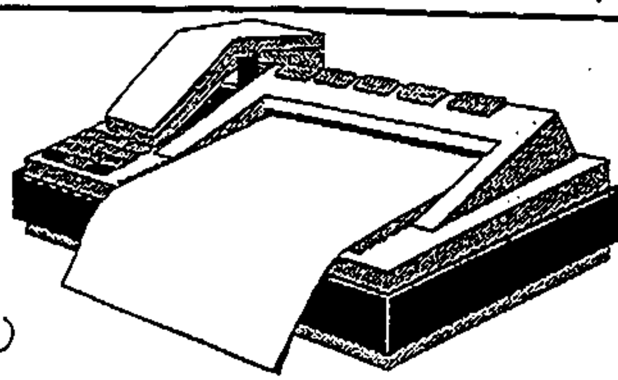
APPENDIX K

WATERWAYS EXPERIMENT STATION

WATER OPERATIONS TECHNICAL SUPPORT

U.S. ARMY CORPS OF ENGINEERS
WATERWAYS EXPERIMENT STATION
ENVIRONMENTAL LABORATORY
AQUATIC ECOLOGY BRANCH
601/634-2398



Date: 8/7/95

Number of Pages: 7 (including this one)

TO:

Name: Mary Flores, PL-R

Office: 817-334-3247

FAX: 817-885-7539

Phone:

FROM:

Name: Jack Killgore

Phone: 601-634-3397

REMARKS:

Mary -

This is a draft of the Cypress Project. Literature Cited is not included. I will be out this week, but let me know what you think. I will send a final copy after I receive your comments. Sorry about the delay

Jake

CEWES-ER-A

7 Aug 95
Draft

MEMORANDUM FOR Mary Flores, CESWF-PD

SUBJECT: Cypress Bayou Water Management Study

1. Reference WOTS request 95-46 relating to restoration of fish habitat in the Big Cypress Bayou, Texas. I am providing recommendations and justification for two alternatives that would benefit fish: placement of gravel bars and managing floodplain hydrology.

Placement of Gravel Bars

2. Gravel bars have been constructed in freshwater streams to mitigate habitat loss and studies have shown a positive response by fishes (Fuselier and Edds 1995 and references therein). In the Cypress Bayou System, rock substrates are uncommon but approximately 40 species of fish collected from this system are known to spawn over sand and gravel (Table 1). Release of paddlefish in the Cypress Bayou System re-introduced another species that spawns only in flowing water over a gravel substrate (Russell 1986). Thus, gravel bars could potentially benefit numerous species of fish including those of special concern.

3. A site visit and subsequent telephone conversations identified two locations where gravel bars could be constructed in the Big Cypress Bayou: 1) tailrace below Lake O' Pines Dam, and 2) bendways between Jefferson and confluence with Black Cypress Bayou (River miles 64-67). These locations were selected for several reasons:

(a) **Discharge can be regulated.** Stable flows must be maintained during the spawning and incubation period to ensure reproductive success of most fishes. For example, paddlefish have been reported to spawn at discharges ranging from 10,000 to 24,000 cfs but move quickly into deep pools if water levels recede (Russell 1986). There are no data on preferred water velocities for spawning, but paddlefish yolk-sac larvae showed a high tolerance to entrainment in swift currents (Payne et al. 1990). Egg incubation is approximately 7 days in water temperatures around 60 °F (March-April in Cypress Bayou system), so stable water levels must remain for at least that long to ensure a significant hatch (Russell 1986). Stranding or desiccation of eggs on gravel may result if water levels recede too quickly.

(b) **Annually occurring flushing flows can remove fine sediments from gravel.** Successful attachment, incubation, and hatching of eggs requires clean gravel. Sediments may reduce gaseous exchange (e.g., dissolved oxygen) between the embryo and surrounding medium. Also, attachment of the egg to the gravel aids in hatching; larvae have difficulty freeing themselves from unattached eggs (Reiser et al. 1989). Since sediment deposition may exceed transport rates in the gravel bars, flushing flows can be created to remove fine sediments prior to spawning season (Jan-Feb). In many cases, flushing flows occur at or above bank-full discharge. Reiser et al. (1989) identifies three general methods used to establish flushing flow requirements and provides details for each method:

(i) Hydrologic Event Methods - Analysis of river gage information
(ii) Channel Morphology Methods - Use of channel-shape parameters (bank-full depth)
(iii) Sediment Transport Mechanics Methods

(c) **Deep pools adjacent to gravel bars provide pre-spawning and rearing habitat.** There are relatively deep pools in Big Cypress Bayou near both sites: immediately below the tailrace of Lake O' Pines and below the confluence with Black Cypress Bayou. These pools may serve as staging areas during pre-spawning movements of adults fishes and provide rearing habitat for larvae that were swept downstream after hatching. For example, prior to spawning when the water is near 50 °F, paddlefish congregate in deep pools and start moving upstream; as with most fishes, photoperiod and water temperature control the timing of spawning (Russell et al. 1986)

(d) **Channel morphometry is compatible with gravel bar formation and longevity.** The site below Lake O' Pines is wide and relatively shallow which promotes moderate to high water velocities. Banks are stabilized with rip-rap, so hard substrates already exist. The site below Jefferson is a series of bendways with well-developed point sandbars. Flowing water consistently occurs along the outside of the bendway. Furthermore, the gravel bar at the bendways would be in deeper water than the bar below Lake O' Pines which offer fish more choices in preferred spawning locations.

4. I have three suggestions on design of a gravel bar:

(a) A heterogenous substrate, ranging from small gravel (1-3 inch diameter) to rather large and flat stones, is recommended. The non-uniform rock/gravel mixture is typical of naturally-formed gravel bars and will probably result in better compaction of substrate, provide velocity refugia for adult fishes, and offer more interstitial spaces for attachment of eggs and invertebrates than a homogenous mixture of gravel. In addition, the shape of the gravel may affect sediment deposition. According to Reiser et al. (1989), a flow separation zone can develop behind angular gravels at high flows, causing greater sediment deposition.

(b) The gravel bar should be centered in the thalweg to ensure consistent flow during low-water periods and reduce sedimentation. The length of the gravel bar is probably more important than its width. The gravel bar should be of sufficient length to ensure that broadcasted eggs have ample time to attach to gravel before being swept downstream. Thus, a narrow (e.g., 20-30 feet) strip of gravel placed along the thalweg is the minimum requirement for a functional gravel bar. If funding is available, the gravel can be extended to the channel margins up to the bank. Rip-rap (stones sizes of 0.5-3 ft diameter) can also be placed on a graded bank for erosion control and additional aquatic habitat (Dardeau et al. 1995).

(c) The "V" shape of the gravel bar should be pointed upstream and the surface of the bar at the middle of the river should be slightly depressed to maintain deepest flow at the thalweg (Fuselier and Edds 1995). The depth of gravel should be such to accommodate these recommendations.

Floodplain Hydrology

5. The floodplain of the Big Cypress Bayou below Lake O' Pines consists of bottomland hardwoods that are seasonally inundated and permanent water bodies such as sloughs, ponds, and oxbow lakes (backwaters). Operation of Lake O' Pines Dam can be modified to manage onset, magnitude, and duration of flooding that benefits aquatic species. Junk et al. (1989) proposed the flood pulse concept explaining how unregulated river systems exhibit a "pulsed" hydrograph in which the rate of rise or fall regulates productivity. Production is maximized at a slow to moderate rate of increase of the hydrograph because fish respond to increased availability of vegetation and associated food and habitat as the moving littoral transverses the aquatic/terrestrial transition zone (Bayley 1991; Junk et al. 1989).

6. The onset of flooding should correspond to spawning periods of fishes. In temperate rivers, fish spawn throughout the year but peaks March through June. Based on larval and adult fish data collected in the Lower Mississippi River Basin, fishes that move upstream to spawn (e.g., suckers, white bass, yellow bass) do so in March and April. Also, most darters, crappie, and black bass spawn during early spring. Other sunfishes, minnows, shiners, and catfish spawn late spring-early summer.

7. Duration of flooding is important for egg incubation since eggs can be stranded and desiccated if water levels drop before hatching. Incubation times range from 2-14 days for most fish species. Long periods of inundation are not recommended, however, because a constant high water level may reduce fish production due to development of stagnant water conditions (Junk et al 1989). Furthermore, the high amplitude can only be maintained for a limited period within the annual cycle if water level has a slow rate of increase and decrease (Bayley 1991).

8. Given these constraints, the following water management procedure is recommended:

(a) A bi-modal hydrograph is recommended with one peak occurring late March-early April (early spawners) and the second peak occurring late May-early June (late spawners).

(b) Each peak should be maintained for two weeks; this will ensure adequate incubation times.

(c) A slow rise and fall should accompany each peak so that the duration of each mode on the hydrograph approximates one month. Extended hydroperiods accommodates variable spawning times within each mode. Slight water fluctuations increase hydraulic circulation and minimize stagnant conditions in the floodplain.

9. Determining magnitude of flooding is problematic because both depth and volume of water must be considered. Depth of flooding should exceed bank-full discharge to ensure access to floodplain by laterally migrating fishes. High amplitude and subsequent decline in water elevation can be estimated from a flow duration curve (Figure 1). Based on gaging data obtained

near Jefferson, the median annual discharge is approximately 130 cfs which is well below bank-full discharge. Figure 1 shows that wet periods (10-20% exceedance) correspond to a range of 1,000 - 2,000 cfs. Thus, a conservative estimate on the high amplitude flood should occur between this range. GIS maps of floodplain habitats inundated at known flood frequencies (e.g., 2-year flood frequency) will improve the estimate since acreage by habitat (e.g., 200 acres of cypress trees) can be determined.

10. Water elevation can also be managed to ensure connection of backwater to river. Floodplain water bodies often become isolated due to sedimentation, levees, or water level manipulation from water control structures. Re-establishing connectivity of permanent floodplain water bodies can promote species richness by providing spawning and rearing habitat for laterally migrating fish and contribute to the overall ecological function of river systems (Amoros 1991; Baker et al. 1991; Beecher et al. 1977). Productivity is usually higher in the lentic and standing waters of these wetlands than in the lotic habitats of the main river (Bayley 1991). When floodplain water bodies are re-connected to the main channel, invertebrates and juvenile fishes are washed from the floodplain, thereby providing increased food for main stream animals (Eckblad et al. 1984; Amoros 1991).

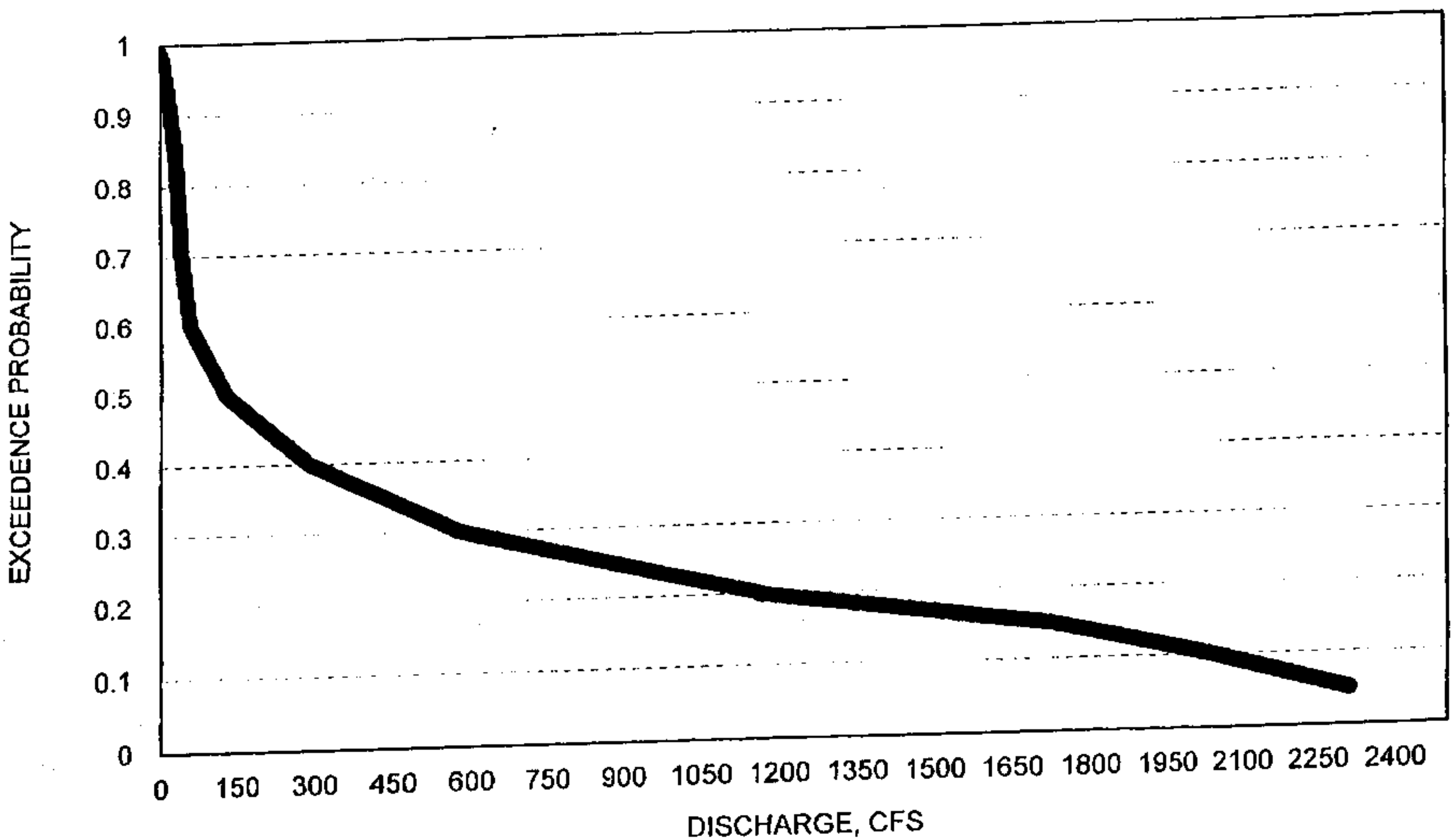
11. The stage when backwaters become connected to the river is unknown but can be derived by surveying the river during known discharges and determining wetland elevations from USGS topographic maps. The bottom elevation of the entrance channel to the backwater is usually below bank-full discharge (pers. obs.) suggesting that slight increases in discharge will provide access to hundreds of acres of permanent floodplain water bodies.

Table 1. Habitat guilds for Cypress and Twelvemile Bayou fishes, based on preferred velocities (horizontal axis) and spawning substrate (vertical axis).

	LACUSTRINE/GENERALISTS	SLACK WATER	SWIFT WATER
OPEN	Gizzard shad Mosquitofish	American eel Threadfin shad Cypress minnow Silvery minnow Ribbon shiner	Skipjack herring Emerald shiner Mimic shiner Freshwater drum
SAND AND GRAVEL	Red shiner Green sunfish Orangespotted sunfish Bluegill Redear sunfish Largemouth bass White Crappie Black crappie	Redfin shiner Pallid shiner Bluehead shiner Pugnose minnow River carpsucker Creek chubsucker Spotted sucker Blacktail redhorse Golden topminnow Flier Warmouth Redbreast sunfish Dollar sunfish Longear sunfish Spotted sunfish Bantam sunfish Spotted bass Mud darter	Chestnut lamprey Blackspot shiner Striped shiner Ironcolor shiner Sand shiner Weed shiner Yellow bass White Bass Scaly sand darter Harlequin darter Goldstripe darter Redfin darter River darter Blackside darter Dusky darter
VEGETATION	Bowfin Common carp Golden shiner Brook silverside	Spotted gar Shortnose gar Alligator gar Grass pickerel Chain pickerel Taillight shiner Lake chubsucker Smallmouth buffalo Bigmouth buffalo Starhead topminnow Blackstripe topminnow Blackspotted topminnow Inland silverside Banded pygmy sunfish Bluntnose darter Swamp darter Slough darter	Longnose gar Black buffalo
CREVICE	Bullhead minnow Black bullhead Yellow bullhead Channel catfish	Blue catfish Tadpole madtom Flathead catfish Pirate perch Cypress darter	Blacktail shiner

BIG CYPRESS BAYOU NEAR JEFFERSON, TX

ANNUAL FLOW DURATION CURVE: 1979-1993



PRELIMINARY ANALYSIS OF THE WATER QUALITY OF CADDO LAKE, TEXAS: RELATIVE EFFECTS OF WATER FLOW AND AQUATIC PLANTS

INTRODUCTION

Caddo Lake is a shallow (mean depth=1.8 m) natural lake located between the states of Texas and Louisiana. Caddo Lake has a Corps of Engineers (CE) spillway, installed in 1914, on the downstream end (in Louisiana) to stabilize and maintain water levels. The lake receives much of its water loading from Big Cypress Creek. Several impoundments have been constructed in the Big Cypress Creek drainage system: Lake O' the Pines (1959), Lake Cypress Springs (1970), and Lake Bob Sandlin (1979). There has been continuing concern that these impoundments, by altering the hydrology of Caddo Lake, may have contributed to a deterioration of water quality or may have exacerbated aquatic plant problems. Specific concerns centered on the possible effects of reduced water flows (Bounds et al 1981) or reduced levels of suspended solids (turbidity) (Smart 1988). Since LOP is a Corps of Engineers reservoir, the Corps' Fort Worth District is concerned that construction and operation of Lake O' the Pines may adversely affect Caddo Lake.

This report was prepared in response to a WOTS (Water Operations Technical Support) Program request from the US Army Engineer District, Fort Worth for a preliminary analysis of the interactive effects of water flows and aquatic plants on water quality problems in Caddo Lake. The report is based on a brief site visit by the authors on 23 May, 1995 and on published reports and personal communications from the Texas Parks and Wildlife Department (TPWD). This report was prepared to identify: 1) factors contributing to dissolved oxygen depletion, 2) the nature and extent of the aquatic plant problem, and 3) possible management options that might be considered to alleviate these problems. This report is part of a larger investigation of possible adverse effects of the operation of Lake O' the Pines (LOP) on the Caddo Lake ecosystem. Specific management recommendations for operation of LOP were not evaluated here, and this report is concerned only with flow in general. A more detailed, quantitative analysis would require collection of field data.

Water Flow and Water Quality

A major public concern is the perception that water quality and aquatic plant problems in Caddo Lake have worsened over the past 35 years. The construction of LOP and other reservoirs along Big Cypress Creek are often to have contributed to the problems. Bounds et al. (1981) suggested that the construction of the upstream reservoirs had reduced flushing in Caddo Lake due to dampening of flood events. This reduced flushing was thought to have contributed to a decline in water quality by allowing the accumulation of decaying organic materials, subsequently resulting in depressed dissolved oxygen levels. Decreases in both the frequency and magnitude of periods of high turbidity associated with flood events were also blamed for an increase in areal coverage by submersed macrophytes. These considerations resulted in the recommendation, by TPWD (Bounds et al., 1981), that the Corps "provide maximum sustained water releases to Caddo when possible."

However, to date there appear to have been no quantitative evaluation of the impacts of LOP on the water quality or aquatic plant community of Caddo. The upper end of Caddo Lake is very shallow and exhibits a complex morphometry due to the occurrence of many cypress breaks, sloughs, cuts, and bayous. In view of this complexity, it would be difficult to determine the effects of changes in hydrologic regime on the flushing of the upper end of the lake without an extensive field sampling effort, perhaps involving dispersion of dyes under different flow conditions. While these studies would provide more detailed information on the effects of the operation of LOP on water flow patterns and water quality in Caddo Lake, we believe that the extensive development of submersed aquatic vegetation and not the operation of LOP exerts the major controlling influence on the water flow and quality conditions in Caddo Lake.

Aquatic Plants

Historical information on the species composition and abundance of aquatic plants in Caddo Lake was obtained from T. W. Schlagenhaft of TPWD. This information consisted largely of TPWD Job Completion Reports and other unpublished documents and were concerned exclusively with the Texas portion of the lake. Rhandy Helton, also of TPWD, participated in the 23 May site visit and provided additional information. The floating, floating-leaved, and submersed aquatic plant species that have been reported for Caddo Lake are listed in Table 1. There are also many emergent aquatic plant species found in Caddo Lake, but these are not expected to cause water quality or water use problems and are not included in Table 1.

Aquatic plant problems in Caddo Lake are not new, and date back to at least 1950. Aquatic vegetation in 1954 was reported by TPWD to have consisted of dense beds of submersed species including pondweeds (*Potamogeton*), watermilfoil[1] (*Myriophyllum*), coontail (*Ceratophyllum*), and muskgrass (*Chara*) extending throughout much of the Texas portion of the lake. Dense beds of the floating-leaved species -- water lily (*Nymphaea*) and lotus (*Nelumbo*) and extensive mats of waterhyacinth (*Eichhornia crassipes*) combined to cover much of the upper portion of the lake.

Waterhyacinth

In 1955, after an extensive (1500-2000 acres) and persistent (4-5 years) infestation of water hyacinths, Texas Parks and Wildlife initiated an herbicidal spraying program. A 2-man crew, using boat-mounted spraying equipment, treated the lake with 2,4-D between March and October 1955. This level of treatment resulted in a reduction in water hyacinth coverage of some 30-35%. During the period between 1956 and 1958 the level of treatment with 2,4-D was increased, and the waterhyacinth population in Caddo Lake was eventually brought under control.

During the period between 1959 and 1965, TPWD sustained a statewide aquatic plant eradication program under the Dingell-Johnson Federal Aid Project F-15-D. The emphasis in this program was directed at waterhyacinth in Lake Corpus Christi and Caddo Lake. Following the federal program, between 1965 and 1967, there was no statewide aquatic plant control program in Texas. Beginning in 1968, TPWD entered into continuing contracts with the Corps of Engineers for control of water hyacinth in Texas waters. Caddo Lake was included in these efforts in 1973, and the water hyacinth population has been kept under control since that time. Under the TPWD Aquatic Vegetation Control Program, known waterhyacinth problem areas are surveyed in winter or early spring prior to the onset of new growth. If waterhyacinths are observed, these sites are chemically treated during the growing season. Finally a post-treatment survey is conducted in the fall to determine the efficacy of the treatment. Waterhyacinths covered an estimated 400 acres in Caddo Lake in 1986, and 107 of these acres were treated in that year.

American Lotus

By 1960, only a few years after the waterhyacinth populations had been brought under control, American lotus (*Nelumbo lutea*) populations had increased to what was perceived as problem proportions (450 acres). TPWD implemented control measures (2,4-D) for lotus at that time. In June, 1961, after about 70% of the lotus acreage had been treated, it became apparent that removal of the floating-leaved species was resulting in a stimulation of the growth of the submersed aquatic plants.

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[1]Identification of some of these species is uncertain. The plant referred to here as "water milfoil" (*Myriophyllum* sp.) is probably parrotfeather (*Myriophyllum aquaticum*).

> "Submerged vegetation became such a problem in the lake that it was felt that some areas of lotus were an asset to the lake as it shaded out the 'moss' and provided good fishing places."

Spraying of lotus was immediately terminated.

Submersed aquatic plants

In 1964, the major submersed aquatic plant species were listed as coontail (*Ceratophyllum*), parrotfeather (*Myriophyllum*), and "water weed" (*Elodea*[2]). In 1973 an attempt was made to clear submersed vegetation from about 50 miles of boat lanes and accesses with 2,4-D. This effort was successful in clearing lanes of "watermilfoil" (parrotfeather), bladderwort, water lilies and naiads, but was less successful for Cabomba. Repeated treatment of the submersed aquatic plants on an annual basis was used to maintain boat access lanes, and submersed aquatic vegetation "virtually fills the Caddo Lake basin each summer" (Bounds et al., 1981).

A survey of the aquatic vegetation in Caddo Lake in 1980 (Bounds et al., 1981) revealed a fairly diverse aquatic plant community (Table 1). Most of the species observed by Bounds are native and not considered to be noxious weeds. Hydrilla (*Hydrilla verticillata*) and Eurasian watermilfoil (*Myriophyllum spicatum*) were not observed in Caddo Lake at that time.

Un update to this species list in 1988 (Smart 1988) indicated that the shallow areas of the lake were dominated by Brazilian elodea (*Egeria densa*) and fanwort (*Cabomba caroliana*) among the submersed flora, and by yellow waterlily (*Nuphar luteum*), white waterlily (*Nymphaea odorata*), and American lotus (*Nelumbo lutea*) among the floating-leaved flora. Very few waterhyacinths were reported. In deeper water (>120 cm), Brazilian elodea shared dominance with the introduced weed, Eurasian watermilfoil (*Myriophyllum spicatum*). Eurasian watermilfoil also existed in large, monotypic beds in the deeper, open water areas of the lake. Hydrilla (*Hydrilla verticillata*) was not reported.

Smart (1988) suggested that the relatively recent appearance of Eurasian watermilfoil in Caddo Lake, and its occurrence in the deeper areas of the lake, indicated a possible increase in submersed aquatic plant coverage of the lake. Based on a simple model of plant distribution in relation to light, Smart suggested that virtually the entire lake was susceptible to plant colonization and growth. At that time, submersed aquatic plants occupied much of the upper portion of the lake, extending into open water to maximum depths of 1.5-1.8 m in most years and occasionally to 2.1-2.4 m. This represented areal coverage by aquatic plants (including both submersed and floating-leaved species) of up to 85% of the lake surface.

[2] The plant referred to here as "water weed" (*Elodea* sp.) is probably Brazilian elodea (*Egeria densa*).

Current Situation

A brief site visit on May 23, 1995, revealed a flora quite similar to that observed in 1980 and 1988 (Table 1). Currently aquatic plants occupy up to 95% of the lake (R. Helton, TPWD, personal communication) suggesting that there has been an expansion since 1988, and affirming the prediction that the entire lake was susceptible to plant colonization and growth (Smart 1988). Although hydrilla was not observed within the lake, Rhandy Helton has reported a small population in Big Cypress Creek, upstream of Caddo Lake. This potential source of hydrilla propagules to the lake is cause for concern.

In spite of the extensive coverage by submersed aquatic plants, the only chemical treatment currently being done on Caddo is for waterhyacinth (Rhandy Helton, TPWD, personnel communication). Waterhyacinth in Caddo Lake continues to be treated under a maintenance control program and since 1990, between 0 and 157 acres have been treated annually . Boat lanes, although vegetated, remain navigable due to the volume of boat traffic utilizing them.

Factors affecting aquatic plant growth in Caddo Lake

The local distribution and production of both aquatic and terrestrial plants is often limited by levels of key environmental resources such as light or nutrients. Among aquatic plants, **floating forms** such as waterhyacinth, usually occupy the uppermost position in the canopy and are not often limited by light (unless they occur beneath a tree canopy). Since these plants are not dependent on the transmission of light through the water column, turbidity, phytoplankton density, water depth, and water clarity are not critical to the growth of established populations. Floating species are dependent on the water column for providing adequate nutrients and are therefore relatively unaffected by sediment composition. Floating plants are, however, affected by atmospheric and hydrologic phenomena such as the direction and magnitude of prevailing winds and currents. **Floating-leaved plants** are also not usually subject to light limitations, but are restricted to relatively shallow water depths (usually <2 m) and are also dependent on the sediment for anchorage and nutrition. **Submersed aquatic plants** are dependent on the transmission of adequate light levels through the water column and, as a result both, their local distribution is usually limited by light availability at a given depth. These plants are also dependent on the water column for provision of the inorganic carbon used in photosynthesis and on the water and sediment for their nutrition (Sculthorpe, 1967; Hutchinson, 1975).

In order to develop effective strategies for managing the aquatic plant problems in Caddo Lake it is necessary to understand the factors potentially limiting the distribution and growth of aquatic plants in the lake. Once the limiting factors have been identified, it will be possible to evaluate the influence (if any) that construction and operation of LOP has had, or could have, on the aquatic plant community in Caddo Lake.

Floating aquatic plants

Without human intervention, aggressive floating plants could easily dominate Caddo Lake. Free-floating aquatic plants occupy the water surface and their well-developed canopies intercept much of the incident solar radiation, limiting the penetration of light into the water column. These species can thus shade out either submersed or floating-leaved forms but since they are not anchored to the sediment are subject to being washed out by high water or wind velocities. However, Caddo Lake, by virtue of its complex morphology, appears to provide abundant protected areas where floating plants could thrive. In view of the past success of waterhyacinth in dominating Caddo Lake, this species seems to have been little affected by water velocities commonly occurring in the upper portions of Caddo Lake even before the construction of LOP.

Since floating plants take up nutrients from the water column rather than from the sediments, they benefit from higher concentrations of nutrients in the water (Gossett and Norris, 1971). Thus the potential production and distribution of floating species might be directly related to nutrient loading. If operation of LOP has decreased nutrient loading to Caddo Lake the potential production of waterhyacinth may have been reduced. However, the effects of chemical treatment (maintenance control) prevent the population of waterhyacinth from ever approaching limits that might be imposed by environmental nutrient availability.

We believe that the construction and operation of LOP is unlikely to have measurably affected the growth of waterhyacinth in Caddo Lake.

Floating-leaved aquatic plants

Floating-leaved plants are morphologically highly adapted for growth in shallow waters, having roots in the sediments for access to nutrients, and leaves at the water surface for access to abundant light (Sculthorpe, 1967). Although these plants are less affected by subsurface light availability than are submersed forms, their specialized morphology limits their distribution to shallow waters. Larger floating-leaved forms (lotus, waterlilies) are generally found in areas of relatively low water velocity as these species are not morphologically adapted to withstand high flows (Wetzel, 1975). In Caddo Lake these floating-leaved species are generally confined to fairly protected areas of shallow (<2 m) water.

Floating-leaved species are largely dependent on nutrients taken up from the sediment (Brock et al., 1983). Since these species can benefit from nutrients deposited with sediments and are relatively unaffected by reductions in light due to high levels of turbidity or competing algae, loading of nutrients and sediments may play a role in the distribution and production of floating-leaved forms (Smith and Wallstein, 1986). However, while increased nutrient and sediment loadings may stimulate growth and distribution, decreased loadings (due to LOP) may not have resulted in measurable reductions in growth due to the large nutrient storage capability of both the root portions of these plant species (Brock et al., 1983) as well as the sediments.

The distribution of floating-leaved species in Caddo Lake is likely limited by water depth. Competitive exclusion by both floating and submersed forms may also act as a secondary limiting factor.

Submersed aquatic plants

Although low light levels often limit the maximum depth of colonization by submersed aquatic plants (Hutchinson, 1975; Spence, 1975), light is unlikely to be exerting a strong limitation on the biomass production of submersed aquatic plants in Caddo Lake except in the deeper areas of the lake (>2 m) or beneath a canopy of cypress trees, waterhyacinths, or other aquatic plants. Extensive beds of submersed aquatic plants, such as those on Caddo, exert a clearing effect on the water column by filtering out suspended material and by removing excess nutrients that promote the growth of phytoplankton. Thus while high levels of turbidity or phytoplankton might restrict the establishment of submersed aquatic plants, once established in shallow waters the actions of the plants themselves counter the inhibitory effects, and the population usually expands into deeper waters.

It appears unlikely that the construction and operation of LOP has had a major impact on the plant community in Caddo by either reduction in inflowing turbidity or nutrient levels. First, it is unlikely that construction and operation of LOP has actually reduced levels of turbidity in Caddo Lake (Smart 1988). Even if turbidity levels of inflowing waters had been reduced by LOP, the ultimate depth distribution of submersed aquatic plants would not have been greatly affected since the deeper areas of the lake are far removed from the inflow. Likewise, if the operation of LOP reduced nutrient loading to Caddo Lake, the effects of this reduction on the submersed aquatic plants might not be detectable. Since submersed aquatic plants are dependent, at least in part, on nutrients derived from the sediment (Smart and Barko, 1985; Barko and Smart, 1986), sedimentation and nutrient loading may play key roles in the long-term distribution and production of submersed aquatic plants. While high levels of nutrients and suspended sediments may reduce light availability, precipitation of these nutrients and sediments within submersed aquatic plant beds provides a continuing source of nutrients (Carpenter, 1981; Barko and Smart, 1986). While high levels of nutrients associated with the sediments are beneficial to the growth of submersed aquatic plants (Barko and Smart, 1986), high concentrations of nutrients (particularly nitrogen and phosphorus) in the water column may be detrimental due to their stimulation of competing epiphytic and planktonic algae (Mulligan and Baranowski, 1969; Sand-Jensen and Sondergaard, 1981; Jones et al., 1983; Moss et al., 1986).

Conclusions

The effects that construction and operation of LOP have had on Caddo Lake are difficult to determine with any degree of certainty. To ascribe changes in water quality or aquatic plant growth and distribution to LOP-mediated changes in flow, turbidity, or nutrient levels appears impossible with the current level of information available. However, the presence of hydrilla in LOP and the report by Rhandy Helton of hydrilla in Big Cypress Creek indicates that, by providing a large expanse of aquatic plant habitat open to colonization by weedy species upstream of Caddo Lake, LOP may have contributed to some of the aquatic plant problems in Caddo Lake. By harboring populations of exotic weedy species such as hydrilla or Eurasian watermilfoil, LOP may have promoted the invasion of Caddo Lake by Eurasian watermilfoil and now serves as a continuing source of hydrilla propagules to the system. In the absence of LOP these troublesome species may not have become established in Big Cypress Creek, and their threat to the ecology of Caddo Lake would be much reduced.

However, while it is difficult to ascertain the effects of LOP on the aquatic plant problems in Caddo Lake, it is obvious that past aquatic plant control operations have contributed to the spread of exotic submersed species. By eliminating or greatly reducing one component of the aquatic vegetation (floating plants) we have created an opening for another component (submersed plants) to exploit. This is an often-repeated pattern in aquatic plant control. Unless we promote the establishment of non-problem native plants to occupy the available niche, we will continue to repeat the cycle (Smart and Doyle 1995).

Caddo Lake, since it is very shallow and fertile will continue to support an abundance of aquatic plants. While we are unable to eliminate or even effect a long-term reduction in the amount of aquatic plant growth in the lake without harming the lake ecosystem, we may be able to choose the dominant species. Several exotic species greatly curtail our ability to use infested water resources and also cause severe water quality problems. These problems arise from their tendency to completely cover the water surface with a thick canopy or mat of leaves (Honnell, Madsen and Smart 1993). This canopy restricts wind-generated mixing of the water column and inhibits gas exchange at the water surface. These factors, in combination with a high respiratory demand associated with excessive biomass production, often result in depletion of dissolved oxygen and subsequent fish kills.

We believe that four exotic species currently present the most serious threats to Caddo Lake. Waterhyacinth by virtue of its extensive mat of interconnected plants is the worst offender (Honnell, Madsen, and Smart 1993). Waterhyacinth strongly dominated Caddo Lake in the past and has been under maintenance control for nearly 40 years. It is likely that TPWD's program of annual monitoring and treatment (when needed) is the primary factor limiting the explosion of the waterhyacinth population. Hydrilla, although a submersed species, also forms a thick mat of entangled shoots at the water surface (Haller and Sutton 1975) and can cause severe oxygen depletion problems. Eurasian watermilfoil and Brazilian elodea likewise form dense canopies and can cause oxygen depletion.

In contrast to the nuisance characteristics of these exotics, many native species do not form extensive surface canopies and thus do not cause water quality problems. If these native species could be established, they might occupy the niche, preventing the recurrence of exotic weedy species as well as providing fish and wildlife habitat.

Management Options

Flow alteration

Based on the limited information available, we believe it is unlikely that alteration of flows into Caddo Lake will alleviate either water quality or aquatic plant problems in the lake. Even removal of LOP would unlikely have lasting effects. Although unregulated (by LOP) storm flows entering Caddo Lake would periodically clear out large areas of vegetation, these areas would be rapidly recolonized. On a day-to-day basis a 2 or 3 fold change in water flow into Caddo Lake would not likely produce any measurable changes in water quality. Most of this increased flow would simply be channelized through the dense vegetation and therefore affect only a small area. We believe the plant community exerts the major controlling influence on dissolved oxygen levels in the lake by restricting flow, impeding gas exchange, reducing mixing, and contributing to oxygen demand.

Improvement in the water quality and overall health of the Caddo Lake ecosystem will likely require changes in both the hydrologic regime and the plant community. Increases in water flushing and mixing will undoubtedly improve water quality, but these may not be possible without changes in the aquatic plant community as well.

Control of aquatic plants with grass carp

The use of grass carp is restricted to private waters in the state of Texas. If grass carp were made available by special act of the legislature, they might be used to reduce the amount of vegetation in Caddo Lake. Unfortunately, while grass carp would provide some short-term relief by reducing the extent of the plant community, they would likely exacerbate the aquatic plant problems over the long term. Eurasian watermilfoil is one of the plants least preferred by grass carp. By selectively feeding on other species, including many desirable native species, grass carp can promote the spread of Eurasian watermilfoil. It is likely that grass carp would eliminate egeria and the many native submersed aquatic plant species that are currently holding the Eurasian watermilfoil in check. By eliminating these competitors, grass carp would allow Eurasian watermilfoil to proliferate. In the long term, the grass carp could provide an opportunity for hydrilla to expand as well. As the grass carp age and their consumption of plants declines, the open niches they had created would likely be filled by the fastest growing, most aggressive weed in the system- hydrilla. We believe that the risk of Eurasian watermilfoil expansion and hydrilla invasion is too great to warrant the use of grass carp .

Control of aquatic plants with herbicides

Annual chemical treatment of waterhyacinth should continue as needed to prevent this species from regaining dominance in Caddo Lake. If waterhyacinth were to expand significantly, even for a relatively short period, it could displace less-problematical submersed and floating-leaved species. Although the expanded waterhyacinth population could ultimately be brought back under control areas vacated by displaced species would be vulnerable to invasion by Eurasian watermilfoil and hydrilla. The herbicide used to control waterhyacinth (2,4-D) will not appreciably damage floating-leaved or submersed aquatic plants if carefully applied according to label recommendations. Therefore there is little danger that chemical treatment of waterhyacinth will contribute to a worsening of the problem and considerable indication that it will help. Although the Corps' Aquatic Plant Control Program will be terminated at the end of this fiscal year, the State of Texas should continue to control waterhyacinth in Caddo Lake.

The use of herbicides to reduce levels of floating-leaved or submersed aquatic plants or to open channels to improve flow is risky. By opening sites for hydrilla invasion the use of herbicides may worsen long-term problems in Caddo Lake. However, small-scale, localized use of herbicides in combination with planting of desirable native species might be worthwhile. This option will be considered later.

Control of aquatic plants with mechanical harvesters

Harvesters will be unable to effect acceptable economical control of the aquatic plant problem in Caddo Lake. However, if used judiciously to open and maintain water flow channels through submersed vegetation, harvesters might improve water quality.

Restoration of the native plant community

By replacing exotic canopy-forming species with less troublesome native species we might be able to improve the overall health of the Caddo Lake ecosystem. Stands of emergent native aquatic plants could be established to help contain waterhyacinth populations, thin out the submersed plant canopy, enhance gas exchange, reduce levels of respiring biomass in the water column, increase water flow and flushing, and provide more favorable levels of dissolved oxygen. Emergent species that might be considered for this effort include the softstem bulrush (*Scirpus validus*), arrowhead (*Sagittaria*), and buttonbush (*Cephalanthus occidentalis*). The floating-leaved American lotus might also be effective.

Replacement of exotic submersed species with native ones would likely require small-scale treatment with herbicides to first eliminate the problem exotic. The goal of this activity would be to restore the historical native submersed plant community. Restoration of the submersed plant community, since it would involve opening up areas with herbicides, would increase the risk of hydrilla invasion and would have to be done on a small-scale and under close scrutiny. Wild celery (*Vallisneria americana*) would be a desirable and appropriate species for restoration.

Recommendations

The following recommendations are made:

1) Continue annual monitoring and treatment (as necessary) of waterhyacinth,
2) Continue monitoring the lake for the presence of hydrilla and immediately initiate a chemical treatment program if it is observed,
3) Establish small-scale test plots of emergent and floating-leaved species and evaluate their performance in controlling waterhyacinth and in improving water quality.
4) Establish small-scale test plots of submersed species and evaluate their ability to withstand re-invasion by egeria. Monitoring will be essential and chemical treatment will be necessary if the plots are invaded by Eurasian watermilfoil or hydrilla during the re-establishment phase.
5) If funds are available, evaluate the use of harvested flow channels to improve water flushing, water quality, and boat access.

Caddo Lake provides nearly ideal conditions for the growth of aquatic plants. Its shallow depth and sheltered coves, Cypress brakes, sloughs, and backwater areas provide abundant habitat for emergent, submersed, floating-leaved and floating growth forms. These Cypress brakes and backwater areas also provide numerous refuges from chemical and mechanical control measures, making plant eradication impossible. Any future management or restoration efforts should realize that even under the best-case scenario (re-establishment of native plant community), Caddo Lake will likely have periodic occurrences of localized oxygen depletion.

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TABLE 1. CHECKLIST OF AQUATIC PLANTS OBSERVED IN CADDO LAKE

CATEGORY	COMMON NAME	SCIENTIFIC NAME	ORIGIN	STATUS (1980)	CURRENT STATUS	PROBLEM POTENTIAL
Floating						
	Duckweed	Lemna	native	present	common	low
	Frogbit	Limnobium spongia	native	present	present	low
	Waterhyacinth	Eichhornia crassipes	exotic	present	common	very high
	Watermeal	Wolffia	native	present	common	low
Floating-leaved						
	American lotus	Nelumbo lutea	native	present	present	low to moderate
	Spatterdock, yellow water lily	Nuphar luteum	native	present	common	low
	Watershield	Brasenia schreberi	native	present	present	low
	White water lily	Nymphaea odorata	native	present	common	low
Submersed						
	Bladderwort	Utricularia	native	present	present	low
	Coontail	Ceratophyllum demersum	native	present	present	low
	Eurasian Watermilfoil	Myriophyllum spicatum	exotic	not observed	common in lower lake	very high
	Fanwort	Cabomba caroliniana	native	present	common	low
	Hydrilla	Hydrilla verticillata	exotic	not observed	not observed	very high
	Muskgrass	Chara	native	present	present	low
	Pondweed	Potamogeton	native	present	present	low
	Parrotfeather	Myriophyllum brasiliense (aquaticum)	exotic	present	not observed	low
	Waterweed	Elodea (Egeria densa)	exotic	present	present	high
	Wild celery	Vallisneria americana	native	present	not observed	low

DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
3909 HALLS FERRY ROAD
VICKSBURG, MISSISSIPPI 39180-6199

REPLY TO
ATTENTION OF

CEWES-EP-L (70-1r)

11 September 1995

MEMORANDUM FOR Commander, USAE District, Fort Worth, ATTN: CESWF-PL-RE, (Ms. Mary Flores), P. O. Box 17300, Fort Worth, Texas 76102-0300

SUBJECT: WOTS Request for Assistance

1. Enclosed is the response to your WOTS request for assistance in providing recommendations for bioengineered solutions to erosion along Big Cypress Bayou near a historic powder magazine in Jefferson, Texas. This response was developed by Messrs Hollis Allen of the Environmental Laboratory and James Leech of the Hydraulics Laboratory after a visit to the site.

2. We appreciate the opportunity of assisting you through the WOTS Program, and if you have any questions, please contact Mr. Allen at 601-634-3845.

FOR THE DIRECTOR, ENVIRONMENTAL LABORATORY:

Joseph L. Decell

Encl

J. L. DECELL, PE
Manager, Water Operations
Technical Support Program

CF:
Mr. Hollis Allen, EN-S
Mr. James Leech, HS-S

CEWES-EN-S 22 August 1995

MEMORANDUM FOR RECORD

SUBJECT: Trip Report of WOTS Assistance--Big Cypress Bayou, Texas

1. Reference: Memorandum, CESWF-PL-RE, 26 May 1995, Subject: Technical Support under the WOTS Program

2. This memorandum presents information received, observations made, and recommendations made as a result of a visit to Big Cypress Bayou, Jefferson, Texas, 10-11 July 1995, in response to a request contained in the referenced memorandum. The field visit, under the Water Operations Technical Support (WOTS) Program, was accomplished by a WOTS team composed of Messrs. Hollis H. Allen and James Leech of the U.S. Army Engineer Waterways Experiment Station Environmental and Hydraulics Laboratories, respectively. The purpose of the visit was to make recommendations on possible bioengineering measures which might be undertaken to control erosion on the east bank of the Big Cypress Bayou adjacent to a historical civil war powder magazine.

2. Background. The Ft. Worth District (SWF), as part of a congressionally funded study, is tasked with developing plans to control erosion on the Big Cypress Bayou. This includes protection of a historic civil war powder magazine about 30-ft back from the bayou. Location of the magazine and the adjacent bayou being eroded are shown on the map (encl 1).

3. Approach. On the afternoon of 10 July 1995, the WOTS team were accompanied to the site by two SWF personnel: Mr. Gene Rice, Jr., project manager from the Study Management Section and Ms. Mary Flores, environmental resource specialist. At the site, about 600 ft of the erosion problem area was observed at ground level. Additionally, aerial photos, maps, and hydrologic data, i.e., streamflows, stage heights and duration, were examined later in the office.

4. Discussion and Observations. Information bearing on the erosion problem which was obtained during discussions with SWF personnel and on-site observations are summarized below.

a. In view of the historical nature of the site, as little real estate as possible should be sacrificed in installing bank protection measures.

b. Insofar as possible, the district would prefer to use bioengineering or other nonstructural methods to retard the bank erosion because of the historical and pristine attributes of the site. Aesthetics is extremely important and measures considered should leave the area with a natural appearance, preferably with "living" elements.

5. Observations made during the site visit on 10 July 1995 are summarized below.

a. The area of concern is a reach of the east bank of the Big Cypress Bayou about 600 ft long about 4 miles downstream of Federal HW 59 bridge. At the time of the site visit, the bayou was exposing an oversteepened section of bank about 25 ft in height from the top bank to the water's edge. A nearly vertical section 8 to 10 ft high existed near the top of the slope. The site is located in a fairly straight reach with the exception of a bend several hundred feet upstream from it.

b. Soils comprising the riverbank in this area appeared to be predominantly fine sands overlying a bed of clay. The clay bed varied in its position from the water's edge as one traversed the site.

c. Several recreational and siteseeing motor boats were observed going by the site while we were there and motor boat wakes were creating toe-scour. Subsequent flow events then rob loosened soil from the toe contributing to oversteepening and subsequent caving of the bank.

d. Vegetation on the shore of the bayou upstream and downstream of the eroded site consisted primarily of bald cypress and oaks and appeared to be fairly stable. In contrast, there was very little vegetation at the eroded site, indicating instability.

e. Examination of the streamflow data obtained by SWF and furnished to the WOTS Team at a later date revealed a wide variation in flows over 71 years ranging from a low of 1.2 cfs to a high of 2930 cfs. There were times when flows dropped dramatically from very high flows to much lower flows. This type of action could cause sudden drawdown or "saturated bank" type failures. These types of failures probably occur following periods of high water when the inability of the streambank to drain combined with the oversteepening of the bank described above results in instability. This failure mechanism is supported by the general shape of the bank which include a vertical scarp near top bank and an obvious shelf further downslope.

12. Recommendations. The following bioengineering recommendations are provided based upon the site visit on 10 July 1995 and subsequent information obtained from SWF. These recommended treatments are fairly generic since no stage data or cross-sections were available for the site.

a. There should be minimal grading of the site with revegetation of existing slopes.

b. Root wads. Root wads are live or dead logs with root masses attached (encl 2, from Bowers, 1992[1]). The fans of the root wads provide an interlocking wall protecting the streambank from erosion. The voids within and between the root wads are filled with a soil mix and planted with live, willow clumps. The root wads are laid on top of a keyed-in shelf of stone and support logs. This shelf includes a layer of bottom support logs flush with one another, shingled together, and running parallel to the streambank. The root mass should be a minimum of 5-ft in diameter and angled slightly upstream towards stream flow. This treatment should be placed at a base elevation that is consistent with water levels during the major part of the growing season, i.e., June through September. The bottom two-thirds of the root wad should be in water during that period of time.

c. Brush layering. Brush layering is a treatment where live willow branches are placed in a "V-like" trench cut into the face of the slope. The trench runs parallel to the contour of the slope. The willow branches are laid in the trench to form a 4-6" layer of criss-crossed stems that is backfilled leaving only the top 6 inches or so of the willow exposed for sprouting (encl. 3, from Allen and Klimas, 1986[2]). This treatment should be installed about 5 vertical feet above the root wads. Depending on the terrain conditions, another brush layer might be employed further up the slope.

d. Erosion control fabric. Erosion control fabric is recommended between the root wads and the brush layers to help control rilling and gullying on the bare slopes. Before the fabric is applied, a seed mix of native grasses should be seeded on the slope and covered with a COIR fabric which is biodegradable and made from coconut husk fibers. This should be one such as DeKoWe 700 made by Belton Industries. The fabric should be keyed in at the top and at the bottom. The fabric should run under the willow branches of the brush layer at the top and down to the willow clumps in the root wads at the bottom.

e. Live willow cuttings. These are live willow cuttings and should be 3-4 ft long and 1/2 to 2 inches in diameter at the

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[1] Bowers, K. 1992. "Little Patuxent River Stream Restoration," Land and Water, July/August 1992.

[2] Allen, H. H. and C. V. Klimas. 1986. "Reservoir Shoreline Revegetation Guidelines," Technical Report E-86-13, U.S. Army Engineer Waterways Experiment Station.

base. These are placed on 5-ft centers in zones between and above the root wads and brush layering treatment. They are buried to a distance so that only about 2 to 6 inches are exposed at the top. They can be inserted into the COIR fabric and into the soil with the aid of a pipe and hammer. The pipe can be used to create a pilot hole and then the willow cuttings hammered gently into the hole. The hole should be closed around the cuttings by driving the pipe down adjacent to the cutting; this tightens the soil around the cutting.

f. The above treatments are illustrated in profile and perspective views (encls 4 and 5). It is important to note that all woody plants, such as willow, be planted in the dormant season, either in the late fall or late winter.

g. The treatments should be complimented by keyed-in rock refusals both upstream and downstream from them to provide transition and prevent flanking.

13. Discussion. The above treatments' success is highly dependent on the probability of the willow becoming established fairly quickly at the onset of the growing season. Slopes will be stabilized with the combination of hard materials, e.g., rock, logs, and the living attributes of the willow and other plants, e.g., roots holding soil together, branches trapping sediment and slowing velocities.

14. If any further information is needed on the above report, please feel free to contact any of the personnel signing below.

Hollis H Allen

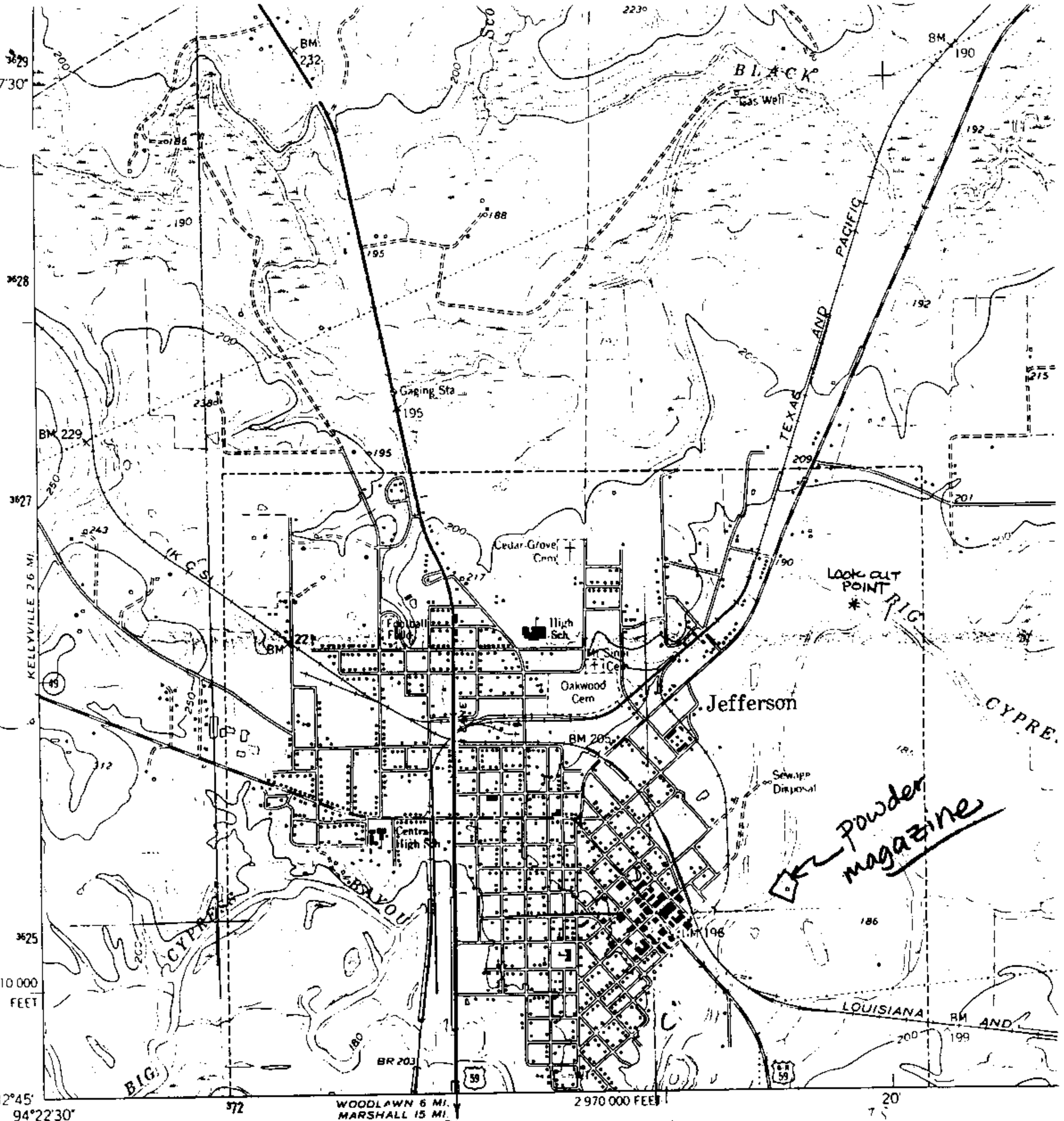
James Leech

Enclosures

Hollis H. Allen
Acting Chief,
Stewardship Branch

Ph: 601-634-3845

James Leech
Hydraulics Engineer
Spillways and Channels
Branch
Ph: 601-634-3025



Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Topography by photogrammetric methods from aerial photographs taken 1957 Field checked 1962

Polyconic projection. 1927 North American datum
10,000-foot grid based on Texas coordinate system, north central zone
1000-meter Universal Transverse Mercator grid ticks, zone 15, shown in blue

Fine red dashed lines indicate selected fence lines

GN MN
0°43' 13 MILS
8° 142 MILS

UTM GRID AND 1962 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

FOR SALE BY
A F

Encl 1

stream. This area reflected the same degradation that was occurring throughout the river. The construction and maintenance of a transmission power line right-of-way through the project site had further precluded the establishment of woody vegetation along the southern and northern streambank. Consequently, severe erosion and bank undercutting were exaggerated in this area. Where there are existing rock formations and woody vegetation, the streambanks were resisting erosion.

Before entering the project area, stream flow can be classified as a riffle. As the stream enters the project area it can be classified as a run until it reaches the first bend in a meander. At the first bend, a pool is formed on the outside of the bend and a point bar of coarse sand is formed on the inside. At the second bend, the stream forms a shallow pool on the inside curve with a comparatively small point bar on the outside curve. At this point the streambank appears to be more stable due to existing rock formations and woody vegetation. The stream, upon exiting the project area, transforms back to a run/riffle sequence.

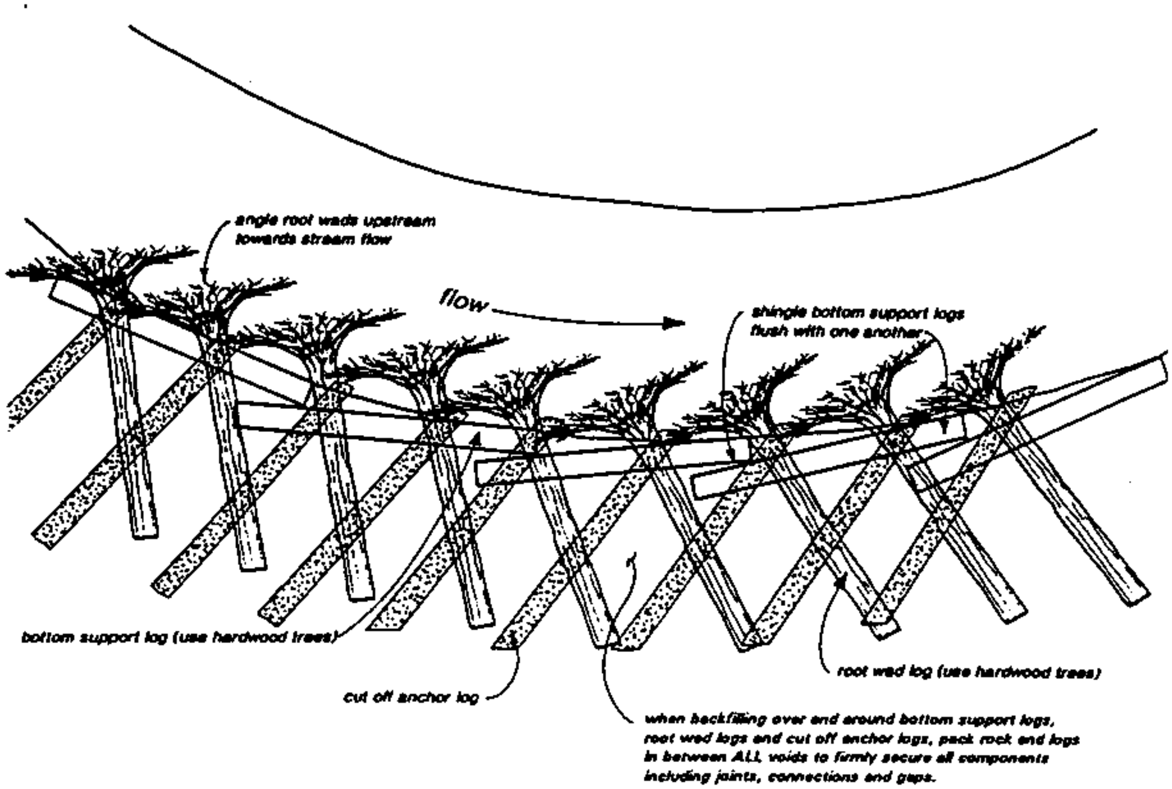
Based on the data gathered from the field visits and the historical research, Biohabitats identified seven methods of streambank stabilization applicable to the project area:

1. Revegetation of the existing slopes with minimal grading.
2. Use of brush mattress made of preconstructed layers of dead and live branches.
3. Placing branch packing with live facines into the streambank.
4. Use of live facines.
5. Placing root wads in the streambank perpendicular to the stream flow.
6. Use of rockfill with branch packing.
7. Using a combination of rockfill, live facines, and branch packing.

An alternatives analysis report was submitted to the SHA outlining the benefits and costs associated with each method. In early 1990, after careful consideration and consultation with the DNR, the SHA selected three measures; revegetation, branch packing, and root wads, as the preferred stabilizati measures.

Because bioengineerin ı rel tively new technique for the SHA, ı standard details or specifications e isted. Consequently, Biohabitats had develop, design, and draft new deta and specifications for each of the pr posed measures and submit them f regulatory agency approval prior to tl project being let for bid. In addition, tl SHA established a peer review wor shop to analyze the bioengineerir designs and make recommendations improve their effectiveness. One co cern during the peer review workshc was that there had been no research document the long term effectivene of bioengineering techniques for stab lization of stream banks, specifically fı particular stream flow velocities ar local soil conditions. This made it difi cult for the group to compare structur stabilization techniques with bioeng neering solutions. Nevertheless, the SH decided to proceed with the projec Biohabitats spent the next five month preparing the final construc av

ROOT WAD CONSTRUCTION–PLAN VIEW

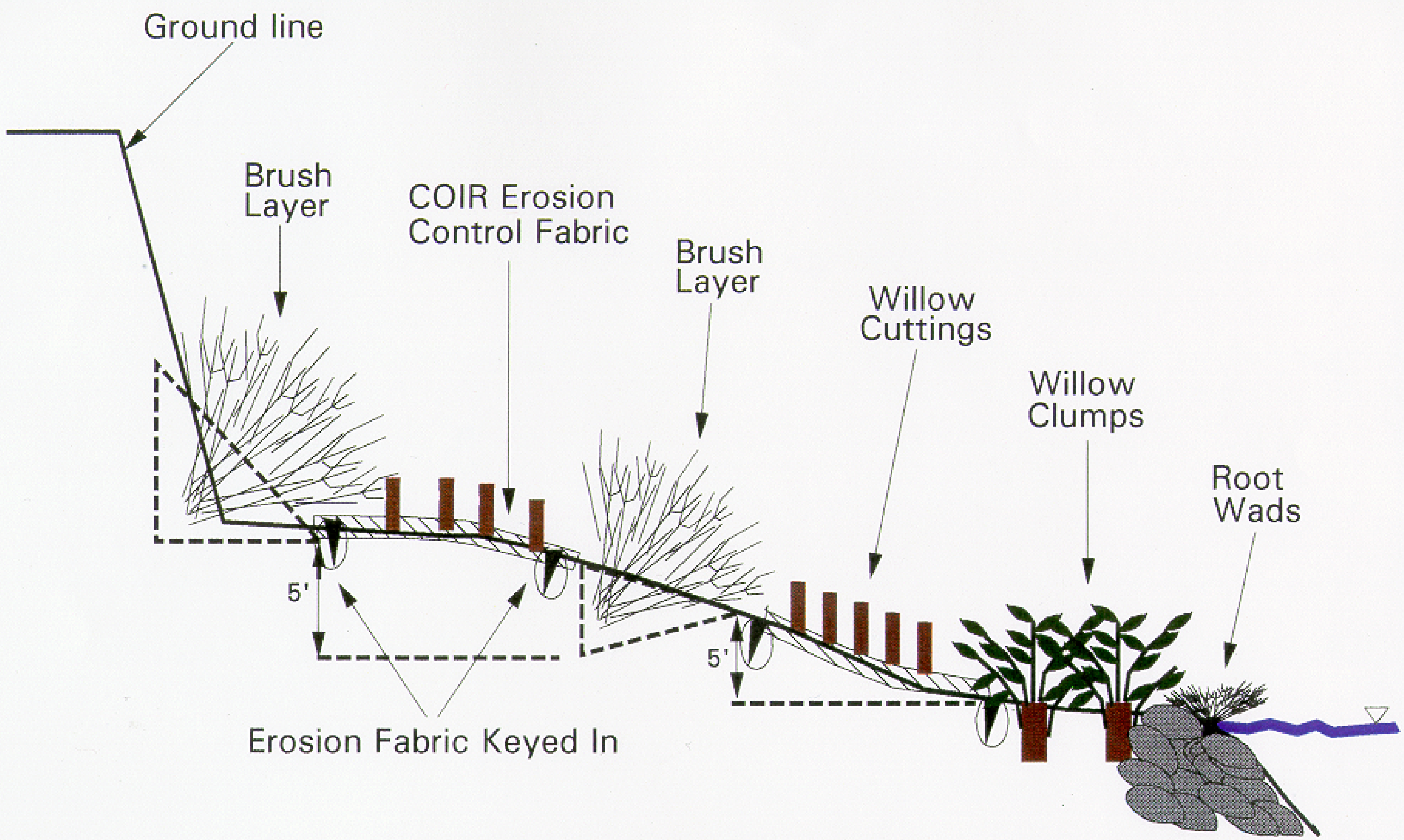


Encl 2

Figure 28. Completed wattling installation

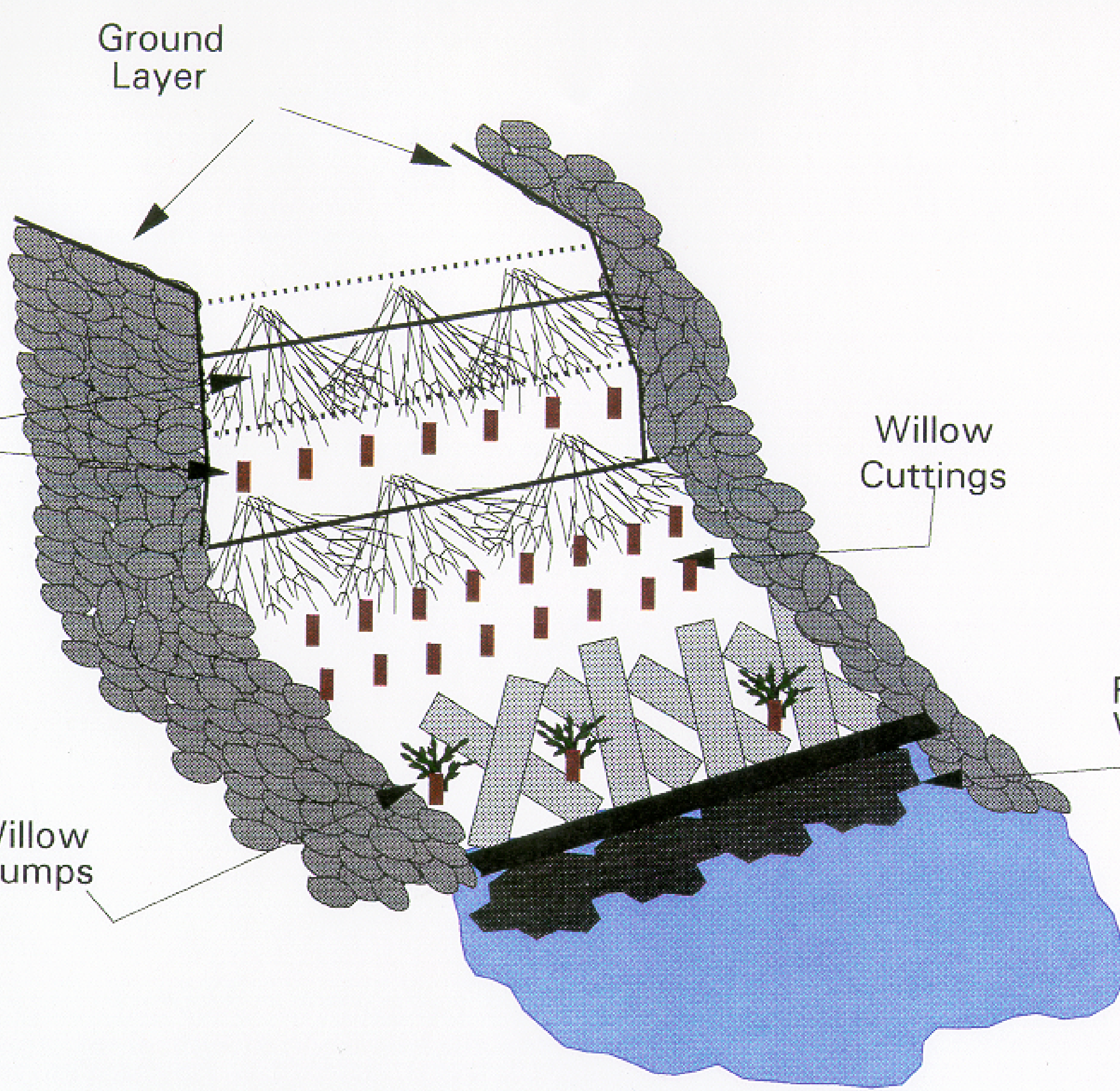
Figure 29. Schematic diagram of brush layering (from Leiser 1983)

Encl 3



Profile (Not to scale)
Bioengineering Treatments
Big Cypress Bayou

Encl 4



Perspective View (Not to scale)
Bioengineering Treatments
Big Cypress Bayou

Encl 5