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	Engineering and Design ENVIRONMENTAL ENGINEERING FOR FLOOD CONTROL CHANNELS	
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US Army Corps
of Engineers

ENGINEERING AND DESIGN

Environmental Engineering for Local Flood Control Channels

ENGINEER MANUAL

EM 1110-2-1205

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, DC 20314-1000

CECW-EH
CECW-O
CECW-P

Engineer Manual
No. 1110-2-1205

15 November 1989

Engineering and Design
ENVIRONMENTAL ENGINEERING AND LOCAL FLOOD CONTROL CHANNELS

1. Purpose. This manual provides guidance for incorporating environmental considerations in the planning, engineering, design, and construction of flood control channels, levees, and associated structures.

2. Applicability. This manual applies to all HQUSACE/OCE and field operating activities (FOA) having responsibility for the engineering and design of civil works projects.

3. Discussion. This manual pertains to projects that involve modifications of natural stream channels to reduce damages due to flooding, bed scour, or bank erosion. The emphasis of this manual is on channels not open to commercial navigation. Channel modifications for flood and erosion control include clearing and snagging; channel straightening; channel enlargement; streambank protection; channel 1 lining; and construction of grade control structures, culverts, levees, and floodwalls. This manual covers some of the principal environmental factors that should be considered in projects that involve stream channel modification, as well as opportunities for incorporating environmental features for attaining environmental quality objectives.

FOR THE COMMANDER:

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Colonel, Corps of Engineers
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CHAPTER 1

INTRODUCTION

1-1. Purpose. This manual provides guidance for incorporating environmental considerations in the planning, engineering, design, and construction of flood control channels, levees, and associated structures.

1-2. Scope. This manual pertains to projects that involve modifications of natural stream channels to reduce damages due to flooding, bed scour, or bank erosion. Although some of the information below may be applied to modification of large rivers, the emphasis of this manual is on channels not open to commercial navigation. Channel modifications for flood and erosion control include clearing and snagging; channel straightening; channel enlargement; streambank protection; channel lining; and construction of grade control structures, culverts, levees, and floodwalls. This manual covers some of the principal environmental factors that should be considered in projects that involve stream channel modification, as well as opportunities for incorporating environmental features into these projects. This manual is intended to be compatible with EM 1110-2-1601 and EM 1110-2-1913.

1-3. Applicability. This manual applies to all field operating activities having Civil Works responsibilities.

1-4. References.

a. 33 CFR 208. 10, Local Flood Protection Works; Maintenance and Operation of Structures and Facilities.

b. 40 CFR 1500-1508, Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act.

c. ER 200-2-2.

d. ER 1105-2-100.

e. ER 1110-2-400.

f. ER 1130-2-303.

g. ER 1130-2-335.

h. ER 1130-2-339.

i. ER 1130-2-400.

j. ER 1130-2-405.

k. ER 1165-2-26.

l. ER 1165-2-27.

m. ER 1165-2-28.

n. ER 1165-2-400.

o. EM 1110-1-400.

p. EM 1110-2-38.

q. EM 1110-2-301.

r. EM 1110-2-410.

s. EM 1110-2-1201.

t. EM 1110-2-1601.

u. EM 1110-2-1913.

v. EP 1110-1-3.

w. EP 1165-2-1.

x. EP 1165-2-501.

y. Clar, Michael, et al. 1983. "Restoration Techniques for Problem Soils at Corps of Engineers Construction Sites," Instruction Report EL-83-1.*

z. Henderson, J. E., and Shields, F. D., Jr. 1984. "Environmental Features for Streambank Protection Projects," Technical Report E-84 -11. *

aa. Hynson, J. R., et al. 1985. "Environmental Features for Streams ide Levee Projects," Technical Report E-85-7 . *

bb. Lee, C. R., et al. 1985. "Restoration of Problem Soil Materials at Corps of Engineers Construction Sites," Instruction Report EL-85-2 . *

cc. Nunnally, R. N., and Shields, F. D., Jr. 1985. "Incorporation of Environmental Features in Flood Control Channel Projects," Technical Report E-85-3.*

dd. Shields, F. D., Jr. 1982. "Environmental Features for Flood-Control Projects," Technical Report E-82-7. *

ee. Smardon, R. C., et al. 1988. "Visual Assessment Procedures for US Army Corps of Engineers," Instruction Report EL-88-l. *

* Available from: Technical Information Center, US Army Engineer Waterways Experiment Station, PO Box 631, Vicksburg, MS 39180-0631.

1-5. Bibliography. Bibliographic references are indicated as needed in the text and are listed in Appendix A. These documents are available for loan from the US Army Engineer Waterways Experiment Station (WES) Technical Information Center Library, PO Box 631, Vicksburg, Mississippi 39180-0631. In addition, copies of the reports are available through the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161.

1-6. Background.

a. Use of this manual requires knowledge of Corps authority in flood damage reduction and environmental policy. Engineer Pamphlet 1165-2-1 provides a digest of Corps authorities. Engineer Regulation 1165-2-26 requires that the Corps provide leadership and take action to restore and preserve the natural and beneficial values of the 100-year floodplain and to avoid development in the 100-year floodplain unless it is the only practicable alternative. Policy documents addressing environmental issues include ER 1105-2-100, chapter 7, which points out that it is national policy that fish and wildlife resources conservation be given equal consideration with other study purposes in the formulation and evaluation of alternative plans. Also, historic properties that are included or are eligible for inclusion in the National Register of Historic Places must be considered in formulating recommendations for project authorization and implementation. Coordination with the State Historic Preservation Officer and the Advisory Council on Historic Preservation is required. Engineer Regulation 2 00-2-2 provides guidance for preparation of environmental impact statements.

b. Engineer Regulation 1165-2-28 states that environmental enhancement is an objective of Federal water resource programs to be considered in planning, design, construction, operation, and maintenance of projects and that opportunities for enhancement of the environment should be sought through each phase of project development. Engineer Pamphlet 1165-2-501 outlines the Corps policy and objectives for full consideration of the environment in planning, development, and management of water and related land resources, consistent with environmental statutes and executive guidelines.

c. Engineer Regulation 1165-2-27 provides guidance for the planning and establishment of wetlands using dredged material from water resources development projects. Relevant guidance in the area of recreation includes ER 1165-2-400, EM 1110-2-410, ER 1130-2-400, ER 1110-2-400, and EM 1110-1-400, Change 1. Engineer Regulation 1130-2-405 provides guidance for overload vehicle trails.

1-7. Checklist of Data Sources . Potential sources of data for planning and design of environmental features for flood control channel projects are listed in Appendix B. These data may be available at the District office, and the various functional elements (e.g., hydrology, hydraulics, environmental resources and geotechnical) should be consulted. Coordination among these elements can also facilitate interpretation of the data in the context of the project.

1-8. Design Procedure. Appendix C is provided to illustrate how the information in this manual can be integrated into a project.

1-9. Glossary. A glossary of terms used in this manual is provided following the appendixes.

CHAPTER 2

STREAM CHANNEL MODIFICATION AND ASSOCIATED ENVIRONMENTAL EFFECTS

2-1. Channel Modification Designs. The basic concept of all flood control channel designs is to reduce flood area and duration by providing a smoother, steeper, or larger channel than the existing stream. Design capacity criteria vary based on project settings. Projects in agricultural areas are often designed to reduce flood durations during planting, growing, or harvesting seasons, while urban channels are typically designed to eliminate flooding in the protected area for all floods smaller than or equal to design events. Several types of channel modifications are commonly used to achieve project purposes, and most projects include several types of channel designs that vary from reach to reach. This chapter discusses some potentially deleterious effects of channel modifications, and designers aware of these effects can mitigate them. Potential environmental problems can be brought into the open, when trade-offs are being made during project formulation discussions with local interests.

a. Clearing and Snagging. Clearing refers to removal of woody vegetation and debris from channel banks and adjacent areas, while snagging refers to the removal of debris, logs, and boulders from the channel. Clearing and snagging are sometimes employed as individual techniques and are normally required for other types of channel modification. Hydraulic effects of clearing and snagging tend to be short lived relative to other types of modification, and cleared and snagged channels often require frequent maintenance or reworking.

b. Excavated Channels. Natural channels are often straightened, enlarged, or both to increase flow capacity or to allow for placement of other structures. Diversion channels are sometimes constructed to provide a separate path for high flows to a receiving water body and to supplement channel capacity. Excavated channels traditionally have had straight alignments and trapezoidal cross sections, although more complex designs are being used with increasing frequency. Channel excavation often requires significant clearing to allow for channel rights-of-way, equipment access, and placement of exca vated material. Dry excavation techniques, draglines, clamshells, and hydraulic dredging are all commonly used for channel excavation. Straightened channels often include features such as grade control structures, slope protection, or paving to prevent channel erosion and instability. Slope protection and grade control structures are also sometimes used on natural or slightly modified channels to control bed and side slope erosion.

c. Paved Channels. Channels designed to carry high-energy flows are frequently paved with nonerodible material, usually reinforced concrete. Paved channels are expensive to construct and are accordingly limited to areas with steep topography or where land costs are high. Concrete channels sometimes have rectangular cross sections to minimize land requirements.

d. Side Slope Protection. Side slope protection is incorporated into channel design when erosive velocities are expected to occur and is widely used to prevent erosion along natural channels. WES Technical Report (TR) E-84-11 and Allen (1978), Keown et al. (1977), and Office, Chief of Engineers (OCE) (1978, 1981c) (see Appendix A) contain thorough reviews and descriptions of side slope protection methods. Methods may be categorized as continuous or intermittent, with riprap revetment as an example of continuous protection while groins and hard points are intermittent designs. Vegetation and rock riprap are two of the most common materials for slope protection, but gabions, tires, soil stabilizing chemicals, and other materials are sometimes used. Construction of slope protection usually involves clearing for access, slope grading, and placement of the protective materials or structure.

e. Erosion and Sediment Control Structures. Several types of structures have been used to control scour and deposition in natural and modified channels.

(1) Grade control. Degradation of the channel invert may be prevented by placing concrete, stone, or sheet piling stabilizer sills across the channel invert. Stabilizers usually do not extend above the channel invert. Drop structures may also be used to provide sudden changes in channel invert elevation without erosion. Drop structures are used to reduce the gradient of the main channel and to admit tributary inflows to a deepened main channel without headcutting. Generalized sketches of stabilizers and a grade control structure are presented in EM 1110-2-1601.

(2) Debris basins and check dams. Debris basins and check dams are sometimes built upstream of flood control channels to trap large bed-load debris. Sediment basins are sometimes used in a similar fashion to trap smaller sediments. This is done to prevent damage to channel linings, aggradation of channels, and deposition at stream mouths. The storage capacity of debris and sediment basins must be maintained by reexcavation after major storm periods.

f. Culverts. Concrete channels are covered at street crossings and in some intensively used areas, thereby forming box culverts. Corrugated metal or reinforced concrete culverts are used to pass flow through embankments such as roadfills. Culverts sometimes develop problems with debris blockage or downstream scour. (See ER 1165-2-118 on covered flood control channels.)

g. Levees and Floodwalls. Levees are earthen embankments that provide flood protection from seasonal or infrequent high water. In urban areas where land costs are high, concrete or masonry walls may be used instead of levees since they require so much less space than a sloped embankment. Sometimes floodwalls are constructed on top of levee embankments. Both levees and floodwalls are frequently used in concert with various types of channel modification. Levee construction usually requires clearing to allow for earthmoving equipment access, excavation of borrow areas, and placement of the embankment. After construction, levee side slopes are seeded or sodded, and vegetation on levees is carefully maintained to avoid conditions that might impede inspection or endanger structural integrity of the levee during floods.

2-2. General Environmental Effects. Environmental effects of channel modification are difficult to categorize because they are interrelated in complex ways. In general, effects may be categorized according to the nature of the affected resource: aesthetics, recreation, water quality, terrestrial habitat, and aquatic habitat. Effects may also be considered primary, secondary, or tertiary. For example, straightening a particular hypothetical channel results in rapid bed and bank erosion (primary impact), which degrades downstream water quality due to increased levels of suspended sediment (secondary impact), which adversely affects the aesthetics and aquatic habitat (tertiary impacts). The effects of channel modification on water chemistry, and particularly the biotic community, are difficult although not impossible to measure. Effects on aesthetic and recreational resources are difficult to quantify, and perception of significance varies from individual to individual. Typical physical changes and environmental effects due to channel modification without environmental consideration are depicted in Figure 2-1. Most channel projects do not begin with natural unaltered streams; hence, the designer may have the opportunity, particularly in urban settings, to greatly improve the stream's environmental conditions. A literature review of the environmental effects of channel projects is provided by Swales (1982).

2-3. Effects of Snagging. Effects of snagging apply to all channel projects except for clearing performed without snagging, which is extremely rare. Snagging may have a positive effect on aesthetic and recreational resources and is occasionally performed to improve boating access. The main effects of snagging relate to aquatic habitat.

a. Invertebrates. Removal of snags usually allows deposits of leaves, twigs, and fine-grained sediments to be swept downstream. These deposits are key habitat and nutrient components for many invertebrates (fish-food organisms). In streams with sandy, shifting beds, snags and the organic debris they trap are the only suitable substrate for many species.

b. Fish. Snagging reduces the area of structures used by both forage and predator fish for cover, orientation, and territoriality. This similarly reduces the total substrate available for primary producers (e.g., algae and mosses) and some invertebrates.

2-4. Effects of Clearing. Limited clearing and debris removal can improve aesthetics and recreational opportunities, but removal of all woody riparian vegetation often has a net detrimental effect on aesthetics and recreation. Major effects of clearing have to do with alteration of terrestrial habitat in the valuable riparian zone. A literature review of the environmental effects of clearing and snagging can be found in WES TR E-85-3.

a. Water Quality. Water quality eff cts of clearing are mostly due to reduced shade and, accordingly, are most significant for small channels. Shade removal may result in increased water temperatures and increased levels of in-channel photosynthesis, which may produce secondary water quality impacts such as diel changes in dissolved oxygen and pH.

b. Terrestrial Habitat. Streambanks and associated vegetation are extremely productive and valuable habitats due to the rich supply of nutrients and moisture, the "edge effect" between the riparian zone and the adjacent upland on one side and water on the other, and the diversity of physical conditions created by channel migration and vegetative succession. The elongate shape of the riparian zone creates a high edge-to-area ratio and often

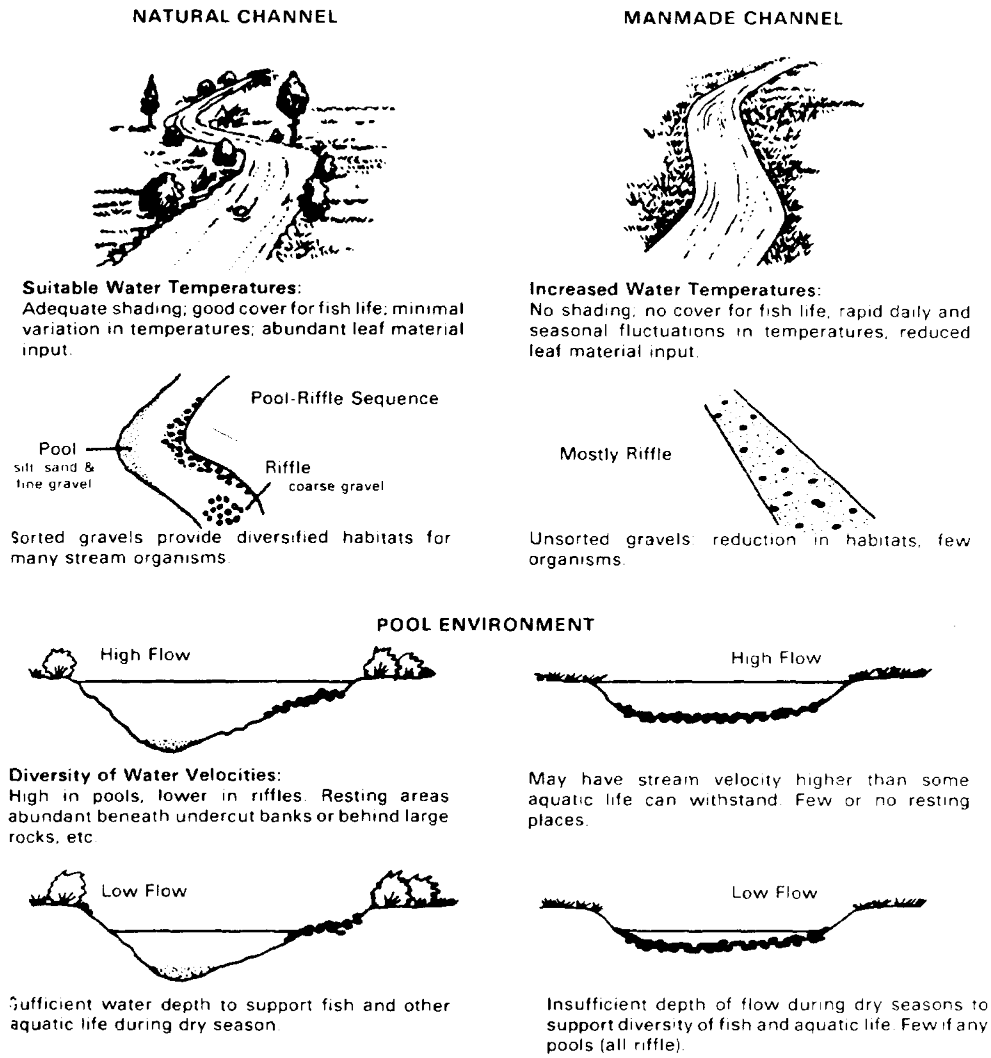


Figure 2-1. Typical physical changes and attendant environmental impacts due to channel modification without environmental design components (from Nunnally and Keller 1979)

provides a natural corridor through developed areas. In prairies and deserts, riparian zones provide an extremely sensitive, scarce, and valuable type of habitat. Removal of riparian vegetation by clearing for channel construction or maintenance, by induced land use changes, or by natural succession caused by drier conditions results in adverse impacts upon dependent faunal species. Long-term effects depend on the extent and frequency of maintenance and the rate of vegetative succession.

c. Aquatic Habitat. Removal of riparian vegetation results in reduced inputs of leaves and twigs, which are important as a food base for some aquatic organisms, and increased in-channel photosynthesis (if photosynthesis is light limited). These changes can shift the aquatic ecosystem from a heterotrophic to an autotrophic state, at least for small streams in the northeastern and northwestern United States. Loss of overhanging vegetation also removes hiding cover for fish.

d. Other Effects. Shade removal may result in invasion of the channel by rooted plants at low flows, which can increase hydraulic resistance and reduce flow capacity. Clearing can also reduce bank stability and result in increased bank erosion, depending on local soil characteristics and channel velocity.

2-5. Effects of Channel Excavation. The primary effects of channel straightening and enlargement are usually the removal of riparian vegetation and changes in channel stability and in the hydraulic and hydrologic regime. Clearing may be reduced adjacent to enlarged channels as a result of the reduced flood risk. Additional information is available in WES TR E-82-7 and WES TR E-85-3. Effects associated with clearing are addressed in paragraph 2.4 above.

a. Channel Instability. Improperly designed excavated channels can experience problems with rapid scour of bed and banks, unwanted sediment deposition, and increased sediment loads. Channel instability increases maintenance costs, degrades water quality and habitat, and may result in damage to bridges and utility crossings.

b. Hydrologic and Hydraulic Effects. Hydrologic and hydraulic effects of channel projects vary widely and can be divided into primary effects, which are intentional, or at least anticipated (e.g., lowered water tables and decreased overbank flooding), and side effects, which are unintentional and usually not anticipated (e.g., more rapid water-level fluctuations, wetland drainage, greater variation of discharge, and increased downstream flood storage). These side effects are usually not well documented. For example, drier conditions on nearby floodplains and contiguous wetlands can result in induced land use changes or shifts in floral and faunal communities. Large increases in mean and maximum velocity or decreases in mean and minimum depth can be extremely detrimental to aquatic organisms.

c. Aesthetics. The aesthetic value of a project area is determined by the combination of landscape components (e.g., landforms, vegetation, and land use), climatic factors, and human perceptions or expectations. The significance of aesthetic effects is a function of changes in landscape components caused by a project and factors related to frequency of viewing and project setting. Modified channels sometimes present a uniform, artificial appearance characterized by straight lines and early-successional stage vegetation. On the other hand, a channel with an overall uncluttered appearance and graceful bridges may be more harmonious with some urban settings than the eroded, debris-laden stream that preceded it. Aesthetic impacts tend to be most severe for channels with straight alignments, extensive clearing, or instability problems.

d. Recreation. Channel excavation effects on recreational resources can be positive or negative and are related to changes in channel depths and velocities, water quality, access, and aesthetics. Habitat changes affect consumptive and nonconsumptive uses of fish and wildlife.

e. Water Quality. Water quality changes associated with channel excavation vary widely from site to site. Many projects are located in urban areas and exhibit poor quality prior to channel excavation. Improved flood control sometimes encourages expansion of agricultural and industrial activities that may in turn contribute to degraded water quality. Turbidity generally increases during construction. Temperature can be expected to increase if shade is removed from a long reach that is narrow enough to be mostly or totally canopied. Dissolved oxygen concentrations may increase or decrease, depending on the effects of channel modification on temperature, photosynthesis, and reaeration.

f. Terrestrial Habitat. Major effects of channel excavation on terrestrial habitat are related to clearing and induced land use changes in riparian zones (see paragraph 2-4). Improved drainage and water table lowering caused by channel excavation can adversely affect wetlands some distance from the channel.

g. Aquatic Habitat. The effects of channel straightening and enlargement on aquatic habitats are similar to those associated with snagging and clearing (described in paragraphs 2-3 and 2-4). In addition, channel straightening without preservation of meanders may result in a reduction in the quantity of aquatic habitat, sometimes by as much as 50 to 60 percent. Even when cutoff meanders are left in place to provide habitat, if not properly designed they often gradually drain, fill with sediment, or undergo water quality degradation. Channel enlargement projects may induce flow interruptions during dry periods with resulting impacts on aquatic communities.

(1) Benthic macroinvertebrates. Benthic macroinvertebrates have been observed to recolonize modified reaches rapidly if water quality and substrate in the modified reach are favorable. Channel projects that do not destroy the armor layer or reduce the overall bed material (substrate) size provide a more suitable benthic habitat. Sandy bed material tends to be shifting and unstable and have low benthic macroinvertebrate density.

(2) Fish. Fish populations in enlarged or straightened channels tend to be more uniform in age and size than in unaltered streams, with smaller sizes dominating. Fish species diversity, density (both numbers and biomass), and catchable game fish numbers and biomass tend to decline following channel modification. These effects on fish populations are due to the more uniform depths, velocities, illumination, and substrate and to the loss of cover. Impacts on coldwater streams tend to be more severe than for warmwater streams, which is expected due to their lower species diversity.

2-6. Effects of Channel Paving. Paved channels tend to be accompanied by most of the impacts associated with snagging, clearing, and channel excavation, and tend to have additional detrimental effects on aesthetics, water quality, and aquatic habitat. Parrish et al. (1978) summarized studies of the effects of concrete channels in Hawaii on water quality and aquatic biota, and many of their conclusions have general applicability.

a. Aesthetics. Conventional reinforced concrete linings present an artificial, unnatural appearance relative to a natural stream channel. Straight lines and uniformity of form, texture, and color are less desirable than the visual diversity offered by most natural meandering channels with vegetated banks. In some cases, the appearance of a lined channel may be perceived as an improvement over a severely degraded setting characterized by caving banks, solid waste, debris, etc.

b. Water Quality. Some lined channels have been observed to experience much greater maximum water temperatures and ranges of diurnal fluctuation of water temperature than nearby natural streams. These effects are often due to the wide, shallow flows; lack of shade; solar heat transfer by the lining material; and focusing of solar energy by the vertical walls. Other water quality parameters are affected by temperature. Algae growth may occur on unshaded channel bottoms and can raise pH levels and increase dissolved oxygen concentrations during the day. The stability imposed by channel lining can decrease levels of suspended solids and turbidity.

c. Terrestrial Habitat. In addition to the effects noted in paragraphs 2-4b for clearing and 2-5f for channel excavation, paved channels with extremely steep, smooth sides can be impassable for some terrestrial animals. Access to and across the channel may be prevented, and animals that fall into the channel may be trapped.

d. Aquatic Habitat. Effects of channel paving on aquatic habitat are related to effects on water quality, substrate, and hydraulics. Water quality effects (paragraph 2-6b) can eliminate species or groups of species. The channel lining itself is a radical departure from the natural bed material that serves as substrate for benthic organisms. Many fish species are also affected by substrate changes since they feed upon the benthic organisms and require certain types of substrate for spawning. Flows in paved channels tend to be extremely shallow at low to normal discharges and extremely rapid at high discharges. These conditions may be unfavorable to some populations of aquatic species.

2-7. Effects of Side Slope Protection. The environmental effects of slope protection are related to the amount of clearing required and the type and extent of the protection works. Completely stabilized channels are no longer free to migrate laterally and to develop diverse terrestrial and aquatic habitats. Vegetative succession proceeds without interruption from channel movement, and no new backwater areas are formed to replace those lost to the natural processes of sedimentation. Available information regarding environmental effects of slope protection is reviewed in WES TR E-84-11.

a. Aesthetics. Most observers perceive the visual contrast between the natural environment and most types of slope protection works as undesirable. The degree of visual impact depends on the type of structure, the materials used, and the amount of revegetation allowed. In some cases, revegetation can completely obscure slope protection structures after a few growing seasons, minimizing the visual impact of the structure.

b. Recreation. Depending on design, slope protection can aid or hinder access to the water s edge for recreation or sightseeing.

c. Water Quality. Water quality impacts of slope protection tend to be similar to the effects of clearing (paragraph 2-4a). In addition, suspended solids and turbidity levels tend to increase during construction, but these decrease after construction is completed and side slopes are stabilized.

d. Terrestrial Habitat. Construction of slope protection has effects on terrestrial habitat similar to those from clearing (paragraph 2-4b). Slope protection structures may hinder wildlife access to the channel and preclude use of banks for denning. Vegetation cleared during construction can sometimes be replaced by natural invasion. At other times, plantings may be required to ensure development of particular plant communities to achieve specific objectives.

e. Aquatic Habitat. Slope protection can have both positive and negative effects on aquatic habitat. Grading and placement of continuous protection destroys habitat diversity provided by physical features such as snags and undercut banks, which are used by fish for protective cover. Stone and other materials provide stable substrate readily colonized by many species of benthic macroinvertebrates. Stabilization of adjacent substrate provides additional habitat for burrowing benthic species. Protection can reduce suspended sediment concentrations and turbidity levels detrimental to aquatic species. On small streams, removal of overhanging riparian vegetation can reduce shading and cause increases in water temperature and photosynthetic activity. Placement of noncontinuous, intermittent structures projecting into the stream creates protected slackwater habitat on the downstream sides of structures and encourages deposition of stabilized substrate.

2-8. Effects of Sediment Control Structures and Culverts. By stabilizing the channel and preventing rapid transport of large volumes of sediment, sediment control structures usually have positive effects on aesthetics, recreation, water quality, and aquatic habitat. Adverse impacts are related to the appearance of the structure and blockage of migration routes.

a. Aesthetics. Sediment control structures may improve or degrade aesthetic resources, depending on the degree to which they are visually compatible with their settings in terms of the scale of the structure and the color and texture of the materials used.

b. Recreation. Some drop structures provide the opportunity for inclusion of water recreation features such as boatways. However, drop structures and culverts can be barriers to boaters or canoeists and should be designed and managed to avoid hazards to boaters, waders, and swimmers at high flows.

c. Aquatic Habitat. Culverts may block fish migration due to their length, the vertical drop in the water surface at the downstream end, poor approach conditions, or flow conditions within the culverts. Drop structures can similarly block fish passage. Extremely long culverts represent a loss of aquatic habitat due to the lack of illumination and natural substrate.

2-9. Effects of Levees and Floodwalls. The primary environmental effect of levee systems is the creation of drier conditions on the protected floodplain, which frequently leads to land use changes. If the natural channel is unaltered and some riparian habitat is preserved between the levees, levees can have less adverse effect on habitats than do other types of channel modification. Reduction of the extent of floodplain inundation may affect the spawning success of some species.

a. Aesthetics. Levee embankments and floodwalls are normally massive and uniform, with rigid, straight lines. Views of the leveed stream are often blocked. However, levees may add visual diversity to floodplains devoid of topographic relief and provide scenic overlooks of the river and riparian area.

b. Recreation. Levee projects can improve access to the leveed stream and riparian lands and lend themselves well to several types of recreational development such as trails or fishing in borrow pits. Floodwalls without pedestrian openings can hinder public access to the water edge.

c. Terrestrial Habitat. Substantial amounts of clearing are sometimes required for embankment construction, borrow areas, and access. After construction, the usual practice is to allow only uniform sod with grass 2 to 12 inches high to grow on the levee embankment, which is of value only to species inhabiting open areas. The levee produces drier conditions on the landside. Land use changes, such as clearing for agriculture, may be induced on the landside, while the changed regime between the levees alters plant and animal species. In general, the deeper and more prolonged flooding and the wider range of flow fluctuations will restrict the development of ground cover and temporarily alter habitats of dependent animal species such as ground-dwelling mammals.

CHAPTER 3

ENVIRONMENTAL CONSIDERATIONS FOR PRELIMINARY DESIGN

3-1. Introduction. Environmental factors should be considered from the outset of flood control channel project planning and design rather than as afterthoughts. Channel projects frequently offer unique opportunities for incorporation of environmental features. Integrating hydrologic, hydraulic, ecologic, aesthetic, and cultural considerations in the design process is necessary because natural streams are systems composed of interrelated physical, chemical, and biological subsystems that are uniquely characteristic to each project.

a. Subsystem Linkage. Stream systems are complex and often differ from one another with respect to physical and chemical characteristics and biological community structure. Chemical and biological subsystems depend to a large extent on watershed characteristics, stream hydrology, and climatic conditions. Relationships between watershed conditions and stream characteristics are discussed in paragraph 3-3.

(1) Chemical subsystem. Stream water chemistry reflects the geology and local climate in the drainage basin and any point or nonpoint source pollution. Water temperature, which controls the solubility of both gases and solids and the rates of chemical reactions, is controlled by climate, water source, water use, flow depth, and, for narrow streams, shade.

(2) Biological subsystem. The plant and animal communities of a given stream are governed both by water quality and the physical characteristics of the stream. Winger (1981) presents a thorough literature review of stream characteristics and a general classification of small streams as warmwater or coldwater; each type has a characteristic morphology, chemical regime, and biological assemblage (Table 3-1).

b. Human Use. Human use of a given stream for recreation or water supply is also governed by the constraints imposed by the physical, chemical, and biological subsystems. For a given level of demand, recreational use depends on width, depth, velocity, accessibility, and water quality. Water clarity and bacterial quality are most often used in stream recreation criteria. Fishery and wildlife resources are controlled by the biological subsystem and are subject to all the influences it experiences. The aesthetic value of a stream is a function of the diversity and composition of the water resource itself, riparian vegetation, surrounding landforms, and adjacent land uses.

c. Systems and Design. The net environmental effect of stream channel modification can be improved by studying the effects on the chemical and biological subsystems from alteration of the physical subsystem. In particular, the designer should strive to maintain the existing width, depth, velocity, and bed material size. Actions that reduce shade (from riparian trees and shrubs) are particularly undesirable for small, low-order streams because cover is an important habitat feature. An integrated approach to planning and design that considers effects on chemical and biological subsystems and

Table 3-1. General Characteristics of Warmwater and Coldwater Streams

Characteristic	Coldwater	Warmwater
Geology	Youthful	More mature
Valley shape	V	U
Temperature	Cold (<20° C)	Cool-warm (>20° C)
Discharge	Low	Medium-high
Velocity	Moderate (high turbulence)	Moderate to high (low turbulence)
Depth	Shallow	Medium to moderate
Width	3 to 20 feet	>10 feet
Bed material	Rubble-gravel	Rubble-sand-mud
Gradient	High	Low
Elevation	High	Low
Turbidity	Clear	Clear-turbid
Pools (riffles)	Short (many riffles)	Long (few riffles)
Temporal variability	High	Low
Aquatic flora	Periphyton	Macrophytes
Shade and cover	Extensive	Sparse
Organic material	Coarse particulate organic matter	Fine particulate organic matter
Distance from source	<5 miles	>10 miles
Stream order	Low (<3)	High (>3)
Competition	Intraspecific	Interspecific
Predatory fish	Few	Many
Fish community	Trout	Bream, bass, sunfishes, catfish, suckers
Fish diversity	Low	High

Source: Winger (1981).

potential human uses can result in a project that is superior in many respects even to preproject conditions.

3-2. Water Quality.

a. General. Water quality in streams depends on chemical and physical properties as reflected by such conditions as nutrient enrichment, turbidity, temperature, dissolved oxygen concentration, atypical concentrations of biodegradable organic materials, and the presence of toxins and other harmful chemicals. Deteriorated water quality not only affects aquatic ecosystems but is often associated with degraded appearance and unpleasant odors and can influence the use and management of water resources.

b. Controls on Stream Water Quality.

(1) Watershed conditions. Water quality in streams is largely a function of watershed and stream characteristics. Streams draining undisturbed watersheds contain suspended and dissolved substances provided by natural weathering of rocks and minerals. Concentrations beyond these natural background levels reflect temporary natural disturbances, such as volcanic eruptions, forest fires, and landslides, or human activities such as agriculture, irrigation, mining, logging, construction, and waste disposal. Human land-disturbing activities and some types of natural catastrophes alter rainfall-runoff relationships and supply large quantities of sediment and nutrients that increase stream turbidity levels, especially during high-discharge events. Erosion of streambeds and banks caused by increased runoff rates and frequencies also contributes to increased turbidities.

(2) Hydrology. Drainage basin hydrology greatly influences water quality. Streams draining areas with low precipitation and sparse vegetation have higher sediment concentrations than streams in more humid regions. During low-discharge periods, streams may have higher water temperatures, lower oxygen concentrations, nutrient enrichment, higher pollutant concentrations, and lower sediment concentrations than during high-flow periods. High discharges, on the other hand, typically have increased sediment concentrations, and stormflows may contain increased pollutant loads, especially in large urban and agricultural areas.

(3) Turbulence. Several aspects of stream water quality are related to turbulent flow. The amount of surface reaeration depends on turbulence, which is largely dependent upon stream gradient, roughness elements, and flow depth. Steep, shallow, high-velocity streams are well oxygenated and well mixed and are more capable of oxidizing organic materials than deep, low-gradient streams with similar temperature regimes. Suspended sediment concentrations, and thus turbidities, are directly related to turbulence.

(4) Organic and chemical pollutants. Stream pollution is typically categorized as originating from either point sources or nonpoint sources. Sewage treatment plants, industrial operations, accidental spills, and other point sources release a variety of substances into streams, some of which are highly toxic. Urban and agricultural runoff are the most common nonpoint sources and supply large quantities of organics, nutrients, and chemical residues from pesticides and herbicides.

c. Cause-Effect Relationships. Although it is clear that water quality is the product of watershed conditions, human activities, and stream characteristics, the effects are often additive in nature. Thus, except for pollutants that may be traced to single sources due to their geographic location or temporal occurrence, or those pollutants that are uniquely associated with specific sources for functional reasons (such as dye used in only one type of manufacturing operation), it may be difficult to isolate individual cause-effect relationships that determine water quality.

d. Data Sources.

(1) Published data. Published water quality data are available from several sources, some of which are listed in Appendix B. Caution should be exercised in extracting data from the public data sources to ensure that meaningful and high-quality data are used.

(2) Data collection. Refer to Chapter 6 for general guidance on data collection.

e. Effects of Flood Control Channel Projects on Water Quality. Water quality parameters that may be affected directly by channel modifications for flood control are turbidity, temperature, dissolved oxygen, and organic constituents. Dredging, excavation, and disposal may release various chemicals through resuspension and leaching. Nutrient levels, chemical pollutants, and turbidity may be increased indirectly as a result of induced land use changes. Studies of the effects of channel projects on water quality are presented in Kuenzler et al. (1977), Simmons and Watkins (1982)., and Shields and Sanders (1986).

(1) Turbidity and suspended sediment. Without preventive measures during construction, turbidity and suspended sediment levels may increase as much as an order of magnitude. Pronounced increases tend to be short term, but postconstruction levels sometimes continue above preconstruction levels due to higher flow velocities, channel erosion, and sediment derived from induced land use changes such as agricultural land conversion. Erosion and sedimentation associated with high sediment concentrations can destroy spawning habitat for fish and benthic substrates critical to macroinvertebrates.

(2) Water temperature. Temperature is an important water quality parameter because it influences chemical and biological stream processes. Aquatic organisms are extremely sensitive to increases in temperature above ambient conditions, and temperature increases may induce early spawning of many organisms. Removal of shade has been observed to result in higher temperatures (1° to 10° C) in and below modified reaches. Channel linings such as concrete further aggravate this condition. Temperature effects of channel modifications may decline through time if shade-producing vegetation is allowed to become reestablished along streams.

(3) Dissolved oxygen. Studies of the effects of channel modifications on dissolved oxygen concentrations have found no effects in some cases and beneficial effects in others. Modifications that increase flow velocities or that convert intermittent streams into permanently flowing streams often produce increases in dissolved oxygen concentrations.

(4) Chemical constituents. Where reduced threat of flooding has encouraged urban development or widespread clearing of land and expansion of agriculture, nutrient levels are often higher in modified than in unmodified channels. Modern agriculture relies heavily on fertilizers, pesticides, and herbicides. Livestock operations generate large volumes of animal wastes that are difficult to dispose. As a consequence, any expansion or intensification of farming operations is likely to result in increased amounts of nutrients, sediments, and bacteria in streams. Induced effects of channel modifications such as these tend to be long term and are likely to intensify through time. A variety of other chemical concentrations may be affected by channel modifications, especially if the channel is excavated or dredged. Soils or sediments exposed by excavation or material disposal may be leached of heavy metals or other substances, some of which may be hazardous or toxic.

f. Water Quality and Project Design. Water quality can influence and be influenced by project design. Many features designed to improve environmental benefits of flood channel projects will not work or will produce few benefits if placed in channels with poor water quality. Conversely, channels can be designed so that water quality is enhanced rather than degraded. Information concerning water quality impacts on flood channel design and environmental features to improve water quality can be found in WES TRs E-82-7 and E-85-3. Sources of water quality data are discussed in Appendix B.

(1) Prediction of effects. In many cases it is possible to predict the type and relative magnitude of changes in water quality of flood control channels with water quality models. These models must include the appropriate mechanisms for simulating transport processes and various physical, chemical, and biological characteristics. Numerical and physical models have been used to estimate erosion and sedimentation in flood control channels. The accuracy and usefulness of water quality/sediment transport models are very dependent upon the skill of the modeler and the quality of the data. The proper application of many models requires training and experience. Although the capabilities for modeling water quality and sediment transport have advanced substantially, it is still difficult to assess the impact of water quality changes on biological resources. Even when sufficient data are unavailable to permit the use of empirical formulas or models, some notion of expected water quality effects can be gained by investigating similar project designs nearby or those located in similar environments elsewhere.

(2) Water quality and environmental features. Biological productivity and aesthetic and recreational benefits of flood control channels are strongly influenced by water quality. Aquatic productivity is influenced by a variety of physical and chemical water quality parameters, including dissolved oxygen, suspended sediment, temperature, nutrients, and presence of hazardous or toxic substances. Water quality parameters that influence appearance and odor have the greatest effect on aesthetics. Recreational benefits are also influenced by odor and appearance, but the presence of biological or chemical contaminants may be the overriding concern for boating and swimming. (Refer to US Environmental Protection Agency, EPA 400/5-86-0001, Quality Criteria for Water 1986, for the water quality criteria for aesthetics, recreation, and aquatic life.)

(3) Preventive measures. Opportunities exist during the planning, design, construction, and maintenance of flood channels to improve water quality or prevent deterioration. WES TR E-85-3 presents information and procedures for selecting and designing features that improve water quality conditions in flood channels.

(a) Short-term water quality impacts associated with construction can be reduced by employing dry construction techniques; using erosion and sediment control devices such as sediment basins; scheduling construction in stages or steps; minimizing areas disturbed and exposure time; protecting disturbed soils with mulches, covers, and chemicals; and using flocculants to induce sedimentation. Techniques for reducing erosion and sedimentation from construction sites can be found in WES Instruction Report (IR) EL-83-l and in manuals, including those by the Soil Conservation Service, US Department of Agriculture (1973), Hittman Associates (1976), and Amimoto (1978).

(b) Existing streamside vegetation can be preserved and new plantings can be designed to provide shade, organic matter, and wildlife and fisheries habitat. Selective clearing and snagging, single-bank construction, and other techniques to preserve vegetation are discussed in WES TR E-85-3.

(c) Instream structures such as fish habitat devices, weirs, and drop structures can be used to add turbulence and to maintain flow through cutoff bendways. In some instances it may be beneficial to supplement inflows to cutoff bendways by pumping. Water quality on completed projects can be improved by coordinating with State and local governments to control pollution through zoning, enforcement of water quality legislation, and employment of best management practices to control runoff and erosion in agricultural areas.

3-3. Fluvial Geomorphology.

a. General. Streams are complex systems composed of hydraulic, geomorphic, biologic, and physical-chemical components. The stream system, in turn, is one part of the overall fluvial system that includes the watershed (Table 3-2). Streams that drain unaltered or undisturbed watersheds tend to be morphologically stable, transporting the water and sediment loads imposed from the watershed without enlarging or aggrading. Human activities or changes in natural conditions in a watershed affect the discharge of water and sediment and can trigger changes in stream systems. In a similar fashion, changes in one parameter of the stream system--water and sediment discharge, slope, channel roughness, width, depth, or channel pattern--may induce changes in one or more of the others. It is therefore essential that those involved in the planning, design, construction, and maintenance of flood control channel projects understand the necessity of treating the stream, its watershed, and associated resources as a unified system. The stability of this system may be studied through geomorphic and sedimentation analyses. These analyses are valuable tools for estimating stream response to channel modifications and the effect of ecological resources. They consist of assessing the stability of the existing system and the system's potential response to project modifications.

b. Ecological Implications of Geomorphic Change. Watershed changes, channel modifications, and resulting geomorphic changes affect aquatic habitat

Table 3-2. The Watershed Subsystem

Watershed Characteristic	Process	Response
Precipitation	Interception	Soil moisture
Solar radiation	Evapotranspiration	Ground water
Temperature	Infiltration	Water discharge
Vegetation and land use	Throughflow	Sediment discharge
Soils	Overland flow	
Geology	Soil erosion	
Topography		

and ecological resources. Erosion in degrading channels produces unstable substrate and may undermine habitat structures and water control structures. Sediment from disturbed watersheds or eroding channels produces sandy, shifting substrate with little habitat value, fills pools and low-flow channels, and covers structures that provide fish habitat. At low flows, large flood control channels typically have shallow depths and uniform flow velocities, whereas at flood discharges they have uniformly high velocities with little cover to provide protection for fish. Geomorphic and sediment analyses can be valuable tools for estimating stream response to channel modifications and the effect on ecological resources.

3-4. Ecological Resources.

a. General. It is a national policy that fish and wildlife resources conservation be given equal consideration with other study purposes in the formulation and evaluation of alternative plans. Fish and wildlife resources include vertebrate and invertebrate animals and their habitat. Streams and adjacent riparian areas are often important and highly valued ecosystems.

b. Effects on Fish and Wildlife. The potential effects of an action (such as lining a stream) on fish and wildlife resources must be described and analyzed before the action is taken. Guidance on this is provided in ER1105-2-100 and its references. There is an assumed positive relationship between habitat quality and fish and wildlife populations, and ER 1105-2-100 requires use of habitat-based methods, supplemented with user-day, population census, or other quantified information, for fish and wildlife impact analysis.

(1) Habitat-based evaluation methods use species, groups of species, or entire animal communities as evaluation elements. The quantity of available habitat is determined from maps and photographs. Habitat quality is derived from a model that relates features of the environment to habitat requirements of the selected species or other evaluation element. The model may be mathematical or descriptive. The more objective and documented the approach, the more repeatable the process. The habitat evaluation method to be applied

should be compatible with project needs in purpose and level of detail. Examples of the various habitat evaluation methods are provided in WES Miscellaneous Paper EL-85-8 (Roberts and O’Neil 1985), and assistance in applying these methods is provided in WES IR EL-85-3 (O’Neil 1985).

(2) A direct evaluation of a species, not just its habitat, may be warranted for species protected by law or those of special significance in the project area. Examples include endangered or threatened species and major sport or commercial fisheries such as salmon. Other fish and wildlife considerations are addressed in ER 1105-22-100.

3-5. Cultural Resources.

a. General. Cultural resources are the physical evidence of past and present habitation that can be used to reconstruct or preserve the story of human presence in an area. This evidence consists of structures, sites, artifacts, and other relevant information about an area. Corps projects must comply with the National Historic Preservation Act (NHPA) and the Archeological and Historic Preservation Act. These Acts require that the impact on significant historic sites or resources be considered and that adverse impacts be minimized through development of management plans for protection of historic and cultural resources affected by a project. Up to 1 percent of the total Federal authorized costs, after the feasibility stage, may be spent for identification, recovery, and preservation of historic properties at authorized Civil Works projects. Compliance with these requirements is accomplished through coordination with the State Historic Preservation Officer (SHPO) and the Advisory Council on Historic Preservation (ACHP). Guidance on consideration of cultural resources is provided in ER 1105-2-100, chapter 7.

b. Cultural Resource Inventory and Impact Assessment. The identification of cultural resources in the study area is accomplished through review of the National Register of Historic Places, the archives and other files of the SHPO, other public records, and prior historic resource investigations. Historic and cultural resources are identified for possible eligibility for National Register listing. An assessment is made of the predicted impact to the identified cultural resources. If properties listed or eligible for listing in the National Register will be affected, review and comments by the SHPO and and ACHP must be obtained pursuant to Section 106 of the NHPA and 36 CFR 800.

c. Mitigation of Adverse Impacts. Prior to construction, plans are developed for mitigation of adverse impacts to properties listed or eligible for listing in the National Register of Historic Places. After the impact assessment described in the preceding paragraph, more extensive surveys, testing, and determination of eligibility for National Register listing may be required. Based on any additional documentation, plans are developed for mitigation of adverse impacts. A Memorandum of Agreement (MOA) is negotiated between the Corps of Engineers and the ACHP and SHPO. The MOA specifies the actions that will be taken by the Corps during project construction to mitigate adverse effects on National Register and eligible properties.

3-6. Aesthetic Resources.

a. General. Streams and adjacent riparian areas are often highly valued as aesthetic resources. An assessment of existing visual quality and evaluation of visual impacts should be a part of planning and design. Procedures for evaluating visual quality and impacts have been developed by the WES (see WES IR EL-88-1).

b. Visual Impact Assessment.

(1) The visual impacts resulting from a flood control channel should be assessed early enough in planning and design so that measures can be taken to minimize adverse impacts, protect existing visual quality, or improve degraded visual quality considerations. The evaluation of the extent and beneficial or adverse nature of visual impacts is dependent in part on the existing visual quality. The acceptability and compatibility of flood control design is affected by the project setting and the expectations of users, e.g., recreationists, residents, or workers in an industrial area. The visual quality of a project area may be improved by a channel project when, for instance, denuded, eroding banks are replaced by a stable bank line and grassed banks.

(2) Visual impact assessment is accomplished by comparing with- and without-project conditions. If resources are not available for preparation of visual simulations, visual impact assessment is limited to determining the changes in vegetation, landform, and other visual resources. Visual simulations of alternative designs can be developed through sketches, rendering (painting the design on a photograph), and a number of computer-assisted methods. After the visual effects have been assessed, adverse visual impacts are identified. These adverse visual impacts provide the basis for reformulation of the project or for implementation of design and construction measures to minimize adverse impacts.

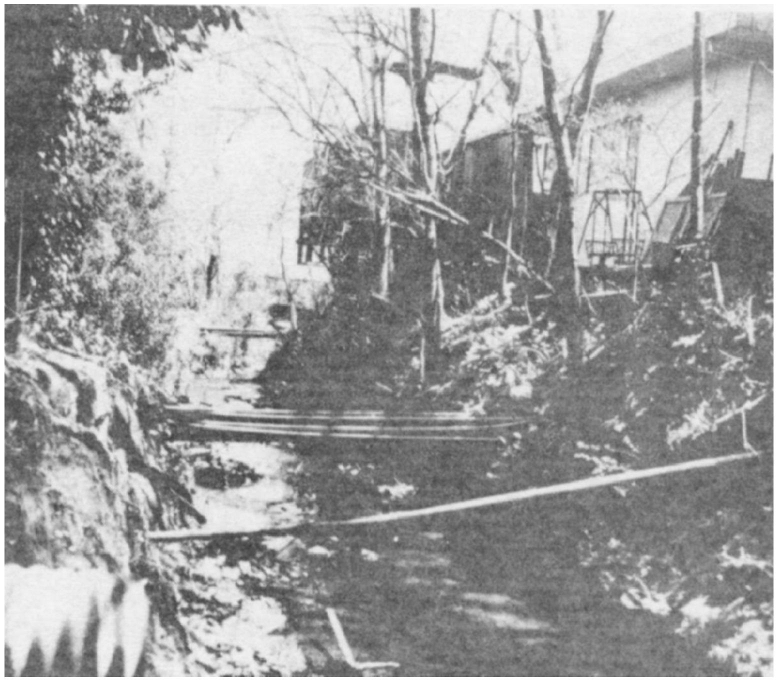
c. Measures to Protect and Maintain Visual Quality. Design, construction, and operation measures can be used to protect and maintain the visual quality of flood control projects. These measures include the following:

(1) Use of vegetation and natural materials can reduce the visual contrast of a flood control structure with the project setting. Vegetation and natural riverine substances, e.g., gravel and rock, can be used alone or in combination with structures to provide a more natural appearance. Minimizing the extent of bank and streamside clearing and using vegetation in the design preserve the natural appearance of the project setting. Restoration of excavated, eroded, and cleared areas can be performed as part of construction activities.

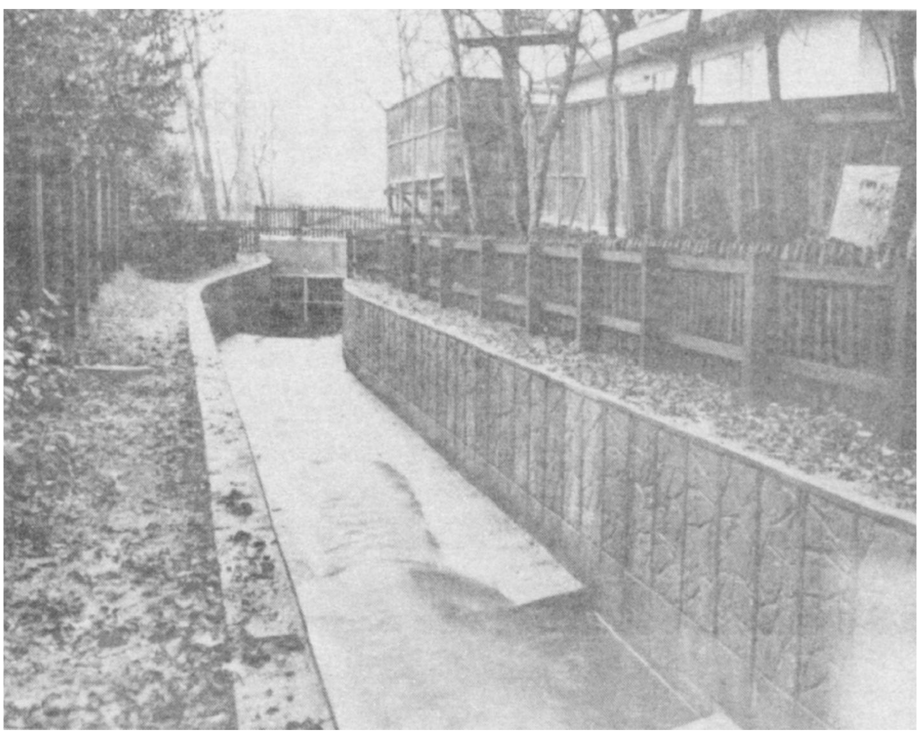
(2) Changes in design elements can improve the visual compatibility of a channel design within a project setting. The design elements of concern are form, line, color, texture, and scale. Depending upon the limits of performance and costs, the various design elements can be changed to improve the visual aspects of the project. For example, concrete can be textured to pick up the texture patterns of the bank line setting. Excavation and disposal areas can be contoured to reproduce the form and scale of the existing landscape. Color can he manipulated in concrete admixtures, staining of grout.

and use of vegetation. Subject to other project design and maintenance constraints, vegetation can be used to modify or screen structural forms and lines. Figure 3-1 depicts a flood control project on Tamalpais Creek. California, that was constructed by the US Army Engineer District, San Francisco. and incorporates several aesthetic measures.

(3) Construction and maintenance procedures can be modified or to minimize destruction of vegetation. Water-based construction minimizes the need for haul roads and clearing for access. Similarly, construction single side of the stream limits the amount of required clearing.



a. View before project



b. View after project. The curving alignment, redwood fence, and special concrete finish contribute to visual effect

Figure 3-1. Enhancement of flood channel aesthetics, Tamalpais Creek, Calif.

CHAPTER 4

ENVIRONMENTAL CONSIDERATIONS FOR DESIGN

4-1. General. This chapter presents concepts and design criteria for features and techniques that may be used to improve the net environmental effect of a channel modification design. Environmental effects of channel projects are outlined in Chapter 2, and considerations for preliminary design are discussed in Chapter 3. Detailed design criteria do not exist for most environmental features due to the limited base of experience and the complexity of environmental effects; therefore, considerable creativity and professional judgment are required. Furthermore, the guidance contained herein supplements but does not replace any of the existing guidance for hydraulic design, such as EM 1110-2-1601 and the Hydraulic Design Criteria (HDC). Detailed hydraulic design often requires use of physical or mathematical models. The guidelines below should be used by a multidisciplinary team composed of environmental professionals and designers. Nonstructural approaches such as land treatment, floodplain management, floodproofing, etc., are not discussed herein.

a. Organization. In this chapter, environmental features are grouped by the type of channel modification design with which they are most frequently associated. An understanding of the undesirable effects of a modification (as presented in Chapter 2) is required to fully appreciate the purpose and function of the environmental features for that type of modification.

b. Environmental Objectives. Channel designers should be involved with the development of project environmental objectives established during the planning stage. Environmental objectives may include specific mitigation, enhancement, or development goals for aesthetic, recreational, water quality, ecological, or historical or cultural resources. An example of a specific environmental objective would be to preserve an existing coldwater fishery. Environmental features should then be selected and designed to satisfy these specific objectives. However, whether or not specific objectives have been established, Corps policy dictates that certain general environmental objectives be pursued for all projects. A review of relevant Corps environmental policies and guidelines is given in ER 200-2-2, ER 1105-2-100, EP 1165-2-1, and EP 1165-2-501. For effective implementation, these policies and guidelines must be considered and observed in the design stage as well as in planning.

c. Environmental Guidelines. General environmental guidelines for channel modification projects include:

(1) Subject to meeting other project objectives, minimize structural channel alterations, particularly if the existing channel is reasonably stable.

(2) Because channel instability impacts aesthetics, water quality, and habitat, pay particular attention to geomorphic and sedimentation analyses for erodible channel stability.

(3) Channel layout should be a detailed process to avoid, as much as possible, destruction of valuable resources such as large trees or historically significant structures.

(4) As an example, suppose that preserving fish habitat were an environmental project objective. One way to accomplish this is to use instream habitat structures. However, instream structures are not suitable on streams with braided channels, high bed-load transport, unstable channels, steep gradients, high discharge, intermittent flow conditions, poor water quality, or no existing or prospective fishery. In addition, successful applications on streams with high suspended loads, bedrock or sand beds, low slopes, bankfull discharges between 1,000 and 10,000 cubic feet per second, extreme flow variation, or warmwater fisheries; streams that drain urban, agricultural, semiarid, or highly disturbed watersheds; or streams that freeze over may require special designs or considerable maintenance. For example, habitat structure designs that depend on scouring for their effect usually do not work well in bedrock streams, whereas some designs will not last on mobile, sandbed streams due to undercutting and flanking.

4-2. Clearing and Snagging.

a. Selective Techniques. Undesirable effects of clearing and snagging may be addressed by using design and construction techniques that allow trees and snags that do not cause significant flow obstruction to remain. "Selective" clearing and snagging is performed using labor-intensive approaches (chainsaws, boats, barges, etc.) rather than heavy equipment such as draglines and bulldozers. WES TR E-85-3 provides a summary of literature pertinent to hydraulic effects of clearing and snagging and offers suggestions for preparing specifications for selective clearing and snagging work. Design of a selective clearing and snagging project should include the selection of either the specific trees and snags or the types of trees and snags to be removed, as well as specification of the methods for disposal of the removed debris, construction methods and equipment, and access controls. Additional considerations include revegetation, bank stabilization, protection of existing vegetation, scheduling, and contractor education. The effects of selective clearing and snagging may be short-lived and thus may require more frequent maintenance at the site. This factor must be taken into consideration when considering this technique, and project formulation should provide for frequent inspection and maintenance.

b. Replacement of Riparian Vegetation. Areas cleared for channel excavation, access, disposal areas, borrow, and, sometimes, for increased flow capacity can be controlled and enhanced to improve the net environmental effects of a project by revegetation. Revegetation must be tailored to achieve specific objectives (e.g., ground cover, habitat, erosion control) through appropriate species selection, placement, and planting methods for the specific site. (Allen 1978, Allen and Klimas 1986, and Hunt et al. 1978 provide more detailed information on these topics.)

c. Preservation of Riparian Vegetation. Destruction of riparian vegetation, either natural or planted, should be minimized during and after project construction.

(1) During construction. Contractor staging areas and access routes should be carefully planned and should include existing roads and cleared areas. Heavy penalties should be assessed for unauthorized clearing, damage to, or destruction of trees. Trees to be cleared may be flagged or marked with paint.

(2) After construction. Easements may be obtained for riparian buffer strips. If the channel is in a cultivated area, compliance with the easement is more likely if the buffer strips are marked with metal posts, low windrows of excavated material, or fences. Fences usually should be passable by resident wildlife species, except where barriers are needed to prevent drowning or maiming of animals, especially large mammals (ER 1130-2-400). (Information on designing buffer strips for channel protection is provided in Steinblums, Froehlich, and Lyons (1984); fence design is discussed in Nelson, Horak, and Olson (1978) and Schimnitz (1980).

4-3. Floodways.

a. General. Floodways (sometimes called bypass or diversion channels) are excavated channels that convey floodwaters over routes that are usually shorter and straighter than those followed by the unmodified stream. Floodways normally are designed to convey flood flows only, and low and normal flows are diverted through the natural channel. Floodways may be designed as multipurpose use areas, as long as the additional use is compatible with the flooding function. Any structures placed in the floodway should be flood proof, well anchored or removable on short notice, and should not obstruct flood flows.

b. Design Considerations. Floodway channels should be sized to convey the design discharge, less the flow diverted through the natural channel during flood events. If the natural channel will be used as a low-flow channel only, a means of diverting low flows and restricting flood flows must be provided. If weirs and culverts are used, both the low-flow channel and culvert should be designed with adequate access for regular removal of sediment and blockages. Inverts of floodways designed for multiple use should be above the seasonal high-water table or should be provided with underdrains to ensure that wet conditions will not interfere with use or maintenance of the floodway. Grade control or drop structures may be needed in the floodway or at tributary junctions.

4-4. Channel Excavation.

a. General. A variety of structural methods can be used to reduce the impacts of channel modification. Because of the lack of standard terminology, some of the terms used in this section have been specifically defined for use herein. Readers should refer to these definitions, which are given in the Glossary.

b. Low-Flow Channels.

(1) General. A low-flow channel is a subchannel constructed inside a larger flood control channel to concentrate flow for biological, recreational, water quality, or aesthetic benefits, and for engineering design needs.

Low-flow channels generally do not perform well on streams with heavy sediment loads. Figure 4-1 is an example of a low-flow channel. Typical low-flow channel cross sections are shown in Figures 4-2b, c, d, and f.

(2) Size. Due to their small size, most low-flow channels are designed by adding them to the cross section required for flood conveyance. Dimensions of low-flow channels should be based on instream flow conditions required to meet engineering, biological, recreational, or water quality needs. For recreational boating, the recommended minimum depths are 2 and 3 feet for non-motorized and motorized boats, respectively; the recommended minimum widths are three times boat length for rowboats and 17 feet for canoes. If fishery or water quality needs dominate, critical instream needs (usually flow velocities and depths) should be established for the month or months during which low-flow conditions are expected. Fishery biologists familiar with local streams can assist in developing these criteria, which can be used to size low-flow channels. Biologic benefits can be further enhanced by incorporating pools and riffles and habitat structures in the design.

(3) Placement. Meandering alignments for low-flow channels are preferable for aesthetic reasons, although placement adjacent to a shady bank may be more desirable. Guidance for meander designs is given in paragraph 4-4f. For low-flow channels constructed in erodible materials, meandering and erosion may be controlled by lining the low-flow channel and the flood channel invert or by burying sills or training dikes at specified intervals. Alternatively, the toe slope of the flood channel may be protected and the low-flow channel allowed to meander freely.

c. High-Flow Channels.

(1) General. High-flow channels are flood control channels with modified cross sections that include a subchannel with high-flow berms on one or both sides (Figures 4-2g, i, j). High-flow berms are inundated infrequently and may be used for parks, trails, or other purposes compatible with their functions as flood channels.

(2) Design. If the existing channel is determined to be stable, the magnitude of its geometric parameters may be considered the regime values. It is preferable that the channel’s desired regime be maintained by the subchannel and that the high-flow berms be designed to be inundated only by flood flows that exceed the channel-forming discharge, normally equal to or larger than the mean annual discharge based on the annual series. A sedimentation analysis should be conducted to properly design this channel modification. If the existing channel is determined to be unstable, the problem of sizing the subchannel is more difficult and will require special attention in performing the sedimentation analyses.

d. Pools and Riffles.

(1) General. Profiles of natural channel inverts typically have alternating "lows" and "highs" that are referred to as pools and riffles. Under normal-flow conditions, pools and riffles provide a variety of water depths and flow conditions, which is needed to maintain biologic diversity and vigor. Pools and riffles tend to be spaced with pool-to-pool distances that fluctuate

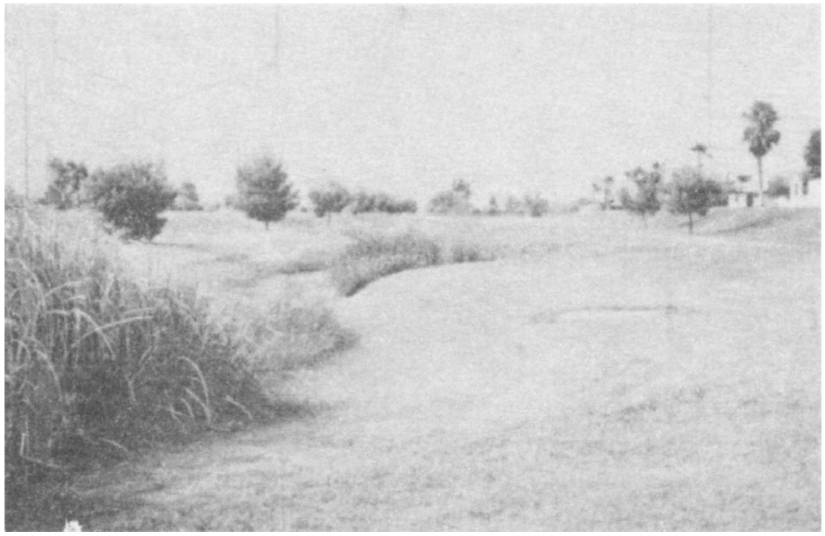


Figure 4-1. Low-flow channel, Indian Bend Wash (USAED, Los Angeles)

about a mean value of five to seven channel widths, being typical of most streams. On meandering streams, pools are located in bends, and riffles are found in straight reaches (Figure 4-3).

(2) Design. Pools and riffles may be placed in subchannels or low-flow channels and in larger channels with sizable fractions of gravel and cobble in their beds. Pools and riffles should not be built on high-flow berms, in floodways, or in channels with sand beds.

(a) Spacing. Spacing of pools and riffles in paved channels is not critical because of the inherent stability of the channel. In unpaved channels, maintenance requirements will be fewer if pools and riffles are spaced and located to reproduce natural channel conditions. Riffles may sometimes be placed at outcrops of erosion-resistant material. If use of natural channel pattern is not feasible because the stream or watershed is unstable under preproject conditions, pool and riffle spacing should fluctuate about five to seven channel widths (measured from the center of one pool or riffle to the next pool or riffle). Channel width should be water surface width for the 1-year return interval flow. Pools should alternate from side to side within the channel, and sediment transport conditions of the channel should not be radically different from preproject conditions. Figure 4-3 shows desired pool-riffle locations for straight and meandering streams.

(b) Size and shape. Size and shape are not as critical as spacing and may be varied to suit hydraulic and biologic needs. Pools should have a minimum low-water depth of 12 inches, and riffles should not project more than 12 to 18 inches above the mean channel invert. Generally, individual pools should not be longer than three channel widths or shorter than one. Pools that are too wide, too deep, or too long may not have the self-flushing capability for sediments that natural pools have. Riffle lengths should be one

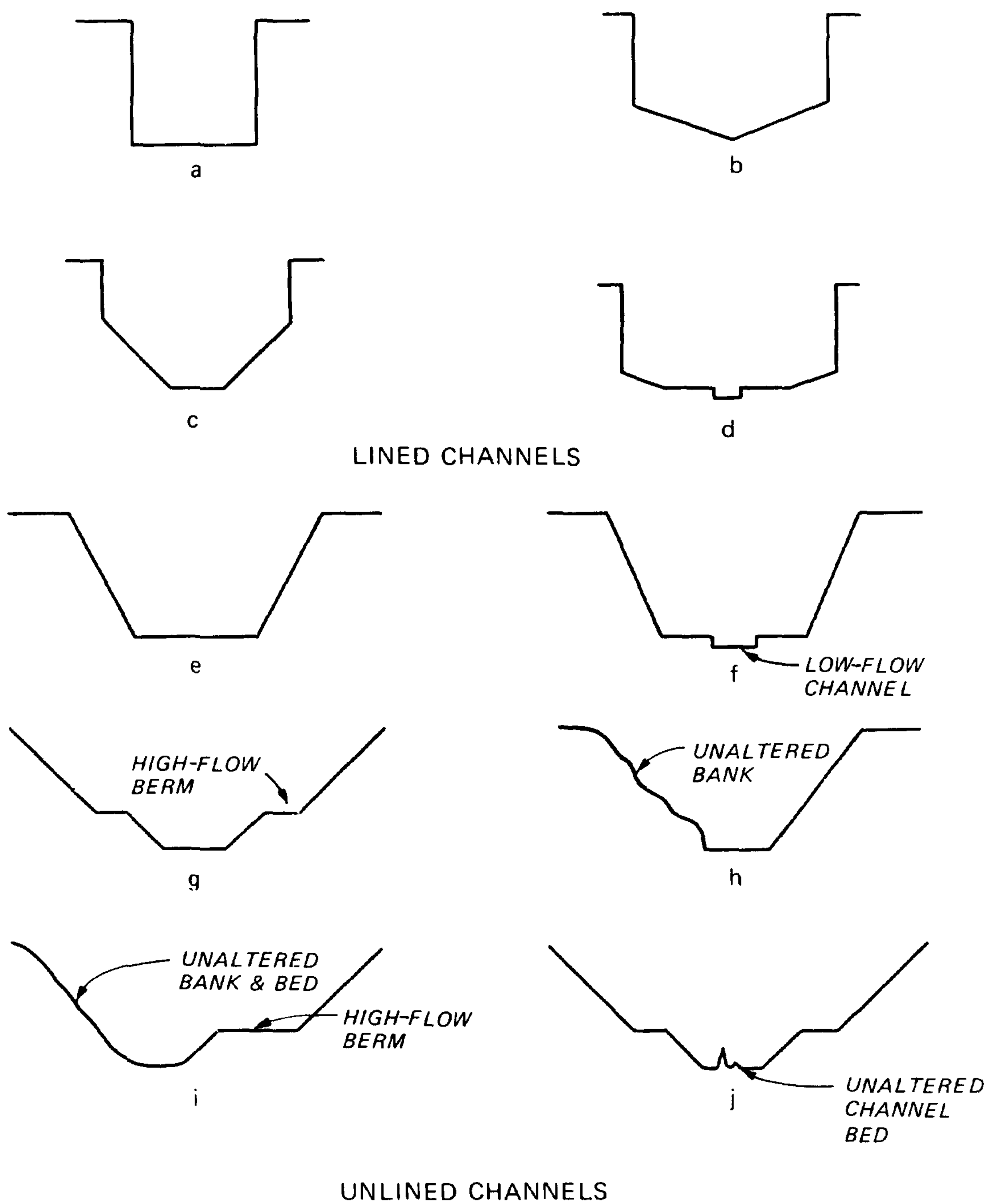
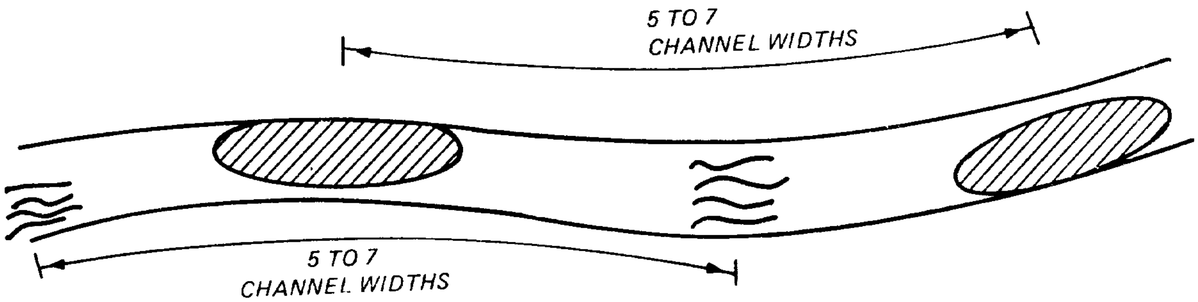
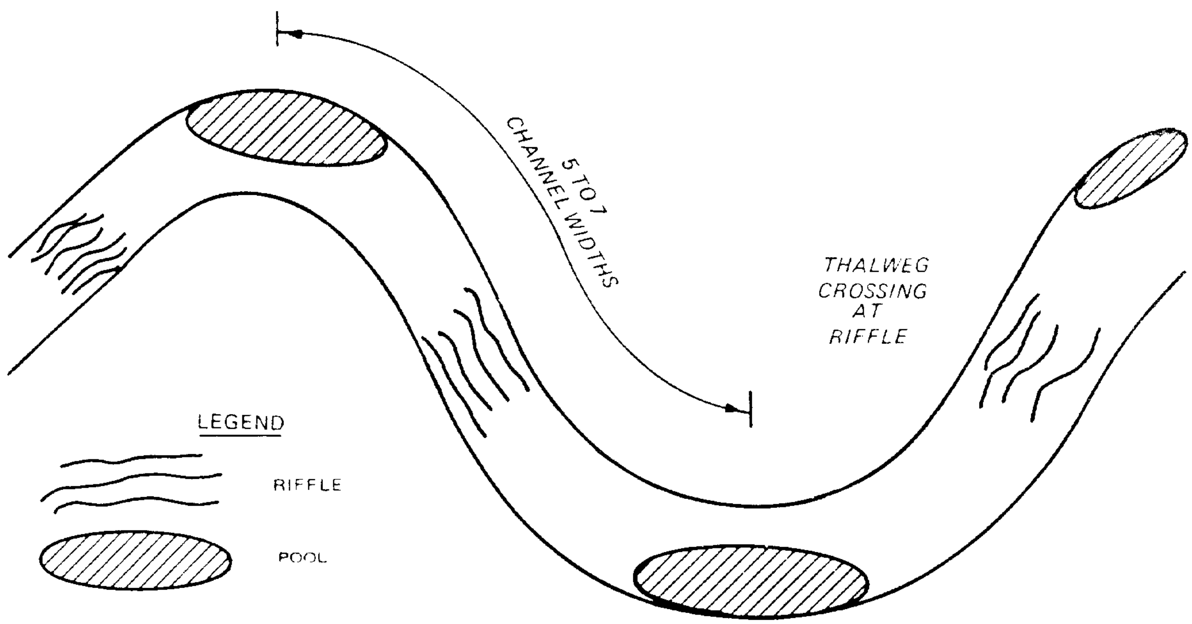


Figure 4-2. Typical flood channel cross sections. Lined channels typically have vertical walls to minimize costs and may be rectangular (a) or may have some modification to concentrate low flows (b, c., d). The most frequently used cross-sectional geometries include trapezoidal (e), trapezoidal with a low-flow channel (f), trapezoidal with a normal-flow channel and high-flow berms (g), and variations in which one bank and/or the channel bed are not disturbed (h, i, j)



a. Straight to slightly sinuous channel



b. Meandering channel

Figure 4-3. Pool-riffle location. Pools and riffles should be spaced irregularly at five to seven channel-width (center-to-center) intervals. Pools should alternate from side to side within the channel

half to two thirds that of pools, and channel width in riffle areas should be 10 to 15 percent wider than in pool areas.

(c) Materials. If riffles are to be dynamic or self-maintaining, construct them of a mixture of natural stream gravel with size distribution typical of the bed material in the unmodified channel. Otherwise, construct them of gabions, cobble, or riprap, sized based on trade-offs between considerations and environmental benefits.

e. Single-Bank Construction.

(1) General. If site conditions permit, single-bank modification is the preferred construction method for channel enlargement (Figure 4-4). The existing channel alignment is followed, and the vegetation on the opposite bank is disturbed as little as possible. Aesthetic impacts are reduced if the work is alternated from one side to the other and if clumps of vegetation are left on the work bank. Preferred equipment varies with stream size. Hydraulic hoes and other small equipment are preferable for small streams because of their maneuverability and the reduced access and rights-of-way needs. However, in some instances, larger equipment may be desirable. On large streams, floating dredges may eliminate the need for haul roads.

(2) Procedures.

(a) Select the work bank. Factors to be considered in the selection process include habitat value of existing vegetation, shade, bank stability, and aesthetics. Trees on the south and west banks provide the most shade during critical midday and afternoon periods. Any special vegetation to be preserved should be marked.

(b) Develop design. The design should cover the selection and removal of snags from the off bank and restrictions on equipment, access, work scheduling, etc. Detailed guidelines are given in WES TR E-85-3.

f. Meandering Alignments.

(1) General. Meandering alignments may be used to improve the aesthetics and stability of flood control channels. Meander geometry is described in terms of wavelength, meander width, and radius of curvature (Figure 4-5), and measurements may be expressed in dimensionless form as multiples of channel width. Natural meander geometry can be related to stream discharge and bankfull width.

(2) Design. Meander geometry specifications include meander wavelength, meander width, stream length and gradient, and channel cross-sectional geometry. Meander geometry of subchannels sized to carry low and normal flows can be patterned after that of the former stream or of similar-sized unaltered streams nearby. Alternatively, refer to Table 3 of WES TR E-85-3 for formulas for meander geometry and to the associated text for application procedures. The formulas and procedures given in WES TR E-85-3 are not meant to replace hydraulic design procedures contained in EM 1110-2-1601.

g. Preservation and Creation of Wetlands.

(1) General. The values of wetlands are well established, and opportunities for including wetland features in flood control channel projects are numerous. Alignment of flood control channels and careful placement of dredged materials to avoid wetlands can minimize losses of these valuable habitats.

(2) Site selection. Desirable site criteria for wetland creations include flat topography, relatively impermeable soils, high ground-water table, plentiful and dependable water supply, and mast-producing hardwood trees and other vegetation with high habitat value. Alluvial floodplains

Figure 4-4. Single-bank construction. The visual effect would have been improved if clumps of trees had been left at intervals along the modified bank

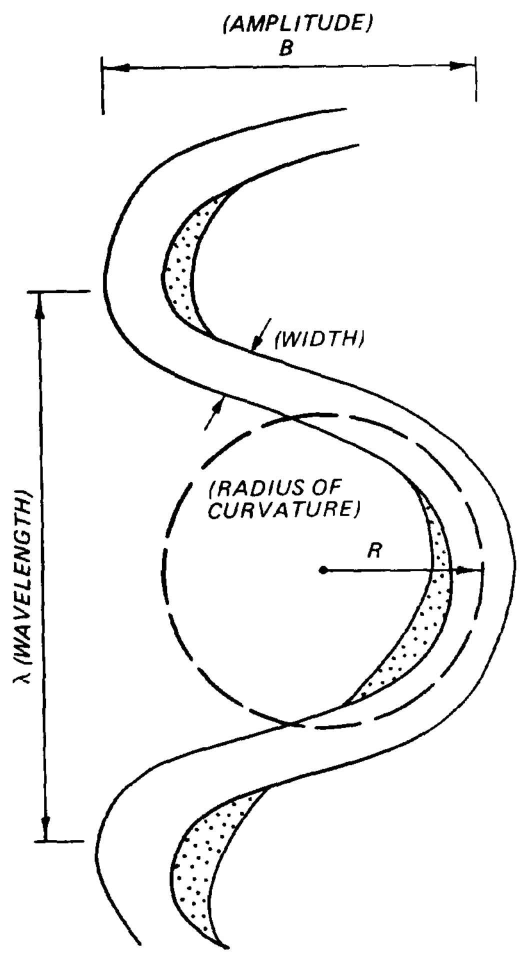


Figure 4-5. Meander geometry

possess many of these characteristics. Several procedures are available for evaluating the habitat value of a specific site (see Fish and Wildlife Service, US Department of the Interior 1980; US Army Engineer Division (USAED), Lower Mississippi Valley, 1980; and Adamus et al. 1987).

(3) Development. Wetlands may be developed with or without water-level control. Wetlands may be created by excavation, by placement of excavated material to block surface drainage, or by building containment levees. Emergency spillways should be provided for levees or dams that might overflow and erode. Gated culverts or other flow-control mechanisms allow water-level management for specific purposes such as duck habitat or timber production. Detailed information on site selection, design, and management of wetlands of various types can be found in the Wildlife Management Techniques Manual (Schimnitz 1980), "The Wildlife Improvement Handbook" (US Forest Service 1969), and in numerous Corps publications (see Environmental Laboratory 1978b and Martin 1986).

h. Preservation of Cutoff Meanders.

(1) General. When bendways with potential habitat value are cut off during flood channel construction, consideration should be given to maintaining the bendways as either lake or channel habitat (Figure 4-6). Feasibility depends largely upon water quality and sediment load. For lakes, inflow quality and quantity need to be adequate to prevent water quality problems. Water budgets for proposed cutoff bendway lakes should include consideration of inputs from and losses to ground water. Perched lakes may require much greater inflow to maintain depths and water surface areas. Engineer Manual 1110-2-1201 provides guidance on predicting the water quality of impoundments using simplified techniques. Stream-connected designs are of questionable value on streams with extremely low summer flows. Refer to EM 1110-2-1203 for discussion of bendway management techniques appropriate for larger rivers.

(2) Impoundment design. Bendway impoundments require channel blocks and appropriate flow-control mechanisms. If tributary or drainage inflow is adequate to maintain water level, only an outlet structure and emergency spillway are needed. Otherwise, a gravity-fed inflow structure or pumped inflow is required. Intake structures should be high enough to avoid heavy sediment concentrations and should be designed to minimize problems of debris jamming or blockage. Wells for supplemental water supply should be located to avoid simply recycling lake water.

(3) Stream-connected designs. Low flows may be diverted through bendways by excavating cutoff channels to depths shallower than the bendways or by using weirs in cutoff channels to divert water through bendways. Bed protection or drop structures may be needed to prevent degradation in the cutoff channel and at junctions of the cutoff channel and bendway. If sediment loads are heavy or if low flows are insufficient to maintain suitable habitat, one or both ends of the bendway may be partially blocked to restrict sediment input and to maintain water levels during low-flow conditions. A culvert placed through an earthen embankment is a simple type of partial blockage. However, culverts are easily blocked by floating debris or sediment. Weirs or sills placed across the mouth of the old bendway may also be used for partial

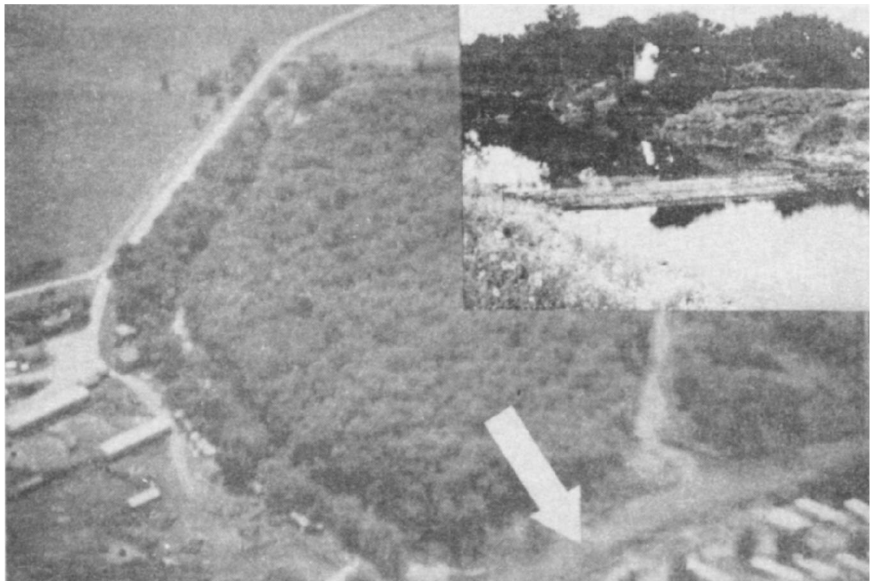


Figure 4-6. Cutoff meander, Souris River (USAED, St. Paul). Cutoff bendways can be maintained for wildlife and recreational benefits. (Inset highlights grade control structure with crest elevation sufficiently high to force normal flows through the bend)

blockage. If the old bendway makes a sharp (near 90-degree) angle with the main channel, sediment deposition will be localized near the junction, which will reduce maintenance effort. In most cases, stream-connected designs will require periodic removal of sediment to maintain the bendways as aquatic habitat. Sumps or sediment traps may be placed at bendway entrances to facilitate maintenance. Complete closure of the upper bendway entrance and constriction of the lower so that it scours on the falling stage may help to reduce rates of bendway sedimentation in some cases.

i. Placement of Excavated Material.

(1) General. Selective placement and treatment of excavated material offer opportunities to reduce impacts and enhance environmental conditions. Environmental factors that should be considered in site selection include topography of the site and its potential for flooding, proposed use of the disposal site and its compatibility with existing and proposed adjacent land uses, the presence of rare or endangered species, the chemical and physical quality of the material, and the existing site habitat value and the abundance of that habitat in the general vicinity. Excavated material should not be placed in stream courses or in designated floodways. Erosion control is discussed in paragraph 5-2 of this manual.

(2) Applications. In flat areas, excavated material may be piled and shaped to provide visual contrast and recreational opportunities such as sledding or skiing; it may be used to construct containment levees for wetland creation; or it may be windrowed to mark limits of buffer strip easements, control side drainage, or provide wildlife refuge. Although habitat

development on flood control channel projects is by no means limited to disposal areas, disposal sites offer excellent opportunities to replace lost habitat with habitat of equal or superior quality. Detailed guidance for habitat development on disposal sites is presented in Environmental Laboratory (1978a); Hunt et al. (1978); Lunz, Diaz, and Cole (1978); Ocean Data Systems, Inc. (1978); Smith (1978); and Soots and Landin (1978).

j. Water-Level Control Structures.

(1) General. Although water-level control structures may have multiple benefits, they are instream structures designed primarily to maintain water levels at a constant or near-constant elevation during nonflood periods for aesthetics, recreation, fish or wildlife habitat improvement, water quality, vegetative control, or related purposes. Earth plugs, gated structures, inflatable dams, and overflow weirs made of sheet pile, gabions, concrete, or other materials are used to control water levels.

(2) Design considerations. Water-level control structures should be designed, built, and operated so that they do not block fish movement, create problems of upstream sedimentation or downstream erosion, or reduce flow capacity under high-flow conditions. Gated structures and inflatable dams prevent most of these problems, although they may be expensive to build. Guidance for the design, construction, and maintenance of inflatable dams is available from manufacturers of these products. Weirs can be designed with low profiles to avoid reducing flood capacities and can be provided with openings or fish ladders. Fish passage problems are addressed in paragraph 4-7. Upstream sedimentation is a common problem for weirs, and streams with heavy sediment loads may require sediment traps or regular cleaning of pools.

k. Instream Habitat Structures.

(1) General. Habitat structures are constructed in channels to modify flow depths and velocities and to provide cover for fish. Use of habitat structures may require a larger channel dimension to provide for the flood capacity. Figure 4-7 illustrates placement of instream habitat structures. Most designs can be placed into one of four categories--sills, deflectors, random rocks, or cover. The first three types of structures are not suitable for use in channels that have dominant bed material of sand size or less.

(2) Structure types.

(a) Sills. Sills are low structures that extend across the entire width of a channel and are intended to produce upstream pools, downstream scour holes, or both. They are often designed with a gap or notch and typically have minimal backwater effects. Sills are better suited to high-gradient streams than are most other habitat structures. Sills may be constructed from logs, rocks, gabions, concrete, sheet metal, or combinations of these materials. The most common problems encountered are flanking and undermining, structural damage caused by floods or ice, and structures built too high such that they are susceptible to failure and impede flood flows and fish movement.

(b) Deflectors. Deflectors are structures that protrude from one bank but do not extend entirely across the channel. The primary purpose of

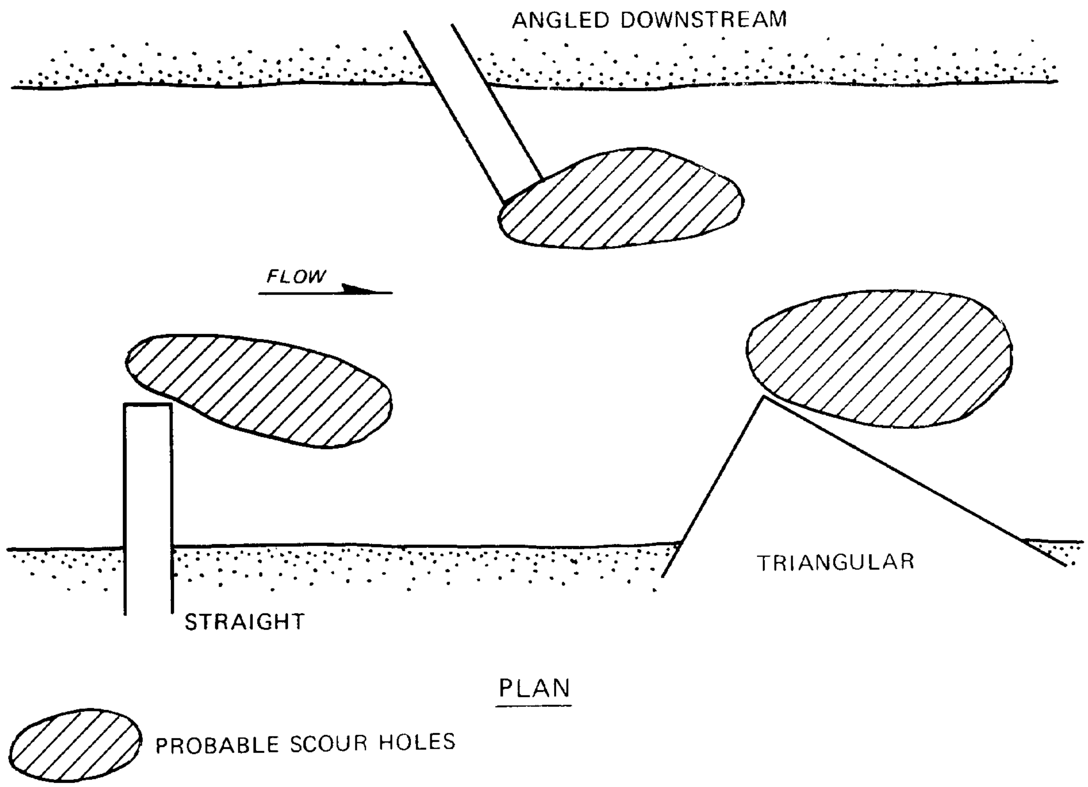


Figure 4-7. Instream habitat structures

deflectors is to scour pools by constricting the channel and accelerating flow. They may be angled upstream, downstream, or perpendicular to the bank and are often alternated from one side to the other. They may be constructed of the same materials as sills, although rock and rock-filled structures are most common. Use of deflection in some streams may create bed scour and erosion to the opposite slope that is not predictable.

(c) Random rocks. Random rocks are large boulders, gabions, or concrete objects placed in a channel well away from either bank to produce scour holes and zones of reduced velocity. Rocks should be used only if velocities are high enough to create scour holes downstream, but their use should be avoided on sand-bed streams and other streams with unstable beds. Rocks used for habitat cover should be durable enough to withstand weathering and abrasion. Rocks may be placed in channels individually or in clusters.

(d) Habitat cover devices. Cover devices include floating rafts fastened to the bank, ledges supported by pilings, anchored trees or brush mats, logs or half-logs anchored above the bed and aligned with the flow, and boulders or gabions placed in deep pools.

(3) Design. Design of habitat structures is an iterative process that involves several steps: determining feasibility of success; determining habitat potential and deficiencies; selecting the structure; planning the layout; sizing the structure; investigating effects of and on flood flows,

sediment transport, and channel stability; and designing the feature in detail. Technical Report E-85-3 (WES) provides detailed design procedures. A summary of experience with habitat structures in modified channels is given in WES TR E-82-7 and in Shields (1983).

l. Sediment and Debris Basins.

(1) General. Debris basins are constructed to trap sediment and debris that would otherwise damage or clog flood channels. Debris basins are required primarily on high-gradient streams and at sites susceptible to mud and debris slides. Sediment basins are used to reduce sediment loads and turbidity, which can adversely affect fish and other aquatic organisms, water quality, and project aesthetics.

(2) Design. Instream sediment traps are constructed by excavating short channel reaches to a greater-than-average depth and width. Debris basins usually have larger required capacities and are constructed by damming the stream, with or without accompanying excavation. Both sediment and debris basins may require periodic cleaning to maintain their trap efficiency. Access and ease of maintenance should be given priority during design. Technical guidance for the design of sediment and debris basins is presented in EM 1110-2-1601 and in Dodge (1948), Moore et al. (1960), Tatum (1963), and Pemberton and Lara (1971).

4-5. Channel Paving.

a. General. Paving is used in channels that experience supercritical flow, in urban areas where narrow, deep channels are often used, and in other situations where flow depths and velocities would be sufficient to cause general scour of channel bed and banks. Reinforced concrete is the most common paving material, but asphalt, grouted riprap, boulders set in concrete, and other materials are sometimes used.

b. Concepts for Improving Environmental Quality in Paved Channels. Environmental quality of paved channels can be improved by increasing low-flow depths, reducing water temperature, and providing resting area and cover for fish. This can be achieved by using low-flow channels (paragraph 4-4b) or pools and riffles (paragraph 4-4d), providing shade, and using materials such as boulder concrete and grouted riprap. Boulder concrete and grouted riprap may improve channel appearance as well. Aesthetic considerations for urban projects are discussed in paragraph 4-9.

4-6. Channel Side Slope Protection.

a. General. Erosion protection of some kind is required for some side slopes of nearly all flood channels. Vegetative protection usually is preferred, but structural protection is required along channels with high flow velocities and at locations subject to local scour or slope instability. Habitat value, aesthetics, water quality impacts, and channel access for people and animals should be given major consideration during selection and design.

b. Structural Protection Measures.

(1) General. Structural protection measures involve placement of natural or manufactured materials along banks to provide direct or indirect protection against scour or bank failure. Design guidance can be found in WES TR E-84-11 and in OCE (1978, 1981c) and USAED, Huntsville (1982), although not all types of designs in these references are appropriate for flood control channels. Practicable designs for flood control channels include soil treatment and stabilization, tree retards, riprap and gabions, rigid revetments such as reinforced concrete, and manufactured bank covers.

(2) Environmental aspects.

(a) Habitat value. Structural bank protection measures provide little wildlife habitat, although riprap is valuable to benthic organisms and some small fish species. Tree retards provide cover for fish, but their use is restricted largely to natural channels.

(b) Aesthetics. Aesthetic impacts of streambank protection are largely visual and may be negative or positive. Extensive use of concrete, manufactured covers, or riprap produces a scene that might be considered inferior to that of a natural stream because of the sharp contrast between these materials and naturally vegetated banks. Appearance of bank protection can be improved where soils and hydraulic conditions permit, by using materials such as stream gravel and cobble or structural designs that incorporate vegetation (paragraph 4-6d) -

(c) Water quality. Increased turbidity associated with the construction of bank protection works may have short-term negative impacts on water quality, but the major long-term impact of successful wide-scale bank protection is to reduce turbidity and sediment concentrations. Reduced sediment concentrations may prolong the life of environmental features such as fish habitat structures and may reduce the costs of channel maintenance. Water temperature increases may sometimes be related to extensive use of concrete and loss of shade.

(d) Channel access. Extensive bank protection works can affect access to the channel by people and animals. Concrete and other smooth surfaces generally increase accessibility as long as slopes do not exceed 1 vertical: 2 horizontal. Large, loose stone is probably less acceptable, but accessibility can be improved by filling large voids with smaller rock, gravel, or soil.

c. Vegetative Protection.

(1) General. Herbaceous or woody vegetation may be used to protect channel side slope areas (depending on the frequency of inundation, velocity, and geotechnical constraints to infrequent flooding) and other bank areas where velocities are not expected to exceed 6 to 8 feet per second. Information concerning maximum permissible velocities for various grasses is given in WES TR E-84-11. Figure 4-8 depicts a flood channel with vegetative bank protection. In addition to erosion resistance and environmental considerations, which are discussed separately below, other factors that need to be considered in the selection process include flood and drought tolerance, soil and

Figure 4-8. Vegetative lining, San Antonio River flood channel (USAED, Fort Worth). This completed reach contains a subchannel that conveys normal flows. The high-flow berms and banks are vegetated. Note the River Walk (Paseo del Rio) inside the flood channel

climatic conditions at the site, and availability of seed, root stock, or other propagules. Additional information concerning these matters is available in WES TR E-84-11, in Whitlow and Harris (1979), and from District offices of the Soil Conservation Service. Native plant species should be used in lieu of exotic species wherever possible. Sources for native plants have been identified by the Soil Conservation Society of America (1984) , and coordination with appropriate State agencies is essential.

(2) Environmental considerations. Terrestrial habitats can be developed to benefit target species or to promote species richness. Plant species selection depends on which goal is chosen. Mixtures of herbaceous and woody vegetation promote wildlife species diversity by providing a variety of foods and types of cover. Local, State, and Federal wildlife biologists can provide information about the food and cover value of various plants.

d. Composite Designs. Several bank protection methods incorporate vegetation into structural designs. These designs have essentially the same environmental benefits as vegetative designs. Four of the most widely used and successful of these techniques are erosion control matting, cellular concrete blocks, seeded soil-covered riprap, and stem-sprouting woody plants in combination with engineering materials. Additional information on these techniques is provided in WES TR E-84-11.

e. Construction Scheduling. Many factors should be considered when the scheduling of construction is important to the success of bank protection projects. Aquatic impacts can be reduced by scheduling work to avoid peak migration or spawning periods and to take advantage of low-flow periods. Careful scheduling is essential for successful establishment of vegetation.

For example, sufficient time must be allowed for plant establishment prior to high flows or dormant seasons. Some plant materials, such as root stock, are perishable if not planted promptly.

4-7. Erosion Control Structures and Culverts.

a. General. Weirs, drop structures, and culverts often create obstructions to fish movement, and consideration of fish movement during design can provide for migration or protect a viable fishery.

b. Weirs and Drop Structures. Ladder-type fishways incorporated into weirs and drop structures create flow conditions that allow fish to swim through the facility. Fishways are recommended at obstructions with heads as low as 2 feet if they are located on streams with viable fisheries. Fish ladder design requires both biologic and hydrologic data. The fish species of concern must be identified, and migration patterns, fish size, swimming speeds, and swimming depths must be known. Required hydrologic data include the operational discharge range, headwater and tailwater curves, and sediment transport. Refer to WES TR E-85-3 for information about the design of ladder-type fishways.

c. Culvert Fishways. Culverts should be designed to produce flows with adequate swimming depths and passable velocities (see Figure 4-9). Resting areas are required below and above the culvert and within the culvert if its length exceeds 100 feet. If scour is expected below the culvert, or if flow depths are expected to be insufficient for fish movement, a low sill should be constructed five to seven pipe diameters downstream of the culvert. Culverts are sized for the design discharge, and barrel velocity is determined for the expected discharge at the time of fish movement. If the velocity exceeds the sustained swimming speed of the fish, the design should be modified by adding baffles or other roughness elements to the culvert invert, reducing the culvert grade, or reducing the hydraulic radius. Additional guidance is available in McClellan (1970), Watts (1974), and Evans and Johnson (1980).

d. Aesthetic Considerations. The appearance of erosion control structures and culverts can be improved by using natural materials or natural-looking finishes. Examples include rock veneer on culvert headwalls and special form liners and colors that produce patterns similar to those of stone or wood. Additional details are given in paragraph 4-9.

4-8. Levees and Floodwalls.

a. General. Levees and floodwalls are often incorporated into flood control project designs. Levees are usually subject to water loading for periods varying from a few days to a few months a year. Refer to EM 1110-2-1601 and EM 1110-2-1913 for general design guidance for levee projects. Environmental features can be incorporated into levee design, construction, and maintenance to enhance aesthetics, fish and wildlife, or recreational resources. Detailed guidance for levee and floodwall environmental features is provided in WES TR E-85-7.

b. Levee Design and Environment. Design decisions for any levee project include choosing sites for the levee and associated facilities, determining

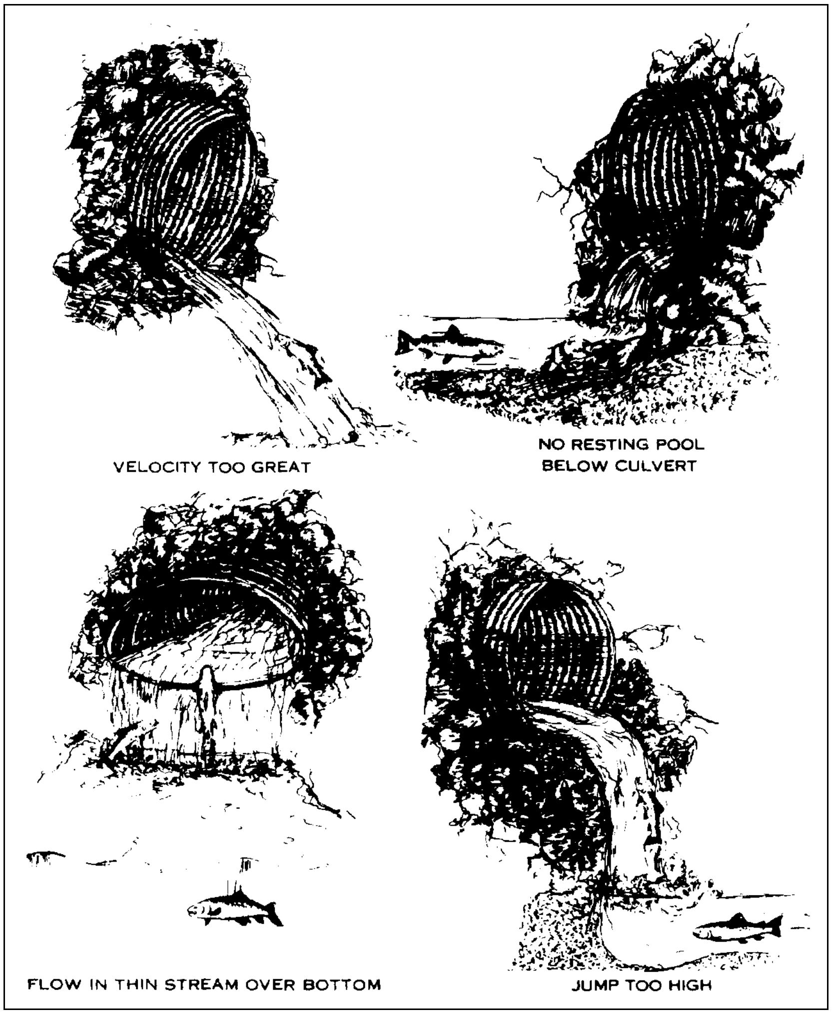


Figure 4-9. Culvert blockages to fish movement
(from Evans and Johnson 1980)

the proper size of the levee and related structures, and formulating plans of work for construction operations. Environmental considerations, as described below, can be incorporated to preserve and enhance environmental resources associated with the levee project.

(1) Avoidance of ecologically sensitive areas and cultural and historic sites. Stream valleys commonly exhibit a wealth of ecologically significant sites and cultural and historic sites. Levee alignment, borrow pit location, and related construction areas should be chosen to minimize the amount of ecologically sensitive area disturbed, subject to other design constraints. Assistance is available from the state and Federal conservation agencies in identifying and locating ecologically sensitive areas.

(2) Tree preservation. Preserving trees that already exist near the levee construction site maintains the scenic and ecological characteristics of the site and reduces the need for revegetation. Only trees that can be

expected to live should be retained, unless the tree in question has value as a den tree. Trees or groups of trees to be preserved should be selected during the design stage of project development. Unique specimens including old trees, unusual species, uniquely sized or shaped trees, and trees with special wildlife value for food, resting, and nesting deserve special attention as candidates for preservation. It is desirable to preserve blocks of trees rather than individual trees. A block of trees can serve as a screen to break up the long, monotonous, and unnatural appearance of a levee, especially where levees are visually dominating. Damage from windthrow is lessened when more trees are present. The value of stands of trees as wildlife habitat can be determined by biologists with data on tree species, size, density, age, and wildlife use. Widths of preserved areas can vary to meet both aesthetic and wildlife needs by considering viewing positions, levee dimensions, and range or habitat requirements of wildlife species to be fostered within the area. Designs should avoid high-velocity passage between tree screen and levee toe.

(3) Overdesign of channels. Overdesign of drainage ditches reduces the need for frequent ditch clearing or mowing and increases their ability to support wildlife habitat and aesthetically pleasing vegetation. Technical Report E-85-3 (WES) provides information concerning resistance factors for channels containing vegetative growth.

(4) Erosion and water quality control during construction. Appropriate erosion and sediment control techniques employed during construction can have significant water quality benefits. Refer to paragraph 5-2 for a detailed discussion of this topic.

c. Environmental Features for Fish and Wildlife.

(1) General. Fish and waterfowl habitat features include basic considerations for design of borrow pits and interior collection ponds, including optional features such as water control structures, artificial islands, fish shelters, and fish stocking. Wildlife habitat features include artificial nesting and perching structures, seeding and planting, and brush piles (Martin 1986) for wildlife habitat management techniques. Technical Report E-85-3 (WES) provides more information on these features and on marsh vegetation establishment, beneficial uses of dredged or excavated materials, land acquisition, controlled access to wildlife areas, and wildlife fence designs.

(2) Fish and wildlife considerations for borrow pit design. Levee borrow pits often fill with water after construction. Well-designed pits can become highly productive habitats. Pond characteristics associated with productivity and species diversity are surface area, shape, wetted edge, and quality and quantity of water (Figure 4-10). Refer to Aggus and Ploskey (1986) for environmental considerations for one borrow pit design based on a series of studies of lower Mississippi River mainstem levee borrow pits.

(a) Borrow pit size. Generally, a simple positive relationship exists between pond and wetland surface area and wildlife productivity. However, large borrow pits may be counterproductive to wildlife if they require destruction of scarce habitat to create relatively abundant open water. A series of small, frequent wetlands can result in higher waterfowl nest densities for the overall area than one large wetland. The Atlantic Waterfowl

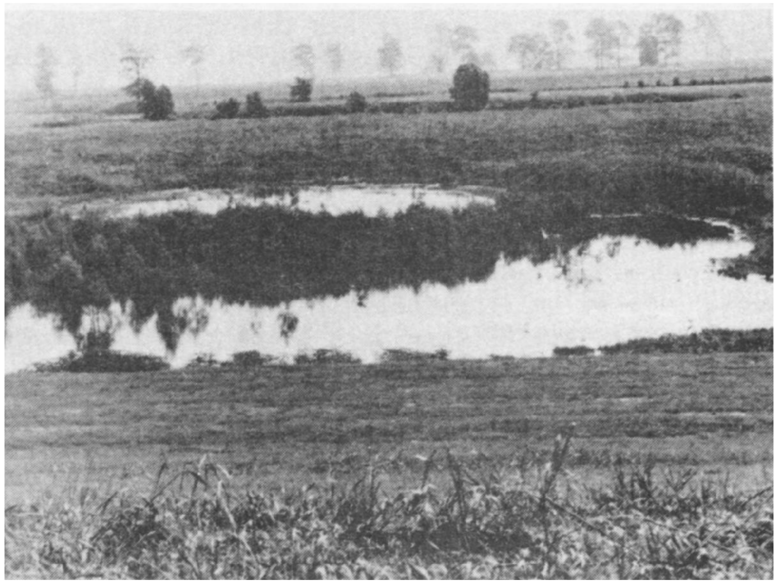


Figure 4-10. Borrow pit extensively used by wading birds

Council (1972) has provided information concerning the creation of artificial wetlands. A minimum size of 1 to 1.5 acre is recommended for waterfowl brood ponds, and 2 acres is the minimum recommended size for pits used for fishing.

(b) Borrow pit shape. Pond and wetland shape influence wetted edge and vegetation/open water ratios that are important to wildlife productivity. Irregularly shaped pits increase wetted edge and benefit waterfowl and some terrestrial species. Irregular shapes also provide more opportunity for bank fishing and add visual diversity. Vegetation/open water ratios can be manipulated by excavating borrow pits with a variety of depths that foster or discourage vegetative growth. Water depths of 6 to 24 inches promote aquatic plant growth, provide good dabbling duck habitat, and create desirable spawning and nursery areas for fish. Depths greater than 3 feet usually discourage rooted plant growth and provide needed open-water areas. Borrow pits may be excavated with a steep drop-off at the bank to a depth of 18 to 24 inches, which is maintained for some distance from shore. At this point there is a second steep drop-off to maximum depth (Figure 4-11). This "step" design provides the needed diversity of depth while reducing the risk of drowning.

(c) Water quality and quantity. Water sources should be sufficient in quality and quantity to sustain fish populations throughout the year. Water temperature, pH, nutrient levels, sediment, and pollutants are important considerations for fish survival and productivity. Periodic inundation from flows from the main channel can be beneficial to the borrow pit fishery. Wetlands and ponds managed for waterfowl also require dependable sources of good water. Water levels are manipulated in the management of many artificial wetlands by using water-level control structures such as those described in paragraph 4-4j. Nelson, Horak, and Olson (1978) provide descriptions of water control management practices and guidance for designing structures. Additional references can be found in WES TR E-85-3.

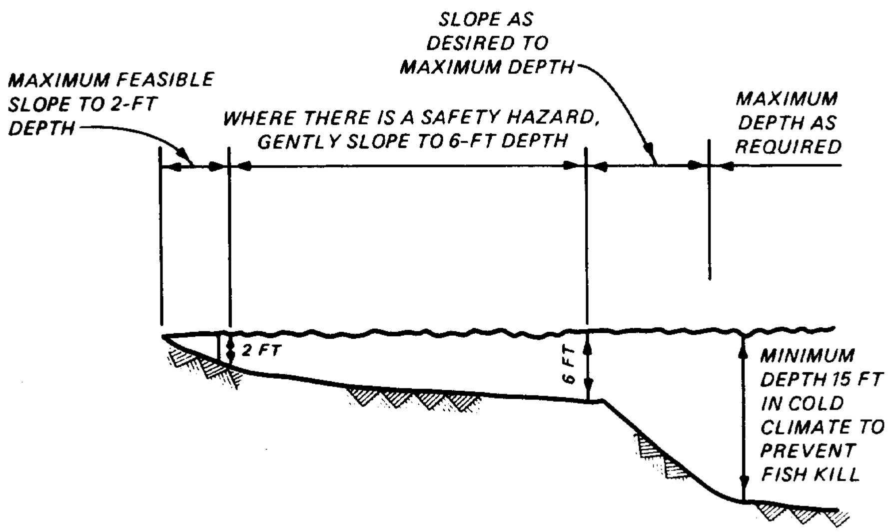


Figure 4-11. Cross section of artificial pond or borrow pit showing design for diversity of depths

(3) Fishery shelters in borrow pits. Fishery shelters constructed of brush, wood, or rubber tires can be used to provide cover, shade, and occasional spawning and feeding sites for fish. These shelters should be designed so that they do not create problems during flood flows. This may be particularly important as a temporary measure for providing cover during the period between removal and reestablishment of riparian vegetation. Refer to Nelson, Horak, and Olson (1978) for information about design and placement of fish shelters.

(4) Interior flood control collection ponds. Interior drainage collection ponds may be used as fish ponds or wildlife wetlands, as long as the standing water does not cause seepage, slope failure, health or aesthetic problems, or inspection problems (Figure 4-12). These problems can be minimized by using impervious core and fill materials that remain stable when wet. Outflow structures may be designed or operated to permanently impound water in collection ponds, or water can be retained by excavation or diking. Runoff, which is the usual water source, may be undependable and may contain varying amounts of sediment, nutrients, or chemical pollutants. Water supply and water quality problems may be alleviated by using stream water or ground water for augmenting runoff during dry periods and for flushing. Flushing rates should exchange the entire volume of water once every 2 to 3 weeks,

(5) Artificial islands. Artificial islands can be used in large ponds to increase wetted edge and to provide needed nesting and loafing areas for waterfowl (Figure 4-13). Islands also provide visual diversity. They can be created by leaving unexcavated areas, by filling, by flooding irregular topography, or by constructing floating platforms. Construction and use of floating islands are described in Will and Crawford (1970) and Fager and York (1975).

(6) Fish stocking. Ponds not connected to bodies of water with fish populations must be stocked if viable fish populations are desired. Species

Figure 4-12. Interior flood control collection pond beside levee in Lewiston, Idaho

Figure 4-13. Artificial islands add habitat and visual diversity to borrow pits and other aquatic areas. Although the island shown here is in an urban area and was landscaped for aesthetics, extensive use by waterfowl for nesting and loafing was observed

should be chosen by biologists familiar with the regional setting and with temperatures and water conditions expected in the ponds. If suitable spawning areas are not available for some of the species stocked, annual stocking may be required. Undesired species, parasites, or diseases should not be introduced into a watershed. Coordination with state and Federal fish and wildlife agencies in developing stocking prescriptions and acquiring fish is required.

(7) Nesting structures and cover. Otherwise acceptable areas for wildlife often provide poor habitat because of the lack of cover and desirable nesting and den sites. Even when care is taken to preserve vegetation, supplemental cover and nesting facilities may be necessary, especially immediately following construction. Perching structures for raptors can encourage predation on burrowing mammals such as ground squirrels. Detailed specifications for construction, placement, and maintenance of artificial cover, perching structures, and nest boxes are available in Martin (1986).

(8) Seeding and planting for wildlife. Vegetation can be planned and managed to provide food or cover that attracts desired wildlife species to the project site. Vegetation also reduces soil erosion. Information about species selection, seedbed preparation, fertilization, seed sources, plant propagation, and measures to ensure plant survival is available in Hunt et al. (1978) and Martin (1981). Seeding and planting should be coordinated with state fish and wildlife agencies. Riverside plantings will be subjected to partial and complete inundation and must, therefore, have a certain degree of flood tolerance to survive. Engineer Pamphlet 1110-1-3 and Whitlow and Harris (1979) identify flood-tolerant species.

(9) Wildlife brush piles. Brush piles provide resting and escape cover for small game and nongame wildlife. Where natural cover is limited, brush piles may be constructed for use by wildlife until natural vegetation becomes established

(a) Location. On the riverside, brush piles should be placed on the landside of stands of trees to protect them from high-velocity flows during floods. Brush piles are not recommended for areas subject to heavy flooding. Brush piles should be located within 200 to 300 feet of other escape cover and should be far enough from the levee so that they will not attract burrowing mammals to the levee toe or interfere with inspection. Long windrow brush piles are usually undesirable in areas that support big game movements.

(b) Specifications. Brush piles should be built by constructing a sturdy base of logs, stumps, or flat rocks and adding smaller limbs and branches as filler material. Brush piles for quail should be at least 15 feet in diameter and 6 to 7 feet high and should have about 6 inches of clearance at ground level. Brush piles designed for rabbits should be 4 to 7 feet high with basal diameter or minimum widths of 10 to 20 feet. Escape entrances must be available at ground level, or brush piles will lose their functional value. Refer to Martin (1986, Section 5.3.1) for detailed information on brush pile use.

d. Environmental Features for Recreation and Aesthetics.

(1) General. Recreational facilities eligible for cost sharing are restricted to facilities that promote general public use and enjoyment of the project (see paragraph 4-9c). The following discussion identifies eligible recreation features that are designed to facilitate use of the levee and associated areas for public recreation and features that enhance the appearance of the levee and related structures. Corps policy regarding recreation facilities is provided in ER 1105-2-100, ER 1110-2-400, ER 1130-2-400, and EP 1165-2-1. Additional information about aesthetic considerations, fishing access, trails, scenic overlooks, and associated facilities is contained in paragraph 4-9 of this manual.

(2) Recreational and aesthetic aspects of borrow pit design. Borrow pits can be used for fishing, hunting, boating, ice-skating, and, if water quality is sufficient, contact activities such as swimming and waterskiing. Access roads, boat ramps, beaches, parking areas, restrooms, and associated facilities stimulate use of water-based recreational facilities. Borrow pits used for swimming, ice-skating, and fishing should be designed with safety considerations in mind.

(3) Levee crowns and access roads. Levee access roads and crowns are easily developed into scenic drives and trails for hiking, jogging, biking, horseback riding, or snowmobiling. Standard widths for maintenance access are sufficient for most uses, although roads used by motorized vehicles must conform to State or local road standards. Access points should be convenient to existing roads, parking facilities, and other community structures. Access sites may consist simply of ramps leading to the levee’s crown and major recreational trail, or they may incorporate various other recreational facilities such as parking facilities, sanitary facilities, picnic areas, interpretive centers, and game fields. Trail utility is increased by rest stops consisting of benches or picnic tables, trash receptacles, water fountains, bicycle racks, and shaded areas that provide opportunities for resting and passive enjoyment of scenery.

(4) Aesthetic considerations for plantings. Well-designed landscaping can lessen the visual impact of a levee project and encourage recreational use. Concerns about root-caused seepage and erosion around the bases of trees can be addressed either by using an overbuilt cross section or by planting materials in concrete tubs or planters that limit root penetration. If tubs are used, long-term costs can be reduced by choosing plants that will not become root-bound. Additional information regarding landscaping of Corps project lands is available in ER 1110-2-400, EM 1110-2-301, EM 1110-1-400, and OCE (1981a,b).

(5) Uses for periodically flooded areas. Interior flood control areas and riverside areas that are periodically flooded may be used for recreational purposes if facilities placed there are floodproof or inexpensive enough to be expendable. Structures placed in flooded areas should be secured against flotation or should be removable.

(6) Interpretive centers, observation areas, and culturally important areas. Observation areas at scenic locations and interpretive centers located

at sites of historical or ecological significance are often used as focal points for trail systems (Figure 4-14). Interpreting points of interest along the levee gives users a sense of regional context and preserves the significance of historic events.

(7) Other recreational facilities. Recreational designs for levee projects often include additional facilities such as fishing access, fishing structures, and boat ramps and swimming beaches, along with associated facilities such as restrooms and picnic areas. Since these uses may conflict with each other, their locations should be carefully planned. Refer to EM 1110-1-400 for design information.

e. Environmental Considerations for Levee Maintenance Activities. Levee maintenance activities generally consist of vegetation management, control of animals that burrow into the levee, upkeep of recreational areas, and levee repair. Options for vegetation management include mowing, grazing, burning, and use of chemicals. Each method fosters different vegetation and wildlife habitat types on levees and adjacent lands. Maintenance operations may be timed and carried out to achieve different environmental goals. Technical Report E-85-7 (WES) discusses levee maintenance options. General maintenance considerations are outlined in Chapter 5 of this manual.

f. Floodwalls. Floodwalls, which are constructed of masonry or concrete, serve a purpose similar to levees. Floodwalls are sometimes built on tops of levees to increase flood protection. Floodwalls can be constructed so that they can be folded or removed when water is at normal levels, to prevent obstructing views of the river or access to the riverbank (Figure 4-15). A folding floodwall consists of a series of concrete panels on hinges. The panels can be raised quickly to a vertical position using a small crane. Once in the vertical position, metal braces that are stored under each panel are bolted to the concrete for additional support. Rubber sealant and gaskets are used to fill cracks between and under panels to make the structure watertight.

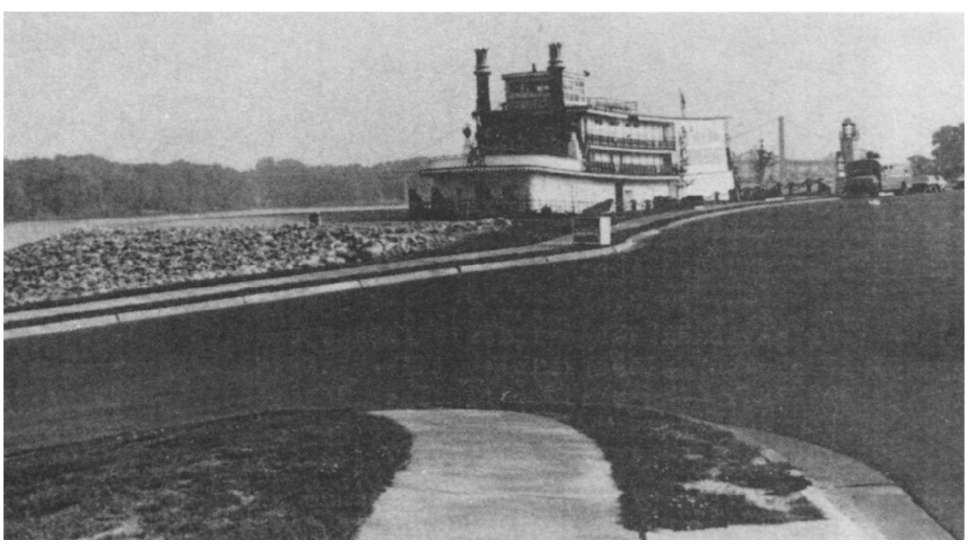
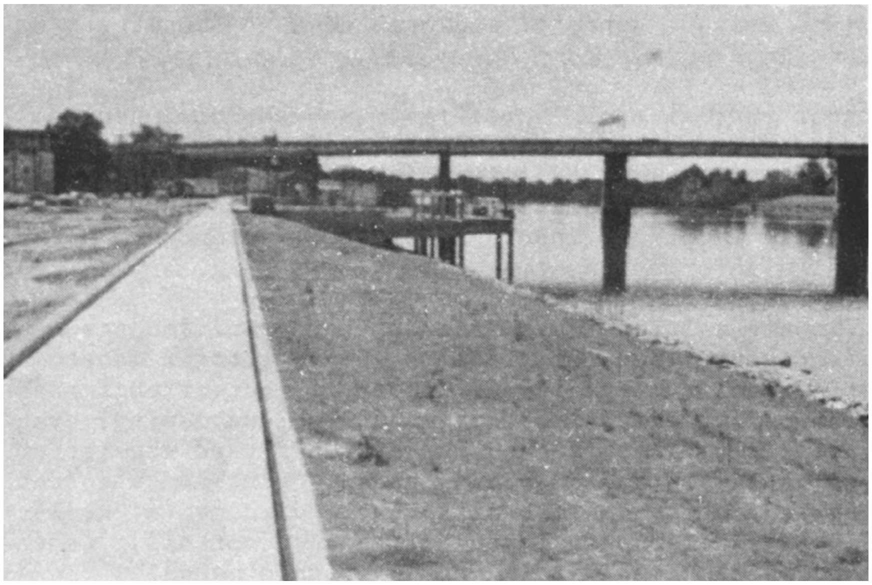
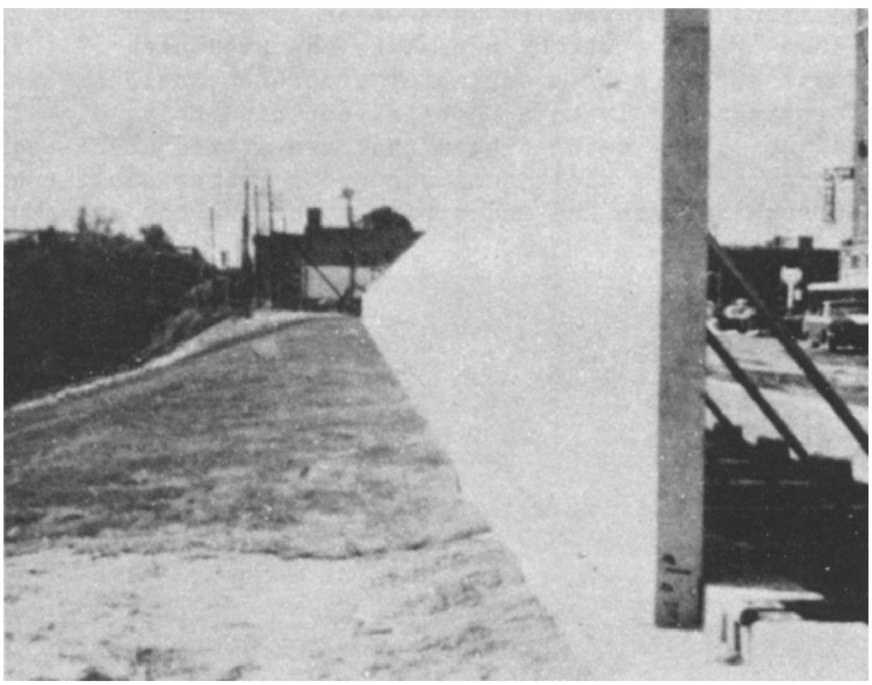


Figure 4-14. Mississippi stern-wheeler showboat that was preserved by being built into the Clinton, Iowa, levee



a. Floodwall in the collapsed position



b. Floodwall in the raised position

Figure 4-15. Monroe, La., folding floodwall
(USAED, Vicksburg)

Removable floodwalls (Figure 4-15) are designed with a base structure low enough to permit viewing and contain several openings through which users may pass. Panels are bolted onto the basic support structure during periods of flooding. Once the panels are installed and plastic sealant is applied to joints, the structure provides full protection. The appearance of concrete walls can be improved by coloring, texturing, or the use of special form liners. Aesthetic treatments for concrete are described in OCE (1969).

4-9. Special Considerations for Urban Projects.

a. General. Consideration should be given to inclusion of recreation features during the planning of water resource projects. An attractive project with well-designed recreational features can have a positive effect on public perception of a channel project (Figure 4-16).

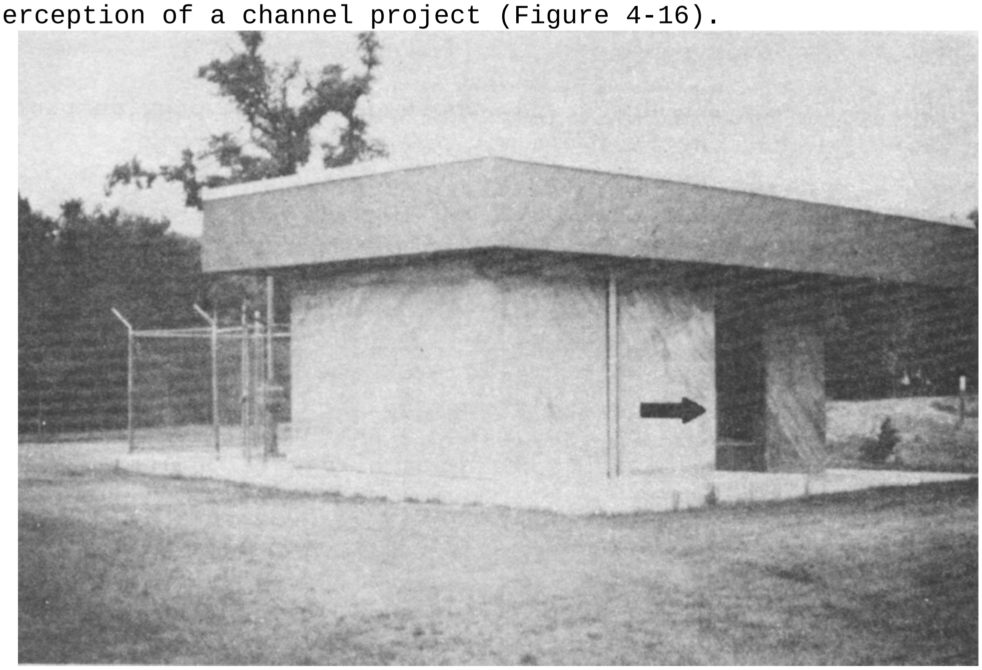


Figure 4-16. Architectural treatment for aesthetics, pumping station in city park, Minot, N. Dak. The arrow points to a fireplace for public use

b. Aesthetic Considerations. Because of the high visibility of urban projects, consideration of aesthetics is important in project planning. Paragraph 3-6 of this manual provides guidance for visual quality assessment of a project area and evaluation of visual impacts of alternatives. The following features can be used to meet design objectives for aesthetics and to reduce adverse visual impacts.

(1) Channel linings, paved surfaces, and concrete. Vegetation may be the most visually pleasing cover for channels, banks, and large open areas. Natural materials such as gravel or cobble may be used effectively for channels requiring nonvegetative linings and for paved areas. Aesthetic concrete treatments are discussed in paragraph 4-8f.

(2) Water displays. Project designers can capitalize on the aesthetic importance of water by using falls, fountains, cascades, and reflecting ponds

as focal points. Sills and deflectors can be used to create turbulent cascades in channels. Water displays generally require several feet of head (such as at dams or grade control structures) and continual flow.

(3) Vegetation. Ground cover, usually grass, should be planted as quickly as possible following final grading. Trees and shrubs can be selected and placed for maximum visual effect. The hydraulic, geotechnical, and climatic condition at the site must be taken into consideration when selecting plants. In addition, other general considerations in the selection and placement of trees and shrubs include the following:

(a) Avoid uniform spacing.

(b) Concentrate plantings in areas of intensive use, high visibility, and superior aesthetic quality.

(c) Stake shrubs and trees and, where necessary, provide protection from rabbits, beavers, and other animals.

(d) Use exotic species with caution; experience has shown a better survival rate using native rather than exotic species.

(e) Irrigate or manually water plantings long enough to ensure survival. Performance criteria guaranteeing minimal survival rates after specified periods of time may be used in planting contracts.

(f) Select, place, space, and prune ornamental trees and shrubs planted within flood channels so that they will not hinder flood flows.

(g) Use low-maintenance varieties wherever possible.

(4) Fencing. Either design fencing to blend with the setting by using colors and substances that are natural in appearance and do not contrast with surroundings, or design it as a major visual element by using ornamental iron or wooden designs.

(5) Architectural design. Design and place structures so that they blend harmoniously with other landscape elements and with the surrounding environment. Subdued earth colors, generous use of wood, and textured finishes can be used to enhance visual effect. Structures in floodways should be designed for removal prior to flooding or should be secured against flotation, made as floodproof as possible, and designed and located for minimal flow resistance.

(6) Bridges and low-water crossings. Trail crossings should be designed so that they are attractive as well as functional. Where feasible, low-water crossings are cheaper and less visually intruding than bridges. Low-water crossings may be placed on the channel invert or raised slightly, as in stepping stone and low culvert designs. Unless they are designed to float during flood events, bridges should be above the design water surface and should not trap debris. Refer to WES TR E-85-3 for illustrations of low-water crossing designs and photographs of a floating foot bridge used over the South Platte River in Denver.

c. Recreation. Engineer Regulation 1105-2-100 limits Federal participation in recreation facilities to basic facilities that are for use by the general public and are not ordinarily provided by private enterprise or on a commercial or self-liquidating basis. Safety and maintenance factors must be taken into consideration in the design of recreation features. EM 1165-2-400 (Appendix B) provides a checklist of facilities that may be provided in recreation development at Corps water resource projects and provides cost sharing guidance for these facilities.

(1) Eligible features. Described below are some of those features eligible for inclusion in flood control channel projects.

(a) Trails. Trails for hiking, jogging, biking, and equestrian use and associated facilities such as picnic areas, parking, comfort stations, etc., are popular recreational features on flood control channel projects. Walking and biking trails should be surfaced for all-weather use, and fencing should be provided in areas where user safety could be a problem. Barricades should be provided in hazardous locations, and bollards or other devices should be used to exclude motorized vehicles. Trails for motorized vehicles, such as trail bikes and snowmobiles, should be located far enough from recreation sites so that other visitors will not be annoyed by noise. Trails that tie into existing trial systems should be compatible in appearance and constructed to equivalent standards. A good system of signs to provide direction, distances, and locations is essential. Extensive trail systems usually require grade-separated crossings at street and road intersections. Trails, trail crossings, and associated facilities should be accessible to and usable by physically handicapped persons. Potential erosion problems should be taken into consideration when designing these trails.

(b) Nature study areas. Natural areas that support unusual or unique ecosystems, possess a variety of natural conditions (geology, soils, etc.), or are rich in biological diversity are well suited for nature areas. Severed bendways, cutoff islands, and wetlands maintained in a natural state are potential nature study area locations. Interpretive displays and signs increase the value of nature areas as outdoor classrooms and learning resources. Trails, signs, and structures should not detract from the natural theme.

(c) Campgrounds and picnic areas. Flood control channel projects often are adjacent to sites suitable for development as picnic areas or campgrounds, and these facilities are popular visitor attractions. Guidance on selecting numbers and types of facilities based on anticipated use and on designing the layout and placement of facilities is available in EM 1110-2-400.

(d) Playgrounds and playing fields. Playgrounds and playing fields are well suited for flood channel projects that include parks and campgrounds.

Although Corps policy no longer permits cost sharing for special-purpose facilities such as tennis courts and softball diamonds, general-purpose playing fields can be included. Children's playgrounds can also be included, as long as they do not employ elaborate designs.

(e) Scenic overlooks. Scenic overlooks can be located at sites that provide attractive views. Overlook parking areas should contain a minimum of 10 spaces (10 by 20 feet), but no more than 30 spaces. Additional facilities that may be included are buildings, covered observation platforms, benches, toilet facilities, water supplies, trash receptacles, and signs or displays that describe the nature and extent of the project.

(f) Historic sites and structures. Historic resources must be taken into account in formulating recommendations for project authorization and implementation. Engineer Regulation 1105-2-100, Chapter 7, defines historic resources as any prehistoric or historic district, site, building, structure, or object included in or eligible for inclusion in the National Register. Preservation of historic properties through avoidance of effects is preferable to any other form of mitigation. Where historic sites exist and can be preserved, they can often be incorporated into recreational plans as centers of attraction (Figure 4-17).

(g) Fishing access areas. Fishing access areas should be located at easily accessible pools or structures that attract fish. Access areas may include parking, boat ramps, water supply and sanitary facilities, trails, and fishing structures. Platforms and steep banks should have fences or safety railings.

(h) Boating, canoeing, and rafting. Studies should be undertaken to ensure that flows and water quality are adequate before boatways are planned for flood control channels. If heavy boating use is anticipated, flood channels should be designed to provide adequate access, suitable low-flow depths, and as few obstructions as possible. Sills and fish habitat structures should be designed so that they will not be hazardous to boaters. Weirs, drop structures, and other barriers must be bypassed or modified for boat passage, or safe portages must be provided. Appropriate warning signs are needed upstream of boating hazards, obstacles, and boat chutes. Boating should be prohibited at unsafe discharges, and clearly marked staff gages or removable warning signs should be provided at all boating access points. Technical Report E-85-3 (WES) provides examples of modified structures and boatways on flood control channels. Figure 4-18 is an example of a flood control structure where boating activities have been carefully integrated into the design.

a. Espada Aqueduct, circa 1900

b. Espada Aqueduct in 1977

Figure 4-17. Espada Acequia. A flood control diversion channel was built to protect this historic Spanish aqueduct from undercutting by flood flows (USAED, Fort Worth)

4-10. Selection of Environmental Features for a Given Project.

a. Environmental Objectives and Environmental Features. Several options usually exist for meeting the environmental objectives or mitigation needs of a given project. Environmental features most often used to effectively address specific environmental objectives are shown in Tables 4-1, 4-2, and 4-3. More detailed information regarding feasibility of environmental features for specific projects is available within the ENDOW microcomputer program. The ENDOW program may be obtained by sending one formatted blank 360-KB floppy diskette to CEWES-IM-SC, PO Box 631, Vicksburg, MS 39180-0631.

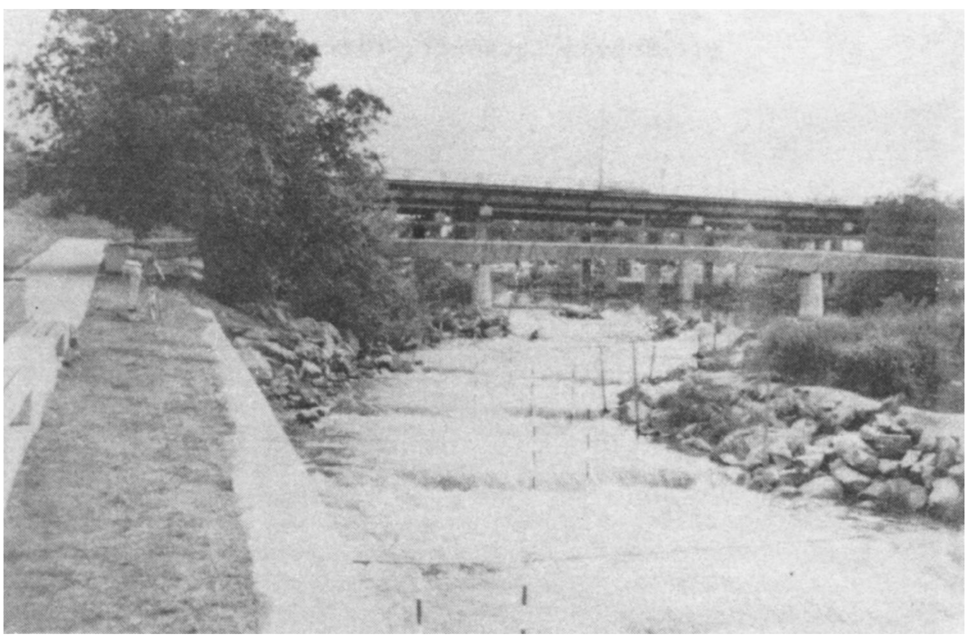


Figure 4-18. Confluence Park boat chute, South Platte River, Denver. A series of 12 pools and weirs drop 10 feet over a run of 330 feet.

Table 4-1

Environmental Features for Channel Side Slope Protection

If you wish to:	Consider using:
Maintain or improve terrestrial riparian habitat value	reinforced revetment, toe protection, bank sloping and revegetation, vegetation, stream corridor management, fencing and buffer strips, or floating plant construction
Provide stable substrate for benthic macroinvertebrates	riprap or quarry-run stone, gabions, or hard points
Provide or maintain fish habitat	tree retards, tree revetments, hard points, earth core dikes
Improve or maintain aesthetic resources	vegetation, combinations of vegetation and structure (composite revetment, excavated bench, earth core dikes, and revegetation of riprap), fencing and buffer strips, stream corridor management, selective clearing, or earth core dikes
Provide access to stream for recreation and/or wildlife	composite revetment, berm preservation and restoration, bank sloping and revegetation, channel relocation, revegetation of riprap, or stream corridor management

* Descriptions of these techniques are given in WES TR E-84-11.

This manual does not mandate use of any particular design or feature for any project. Conversely, features not associated with a specific objective in the tables below may be successfully used to achieve that objective in some situations. Innovation is encouraged.

b. Feasibility of a Given Feature. The success or failure of a given environmental feature is most strongly influenced by stream and watershed conditions. For example, although instream habitat structures are often excellent features to preserve aquatic habitat, they are not generally suitable for braided or unstable channels, ephemeral streams, streams with poor water quality, or channels with no existing or prospective fishery.

Table 4-2

Environmental Features for Channels

If you wish to:	Consider using:
Limit bed and bank erosion	meandering alignments, grade control structures, side slope protection, armor, channel lining (asphalt or concrete), vegetative plantings, or vegetative buffer strips
Avoid bed aggradation	low- and normal-flow channels, sediment traps, revegetation of disturbed areas, selective clearing and snagging, or vegetative buffer strips
Prevent ground-water table lowering	water-level control structures, greentree areas, or maintenance of oxbows
Maintain low-flow depths and velocities	low- and normal-flow channels, floodways and bypass channels, pools and riffles, instream habitat structures, water-level control structures, or sediment traps
Maintain water quality	selective clearing and snagging, single-bank construction, vegetative buffer strips, floodways and bypass channels, low- and normal-flow channels, or diversion of flow to allow dry excavation
Preserve aquatic habitat	selective clearing and snagging, instream habitat structures, single-bank modification, meandering alignments, pools and riffles, construction of substrate, fishways, water-level control structures, maintenance of oxbows, or seasonal restrictions on construction activities
Avoid loss of riparian vegetation	selective clearing and snagging, single-bank modification, greentree areas, vegetative plantings, revegetation of disturbed areas, preservation of islands formed by bendway cutoffs
Create or maintain terrestrial diversity	stream corridor management, vegetative plantings, or shaping and placement of dredged and excavated material

(Continued)

* Descriptions and additional information regarding these environmental features are contained in WES TR E-82-7 and TR E-85-3.

Table 4-2 (Concluded)

If you wish to:	Consider using:
Create wetlands	greentree areas, oxbow maintenance, placement of dredged or excavated material
Improve or preserve instream aesthetics	meandering alignments, pools and riffles, single-bank modification, water-level control structures, water displays, special materials and finishes for channel walls
Improve or preserve streamside aesthetics	selective clearing and snagging, single-bank modification, vegetative plantings, contouring dredged material disposal areas, preservation of vegetated buffer strips, special finishes for concrete, water displays
Improve or preserve instream recreation opportunities	selective clearing and snagging, low- and normal-flow channels, water-level control structures, oxbow and bendway maintenance

Table 4-3

Environmental Features for Levees and Floodwalls

If you wish to:	Consider using:
Provide fish habitat	special designs for borrow pits and collection ponds, water control structures, or fish shelters in borrow pits
Preserve or create wetlands	avoidance measures, alignment of levee to increase riverside land area, minimal clearing, overdesign of drainage ditches, artificial islands in borrow pits and collection ponds, or vegetation
Preserve or create upland habitat	avoidance measures, tree preservation, minimal clearing, overbuilt levee embankments, vegetation, brush piles, fencing, or selective vegetation maintenance and management
Provide recreation opportunities	special designs for borrow pits and collection ponds, roads and trails, interpretive features, observation areas, boat ramps, fishing access, or swimming beaches
Improve or maintain aesthetic resources	ornamental plantings, special designs for borrow pits and collection ponds, folding floodwalls, or special architectural treatments for floodwalls, pumping stations, and other structures

* Descriptions and additional information regarding these features are contained in WES TR E-85-7.

CHAPTER 5

ENVIRONMENTAL CONSIDERATIONS FOR OPERATING AND MAINTENANCE

5-1. General. The manner in which construction and maintenance activities are carried out is a major factor affecting the environmental quality associated with flood control channel projects. This chapter identifies desirable concepts for environmental improvements that should be incorporated into work plans for construction and maintenance. These concepts are applicable to all types of flood control projects. Construction and maintenance procedures applicable to specific designs, such as levees or clearing and snagging, can be found in the corresponding sections of Chapter 4. Maintenance of local flood protection projects is governed by 33 CFR 208.10, ERs 1130-2-303, 1130-2-335, and 1130-2-339, and EM 1110-2-301. Maintenance requirements will be in accordance with Local Cooperating Agreements, and specified in the operation and maintenance manuals.

5-2. Erosion and Sediment Control. Erosion and associated sedimentation from work areas should be minimized by employing appropriate sediment control techniques. Erosion can be minimized by controlling runoff, performing work during the dry season, limiting the time that areas are disturbed, and employing temporary covers or mulches, such as wood chips or straw. Brush or fabric barriers, vegetative filter strips, and sediment basins can be used to trap sediment from eroding areas. Some soils can be chemically treated to reduce erosion of exposed surfaces, but chemical treatment depends on soil characteristics and is therefore site specific. As a general rule, stream fording, subaqueous construction, and amphibious operations should be avoided. Refer to WES IR EL-83-l and EL-85-2 for detailed guidance concerning all types of soil stabilization measures and erosion and sediment controls.

5-3. Minimizing Disturbance.

a. General. Construction and maintenance of flood control channels and structures should be planned and carried out to minimize ecological disturbance. Guidelines should specify preferred equipment; access controls; timing of work; and frequency, amount, and location of vegetation removal.

b. Preferred Equipment. Equipment used in channel maintenance should be a as small as feasible to minimize access requirements and disturbance of riparian vegetation. Channel work should be accomplished from one side, insofar as possible. Where mechanical mowing of banks is required, light equipment should be used to avoid damage to turf and nearby trees and shrubs.

c. Access Controls. The number and width of access routes should be minimized, and advantage should be taken of existing roads, trails, and clearings. Mowing of travelways and staging areas should not be required, and a permanently maintained travelway along the stream is not mandatory on all projects. Where a travelway is required, an uncleared buffer strip should be left along the channel. In some cases, recreational trails can double as maintenance travelways.

d. Considerations for Scheduling. Many factors, some of which have conflicting requirements, should be considered when scheduling construction of these projects. Peak migration or spawning periods should be identified so that they are avoided wherever possible. Periods of intensive recreational usage should also be avoided. The success of establishing vegetation is largely dependent upon the time of planting. The dormant season is usually most favorable for the success of woody vegetation, but is also often associated with higher flow periods. On the other hand, for other vegetation, planting during the growing season is more desirable. Construction activities may favor lower flow periods because of ease of access and turbidity control. These and other local factors must be considered when scheduling construction for the specific project.

e. Frequency, Amount, and Location of Vegetation Removal. Maintenance frequency should be determined on an as-needed basis rather than at specified regular intervals. Vegetation removal for channel maintenance should be restricted to that necessary for proper operation of equipment and maintenance of channel capacity. Care should be taken to avoid damage to trees and shrubs left during project construction. Wildlife dens, burrows, and nesting sites should be protected to the extent feasible and commensurate with safe project operation.

5-4. Aquatic Plant Control.

a. General. Several management measures are available for preventing or controlling aquatic plant infestations that might reduce flow capacity or interfere with the use of flood channels. The control technique to be used is dependent upon the species of aquatic plant causing the problem, its magnitude, its location, and the characteristics of the channel. The degree of control required to bring the problem to an acceptable level must also be a consideration. See Dumas (1976a,b) and Long (1979) for further details on the identification and assessment of aquatic plant problems and for assistance in choosing control measures to be used. In cases where potential aquatic plant problems can be identified at a very early stage, technology called "prevention methodology" is available to minimize the problem such that large-scale control operations are avoided (see Killgore 1984).

b. Aquatic Plant Control Techniques. Aquatic plants that cause problems in flood control channels are of two basic types: floating plants such as waterhyacinth, and submersed plants such as hydrilla or Eurasian watermilfoil that are rooted in the channel substrate. Tarver et al. (1979) present pictures and descriptions of these species. Biological, chemical, and mechanical methods, individually or in combination, may be used to control aquatic plants.

(1) Biological control. Biological control employs organisms that feed on the target organism or affect it in some other way to reduce its numbers or growth. Biological control agents potentially available for use in aquatic plant control are insects for control of alligatorweed (Environmental Laboratory 1981) and waterhyacinth (Sanders et al. 1979), plant pathogens for control of waterhyacinth (Sanders et al. 1979), and herbivorous fish (Addor and Theriot 1977) for control of submersed species. A computer model is available from WES as a decision-making aid in planning for the use of herbivorous fish. The model runs on an IBM personal computer with color graphics. In general, biological methods are relatively inexpensive but take considerable time to become effective.

(2) Chemical control. The application of safe and effective chemical agents is a proven method for aquatic plant control. Approved chemical agents for aquatic use may be liquids that can be sprayed onto floating plants or inserted under the water for controlling submersed plants, or they may be solids that can be applied by spreaders, for example, over the surface of the channel. Chemical methods are generally readily available and are relatively inexpensive when compared to other methods. See Dumas (1976b) and Westerdahl and Getsinger (in preparation) for lists of available chemical agents and techniques for their use. These documents contain valuable information on chemicals for aquatic use; however, to obtain the most current information on effective and approved products, the user should consult his Corps District contact for aquatic plant control.

(3) Mechanical control. Mechanical devices for controlling aquatic plants vary from deflecting booms and screens or clipping bars mounted on boats to more sophisticated systems whereby the plants are cut and removed from the water to disposal areas. Although mechanical methods are generally rather costly, they are sometimes desired over other methods since no organisms or chemicals are added to the environment. See Culpepper and Decell (1978), Dumas (1976a), and Smith (1980) for descriptions of mechanical control hardware and techniques that may be applicable for controlling aquatic plants in flood control channels.

CHAPTER 6

ENVIRONMENTAL DATA COLLECTION AND ANALYSIS

6-1. General Considerations. Most flood control channel projects will not require detailed environmental studies. However, extensive, sensitive, or extremely complex projects may require a more intensive effort. In the process of planning and designing these projects, assessment of potential environmental effects and opportunities requires site-specific data collection efforts. While the details of data collection and analysis are specific to each project, there are basic requirements that are common to all data collection programs. This chapter does not direct data collection efforts but outlines the general steps to be considered when undertaking data collection programs (Figure 6-1). Engineer Manual 1110-2-1201 presents specific information concerning water quality data.

a. Problem Identification. Before objectives for a data collection effort are set, the problem to be addressed must be clearly identified. The general (and sometimes specific) nature of the problem may be ascertained from a variety of sources. These include Environmental Assessments, Environmental Impact Statements, Feasibility Reports, Reconnaissance Reports, consent decrees, statutes, regulations, and interagency agreements.

b. Establishment of Objectives.

(1) Need for objectives. The most essential part of an environmental data collection and analysis effort is the establishment of clear objectives. If this is not done, the net result is often either an inability to solve the problem for which the data were generated or a mass of data that defies rational analysis. Without good objectives, any data collection/analysis effort faces a high probability of failure. The various stages of the project may warrant different details of problem identification and objectives.

(2) Nature of objectives. An approach to setting objectives is presented in Phenicie and Lyons (1973). Objectives must be attainable, oriented in a positive direction with no unproductive branching, and measurable to allow evaluation of progress and results. Wording must be clear, unambiguous, concise, and simple. The types of data needed to measure success or results should be specified.

c. Study Design.

(1) The design describes how objectives will be met and includes decisions on parameter and variable selection, data collection methods, study milestones, resource allocation, and necessary reports. Use of CPM (Critical Path Method) logic networks is often helpful in outlining work to be accomplished and the sequence of events.

(2) Simple before-and-after studies of the project area may be used to document changes but usually are insufficient to establish causal relationships (i.e., observed effects result from specific actions or variables). If the study is to identify cause-and-effect relationships, it is necessary to

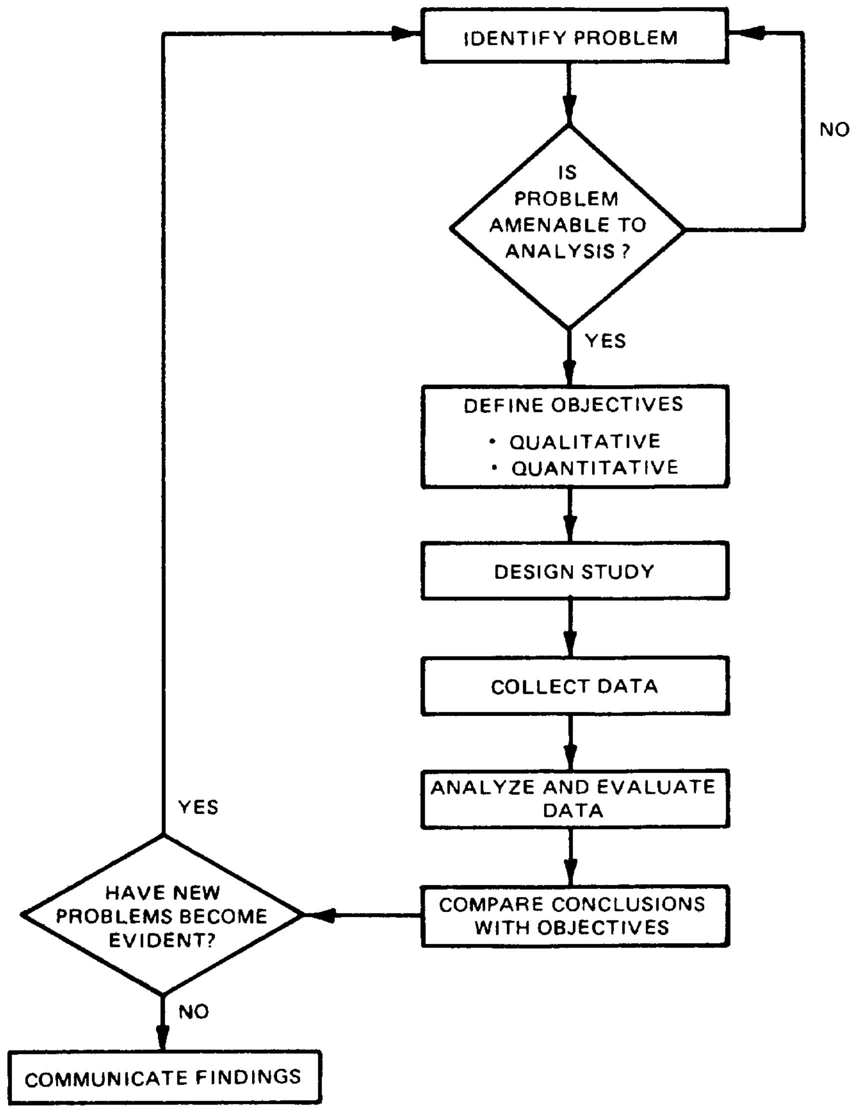


Figure 6-1. Major steps in conducting environmental studies

identify and control for other variables or processes that might influence similar results. Temporal changes in environmental processes can sometimes be accommodated by using control areas within or in the immediate vicinity of the project site. Environmental conditions in control areas should be as similar as possible to those of the project area.

d. Types of Data.

(1) There are two basic kinds of data: qualitative and quantitative. Qualitative data consist of descriptive, nonnumerical information. Quantitative data are numerical and usually reference temporal or spatial information. Qualitative approaches are especially useful if only descriptive data are required, if the study is preliminary in nature, if a short suspense has been set, or if quantitative techniques do not apply. Quantitative data are

preferable because they can be expressed as a testable hypothesis. It is often useful to express the hypothesis as a question, for example, "Will (has) the project increase(d) (decrease(d)) some variable" (e.g., density)? The objective of data collection and analysis then essentially becomes the verification or rejection of a hypothesis.

(2) For scientifically and legally defensible conclusions, baseline monitoring and reference data should be quantitative and reproducible and the experimental design such that hypotheses concerning change can be statistically evaluated. Quantitative data sufficient for application of statistical tests are often quite expensive, a fact that underlines the importance of careful selection of parameters for measurement.

e. Documentation. Documentation of study findings is critical to the future use of the environmental data collected. Reporting requirements should be incorporated into the study design, taking into consideration the report format to be used. A common format used in reports of results consists of the following parts: Introduction, which contains background information, the problem, and how specific objectives will lead to resolving the problem; Materials and Methods, which includes a description of the study area and detailed field and/or laboratory procedures, sampling techniques, and methods for analyzing the data; Results, which gives measurements of variables and results of hypothesis testing; Discussion, which presents and explains the results; Conclusions and Summary; and Literature Cited.

6-2. Data Collection. This section provides guidance for planning a sampling program that will meet stated objectives of the study design. The most critical aspect of data collection is the selection of appropriate parameters to sample and measure.

a. Primary Considerations. The quality of information obtained through the sampling process is dependent upon collecting a representative sample and using appropriate sample collection and data management techniques. Time, costs, and equipment constraints may limit the amount of information that can be gathered. Under such conditions, careful tailoring of the data collection program is required. In this document, the term sample refers to a set of observations or measurements taken to describe or characterize environmental conditions. Individual observations or measurements are called sample elements, and the number of sample elements constitutes the sample size.

b. Representative Sampling. The purpose of sampling is to define biological, physical, or chemical characteristics of the project area environment. This requires that samples be taken from locations that are typical of ambient conditions found at the project site. Failure to obtain samples that are truly representative of a given location will result in inaccurate data and misinterpretations. Samples can be random, haphazard, or stratified and will be specified in the sampling design. Elliot (1977) and Green (1979) provide information on these aspects.

c. Sampling Site Selection and Location. The following general factors should be considered in selecting a sampling site:

(1) Objectives of the study.

(2) Accessibility of the site to personnel and equipment.

(3) Representativeness of the site.

(4) Available personnel and facilities.

(5) Other physical characteristics.

Statistical texts and field manuals in geology, hydrology, biology, and other environmental disciplines should be consulted for information about specific factors to consider in sample site selection.

d. Sample Size. Guidance in this section is limited to general concepts. The larger the sample size, the better environmental conditions will be defined. The mean of a series of replicated measurements is generally less variable than a series of individual measurements. Statistical analysis generally requires at least two characteristics, usually mean and standard deviation, to describe a sample. The sample size necessary to describe a distribution is proportional to the heterogeneity of the variable to be measured. Refer to Snedecor and Cochran (1967), Elliot (1977), Green (1979), or other statistical texts for numerical and graphical techniques to determine sample size.

(1) Consideration of the above factors suggests that replicate samples should be collected when money and time permit. A minimum of three replicates is required to calculate standard deviations. Aside from replication, the sample size needed depends on temporal and spatial variability of the phenomenon and the desired degree of precision.

(2) An additional factor that will limit the sample size is financial resources. In this case, the sample size that can be analyzed is determined by the ratio of available dollars and cost per observation:

$$\text{Sample size} = \frac{\text{Dollars available}}{\text{Cost per observation}}$$

This approach will provide one method of estimating the sample size that can be collected and analyzed. However, should the calculated sample size be insufficient to establish an adequate sampling program (i.e., sample size insufficient to allow replicate measurement at all locations), one of the following trade-offs will have to be accepted:

(a) Reduce the replicate sampling at each station.

(b) Maintain replicate sampling but reduce the number of sampling locations.

(c) Increase the financial resources available for sampling.

The distinction between options (a) and (b) above should be based on project-specific goals. If option (a) is selected (more stations, fewer replicates), the results will provide a better indication of distribution patterns in the project area (synoptic survey), but it will be difficult to compare individual stations. On the other hand, if option (b) is selected (fewer stations, more replicates), the results will provide a better indication of variability at one location and comparison between sampling stations. However, the project area will be less described.

(3) Consideration should be given to collecting a larger sample than that determined by the above process in the event they are needed for additional analysis or backup. If more data are needed, it is easier to analyze additional sample elements already on hand than to remobilize a field crew. Also, the additional variable of different sampling times is avoided with this approach.

e. Sampling Collection, Handling, and Analysis. Refer to EM 1110-2-1201 and references contained therein for information concerning collection, handling, and analysis of water, sediment, and biological samples.

6-3. Data Analysis, Interpretation, and Presentation of Results.

a. Data Analysis Plan. A plan for data analysis should be formulated at the experimental design step since the type of analysis selected will guide the sample size and frequency of measurements that must be taken. Techniques available for data analysis include descriptive analysis, maps and graphical analysis, and statistical analysis.

(1) Descriptive analysis. Presentation of the results of some analyses often consists of descriptions based on visual observations, inductive reasoning, and perhaps a few measurements: for example, "The habitat structures placed in the flood channel have provided flow depth and velocity variation. Prior to placement of the structures, water depths and flow velocities were relatively uniform across and along the channel. After the structures had been in place for 6 months, scour holes several feet deep had developed at the riverward end of each structure." The value of descriptive analysis can be substantial if it can be established that other factors that could affect results were controlled, constant, or not applicable.

(2) Maps and graphical analysis. Patterns inherent in data can often be revealed by mapping or graphing the data. Maps are used to show two- and three-dimensional spatial patterns, whereas graphical approaches are most useful for showing temporal relationships or variations within a single dimension, such as distance or depth.

(a) Maps. Phenomena to be mapped may be distributed in a continuous or discrete manner. Discrete distributions are composed of individual elements that are countable or measurable (such as people, fish, or trees), whereas continuous distributions have no recognizable individuals (e.g., air temperature or rainfall). Patterns are often enhanced by grouping all values into five or six classes and mapping each class with a separate tone or color.

(b) Graphs. Graphic techniques specialized for certain disciplines or types of data are too numerous to describe. As with maps, however, graphic techniques vary with the type of data. Discrete data are often graphed as frequency histograms, with frequencies on the vertical axis and classes or categories on the horizontal axis. More complex maps and graphs, such as three-dimensional contour plots, trend surfaces, and perspective plots, are also useful but more difficult to comprehend. Various mapping and graphic options are available as part of most data management systems. Continuous data are usually plotted as curves, with the spatial or temporal dimension on the x-axis and the values of the variables on the y-axis.

(c) Common errors. When using maps and graphic techniques, one must be careful not to draw conclusions that implicitly depend on interpolation between data points (Figure 6-2) or extrapolation beyond the range of the data (Figure 6-3), unless such interpolation or extrapolation can be justified. A choice of scales or coordinate axes that unduly exaggerate or minimize point scatter or differences should be avoided.

(3) Statistical analysis.

(a) General. Statistical analysis can be used to summarize or describe data. Statistics can also be used as a formal decision-making tool to decide whether measured temporal or spatial differences between samples are real or whether they may be the result of sampling variability. Commercially available data management software systems have options for computing and displaying several types of statistics. Large amounts of data can be summarized by calculating statistics such as measures of central tendency (mean, median, and mode) and dispersion (standard deviation and range). Statistics can be used to compare sets of data to determine if differences exist among them and, if so, whether the differences are meaningful.

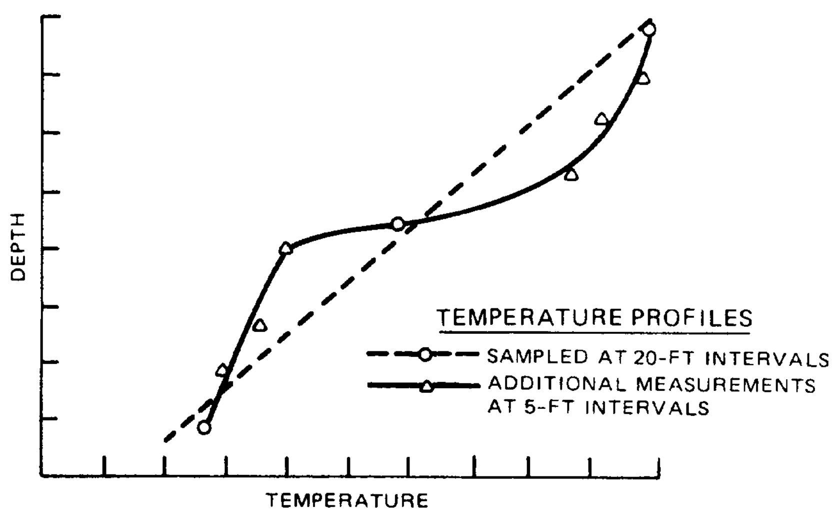


Figure 6-2. Error caused by improper interpolation. Depth-temperature relationship appears linear when sampled at 20-foot intervals, but non-linear when sampled at 5-foot intervals

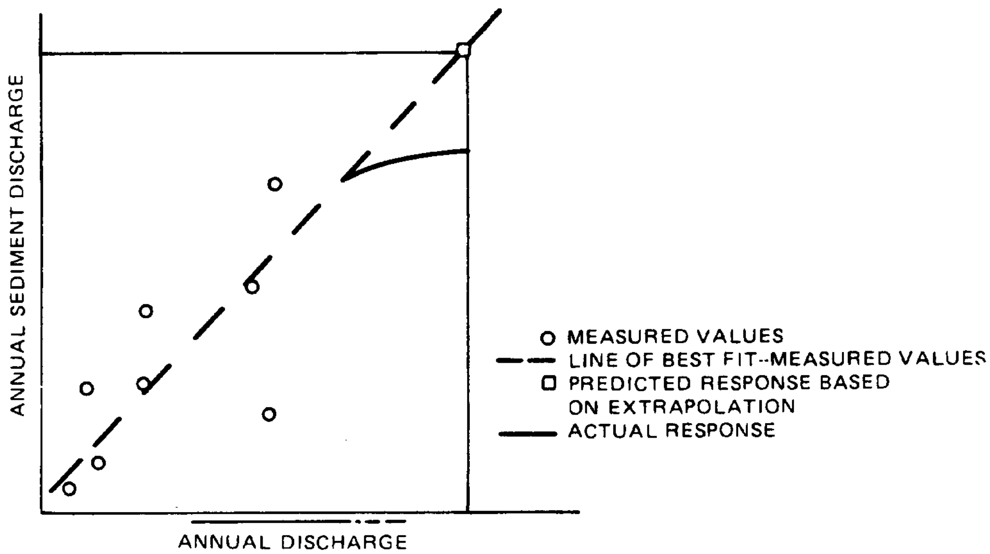


Figure 6-3. Error caused by improper extrapolation

(b) Hypothesis testing. Formulas are available for determining if observed differences between sample data sets are real, or if they may have occurred by chance due to the size or selection of samples used in calculating the statistics. These techniques are called significance tests, and theories and formulas for their use are given in basic texts on statistics and experimental design. Users should be cautioned, however, that observed differences may be statistically significant and yet not be very meaningful. Special techniques have been developed for analysis of biological data, particularly benthic data. Sokal and Rohlf (1969) provide a review of several of these techniques.

b. Data Interpretation.

(1) Editing. Data base checking and editing should precede analysis. Extreme errors may be detected by computer programs that check for boundary conditions and ensure that data values are within reasonable limits. Quality work requires human judgment. Simple computer-generated plots of the raw data should be examined for unreasonable values, extreme values, trends, and outliers.

(2) Analysis. The next step in data interpretation is to ensure that the assumptions upon which the data analysis plan is based are still valid. New information or failure to collect all the data required by the original analysis plan may necessitate modification. The final conclusions should not be limited to acceptance or rejection of hypotheses, but should extend to clear, verbal expression of the implications of the observed results. Decision-makers who are not technical specialists may fail to grasp these implications unless they are clearly communicated.

c. Presentation of Results. Results should be presented in a format appropriate for the majority of the intended audience. Presentation of large volumes of numerical data is generally undesirable; however, provision should be made for long-term data storage and retrieval (computer disks, microfiche, etc.). Graphic displays can effectively serve as examples of major findings or conclusions.

6-4. Data Base Management.

a. General. The success of any study effort, especially one involving multiple investigators and disciplines, will be heavily influenced by the quality of data management, storage, and efficiency of information retrieval and by the compatibility between data units and the formats and programs for data reduction and analysis. A carefully designed plan for handling information will guarantee that once field and laboratory work are completed, information will be readily available for examination and analysis, in a form useful to management.

b. Data Management Plan. A data management plan detailing procedures for handling data storage and retrieval should be formulated at the outset of an environmental study. The simplest type of data base contains only data developed for a single study. Efforts should be made to ensure standardization of measurement and reporting procedures so that there will be internal compatibility among the environmental data files within the Corps field office. Once the data base is developed, the data base manager should be conservative in decisions about changes in procedures or data units and should permit such changes only where useful information benefits can clearly be identified.

c. Data Base Incompatibility. Frequently, various studies associated with one project will be conducted by several different agencies or contractors. The same scope of work might be performed by different contractors at different times. Besides reinforcing the need for standardization, the probability of a multiple-contractor operation brings up logistical questions about information storage, retrieval, and analysis. Federal agencies, academic institutions, and consulting companies who ordinarily conduct Corps contracts will usually have their own computer support. This situation could lead to the formation of incompatible data files. Data base incompatibilities will create problems for those who have responsibility for synthesizing the products of multiple investigators and will hamper comparisons over time. A solution is to permit each contractor to use the computer hardware and software of his choice, but to require the contractor to transmit information to the Corps field office in a machine-readable form compatible with Corps format and units.

CHAPTER 7

MITIGATION DECISION ANALYSIS

7-1. Policy. Care must be taken to preserve and protect environmental resources, including unique and important ecological, aesthetic, and cultural values. The Fish and Wildlife Coordination Act of 1958 (Public Law 85-624, 16 U.S. C. 61 et seq.) requires fish and wildlife mitigation measures when appropriate and justified. The National Historic Preservation Act of 1966 (Public Law 89-665, as amended, 16 U.S.C. 470 et seq.) does the same for cultural resources. The Water Resources Development Act of 1986 (Public Law 99-662) and implementing guidance provide further policy on fish and wildlife mitigation, including cost-sharing provisions. Specific Corps mitigation policy on fish and wildlife and historic and archaeological resources is included in 1105-2-100.

7-2. Definitions.

a. Mitigation. The Council on Environmental Quality (CEQ), in its Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act (40 CFR Part 1508.20), published a definition of mitigation that has been adopted by the Corps (ER 1105-2-100) and includes: avoiding the impact altogether by not taking a certain action or parts of an action; minimizing impacts by limiting the degree or magnitude of the action and its implementation; rectifying the impact by repairing, rehabilitating, or restoring the affected environment; reducing or eliminating the impact over time by preservation and maintenance operations during life of the action; and compensating for the impact by replacing or providing substitute resources or environments. These will be referred to as the five elements of mitigation.

b. Significant Resources and Effects. Significance includes meanings of context and intensity. Context refers to the degree of technical, institutional, and/or public recognition accorded to a resource at local, regional, or national levels. Intensity refers to the severity of impacts as measured in duration, location, and magnitude of effects. The criteria for determining the significance of environmental resources and effects are provided in ER 1105-2-100. Significance of historic resources is further defined as a property listed in or determined to be eligible for listing in the National Register of Historic Places (ER 1105-2-100, Chapter 7).

7-3. Key Concepts for Mitigation.

a. General.

(1) Significant resources are to be identified and specifically considered in all phases of a project. If significant losses to those

resources will occur because of the project or action, then appropriate consideration of mitigation for those losses must be accomplished. For fish and wildlife losses, consideration of mitigation must be given to any losses which are not negligible losses. The extent of mitigation recommended should be that which is determine to be justified.

(2) Mitigation consists of avoiding, minimizing, rectifying, reducing, or compensating for the impacts. The five elements of mitigation are logically stepwise, i.e ., it is better, easier, and often cheaper to avoid an impact than to compensate for it. The elements are iterative in that the results from one step may require reexamination of previous actions. The first elements of mitigation can often be accomplished through the use of good engineering practices, e.g., changes in project design.

(3) Impacts resulting from flood control measures that involve dredged material disposal and hydraulic changes are largely to wetlands, vegetated shallows, stream bottoms, and riparian zones. Chapter 2 of this manual and ER 1105-2-100, Chapter 7 discuss potential impacts on these resources.

b. Early and Continuous Coordination and Public Involvement. Planning for mitigation must occur concurrently with overall project planning activities and with the involvement of personnel from all appropriate state and Federal agencies (ER 1105-2-100). An integrated planning effort ensures that the significant resources are correctly identified, significant impacts are determined, all the elements of mitigation are considered, and the mitigation actions taken or recommended are the best possible.

c. Monetary and Nonmonetary Concerns. Both monetary and nonmonetary aspects of significant resources and effects will be considered. Monetary aspects are quantified using dollars, and nonmonetary aspects are quantified using a variety of appropriate measures such as Habitat Units, acres, population data, Visual Impact Assessment Units, parts per million, or use-days.

d. Mitigation Objectives. Mitigation objectives should be stated as a quantification of the amount of compensation required for significant losses to significant resources. Both the identity and character of the significant resources and the amount of losses to them should be clearly documented.

e. Incremental Cost Analysis. Incremental or marginal cost analysis is a process used in designing a compensation plan that meets the mitigation objectivities. It investigates and characterizes how the cost of a unit of output increases as the level of output changes, e.g., charge in dollars per Habitat Unit with increasing Habitat Units. An analysis will result in an array of implementable mitigation actions, ranked from most to lease cost effective. A mitigation measure such as fencing a greenbelt to exclude grazing or placement of a spawning channel becomes an increment when it is combined with other measures into a plan and analyzed to determine the most cost-effective solution.

f. Justification for Mitigation. Justification for fish and wildlife mitigation or any environmental enhancement will be accomplished by determining that each measure or separable increment will have monetary and non-monetary benefits/values that equal or exceed the monetary and non-monetary costs. Such justification will be presented when the mitigation or enhancement proposals are recommended for approval. ER 1105-2-100 Chapter 7 provides requirements for fish and wildlife mitigation and enhancement.

7-4. Examples.

Many of the design items in Chapter 4 of this manual are suitable approaches to one or more of the mitigation elements. Examples of each of the elements are listed below:

a. Avoid - preserve a public access point; redesign channel around critical habitat or archeological site.

b. Minimize - perform single-bank channel modification; use less riprap and more vegetation for channel side slope protection.

c. Rectify - recontour and revegetate disturbed areas; restore flow to former wetlands.

d. Reduce - control erosion; place restrictions on movements of construction and maintenance personnel and equipment.

e. Compensate - develop a greenbelt habitat using dredged material; recreate a spawning channel.

APPENDIX A

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APPENDIX B

POTENTIAL SOURCES OF DATA

These data may be available at the District office, and the various functional elements (e.g., hydraulics, hydrology, environmental resources, geotechnical) should be consulted. Coordination among these elements can also facilitate interpretation of the data in the context of the project.

Type of Data	Sources
1. Watershed conditions	
a. Climate	National Weather Service climatic summaries; US Weather Bureau Technical Paper 40, "Rainfall Frequency, Atlas of the United States"
b. Topography	USGS topographic maps; city and county topographic surveys; aerial photos
c. Soils/geology	County soil surveys, state geologic survey sheets; aerial photos
d. Sediment yield	Local SCS office; state natural resource surveys
e. Land use/cover	Local planning agencies, USGS 1:250,000 land use quadrangles (LUDA sheets); aerial photos
f. Hydrology	(See sources under Climate); USGS National Water Data Exchange (NAWDEX) file; drainage district maps
g. Water quality	USGS Water Supply Papers ("Quality of Surface Waters of the United States" and "Quality of Surface Waters for Irrigation, Western United States"); data collected under the National Water Quality Network, data published by other Federal agencies (Tennessee Valley Authority, US Public Health Service, Bureau of Reclamation, Department of Agriculture, US Environmental Protection Agency (USEPA), etc.); and reports of various state and local agencies. Federal agencies that collect water data coordinate their activities through the NAWDEX maintained by the USGS. The USEPA maintains water quality data in its STORET file, which can be accessed by

Type of Data	Sources
1. Watershed conditions (Cont.)	
g. Water quality (Cont.)	computer.* Data may also be available within the District from studies conducted for other projects in the watershed.
2. Stream and floodplain	
a. Stream morphology	Large-scale topographic maps; aerial photos; field measurements; close-range photography; drainage district records
b. Streambank stratigraphy	Exposed sections; construction test borings; soil maps; drainage district records
3. Historic data on land use, floods, prior modifications	Drainage districts, courthouse records, old surveys, longtime residents, archives, newspaper files
4. Unique resources	
a. Historical sites, including prehistoric archeological sites	National Register of Historical Places; State Historic Preservation Officer; National Park Service archeologists; professional archeologists, courthouse records, archives; local historians and historical societies
b. Trees	National Register of Big Trees; American Forestry Association; state tree registers.
c. Threatened and/or endangered species	US Fish and Wildlife Service Regional Offices, Office of Endangered Species, Washington, DC; National Oceanographic and Atmospheric Administration, National Marine Fisheries Service Regional Offices, Protected Species Management Branch; state fish and game or conservation agencies.

* Contact: NAWDEX, USGS, 421 National Center, Reston, VA 22092 (703-860-6031) and STORET User Assistance Section, Section Chief WH-553, Office of Water Regulations and Standards, USEPA, Washington, DC 20460 (202-382-7220).

APPENDIX C

SAMPLE PROCEDURE FOR THE DESIGN OF FLOOD CONTROL CHANNEL PROJECTS

I. Establish Project Objectives

- A. Flood damage reduction--level of protection desired
- B. Environmental
  1. Water quality
  2. Recreation
  3. Fish and wildlife
  4. Historic preservation
  5. Aesthetics

II. Identify Alternatives for Achieving Project Objectives

- A. Nonstructural
- B. Structural
  1. Reservoirs
  2. Levees
  3. Flood control channels

III. Evaluate Alternatives and Select General Plan

IV. Detailed Project Design for Flood Control Channels

- A. Data collection and analysis, existing conditions
  1. Watershed conditions
     - a) Climate
     - b) Topography
     - c) Soils/geology
     - d) Sediment yield

e) Land use/cover (existing and recent changes)

f) Hydrology

2. Stream and floodplain (each reach)

a) Hydrology

i. Generate flood frequency series

ii. Determine corresponding stage data

iii. Calculate flow duration curves (hydrographs)

b) Hydraulics

i. Identify resistance components and determine existing n values at various discharges

ii. Determine amount and size distribution of bed load and suspended load

c) Geomorphology

i. Survey cross section and existing channel grade

ii. Establish relationship of cross-section geometry to discharge

iii. Measure pool-riffle spacing and meander geometry and relate to discharge and channel width

iv. Evaluate stability of bed and banks

v. Measure size distribution of bed and bank material

vi. Measure cohesiveness of banks

vii. Identify and map locations of "hard points" in bed or bank

d) Stratigraphy (from test borings, exposed sections)

i. Determine stratigraphic sequence

ii. Describe stratigraphic units in detail

iii. Establish average depth to seasonal water tables

e) Existing structures

i. Types

ii. Locations

iii. Design

iv. Scour and deposition patterns

f) Ice

i. Recorded thickness

ii. Average dates of freeze and breakup

iii. Damage

iv. Flow patterns and blockages

g) Ecology

i. Map riparian vegetation and locate and identify unique or valuable trees

ii. Evaluate terrestrial ecology

iii. Evaluate aquatic ecology

h) Water quality

i. Physical

ii. Chemical

iii. Biological

i) Aesthetic resources - identify, describe, and photograph major components

j) Historical and recreational resources - identify and describe major resources, with particular attention to historical and archeological components

B. Flood control channel design

1. Fix exact location and alignment geometry of channels

2. Hydraulic design

a. Rapid-flow channels - use lined channels; choice of environmental features severely limited

b. Tranquil flow channels

i. Select best combination of channel cross-section alignments and construction techniques to meet flood control and environmental objectives (see paragraph 4-1c)

ii. Select additional features to meet environmental objectives (see Tables 4-1, 4-2, and 4-3)

iii. Establish downstream water-surface elevation and the water-surface control line, including freeboard

iv. Select n values for each reach

v. Size channel

vi. Check channel stability for anticipated flows (if unstable, stabilize by one or more of the following: adjust cross section; adjust grade, line, or armor channel; provide grade control; provide bank protection)

3. Review design for maintenance considerations; adjust design if necessary

4. Review design for aesthetics; adjust if needed

C. Design environmental features of project that are not part of the flood channel proper

D. Develop detailed cost estimates; if cost too high, modify project design beginning at step IVB

GLOSSARY

Aggradation: Deposition of sediment in a channel, on a floodplain, or other surface in sufficient quantity to increase local elevation.

Annual series: The discharge record consisting of the greatest discharge occurring in each year.

Armor: A coarse layer of gravel or cobble that develops on a streambed through winnowing away of fines.

Autotrophic: A condition in which oxygen production by plants exceeds respiration by plants and animals. Sunlight and inorganic compounds are the primary energy source.

Baffle: A plate, wall, screen, or other device to deflect or impede flow.

Bedforms: Ripples, waves, dunes, and related forms that develop under various flow conditions on the beds of alluvial streams with significant bed-load transport.

Bed load: Sediment, usually sand size or larger, that is transported along the bed by rolling, skipping, dragging, or saltation.

Benthic: Of, pertaining to, or related to the bottom of a stream or other body of water.

Berm: A terrace or ledge formed within a channel at base of the streambank. Also, a terrace or ledge cut on a slope or embankment to divert water or intercept sliding earth.

Bollards: Heavy post and chain fixtures used to exclude wheeled vehicles from protected areas.

Borrow pit: A hole created by excavating levee embankment material.

Braided channel: A channel pattern characterized by numerous intertwined channels.

Bypass channel: A short flood diversion channel constructed to bypass a natural stream reach or features of special interest such as wetlands. Bypass channels may be constructed to convey all flows or flood discharges only.

Check dam: A low dam constructed of logs, loose rock, or other material, to control water flow and check erosion.

Climax community: A mature, relatively stable biotic community representing the culmination of ecological succession.

Cobble: Gravel and stones that have been rounded by abrasive action of flowing water or waves.

Coldwater stream: A stream with water temperatures low enough to support salmonid fishes.

Collection pond: Pond located on the landside of a levee where interior floodwaters collect.

Community: All of the populations of plants or animals in an area or volume; a complex association usually containing both animals and plants.

Cross-sectional area: The area of a section of a channel at right angles to the direction of flow.

Crown: The top of a levee.

Cutoff island: An island created in a bend or meander by excavating a bypass or diversion channel across the meander neck.

Debris: Inorganic sediment or trash such as tires of shopping carts.

Debris basin: A basin constructed to trap sediment or debris that would clog or damage a flood channel.

Drop structure: A grade control structure that provides for a vertical drop in the channel invert between the upstream and downstream sides.

Ecosystem: A community and its environment including living and nonliving components.

Ephemeral stream: A stream that flows only during runoff events.

Equilibrium: A condition of fluvial systems in which watershed and channel parameters are balanced.

Evapotranspiration: The combined moisture loss from evaporation and transpiration.

Extrapolation: Estimation of a function at a point which is larger or smaller than all the points at which the value of the function is known.

Fabridam: A dam constructed of fabric and rubber that can be inflated with air or water.

Fish ladder: A fishway that provides passage over or around a vertical obstruction.

Fishway: A structure designed to allow fish passage around, over, or through obstacles.

Flap gate: A gate hinged at the top and allowing flow in only one direction.

Flood channel: Any partially or completely excavated channel intended to convey above-normal discharges. Flood channels may be sized to convey any return interval discharge above the 2-year or other normal bank-full discharge.

Flood diversion channel: (See Floodway.)

Floodwall: A wall constructed of masonry or concrete to provide flood protection from seasonal high water.

Floodway: A natural or constructed channel that conveys flood flows.

Flume: An open channel constructed of wood, steel, or reinforced concrete and used to convey water for various purposes, including grade control.

Form liner: A liner for concrete forms designed to produce a special finish.

Gabions: Rock-filled wire cages used on streams for erosion control and construction of dams and other structures.

Grade control structures: Any of several types of structures used to control channel gradient (see stabilizer, drop structure, and flume).

Greenbelt: A linear park, usually located along a stream corridor or other right-of-way.

Greentree reservoir: A shallow reservoir in which water levels are manipulated for wildlife and timber production.

Habitat: The physical location in which a population of plants or animals lives,

Hard point: A slope protection technique whereby "soft" or erodible materials are removed from a bank and replaced by stone or compacted clay. These features may also occur naturally along banks where currents have removed erodible materials leaving nonerodible materials exposed.

Headcut: An abrupt change in the longitudinal profile of a stream. Headcuts typically migrate upstream through time.

Heterotrophic: A condition in which respiration by plants and animals exceeds oxygen production by plants. Primary energy sources are organic compounds.

High-flow channel: A channel design employing a subchannel for normal and low flows and high-flow berms that are flooded on an infrequent basis. When the existing natural channel is used for the subchannel, excavation may take place from one or both sides, but the existing channel is disturbed as little as possible.

Hydraulic radius: Equal to A/P , where A is cross-sectional area and P is wetted perimeter. Roughly comparable to average depth in wide, shallow streams.

Interior collection pond: (See Collection pond; sometimes called interior drainage pond.)

Intermittent stream: A stream that ceases to flow seasonally or occasionally because bed seepage and evaporation exceed the supply of water.

Interpolation: Estimation of an intermediate value of one variable (dependent) as a function of a second variable (independent) when values of the dependent variable corresponding to several discrete values of the independent variable are known.

Invert: The bed of a channel or culvert.

Knickpoint: (Same as Headcut.)

Leaching: The removal of materials from a porous medium due to erosion or dissolution occurring because of the passage of water or other fluid through the medium.

Levee: An embankment constructed to provide flood protection from seasonal high water.

Low-flow channel: A subchannel designed to concentrate low flows for biologic, recreational, or aesthetic reasons.

Macroinvertebrates: Large invertebrates found in streams and consisting largely of larval insects, worms, and related organisms.

Manning's n: A resistance coefficient used in the Manning equation for uniform steady flow, $V = \frac{1.49}{n} R^{2/3} S^{1/2}$, where V is mean velocity, R is hydraulic radius, and S is slope, all expressed in non-SI units.

Meander: A broad, looping bend in a stream channel.

Meander amplitude: Amplitude of center line of meandering channel usually expressed as a multiple of stream width (see Figure 4-5).

Meander wavelength: The average distance from crest to crest, or trough to trough, in a series of meander waves.

Natural stream channel: A channel whose alignment, dimensions, cross-sectional shape, and grade have not been modified.

Overbuilt levee: A levee with a cross section larger than that required to meet all engineering considerations.

Oxbow lake: A lake formed in a former stream meander that has been abandoned naturally or cut off during channel construction for navigation or flood control purposes.

Paddleway: A reach of a low-gradient stream developed for canoeing; also called boatway.

Perched lake: A lake whose bed is above the ground-water table.

Periphyton: Invertebrates and plants that attach to solid substrates in aquatic systems. The association of aquatic organisms attached or clinging to stems and leaves or other surfaces projecting above the bottom.

Point bar: A crescent-shaped bar of coarse sediment built out from the convex bank of a meander.

Pool: Topographically low area produced by scour. Pools are located opposite point bars on meandering streams.

Population: An interacting group of organisms of the same species.

Propagule: Seed, cutting, tuber, bulb, rhizome, or other vegetative component used to propagate plants.

Regression: A functional relationship between two or more variables that is of ten empirically determined from data and is used to predict values of one variable when values of the other variables are known.

Resistance coefficient: An empirically derived coefficient used in uniform flow equations to account for flow resistance.

Riffle: A topographically high area in a channel created by the accumulation of relatively coarse-grained sediments.

Riparian vegetation: Vegetation along the bank of a watercourse.

Salmonid or salminoid: Collective term referring to salmon, trout, grayling, or white fish, all of which are found in coldwater environments.

Saltation: Movement of sediment along a channel bed by intermittent bouncing.

Sediment basin: A basin constructed to trap sediment eroded from a slope or being transported by a stream.

Selective clearing and snagging: A modified version of clearing and snagging that limits the types and amount of snags and vegetation removed and uses construction methods that create minimal disturbance.

Sill: A low dam designed to prevent erosion or to create pools for fish habitat.

Sinuosity: A measure of meandering calculated as a ratio of stream length to valley length.

Stabilizer: A low sill across a channel, used to prevent bed erosion.

Stable channel: A channel with no net erosion or deposition over a period of several years; a graded stream.

Stilling basin: An enlarged area in a channel that is deep enough to reduce flow velocity.

Stream power: The product of a stream's discharge rate Q and slope S.

Subchannel: A channel inside a larger flood control channel that is used to convey low and/or normal flows (see low-flow channel).

Substrate: Surface to which stream biota adhere or within which they live.

Suspended load: That portion of a stream’s sediment load that is carried suspended on the flow rather than in contact with the bed suspension.

Thalweg: A line connecting the deepest points along a channel.

Threshold: A point or value that, if exceeded, creates either positive or negative feedback. Positive feedback destroys equilibrium conditions in fluvial systems, whereas negative feedback tends to restore them.

Throughflow low: That part of storm runoff that moves through the soil (same as
interflow).

Toe: The lower portion of a channel bank or where a levee slope meets the ground.

Tree retards: Slope protection structures made of large trees. Tree retard systems generally consist of groups of trees cabled together, placed perpendicular to the bank line, and anchored in place using cables with fabricated weights. A small stone root is constructed into the bank line to anchor the landward end of the tree and protect the landward end of each retard from flanking by overtopping flows.

Turbidity: Reduction in transparency caused by suspended solids or colloids.

Unit discharge: Discharge per unit width (Q/W).

Warmwater stream: A stream with water too warm to support salmonid fishes.

Water control structure: A device, such as a weir or gated structure, used primarily to control water level.

Wing deflector: A low structure projecting from a channel blank used to create scour holes for fish habitat purposes.

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