation, sediment entrapment, and lower cost than traditional engineering approaches for bank protection. Disadvantages of wattling bundles are that they are labor intensive, and appropriate woody species are sometimes difficult to locate and acquire in the necessary quantities.

87. Brush layering. Brush layering is a technique in which cut, live woody branches (willow, hybrid poplar, etc.) are successively placed in V-like trenches along contours on a slope. The general principles of installation are presented in Figure 29. The bottom of the trench should be sloped slightly downward so as to catch and retain

Figure 26. Assembly of a wattling bundle

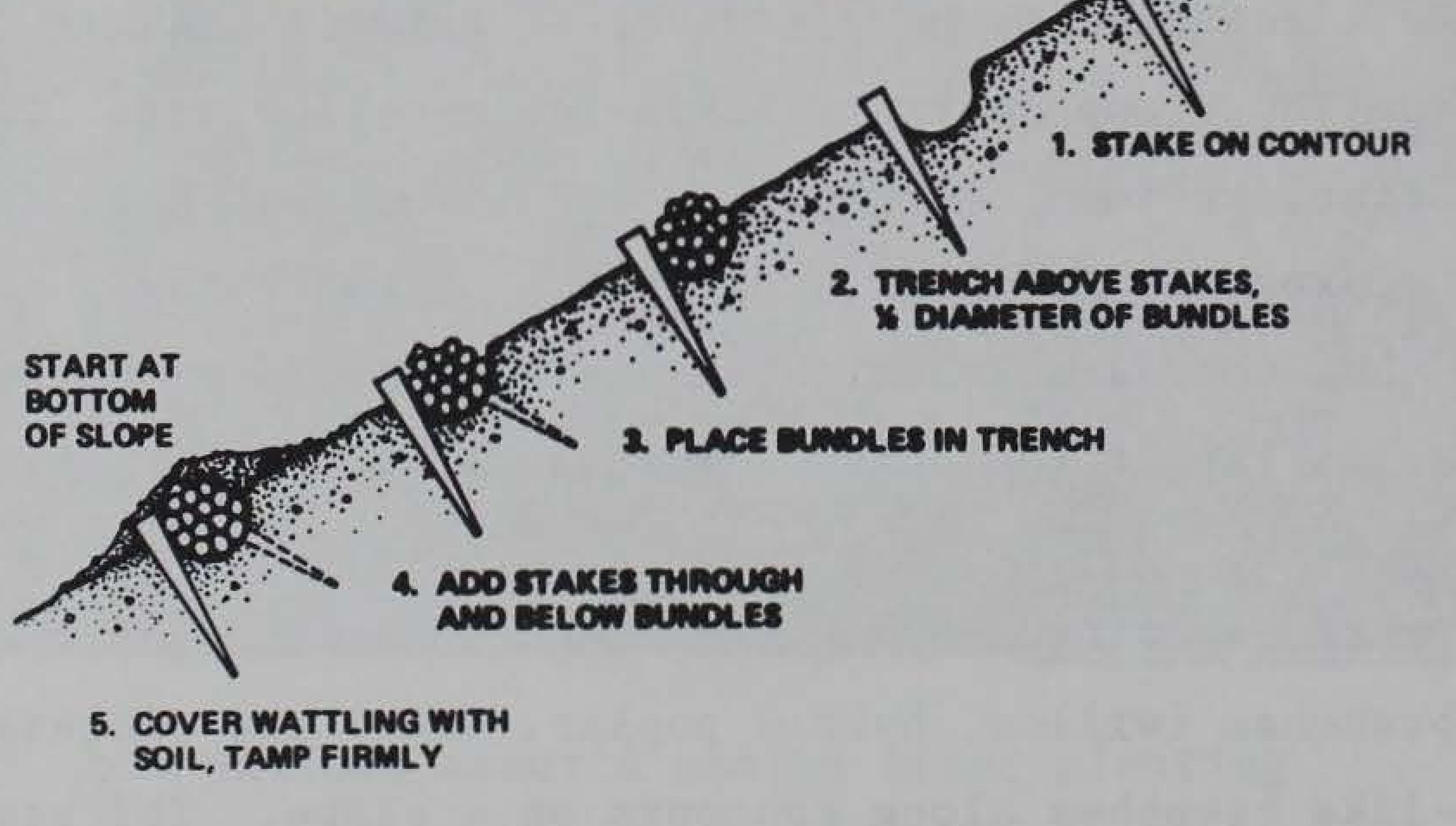


Figure 27. Procedures for installing wattling bundles (from Leiser 1983)

Figure 28. Completed wattling installation

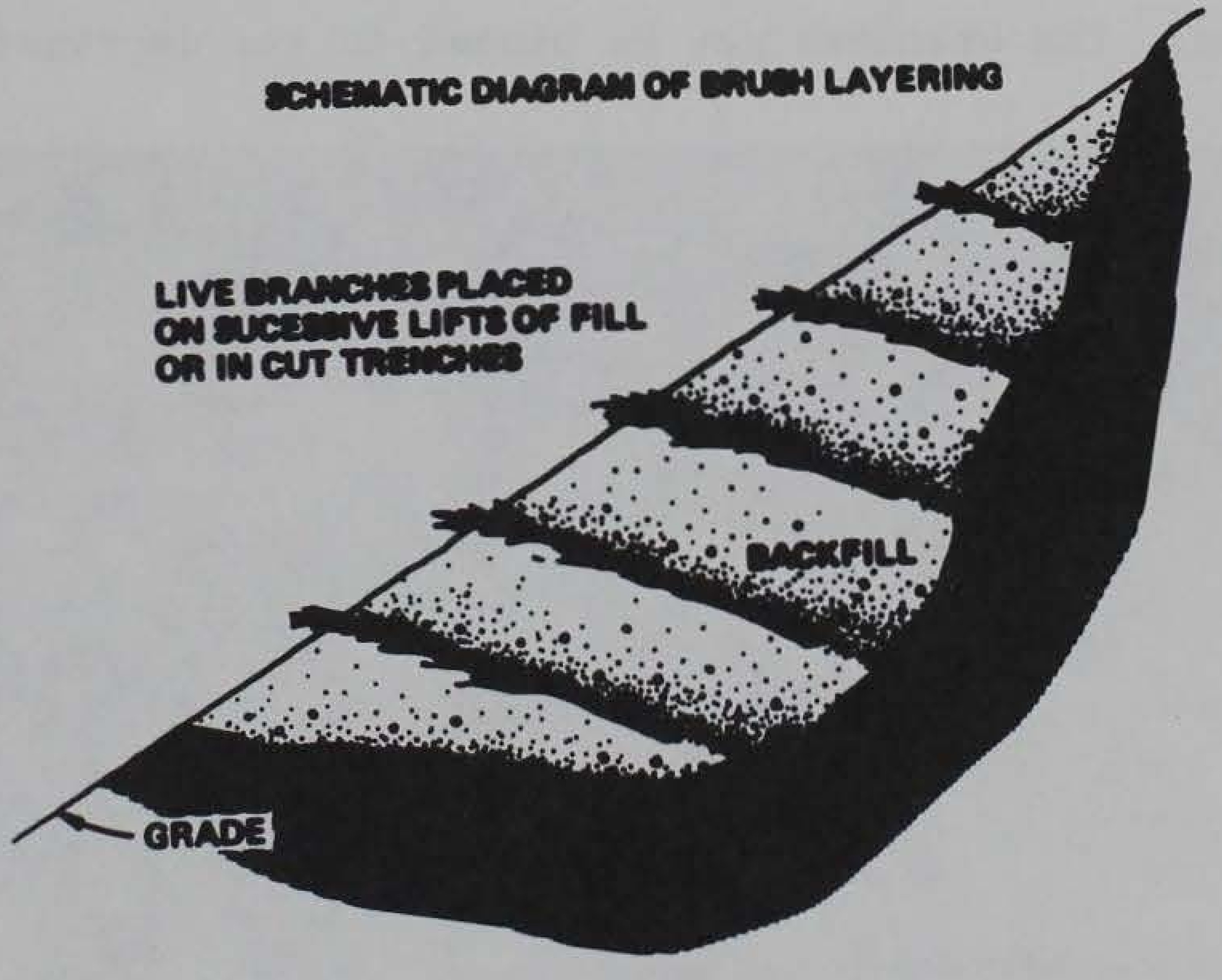


Figure 29. Schematic diagram of brush layering
(from Leiser 1983)

water. The cut material may vary in length depending on the depth of trench one can dig into the reservoir shoreline but generally will range in length from 0.5 to 1.0 m (Leiser 1983). Branches should be long enough to reach moist soil back in the sloped bank. Cut branches should be laid in a crisscross pattern, and branch ends should not protrude excessively over the lip of the trench. Excessively protruding branches (>15 cm) could dry the live plant material and kill it.

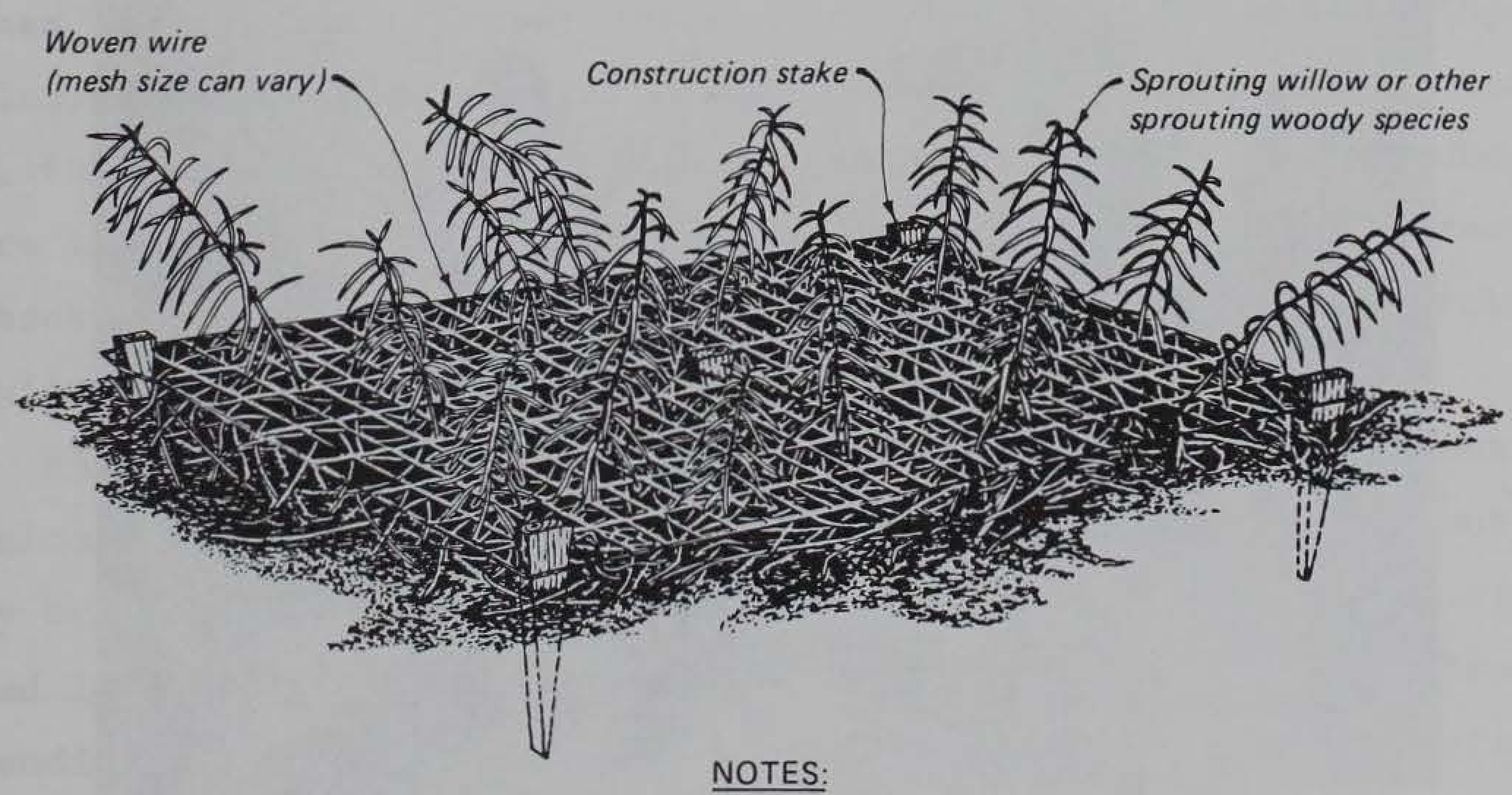
88. Brush layering has the same advantages as wattling bundles except that it can be partially installed by machinery when slopes are shallow enough in gradient to support machinery. Graders or bulldozers can cut the trenches with their blades so that field crews can lay the branches of plant material in the trenches by hand. Brush layering has the same disadvantages as wattling bundles. Figure 30 shows an installed section of brush layering.

89. Brush mattress or matting. This procedure is also commonly used in Europe for streambank protection (Seibert 1978). It involves digging a slight depression on the bank and creating a mat or mattress from woven wire or single strands of wire and branches from sprouting trees or shrubs. The branches may be placed in the depression with or

Figure 30. Installed section of brush layering

without woven wire. In either situation, live, freshly cut branches are tied down by a combination of stakes and woven wire or a network of wire or other material to hold them in place (Figure 31). Branches can vary in length but are normally cut 1.0 to 3.0 m long and 1.0 to 2.5 cm in diameter. The branches are crisscrossed and turned alternately so that the butts protrude slightly out of opposite sides of the mattress. This crisscrossing and alternate facing of branches creates a more uniform mattress with few voids. The branches are laid down and covered, staked, and tied with wire; then, the structure is partially covered with soil and watered. Covering with soil and watering several times in succession will fill the air pockets with soil and facilitate sprouting. The structure is covered with only enough soil so that some branches are left partially exposed on the surface (Figure 32).

90. The brush mattress has the advantage of covering a large surface area with live sprouting material in a fairly short period of time. It provides protection from animals digging out the plants because of



NOTES:

Width and length of mattress tailored to the situation.

Stakes vary in length depending on the soil, but normally are 0.6 to 0.9m long.

Figure 31. Brush mattress

a. Installation

b. Following installation

Figure 32. Brush mattress installation. (Note that it is only partially covered with soil)

the wire and soil cover. It is also resistant to waves and currents. Disadvantages of brush mattresses are that: (a) they can be covered with too much sediment if laid flat on a sandy bank, which will smother the vegetative material and prevent sprouting, (b) additional cuttings or transplants are difficult or impossible to later plant through the matting, and (c) the mattress must be thoroughly anchored and protected from undercutting. One method for anchoring and protecting from undercutting is to extend the mattress into an excavation at the toe of the slope and to anchor it with wattling bundles at the toe, as shown in Figure 33. A light stone bolster at the toe of the mattress (Figure 33) also aids in anchoring and preventing undercutting.

91. Revetment or crib structures. Other more expensive and elaborate structures have been recommended for shoreline protection of streams and reservoirs and may be appropriate where banks are almost vertical.

92. The "pile and facine revetment" (Figure 34) is a structure in which either timber or metal piles are driven in front of an eroding bank and spaced on about 2-m centers; they are driven below the scour level, with tops extending above the normal pool level of the reservoir. Facines are bundles of brush or tree branches (similar to wattling bundles) that are placed horizontally between the piles and the bank; then, the brush or branches are weighted down with soil and sandbags. Before the plant material is placed, a woven wire fabric is fastened to the back side of the piles and secured to the top cable, interconnecting the piles.

93. Another type of structure that has been used on streambanks and along waterways is a timber crib wall (Figure 35) where sprouting woody branches are layered between the stretchers.* Stretchers are placed lakeward of the slope, with headers installed into the slope perpendicular to the cribbing. Successive lifts of live brush with soil placed on top of it are sandwiched between each layer of stretchers. Gray and Leiser (1982) include drawings and specifications for several

* Stretchers are the frontal, horizontal members of a crib wall.

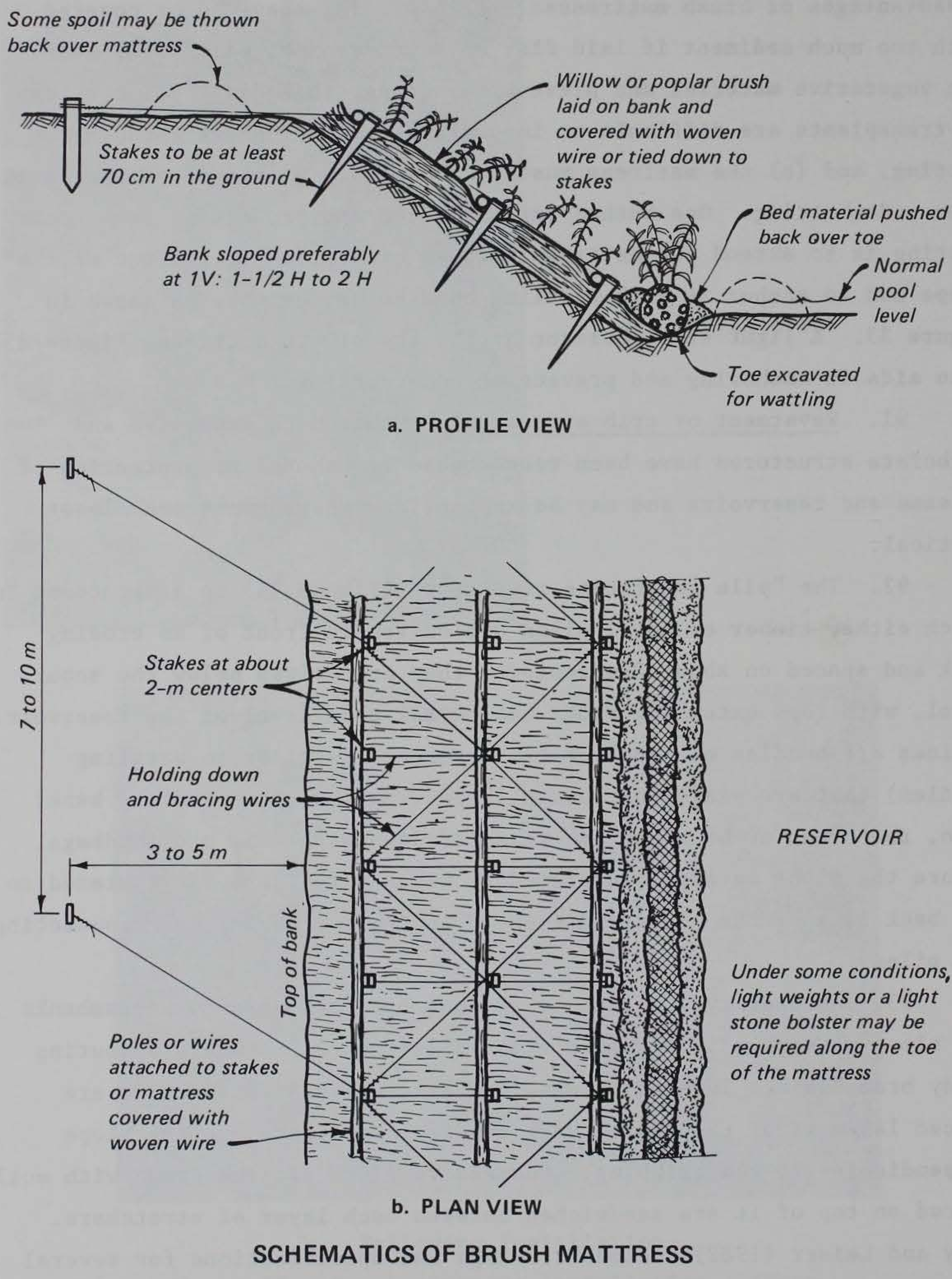


Figure 33. Schematics of a brush mattress on a sloped bank

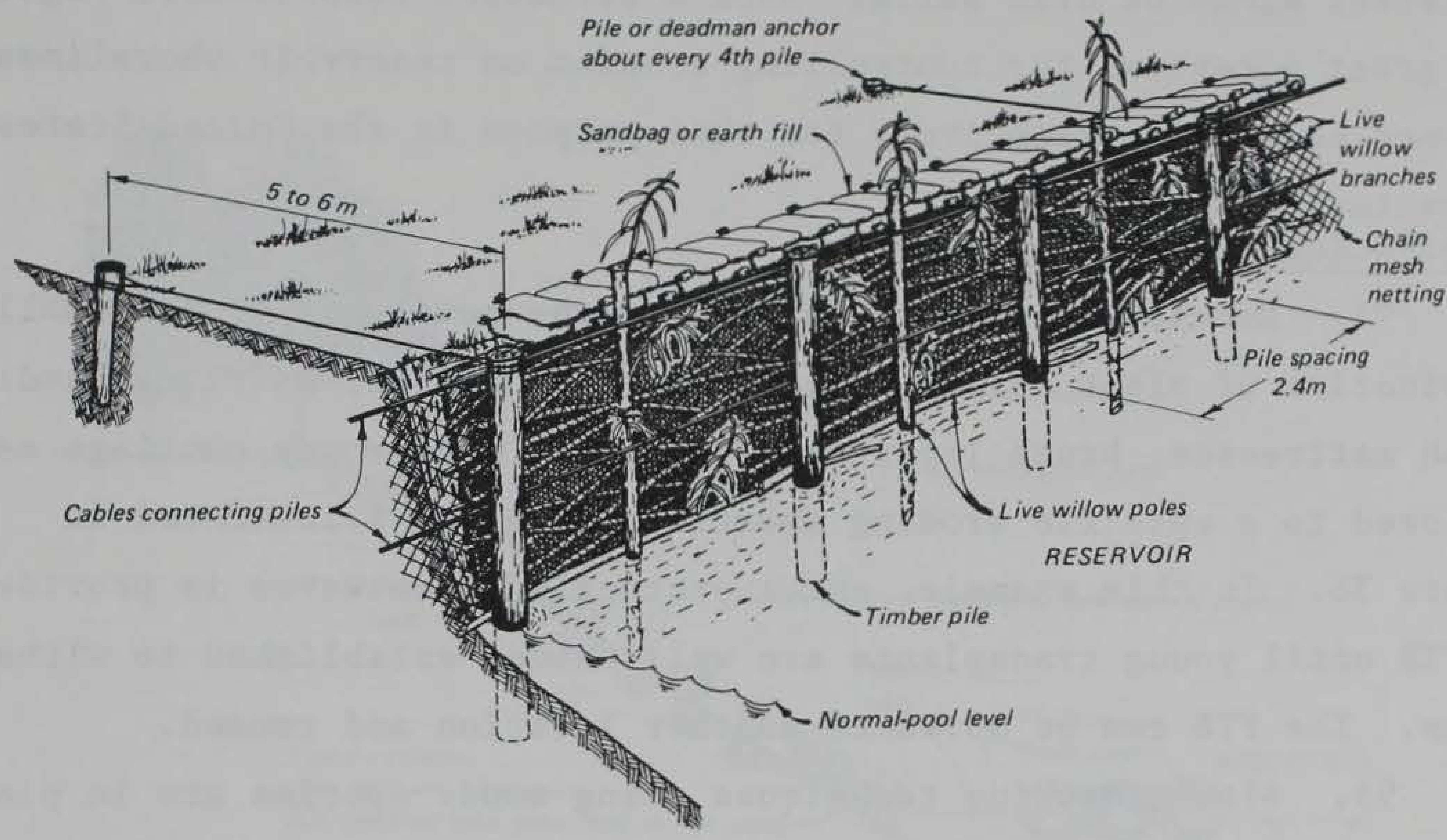


Figure 34. Pile and facine revetment

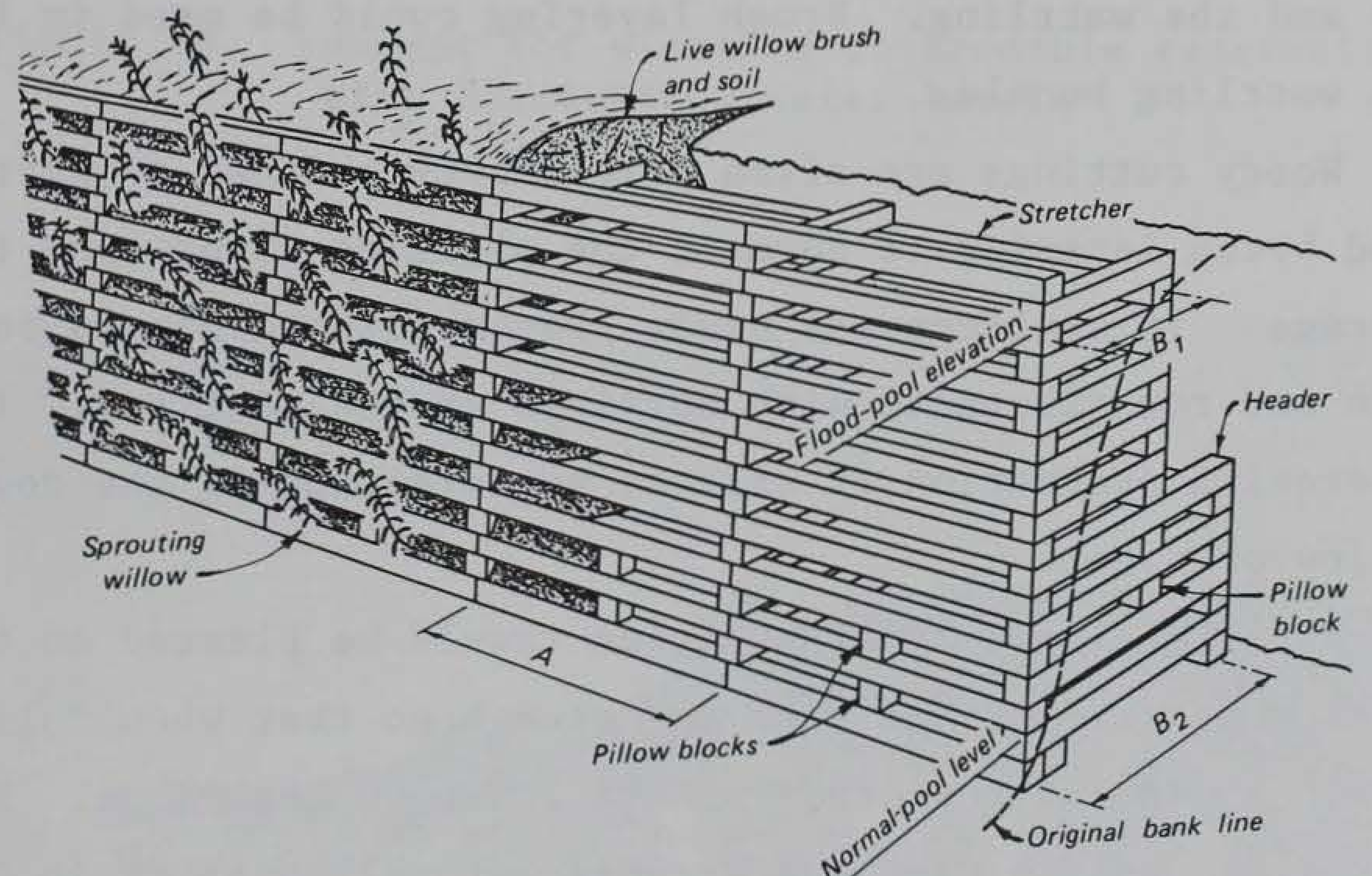


Figure 35. Timber crib wall with sprouting willow brush

different kinds of crib walls. Such a structure coupled with vegetation has great potential for controlling erosion on reservoir shorelines, but has not been used extensively for that purpose in the United States.

Conceptual plan using a combination of techniques

94. Except for techniques such as the revetment or crib wall, a combination of plant rolls, willow/fence structures, wattling bundles, brush mattresses, brush layering, and use of live woody cuttings may be tailored to a specific eroding shoreline site, as illustrated in Figure 36. In this example, extra protection from waves is provided by an FTB until young transplants are well enough established to withstand waves. The FTB can be moved to another location and reused.

95. Bioengineering techniques using woody species are in place higher on the slope (Figure 36). Although it is not shown in the figure, a willow/fence structure could be used between the herbaceous vegetation and the wattling. Brush layering could be used in lieu of or along with wattling bundles.

96. Woody cuttings are often placed between rows of wattling bundles and brush layering to augment the planting effort and to speed plant coverage. If cuttings are used, they should be placed so that cuttings in one row alternate with cuttings in the next row. In this way, more erosion protection is offered by interrupting the downward overland flow of water.

97. Finally, flood-tolerant trees should be planted on the upper margins of the reservoir, but back far enough so that when fully grown, they will not shade out the other plants lower on the slope. Figure 37 shows an ideal shoreline planting arrangement, although it is located along Currituck Sound in North Carolina rather than a reservoir shoreline. Nevertheless, the concept is the same, with grasses or grasslike plants lakeward of shrubs and trees.

98. The combination of techniques shown in Figure 36 is only one concept; other combinations could be used depending on site-specific characteristics. In some cases, it may be best to dispense entirely with herbaceous plants because of the steepness of the bank and the lack

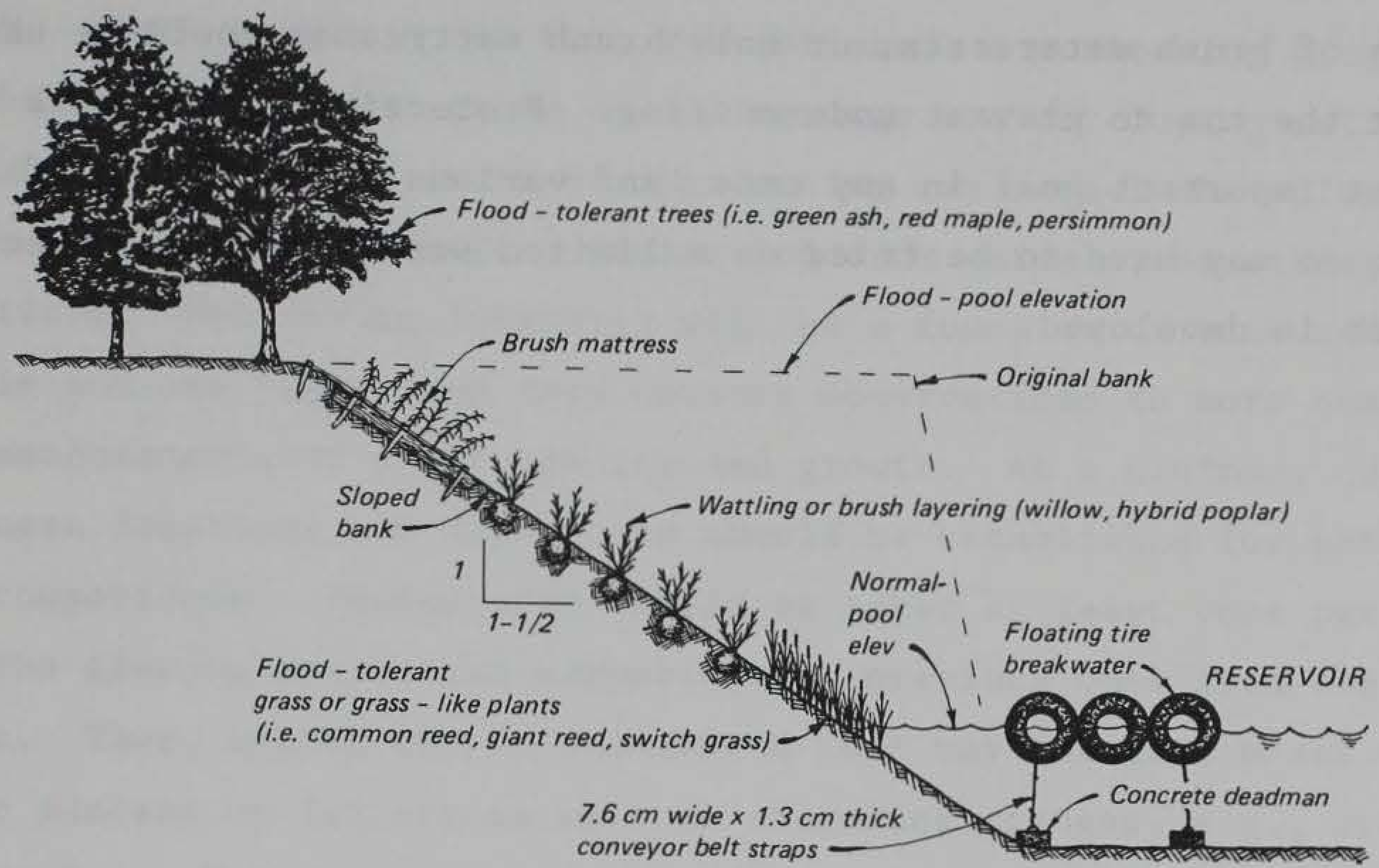


Figure 36. Concept for planting on erodible reservoir with fluctuating water levels

Figure 37. Shoreline planting arrangement with grass or grasslike plants lakeward of shrubs and trees

of a shoreline bench on which to plant them. Often, only woody plants are used on slopes. For example, only wattling bundles could be used at the toe of brush mattresses, or only brush mattresses could be used with rock at the toe to prevent undercutting. Protection of the bank toe is the most important goal in any case, and various combinations of techniques may have to be tried on a limited scale until an effective approach is developed.

PART V: POSTPLANTING OPERATIONS AND MAINTENANCE

99. After planting has been accomplished, a monitoring program should be established to ensure that plantings are developing satisfactorily and performing as desired. Monitoring may reveal that plants need irrigation, fertilization, protection from animals, or other remedial actions. Monitoring intensity will be a function of time and money available and can range from very cursory observations to more quantitative measurements of plant density and growth. At a minimum, long-term camera locations and directions should be established for periodic visual comparisons. Photographs should be taken at least once per year during the growing season and compared with previous ones from the same location. Thus, trends can be documented that may indicate plant establishment success or failure as well as shoreline changes, e.g., erosion or no erosion. More quantitative vegetation measurements can be made if time and money permit. Numerous references are available that give guidance on vegetation monitoring and sampling, including Daubenmire (1968), Kershaw (1973), and Chapman (1976).

100. The monitoring operation may indicate that certain vegetation management or maintenance tasks need to be undertaken to ensure that long-term objectives are met. The degree of management required often depends on answers to the following questions adapted from Hunt et al. (1978):

- a. What was the project goal, i.e., to control erosion, to develop habitat, or to improve aesthetics?
- b. What were the intended level and timing of management in the project design?
- c. How suitable were the plant species selected? Did the plants grow satisfactorily?
- d. Are the quantity and quality of established vegetation adequate in relation to their intended purpose, i.e., is the vegetation dense enough for shoreline erosion control or is the vegetation suitable for fish spawning habitat?
- e. Have any perturbations occurred, such as detrimental wildlife or human use, storm damage, or unusual weather occurrences, such as drought?

101. Management or maintenance efforts that might have to be implemented after planting include soil treatments, vegetative manipulations or protection, and additional planting. Soil treatments may involve fertilizing, mulching, adding soil amendments such as lime, and cultivating. Vegetative manipulations or protection may include weeding or thinning, pruning, staking woody stems, and installing fencing around individual plants or the entire site to provide protection from animals or humans. Additional plantings may be necessary to replace unsuccessful propagules, increase plant density, expand the vegetative cover to include more shoreline, or alter the site by adding new vegetation.

102. If fertilization appears to be necessary, comparison of the nutrient needs of the plant species with an analysis of recent soil samples should dictate type and amount of fertilizer application. Split applications of fertilizer, especially during the first year after planting, are often recommended throughout the growing season on erodible sites to ensure successful establishment.

103. Weeding and cultivation of a shoreline site may be necessary for a limited time after planting to control unwanted vegetation and to increase the porosity of the surface soil for water penetration. Care often needs to be exercised to protect the transplants from being overrun with weedy annuals such as cocklebur (*Xanthium* spp.), pigweed (*Chenopodium* spp.), beggar ticks (*Bidens* spp.), and others. Periodic cultivation between and among rows and individual transplants will preclude this problems. If mechanical cultivation is considered inappropriate because of labor costs or inaccessibility of sites, selective herbicides that are rapidly biodegradable can be applied with hand-held equipment and directed only to those areas and plants where control is desired. Caution must be exercised, however, to ensure that the user adheres to environmental regulations and procedures when using herbicides, i.e., with regard to appropriate coordination and clearances with other agencies, application rates, etc.

104. New plantings should be protected from various environmental stresses caused by drought, disease, pests, and animals. If plants are

likely to be subject to drying conditions, irrigation systems may have to be installed temporarily. This often can be achieved by using portable gasoline water pumps and irrigation pipe with overhead sprinklers. Water can be pumped from the reservoir to drier sites higher on the shoreline. The decision to irrigate must be based on economics, contrasting the cost of replanting and increased plant mortality against the cost of irrigation. On many sites, irrigation may not be necessary due to adequate summer rainfall, whereas on other sites, the increase in survival may be worth the cost. Some species which are both flood and drought tolerant may be irrigated for 1 or 2 years, then allowed to survive without further irrigation (Leiser 1983).

105. Infestations of diseases and insects on new transplants may reach levels that require some control measures. Fungi, smuts, viruses, and bacteria can be controlled by cutting and burning diseased plants or by applying appropriate chemical control agents. Chewing, burrowing, or disease-carrying insects may be controlled biologically (by releasing predators) or chemically (by applying insecticides).

106. Temporary protection of young plants from animal browsing may have to be provided by building cages for individual plants or by installing fences around the entire site (Figure 38). Individual cages were necessary at Lake Wallula, to prevent beavers from completely decimating willow transplants (Comes and McCreary 1986). At Lake Texoma, domestic livestock had to be kept away from the shoreline with a barbed-wire fence (Lester et al. 1986).

Figure 38. Fenced willow plantings at Lake Wallula to prevent beaver depredation

PART VI: COSTS

107. Costs for shoreline revegetation, as might be expected, are dependent upon several factors. A partial listing of probable cost considerations is given below.

- a. Project goal. Costs will generally be greater for erosion projects than for projects that focus only on wildlife or fisheries habitat or aesthetic improvement.
- b. Accessibility of the site. Sites that lack access roads and are far removed from marinas may be costly to revegetate. Plant propagules must be carried to the site by boat and/or aircraft or transported by some other unconventional means, unless sufficient plant propagules exist in the immediate area.
- c. Type of plant propagule. Seeds are much less costly than transplants. Among types of transplants, containerized or balled-and-burlapped materials will be much more expensive to acquire and plant than bare-root materials. Transplants that are grown by contract or acquired through commercial nurseries will normally be much more expensive than those acquired from the wild.
- d. Other factors. Other factors influencing costs are total plant numbers desired, availability of particular species, and plant nursery overhead. A cost estimate for planting can be made more readily when types of species, numbers, and propagation methods are identified on a site-specific basis.

108. Most of the costs of vegetating reservoir shorelines are for labor, compared to traditional methods of erosion control where costs are associated with construction material and machinery. Costs for vegetating reservoir shorelines for erosion control purposes are usually only a fraction of the cost of using traditional methods such as riprap. Schiechtl (1980) cites a few rare examples where a direct comparison between bioengineering and traditional engineering costs has been made. He cites Luchterhandt (1966), who made cost comparisons of different slope stabilization works along railway tracks in Germany. The projects were originally planned and calculated according to the conventional engineering methods (hard construction) but were then implemented with bioengineering (use of vegetation with structural materials) methods.

The cost was only one-ninth to one-fourth that calculated for hard construction.

109. Schiechtl (1980) reports another example where costs were compared for protecting a streambank near Tyrol, Austria, where a power station was to be located. The project objective was to stabilize the banks of the channel below the waterline. The best bid was equivalent to $10 per square metre if done with concrete paving alone. Instead, the bank was stabilized with a combination of small rocks with the additional protection of joint planting (use of willow mattresses with wattling bundles for toe protection buttressed by small rocks at the toe, similar to Figure 32). The larger part of the slope was planted only with willow cuttings, without the rock. By using bioengineering methods, the cost of the project was reduced by 94 percent.

Costs of Standard Vegetation Establishment Techniques

110. Costs of vegetation establishment will vary considerably, but the following information is provided as a general estimate of the effort involved for vegetating an area using the different techniques discussed in this report. Most are expressed in terms of man-hours because of variation in prices from one part of the country to another. Also, use of man-hours allows easier comparisons among methods.

Standard seeding

111. The cost for broadcast seeding per square metre can vary considerably according to some literature sources. Reported costs in man-hours per square metre vary from 0.004 (Kay 1978) to 0.07 (Schiechtl 1980) depending on the degree of slope and the type of seeds used.

Hydroseeding

112. Depending on the material used and the distance to adequate water, 4,000 to 20,000 sq m can be hydroseeded by one hydroseeder machine per day (Schiechtl (1980). A hydroseeder normally uses a two-man crew. Fowler and Hammer (1976) reported the cost for using a modified hydroseeder on TVA reservoirs. Production cost (seed,

fertilizer, labor, vehicle operation) for applying 20 lb of Italian ryegrass (*Lolium multiflorum*) seeds per acre and 6-12-12 fertilizer (200 lb/acre) was about $18 per acre.

Aerial seeding

113. Costs for large-scale aerial seeding (helicopter, labor, and seed) amounted to $5.59 per acre for over 1,000 acres on a TVA reservoir (Fowler and Hammer 1976).

Hydromulching

114. Mulch is often applied over seeds by a hydromulcher similar to a hydroseeding machine. For hydromulching or mechanical mulching without seeds, about 0.12 to 0.50 man-hours per square metre is estimated (Schiechtl 1980). Mulching after seeding increases the cost per square metre considerably. Hydromulching with a slurry of wood fiber, seed, and fertilizer can result in a cost of only 0.008 man-hour per square metre, according to calculations derived from Kay (1978), who reviewed contractor costs in California. The above man-hour calculations assume the following: use of a four-man mulching machine at $64 per hour (including labor), seed plus fertilizer at $150 per acre and fiber at $150 per ton applied at a rate of 0.75 ton per acre, an application rate of 2 tons per hour, and a markup of 30 percent for overhead (including equipment depreciation) and profit.

Sprigs, rootstocks or plugs, rhizomes, and tubers

115. Costs for digging grasses and other herbaceous plants in their native habitat and transplanting propagules of these will vary depending on the harvesting system used, the placement of the plants, and the site. For digging, storing and handling, and planting 1,000 plants of sprigged wetland grasses and sedges, Knutson and Inskeep (1982) reported a rate of about 10 man-hours. Sprigs of this type were placed on 0.5-m centers, which would cover 250 sq m. For the same kinds of plants, Allen, Webb, and Shirley (1984) reported a rate equivalent to 400 plants per 10 man-hours for digging, handling, and planting single sprigs. According to Knutson and Inskeep (1982), using plugs of

any species (grass or forb) is at least three times more time-consuming than using sprigs (30 man-hours per 1,000 plugs).

Bare-root tree or shrub seedlings

116. Depending on type of plant and local conditions, the reported costs of planting vary considerably. On good sites with deep soils and gentle slopes, the authors have experienced planting up to between 100 and 125 plants per man-hour. Logan (1979), however, estimated that only 200 to 400 plants per day per person could be achieved on sites like the banks of the upper Missouri River. Logan (1979) noted that planting stock costs for bare-root material supplied by Federal and state government sources range from $26 to $80 per thousand, primarily for coniferous species. Table 2 gives estimated planting stock costs from various sources (Logan 1979).

Ball and burlap trees or shrubs

117. Planting costs for this type of transplant will range from 10 to 25 plants per man-hour (Schiechtl 1980).

Containerized planting

118. The cost of plantings varies depending on plant species, pot type, and site conditions. By using pots other than paper, 20 to 40 plants per man-hour can be planted. With paper pots, up to 100 plants per man-hour can be planted (Schiechtl 1980). Logan (1979) states that the cost for hand-planting containerized stock ranges from one-half the cost of bare-root seedlings to a cost equal to or exceeding that of the container seedling. Containerized stock costs range from $40 to $500 per thousand, depending on the location of the nursery, size of container, amount of time the stock is grown in the container, and the species. Shipping or transportation costs are usually computed at 20 percent of the cost of plant material. See Table 2 for planting stock costs.

Table 2

Costs of Individual Transplants*

Type of Plant Material	Source			
	Government	Private	Wilding**	Contract
Bare-root 15-24 in. minimum size	\$0.08-\$0.18	\$0.10-\$0.36	\$1.00-\$1.50	\$0.08-\$1.50
Container-grown 2 × 2 × 8 in.	\$0.40-\$0.50	\$0.50-\$1.50	N/A	\$0.50-\$1.50
Larger container	N/A	\$1.50-\$7.50	N/A	\$1.50-\$7.50

* Costs are estimates based on averages from various sources (Logan 1979).

** Wilding is a bare-root plant dug from natural stands in the field.

Costs of Specialized Planting Techniques in Erodible Environments

119. As for standard techniques, costs for specialized approaches will vary depending on types and combinations of techniques used, local site conditions, and many of the factors that were discussed previously.

Plant roll

120. Three 2-m plant rolls, each containing four plant-clumps on 0.5-m centers, can be planted in 1 man-hour according to information derived from Allen, Webb, and Shirley (1984). This rate includes time for digging the plants, constructing the roll, and burying it.

Erosion control fabric

121. Costs of the Paratex erosion control fabric previously mentioned were about \$6.30/sq m as derived from Allen, Webb, and Shirley (1984). These costs are based on an hourly labor rate of \$6.00 plus \$0.10/plant for digging, gathering, and transporting. Costs of materials are included; other direct and indirect costs are not included. Costs also assume that plants are placed on 0.5-m centers.

Willow/fence combination

122. Construction of a 1.2-m-tall fence with willows laced through the woven wire every 0.5 m requires about 1 man-hour per 6 m of length. This rate was obtained by untrained student labor during training sessions on a sandy shoreline and probably could be improved as the crew became more proficient.

Wattling bundles

123. Leiser (1983) gives costs and labor for installation of wattling bundles and placement of unrooted willow cuttings on a small job (about 1 acre) at Lake Tahoe, California, in 1973 (Table 3).

Brush layering

124. There are few references on the cost of brush layering. Schiechtl (1980) reports the cost is low, presumably in comparison to techniques using riprap or other similar materials. In the training session mentioned earlier, a crew of 20 students using hand tools installed about 20 m of brush layering along one contour-slope in about 30 min. This equates to 2 m per man-hour. Often, costs can be reduced if machinery such as bulldozers or graders can gain access to the shoreline site and reduce the hand labor required in digging the trenches. This only requires workers to fill the trenches with brush, which can also be covered with machinery. This mode of operation was used extensively by Soil Bioengineering Corporation of Marietta, Ga., to control streambank erosion on parts of the Tennessee-Tombigbee Waterway in Alabama and Mississippi.

Brush mattress or matting

125. The cost of the brush mattress is moderate according to Schiechtl (1980), requiring 2 to 5 man-hours per square metre. The same student workers mentioned above installed about 18 sq m of brush mattress at a rate of about 1 man-hour per square metre. This rate included harvesting the brush, cutting branches into appropriate lengths, and constructing the mattress.

Revetment or crib structures

126. Revetments made from piles, facines, and crib walls, with sprouting woody branches placed between the stretchers, are expensive,

Table 3

Costs of Installing Wattling and Willow Cuttings at Lake Tahoe in 1973 (Leiser 1983)

1. Prepare and install wattling (1,140 lin ft)	
a. Labor	Man-Hours
(1) Scaling or cutting back the bank or slope (1/2 total)	2
(2) Cutting	27
(3) Prepare (stack, tie, load)	28
(4) Layout	9
(5) Install	75
(6) Downtime (rain, 1/2 total)	10
(7) Travel (from Sacramento, Marysville, 1/2 total)	42
	193
	(@ $9/hr* = $1,737)
b. Material	Dollars
(1) 840 Con Stakes (2 × 4 × 24 in.) @ $0.25 ea**	$210
(2) Miscellaneous (twine, gas, etc.)	50
(3) Willows (obtained from Forest Service)	0
c. Equipment	
(1) Chain saw	25
(2) Transportation and trucking	200
(3) Miscellaneous (shears, mattock, shovel, hammer, etc.)	25
	Total $2,247
Unit Cost: $2,247 ÷ 1,140 = $1.97/lin ft, or about $2/lin ft for wattling	
2. Prepare and plant willow cuttings (8,000 cuttings)	
a. Labor	Man-Hours
(1) Scaling (1/2 total)	2
(2) Cutting	9
(3) Prepare	34
(4) Plant	76
(5) Downtime (rain, 1/2 total)	10
(6) Travel (from Sacramento, Marysville, 1/2 total)	42
	173
	(@ $9/hr* = $1,557)
b. Material	Dollars
(1) Willows (obtained from Forest Service)	$ 0
(2) Miscellaneous (twine, auxin solution, etc.)	50
c. Equipment	
(1) Transportation and trucking	200
(2) Miscellaneous (shears, drills, hammers, etc.)	25
	Total $1,832
Unit Cost: $1,832 ÷ 8,000 = $0.229 each, or about $0.23 per willow cutting	
Or	
$0.06/sq ft (based on planting willows at about 2-ft centers)	

* $7/hr + $2/hr subsistence.

** 1.36 ft on center for stakes (except doubled at overlap, so probably 1.5 ft on center).

but the steepness of the bank and the potential loss from erosion may justify the expenditure. Gray and Leiser (1982) give cost comparisons for low toe walls or retaining structures. Among them is the cost of a timber crib similar to the one shown in Figure 35. Cost per square foot of front face is directly related to the height of the wall. Costs by Gray and Leiser (1982) given in Table 4 are for materials, structural fill or crib fill, and assembly and are based on 1978-79 unit price data. They do not, however, reflect procurement and installation of sprouting woody branches between the stretchers, and they do not include excavation, foundation preparation, and backfilling. These costs vary widely from site to site.

Table 4

Costs of Timber Cribs (Gray and Leiser 1982)

Height Range ft	Unit Cost $/sq ft	Remarks
6-9	8-10	Higher walls require successively wider bases (longer headers) and are more expensive
10-15	10-12	
16-21	12-14	

PART VII: SUMMARY

127. This report has presented a conceptual framework for planning and implementing shoreline revegetation projects on reservoirs having varied frequencies and durations of fluctuating water levels. It has synthesized information from several EWQOS reservoir field sites where revegetation studies have been conducted as well as similar research reported by other investigators. Much of what is presented relative to plant species and specific planting methods to be employed will have to be tailored to specific site conditions; however, there are still salient points that can be applied generally to any reservoir shoreline revegetation project. These are summarized below.

Planning

128. It is probably not prudent or practical to try to vegetate large expanses of reservoir shoreline in any single year. An incremental approach permits periodic evaluation and changes in methodology.

129. Stretches of shoreline to be vegetated should be chosen based on clearly defined priorities, i.e., a campground/picnic area that is being jeopardized by erosion. Choose those areas that have a reasonable chance of success when wave-energies, soils, bank morphometry, and the probability of disturbance by animals and people are considered.

130. Choice of proper plant species is very important. Plants most likely to work effectively are those that were growing within the original riparian ecosystem before a reservoir was constructed. As a general rule, plant species selected should have the ability to develop extensive roots or rhizomes quickly and achieve rapid height growth. Other characteristics to consider are mature plant height (favor taller species) and date of first leaf flush (favor species that remain leafless until later in the growing season). The most important thing to remember when acquiring plant materials is to plan well ahead, by at

least 1 to 2 years. By allowing adequate leadtime, plants can be selected and grown under contract if necessary.

Site Preparation

131. Proper site preparation depends on development of a detailed landscape plan. Generally, grass or grasslike plants should be placed lakeward of shrubs, followed by shrubs or shrublike trees. Larger trees should be placed further inland or further up on the slope. Site preparations may include sloping and shaping the bank, protecting the site from wave action where necessary, eliminating undesirable vegetative competition, protecting the site from animals and people in some cases, providing irrigation, moving topsoil to the site, and treating the site with soil amendments.

Planting Methods

132. Proper timing is the most important factor to consider in planning for the availability of propagules and appropriate site conditions. Often, there is only a short period for planting in the fall, after which reservoir water levels rise.

133. Transplanting is usually the most practical method of achieving good planting success, but can be augmented with seeding. However, seeding has generally been effective primarily on mudflats. Seeding should occur only when water levels are stable long enough to allow germination of seeds and plants to attain summer height. Transplanting is usually more practical when sprigs are used for herbaceous plants and bare-root propagules or cuttings are used for woody plants, because these materials are easily obtained and are least expensive. For erodible shorelines, expedient breakwaters should be considered with a combination system of specialized planting techniques such as plant rolls, brush mattresses, wattling bundles, and brush layering, as the situation dictates.

Postplanting Operations and Maintenance

134. The most important aspects of the revegetation project are monitoring and maintenance. Monitoring should be included in every project even if the effort is very cursory. Without monitoring, time and money spent on planting could easily be wasted. Monitoring will often indicate the necessary remedial actions such as protecting the plants from animal browsing and burrowing, fertilizing, additional planting efforts, irrigating, and other possible actions. Once needs are detected, they should be addressed with appropriate maintenance as soon as possible to prevent site deterioration.

Costs

135. Costs for vegetating reservoir shorelines are dependent upon such things as project goals, access to the shoreline, types of plant propagules, and other factors. Costs are much higher for erosion control projects than for habitat development. Costs for vegetating reservoir shorelines for erosion control purposes, however, are usually just a fraction of the costs of using traditional methods such as riprap.

136. In summary, with proper planning, site preparation, use of appropriate plant establishment methods at the right time, and postplanting monitoring and maintenance, reservoir shorelines with fluctuating water levels can be vegetated to satisfy multipurpose objectives. Revegetating reservoir shorelines will aid in preventing turbidity, improve water quality, establish habitat for fisheries and wildlife, prevent erosion, and enhance reservoir aesthetic value.

REFERENCES

Allen, H. H. 1978. "Role of Wetland Plants in Erosion Control of Riparian Shorelines," Proceedings, Wetland Functions and Values: The State of Our Understanding, American Water Resources Association, November 1978, Buena Vista, Fla., pp 403-414.

__________. 1983. "Planting Techniques to Stabilize Reservoir Shorelines at Lake Wallula, Oregon/Washington," Environmental and Water Quality Operational Studies Information Exchange Bulletin, Vol E-83-3, US Army Engineer Waterways Experiment Station, Vicksburg, Miss., pp 1-3.

Allen, H. H., and Aggus, L. R., eds. 1983. "Effects of Fluctuating Reservoir Water Levels on Fisheries, Wildlife, and Vegetation; Summary of a Workshop, 24-26 February 1981," Miscellaneous Paper E-83-2, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Allen, H. H., Webb, J. W., and Shirley, S. D. 1984. "Wetlands Development in Moderate Wave-Energy Climates," Proceedings of Dredging '84, Waterway, Port, Coastal and Ocean Division, American Society of Civil Engineers, November 14-16, 1984, Clearwater, Fla., pp 943-955.

Broadfoot, W. M., and Williston, H. L. 1973. "Flooding Effects of Southern Forests," Journal of Forestry, Vol 71, No. 9, pp 584-587.

Chapman, S. B., ed. 1976. Methods in Plant Ecology, John Wiley and Sons, New York.

Comes, R. D., and McCreary, T. 1986. "Approaches to Revegetate Shorelines at Lake Wallula on the Columbia River, Washington-Oregon," Technical Report E-86-2, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Daubenmire, R. 1968. Plant Communities, a Textbook of Plant Synecology, Harper and Row, New York.

Environmental Laboratory. 1978. "Wetland Habitat Development with Dredged Material: Engineering and Plant Propagation," Technical Report DS-78-16, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Fowler, D. K., and Hammer, D. A. 1976. "Techniques for Establishing Vegetation on Reservoir Inundation Zones," Journal of Soil and Water Conservation, Vol 31, pp 116-118.

Fowler, D. K., and Maddox, J. B. 1974. "Habitat Improvement Along Reservoir Inundation Zones by Barge Hydroseeding," Journal of Soil and Water Conservation, Vol 22, pp 263-265.

Gray, D. H. 1977. "The Influence of Vegetation on Slope Processes in the Great Lakes Region," Proceedings of the Workshop on the Role of Vegetation in Stabilization of the Great Lakes Shoreline, Great Lakes Basin Commission, Ann Arbor, Mich., pp 5-29.

Gray, D. H., and Leiser, A. T. 1982. Biotechnical Slope Protection and Erosion Control, Van Nostrand Reinhold Company, New York.

Hoffman, G., et al. 1986. "Approaches to Revegetate Lakeshores at Lake Oahe, South Dakota," Technical Report E-86-, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Hook, D. D. 1984. "Waterlogging Tolerance of Lowland Tree Species of the South," Southern Journal of Applied Forestry, Vol 8, No. 3, pp 136-149.

Hunt, L. J., et al. 1978. "Upland Habitat Development with Dredged Material: Engineering and Plant Propagation," Technical Report DS-78-17, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Kadlec, J. A., and Wentz, W. A. 1974. "State-of-the-Art Survey and Evaluation of Marsh Plant Establishment Techniques: Induced and Natural; Vol I: Report of Research," Contract Report D-74-9, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Kay, B. L. 1978. "Mulches for Erosion Control and Plant Establishment on Disturbed Sites," Proceedings of ALCA's 1978 Revegetation Erosion Control Symposium, August 1-3, 1978, Denver, Colo., pp 111-129.

Kershaw, K. A. 1973. Quantitative and Dynamic Plant Ecology, American Elsevier Publishing Company, New York.

Knutson, P. L., and Inskeep, M. R. 1982. "Shore Erosion Control with Salt Marsh Vegetation," Coastal Engineering Technical Aid No. 82-3, US Army Engineer Coastal Engineering Research Center, Vicksburg, Miss. (available from National Technical Information Service, Springfield, Va.).

Leiser, A. T. 1983. "Reservoir Shoreline Revegetation," paper presented at US Army Corps of Engineers training course, Wetlands Development and Restoration, Duck, N. C. (available from US Army Engineer Division, Huntsville, Huntsville, Ala.).

Lester, J. E., et al. 1986. "Lakeshore Revegetation Studies at Lake Texoma on the Red River, Texas-Oklahoma," Technical Report E-86-1, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Logan, L. D., comp. and ed. 1979. "Guidelines for Streambank Erosion Control Along the Banks of the Missouri River from Garrison Dam Downstream to Bismarck, North Dakota," USDA Forest Service, State and Private Forestry, Missoula, Mont.

Luchterhandt, J. 1966. Gruenverbau, Bauverlag, Wiesbaden, Berlin.

Pierce, G. J. 1983. "New York State Department of Transportation Wetland Construction," National Wetlands Newsletter, Vol 5, No. 6, pp 12-13.

Ploskey, G. R. 1983. "A Review of the Effects of Water-Level Changes on Reservoir Fisheries and Recommendations for Improved Management," Technical Report E-83-3, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Schiechtl, H. 1980. Bioengineering for Land Reclamation and Conservation, The University of Alberta Press, Edmonton, Alberta, Canada.

Seibert, P. 1968. "Importance of Natural Vegetation for the Protection of the Banks of Streams, Rivers, and Canals, Council of Europe Nature and Environment Series 2, Freshwater (available from Manhattan Publishing Company, New York).

Shaw, G., and Ross, N. 1977. "How to Build a Floating Tire Breakwater," Information Bulletin No. 1, University of Maine/University of New Hampshire Cooperative Institutional Sea Grant Program, Sea Grant Publications, Ira C. Darling Center, Walpole, Maine.

Shetron, S. G., Allen, H. H., and Landin, M. C. 1986. "Field Guide for Low-Cost Vegetation Establishment and Maintenance," Technical Report in preparation, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Sigafoos, R. S. 1964. "Botanical Evidence of Floods and Floodplain Deposition, Vegetation, and Hydrologic Phenomena," US Geological Survey Professional Paper 485-A, Washington, DC.

Teskey, R. O., and Hinckley, T. M. 1977a. "Impact of Water Level Changes on Woody Riparian and Wetland Communities; Vol I, Plant and Soil Responses," FWS/OBS-77/58, Fish and Wildlife Service, US Department of the Interior, Washington, DC.

_________. 1977b. "Impact of Water Level Changes on Woody Riparian and Wetland Communities; Vol II, Southern Forest Region," FWS/OBS-77/59, Fish and Wildlife Service, US Department of the Interior, Washington, DC.

_________. 1977c. "Impact of Water Level Changes on Woody Riparian and Wetland Communities; Vol III, The Central Forest Region," FWS/OBS-77/60, Fish and Wildlife Service, US Department of the Interior, Washington, DC.

_________. 1978a. "Impact of Water Level Changes on Woody Riparian and Wetland Communities; Vol IV, Eastern Deciduous Forest Region," FWS/OBS-78/87, Fish and Wildlife Service, US Department of the Interior, Washington, DC.

_________. 1978b. "Impact of Water Level Changes on Woody Riparian and Wetland Communities; Vol V, Northern Forest Region," FWS/OBS-78/88, Fish and Wildlife Service, US Department of the Interior, Washington, DC.

_________. 1978c. "Impact of Water Level Changes on Woody Riparian and Wetland Communities; Vol VI, Plains Grassland Region," FWS/OBS-78/89, Fish and Wildlife Service, US Department of the Interior, Washington, DC.

US Department of Agriculture, Agriculture Research Service. 1981. "Revegetation of Reservoir Shorelines at Lake Wallula and McNary Dam, Oregon/Washington," unpublished annual report to the US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

US Department of Agriculture, Forest Service. 1980 (Jul). "Burned Area Emergency Rehabilitation Handbook," Forest Service Handbook 2509.13 (FSH 11/78), Washington, DC.

__________. Undated. Research and Demonstration of Improved Surface Mining Techniques in Eastern Kentucky, Revegetation Manual," Report ARC-71-66-74, prepared for Appalachian Region Commission and Kentucky Department of Natural Resources.

Van Kraayenoord, C. W. S. 1968. "Poplars and Willows in New Zealand with Particular Reference to Their Use in Erosion Control," <u>International Poplar Commission, 13th Session,</u> Montreal, Canada.

Whitlow, T. H., and Harris, R. W. 1979. "Flood Tolerance in Plants: A State-of-the-Art Review," Technical Report E-79-2, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.